CLIMATE READY DC

RESILIENT DESIGN GUIDELINES

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HOW TO USE THIS DOCUMENT

The Climate Ready DC Resilient Design Guidelines ("the guidelines") are intended, first and foremost, to be a practical reference for District of Columbia agencies, engineers, architects, planners and stakeholders who are responsible for, and/or have an influence on, planning, design, or construction of projects in the District. While primarily intended for use on public projects, the guidelines can also be used as a resource for private development. This document provides a methodology for conducting a climate resilience needs assessment and suggests steps for planning, designing, and constructing projects to support resilient outcomes in the built environment. The guidelines can inform new construction as well as renovations and modernizations.

The guidelines are organized into four major sections:

Section 1 provides an overall introduction to the need for resilience in the District and describes who the guidelines are intended for, how they are organized, and which vulnerabilities are addressed. Topics such as the District's overall resilience goals, how the guidelines relate to the Climate Ready DC Program, and an overview of the resilient design process are also covered.

Section 2 covers, in greater detail, the two primary climate change vulnerabilities that the District faces: flooding (due to sea level rise, as well as storm events) and increased heat. The latest scientific projections of predicted impacts are provided and climate-adjusted design targets are presented for each of the vulnerabilities.

Section 3 presents a detailed methodology for evaluating heat and flooding vulnerabilities and factoring that information into decision-making for building and site/landscape projects in the District. Part of this process involves understanding the operational requirements of facilities (criticality) and their life expectancy—both of which will influence resilient design decision-making.

Section 4 describes 11 overarching considerations that relate to development in the District and subsequently presents 40 detailed strategies that can help enhance resilience of buildings and other facilities. The detailed strategies are organized into two broad categories: *Buildings and Site & Landscape*. Specific guidance is offered for each strategy, and icons provide further information about applicability, relative costs, and relevant District rules and regulations.

The Appendix contains a glossary, a description of how the climate-adjusted design parameters were calculated, a summary table of the resilient design strategies, and other pertinent information.

SECTION 1: INTRODUCTION AND CONTEXT

The District of Columbia's climate is changing, putting our buildings, roads, critical infrastructure, and people at risk. While codes and standards are typically designed to incorporate historic weather, these may no longer be sufficient to meet the demands of higher temperatures, more intense precipitation, and increased flooding along our rivers. As part of the Bowser Administration's implementation of the District's Climate Ready DC (CRDC) Plan, these guidelines provide a path to incorporate future climate conditions into District planning.

The strategies outlined are intended for project teams interested in exceeding baseline requirements to enhance a project's climate readiness. All projects must still comply with applicable codes and regulations.

OVERALL GOAL OF THE RESILIENT DESIGN GUIDELINES

The guidelines are intended to provide District municipal planning and regulatory staff, building owners, developers, facility managers, and other stakeholders with information needed to integrate resilient design into new construction or renovations of existing facilities. Since climate is changing, all projects must consider future risks to ensure that these projects can safely serve the needs of people, businesses, municipal facilities, and organizations today and in the years to come. Ultimately, the goal is to protect property, save lives, and ensure business and service continuity in the face of future climate shocks and stresses.

APPLICABILITY

This document focuses on buildings and site/landscape features, including site strategies that relate to public space, but does not include roadways, bridges, and other larger infrastructure projects. For example, on a school project, these guidelines would be a useful reference for designing the building and site and landscape around it, including internal roadways and sidewalks—but not the District roadways leading to the school.

Notably, these guidelines do not address the social aspects of resilience. Emergency planning, community engagement, and organizational/business resilience are all key to ensuring that District communities can access necessary information during a disaster, receive assistance or supplies, and return to work as soon as possible. While these social policies are important, this guide focuses on strategies specific to the built environment.

DEFINING RESILIENCE

Resilience is relevant at different scales to individuals, households, communities, and larger regions. The intent of resilient design is to create buildings and communities that can maintain functionality and keep residents safe in the face of natural disasters, heat waves, loss of power, and other disturbances.

Relative to climate change, resilience involves adaptation to the wide range of regional and localized impacts that are growing in frequency and magnitude due to climate change. In the District, these impacts will include more intense storms, increased precipitation, heat waves, and power outages. “Resilient design” is the intentional design of buildings, landscapes, communities, and regions in response to these vulnerabilities.

THESE GUIDELINES ADOPT THE DEFINITION USED IN RESILIENT DC:

“Resilience is the capacity of individuals, communities, institutions, businesses, and urban systems to survive, adapt, and thrive, no matter what kinds of chronic stresses and acute shocks they experience.“ [1]

PRIMARY FOCUS ON FLOODING AND EXTREME HEAT

This document primarily addresses flooding and extreme heat as studies show these will likely be the most chronic and widespread challenges brought on by climate change.

Flooding will occur along the District's two rivers, the Potomac and Anacostia, and their many streams and tributaries, as well as low-lying areas in other parts of the District. In the near term, flooding will accompany severe weather events as the District is increasingly experiencing "blue sky" or "sunny-day" flooding, driven by sea level rise and tidal cycles.

Rising temperatures, along with longer and more-severe heat waves, will put District residents at risk and put stress on buildings and infrastructure. Importantly, heat is not evenly spread throughout the District. Some neighborhoods are currently warmer than others due to a phenomenon known as the urban heat island effect. Human development, including dark rooftops and pavement, vehicular traffic, waste heat from mechanical systems, and impervious surfaces, absorbs and traps heat. This effect, paired with climate change, can cause cities, and certain neighborhoods within those cities, to heat up at faster rates compared to less urbanized areas.

The District also faces other vulnerabilities not directly addressed in this document. Pandemics, as demonstrated by the coronavirus (COVID-19), present a level of vulnerability largely unseen prior to the 2020 outbreak. Earthquakes can be a threat even outside of major seismic zones, as the District learned in August 2011 with the Magnitude 5.8 earthquake in Virginia, centered 90 miles southwest of the District. Terrorism is another concern, especially with the District being the Nation's Capital.

Any of these disruptions can result in power outages, travel interruptions, and other impacts. To this extent, some of the strategies described in this document may also enhance resilience to these vulnerabilities, but the guidelines were not developed with that goal in mind.

RESILIENT DESIGN PROCESS

Achieving resilience for a particular building or facility in the District involves understanding the vulnerabilities faced (both today and in the future), understanding the specific needs of a facility over its expected lifetime, and deciding on specific strategies that can be employed to minimize risk to that facility over its lifespan. This resilient design process is summarized in the flowchart to the right.

ASSESS PROJECT CRITICALITY AND LIFESPAN

DEFINE CLIMATE RISKS BY LOCATION

SELECT CLIMATE-INFORMED DESIGN PARAMETERS

IDENTIFY APPLICABLE RESILIENT DESIGN STRATEGIES

Section 3 describes this process in detail, drawing on the flooding and heat-related vulnerabilities for the District described in Section 2. A checklist is also provided in Appendix D to help project team members accomplish each step in the process.

Incorporating resilience into projects early in the design process can save money and reduce risks. Actions taken during planning and development can proactively address climate challenges, while actions that are available later in the process are often more limited, more expensive, and more difficult. Ideally, climate resilience design decisions should be made in project planning and early construction. If possible, assess climate risk before determining the building site to limit exposure to climate hazards. If a project is already sited, identify climate hazards relevant to the site and design options for mitigating risks. Figure 1 highlights the activities in a project lifecycle where incorporating resilience thinking could be especially beneficial.

Figure 1: Opportunities to Strengthen Resilience throughout Project Lifecycle

1 INITIATION

- **1.1 Project Initiation**
- 1.2 FCA Report
- **1.3 Budget Estimate Financial Feasibility**
- 1.4 Budget Controls Cost Structure
- 1.5 Document Control
- 1.6 Project Work Plan/QA
- 1.7 Project Kick Off Meeting

2 PLANNING

- 2.1 Existing Conditions
- 2.2 Benchmarking
- 2.3 Site Evaluation
- **2.4 Comprehensive Plan**
- 2.5 Financial Feasibility
- 2.6 Risk Evaluation
- 2.7 Outreach Plan
- **2.8 Concept Design**
- 2.9 Contracting Strategy
- 2.10 LEED Planning

3 DESIGN

- **3.1 Pro-design**
- 3.2 Concept (15%)
- **3.3 Schematic Design (35%)**
- 3.4 Design Development (65%)
- 3.5 Construction Development (100%)
- 3.6 Compliance Submittal

4 CONSTRUCTION

- 4.1 Staffing Plan
- 4.2 Pre-Const. Meetings
- 4.3 Mobilization
- 4.4 Submittals
- 4.5 Site Surveys
- **4.6 Utilities**
- 4.7 Daily Reports
- **4.8 Const. Management**
- 4.9 Safety Plan Monitoring
- 4.10 Site Visits
- 4.11 Photos & Testing

5 O&M

- 5.1 Physical Descriptions
- **5.2 Functional Descriptions**
- 5.3 Troubleshooting
- 5.4 Preventative Maintenance
- 5.5 Corrective Maintenance
- 5.6 Training Plan
- **5.7 Roles and Responsibilities**

6 CLOSE OUT

- 6.1 Close-Out Checklist
- 6.2 Deficiencies List, Substantial Completion, Final Inspection
- **6.3 LEED Construction**
- 6.4 Drawings/As Built
- 6.5 Waivers of Liens
- 6.6 Final Acceptance
- **6.7 Lessons Learned**
- 6.8 Archiving
- 6.9 Warranty Walk Throughout

SECTION 2: UNDERSTANDING VULNERABILITIES INTHE DISTRICT

Climate change is expected to bring warmer temperatures, an increase in the intensity of extreme weather, and flooding from sea level rise, storm surge, and precipitation. This will increasingly stress infrastructure and facilities, challenging their abilities to reliably deliver services.

This section introduces current projections for sea level rise, extreme precipitation, and elevated temperatures and offers corresponding design parameters that can be used to account for climate change in design.[i] Generally, two climate change projections are presented; a high emissions scenario, which assumes concentration of greenhouse gasses continue to increase over time; and a low emissions scenario, which assumes concentrations stabilize shortly before 2100.[ii] Section 3 provides guidance on how to select climate-informed design parameters, including how to choose between those based on high and low emissions scenarios.

Planning for climate change necessitates a certain degree of uncertainty. The science is continuously improving, and the District will update these design assumptions periodically to incorporate new information. In the interim, these proxies provide an improved buffer of safety compared to historically-based design parameters.

FLOODING

Climate change will increase flooding in the District through both sea level rise and changing precipitation patterns. The Potomac and Anacostia Rivers, as well as their tributaries, can experience flooding in three different ways:

1. Riverine flooding from more frequent storm events causing flash flooding downstream;
2. Interior flooding caused by inadequate drainage capacity or filled-in streams not being able to carry water away; and
3. Coastal flooding because of sea level rise and storm surges.

Flooding endangers residents, reduces property value, and causes economic hardship due to closures. Flooding can also have secondary impacts on health, such as mold growth from flooded buildings, polluted downstream surface waters, and increased insects. Preparing for flood events through smart and forward-looking design can keep residents safer while saving money.

i. Climate change projections are drawn from DOEE's 2015 Climate Projections and Scenario Development report. The projections also include more recent and comprehensive sea level rise projections from the National Oceanic Atmospheric Administration (NOAA).

ii. Emissions scenarios are based on the Intergovernmental Panel on Climate Change (IPCC) Representative Concentration Paths (RCP) in the fifth IPCC report in 2014. The RCPs are 21st century pathways that make different assumptions about the concentration of carbon in the atmosphere in watts per square meter (w m-2). Low emissions scenarios are based on RCP 4.5 (w m-2) which is considered an intermediate stabilization pathway. High emissions scenarios are based on RCP 8.5 (w m-2) which is considered a "scenario without additional effort to constrain emissions" pathway. Emissions scenarios are based on the Intergovernmental Panel on Climate Change (IPCC) Representative

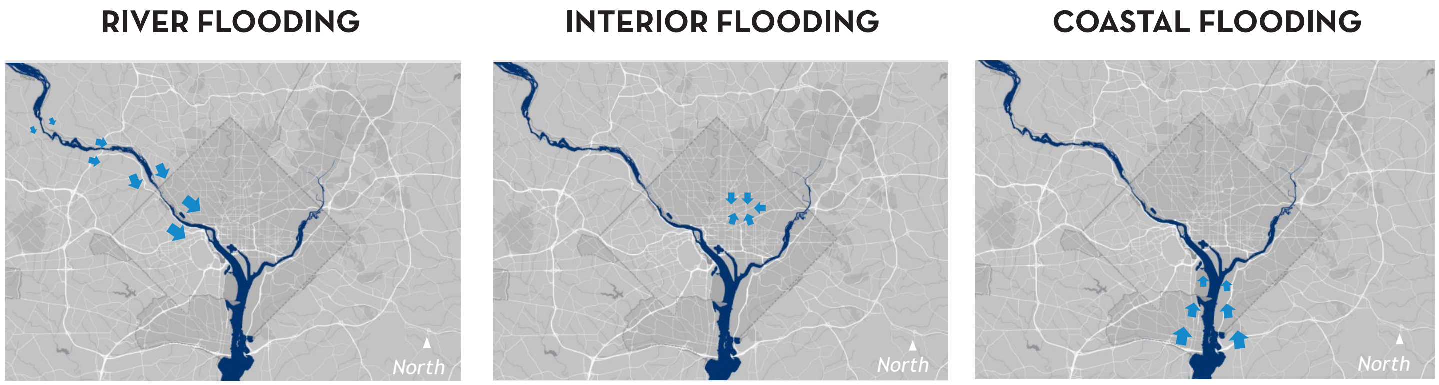


Figure 2: Types of Flooding in Washington, DC.
Source: DC Silver Jacket's "Interior Flooding in Washington, DC"

CONCEPTS TO CONSIDER IN THE DISTRICT'S PROPOSED UPDATED FLOOD HAZARD RULES (2021)

Flood Hazard Area (FHA) – the land in the floodplain within the community subject to a 0.2-percent (0.2%) chance or greater chance of flooding in any given year.

Base Flood Elevation – the elevation of the base (100-year) flood, including wave height, relative to the National Geodetic Vertical Datum (NGVD), North America Vertical Datum (NAVD) or other datum specified on the Flood Insurance Rate Map (FIRM).

High Flood Elevation – the elevation of the high (500-year) flood, including wave height, relative to the National Geodetic Vertical Datum (NGVD), North America Vertical Datum (NAVD) or other datum specified on the Flood Insurance Rate Map (FIRM).

Freeboard – a factor of safety usually expressed in feet above a flood level for purposes of floodplain management. "Freeboard" tends to compensate for the many unknown factors that could contribute to flood heights greater than the height calculated for a selected size flood and floodway conditions, such as wave action, bridge openings, and the hydrological effect of urbanization of the watershed.

Design Flood Elevation – the high flood elevation, or the base flood elevation plus a freeboard safety factor of two feet (2 ft.), whichever is higher.

SEA LEVEL RISE

Global sea levels are rising, and the speed at which this is happening exceeds even the most extreme projections from just a few years ago. The impact will be seen and felt in low-lying portions on the District well within the life expectancy of buildings being renovated or constructed today. The District is already seeing an increase in nuisance flooding (sunny-day flooding) from high tides, and that trend is expected to continue as river levels rise. Higher water levels also worsen flooding during coastal storms, such as hurricanes, with associated winds that push water onshore.

The Federal Emergency Management Agency (FEMA) identifies the 100-year and 500-year floodplains for Washington, DC. These are based on historic flood data and do not account for increasing risk associated with climate change. The 2017 DC Construction Codes, effective in May 2020, require buildings in the flood hazard area (the 100-year and 500-year floodplains) to be elevated or flood-proofed to the high flood elevation or to two (2) feet of freeboard above the base flood elevation, whichever is higher.[2] The DC Flood Risk Tool allows users to determine whether specific addresses are within the floodplain.[3]

To fully account for predicted sea level rise, these guidelines recommend future development should first aim to avoid building in the 100-year and 500-year floodplains. However, if building in the floodplain cannot be avoided, the developer should use a climate-adjusted design elevation, which often exceeds existing and proposed floodplain regulations. For example, the District's proposed updated Flood Hazard Rules include heightened standards for newly constructed or substantially improved structures within a Tidal Shoreline Buffer area. As such, project teams should check that they are in compliance with the code.

The variables used to calculate a climate-adjusted flood elevation, can be found in the following locations:

- 500-year flood elevation (high flood elevation) for a given site is listed in the Flood Profiles section of Exhibit 1 in the DC Flood Insurance Study. Note that lettered cross sections represent the most accurate flood elevation values. Use the highest flood elevation value at the upstream boundary of the project.
- 100-year flood elevation (base flood elevation) is often also listed in the DC Flood Insurance Study but can also be found at dcfloodrisk.org.
- Expected sea level rise should be pulled from Table 1 (see guidance in Section 3 for choosing design parameters based on criticality and lifespan).

SEA LEVEL RISE ADJUSTED FLOOD ELEVATION

Design Flood Elevation [Compare the 500-year flood elevation with the 100-year flood elevation plus 2ft. and select the highest]	+	Expected Relative Sea Level Rise	=	Sea Level Rise Adjusted Flood Elevation

Table 1 below summarizes the suggested adjustment to apply depending on the lifespan of the project and level of risk the asset owner is willing to accept. The project's criticality and lifespan will impact which timeframe is selected.

Table 1: Sea Level Rise Design Values for the District

CRDC FOCAL AREA	DESIGN / PARAMETER VALUES (INCREASE FROM MEAN SEA LEVEL)[iii,iv]			
	INTERMEDIATE	INTERMEDIATE-HIGH	HIGH	EXTREME
2020	0.56 ft	0.72 ft	0.85 ft	0.92 ft
2050	0.56 ft	2.23 ft	2.92 ft	3.31 ft
2080	3.05 ft	4.46 ft	6.07 ft	7.32 ft

INCREASED PRECIPITATION INTENSITY

While low-lying portions of the District will face increased flooding related to sea level rise, all portions of the city are at risk of flooding from extreme precipitation events. There is now clear evidence that storm events are becoming more intense and happening more frequently. The northeast, including the District, has seen a greater increase in extreme precipitation than any other region of the country.[4]

The District expects to see higher quantities of rain in shorter durations of time, creating new challenges for both inland and waterfront properties. Intense storms increase the chances that stormwater management systems will become overwhelmed and flooding will occur in vulnerable locations throughout the city. Increased rain and snowmelt can also exacerbate riverine flooding as more water comes down the watershed and can cause streams and rivers to overflow their banks.

iii. This table provides the recommended design values consistent with calculation of Design Flood Elevation + SLR [select appropriate value from chart above] = the Sea Level Rise Adjusted Flood Elevation.

iv. This table is derived from Sea Level Rise (SLR) projections from NOAA (National Oceanic and Atmospheric Institute) and reflects changes in mean sea level over time.

Therefore, the design storms that inform core decisions, such as the size of storm sewers, must be adjusted. Table 2 shows projected increases in precipitation in three ways for different time periods through the century: the annual number of days with greater than 1-inch accumulation; the design storm accumulation for a 15-year storm event in a 24-hour period; and the accumulation for a 100-year storm event. These values can be used to size building drainage systems, onsite rainwater retention, and stormwater infrastructure. Each projection indicates the mean increase followed by the range of findings based on different models. Section 3 provides guidance for choosing a timeframe and a high or low emissions scenario.

Table 2: Sea Level Rise Design Values for the District

HAZARD	TIMEFRAME	LOW EMISSIONS SCENARIO[v]		HIGH EMISSIONS SCENARIO[vi]	
		MEAN	RANGE	MEAN	RANGE
Days per year with Precipitation Accumulation >1 inch	Historical	9.8 days/year			
	2020s	12.5	8.8 to 16.3	12.3	8.5 to 16.0
	2050s	13.7	9.4 to 18.0	13.2	9.1 to 17.2
	2080s	13.5	9.3 to 17.7	14.6	11.0 to 18.2
15-year 24-hour Design Storm Accumulation (inches)	Historical	5.2 inches			
	2020s	6.3	5.3 to 7.3	6.9	5.6 to 8.3
	2050s	6.8	5.6 to 7.9	6.5	5.7 to 7.4
	2080s	6.4	5.5 to 7.3	8.4	7.2 to 9.6
100-year 24-hour Design Storm Accumulation (inches)	Historical	8.3 inches			
	2020s	11.0	7.4 to 14.6	12.1	8.8 to 15.5
	2050s	11.1	8.1 to 14.2	9.9	7.9 to 12.0
	2080s	13.1	10.4 to 15.9	13.6	11.1 to 16.2

To incorporate future impacts, users should choose the mean value for either the low or high emission scenario depending on the criticality of the project.

v. Low emissions scenario is based on IPCC RCP 4.5.
vi. High emissions scenario is based on IPCC RCP 8.5.

EXTREME HEAT

Climate change is expected to result in significantly warmer average temperatures as well as longer, hotter, and more frequent heat waves. High temperatures can be lethal. Those most at risk include young children, people over 65 years of age, pregnant women, and those with pre-existing medical conditions.[5] The Centers for Disease Control and Prevention (CDC) reports that in the United States, heat exposure causes more deaths than any other weather-related natural disaster averaged over the past 30 years.[6] Power outages that occur during heat waves (when air conditioning loads are greatest, putting stress on the power grid) dramatically increase health risks.

Heat can also impact buildings, infrastructure, and mechanical systems. During extreme heat, increased cooling demand raises the operating costs of our buildings. Paved surfaces deteriorate faster, railroad tracks are more likely to buckle, and planes have greater difficulty taking off.

As temperatures rise, insect ranges are also expanding northward—creating risks for both building structures and public health. Eastern subterranean termites are currently the most destructive termites in the Washington, DC area,[7] though invasive Formosan termite ranges may extend northward as the climate warms—they are currently found as far north as North Carolina.

Disease-carrying insects, especially mosquitoes, are also expanding north. More than a dozen diseases are carried by mosquitoes, including West Nile virus, Zika virus, Chikungunya virus, eastern equine encephalitis, dengue, and malaria; and these diseases are expanding from tropical regions to temperate regions.[8] The first case of West Nile virus was found in Washington, DC in 2002, and it has been found in the District every year since, according to DC Health.

URBAN HEAT ISLANDS

Pockets of higher-than-average temperatures are not evenly spread across the District. Denser urban areas generally have more pavement and buildings that absorb heat, compared to less developed areas, resulting in what is called the urban heat island (UHI) effect. The UHI effect is exacerbated by waste heat released from air conditioning and cars, as well as lack of vegetation (which cools an area through evapotranspiration). The map displayed in Figure 3 shows temperature differentials in the afternoon on a hot summer day. For a more detailed map, use this online version.[9]

The map of the District shows temperature differentials in the afternoon on a hot summer day. Deeper red indicates the hottest areas.

URBAN HEAT ISLAND

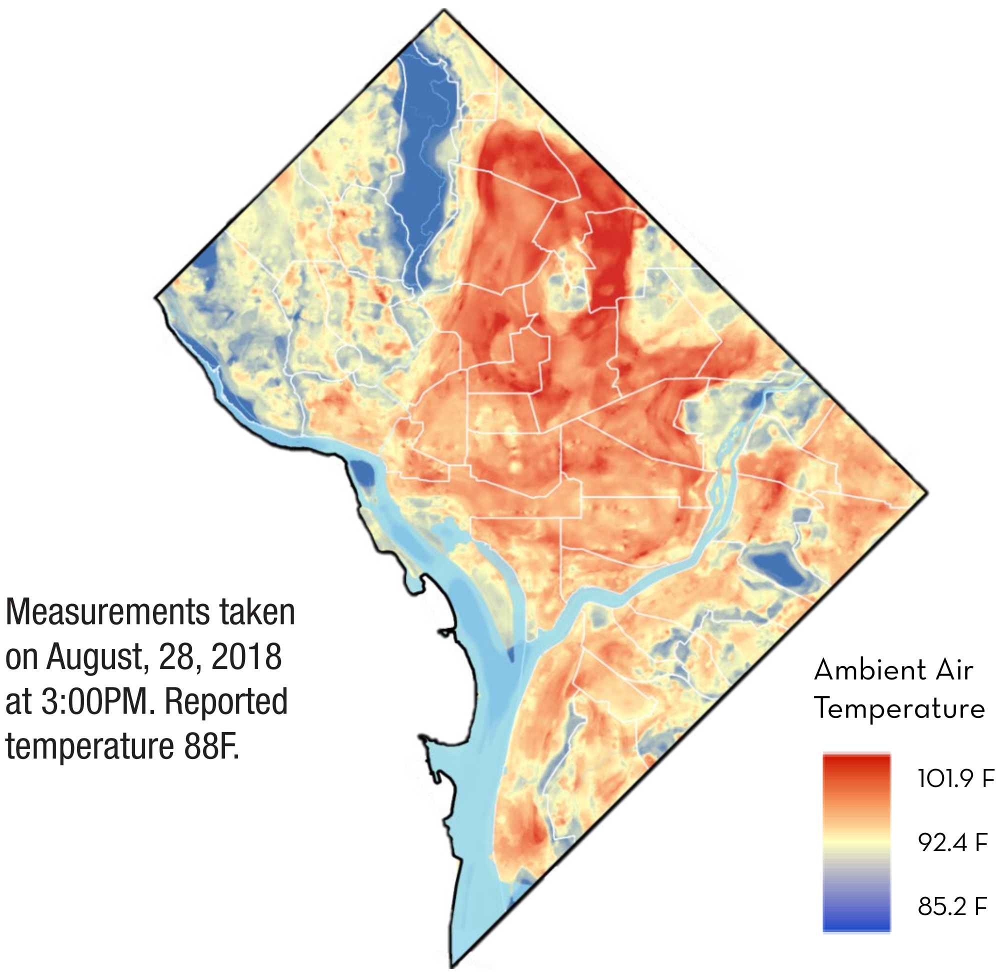


Figure 3: Urban Heat Island Effect in the District
Source: Shandas, V.; Voelkel, J.; Williams, J.; Hoffman, J. Integrating Satellite & Ground Measurements for Predicting Locations of Extreme Urban Heat. Climate 2019, 7.5.

Table 3 shows projected increases in the number of days with temperatures over 95°F and with a heat index over 95°F at different periods through the century. Each projection indicates the mean number of days based on different climate models followed by the range. Section 3 provides guidance for choosing a timeframe and a high or low emissions scenario.

Table 3: Extreme Heat Design Projections for the District[vii]

HAZARD	TIMEFRAME	LOW EMISSIONS SCENARIO[VIII]		HIGH EMISSIONS SCENARIO[IV]	
		MEAN	RANGE	MEAN	RANGE
Days per year with Maximum Temperature >95°F[9]	2000s	13.1 days/year			
	2020s	18.3	6.7 to 29.9	20.3	6.8 to 33.9
	2050s	31.8	12.4 to 51.2	46.5	23.2 to 69.9
	2080s	41.2	17.8 to 64.6	72.4	39.2 to 105.6
Days per year with Maximum Heat Index >95°F[10]	2000s	29.1 days/year			
	2020s	48.8	34.7 to 62.9	51.7	37.0 to 66.3
	2050s	68.2	48.8 to 87.6	80.3	60.7 to 99.8
	2080s	76.5	56.4 to 96.6	106.4	82.3 to 130.5

Table 4 provides the number of Cooling Degree Day (CDD) above historical values based on a 72°F base temperature, considered the baseline for District facilities. Additional baselines are available in Appendix B. Section 3 provides guidance for choosing a timeframe and a high or low emissions scenario.

Table 4: Annual Cooling Degree Day Projections, Using 72°F as Base Temperature

PROJECTED CHANGE IN COOLING DEGREE DAYS OVER HISTORICAL VALUES[X]		
PERIOD	LOW EMISSIONS SCENARIO	HIGH EMISSIONS SCENARIO
2020s	416	434
2050s	701	904
2080s	888	1522

vii. As measured in the shade and accounts for humidity.
viii. Low emissions scenario is based on IPCC RCP 4.5.
ix. High emissions scenario is based on IPCC RCP 8.5.
x. Table based on a reference temperature of 72°F. Positive numbers represent increases from historical values. Values represent ensemble means.

SECTION 3: APPLYING RESILIENCE IN THE DISTRICT

After understanding the primary regional vulnerabilities facing the District, project teams need to make smart decisions about which design parameters to use and which resilient design strategies to integrate into a project. As noted, the climate projection tables in Section 2 typically provide different design parameters for a "high emissions scenario" and a "low emissions scenario," as well as parameters for three different decades: 2020s, 2050s, and 2080s.

This section offers guidance for choosing among the different options.

Together the following three factors create a resilience profile for a project. These factors should be assessed in advance of the project initiation.

CRITICALITY

The nature of a project—its function and the population it serves—plays a very important role in determining the resilience requirements. The more critical the function or the more vulnerable the population, the greater the required resilience measures. Hospitals and schools, for example, exhibit greater criticality than an office building.

LIFE EXPECTANCY

Some projects have a much longer life expectancy and will need to address different climate conditions over a long period of time with significant uncertainty about those conditions. Others have a shorter life and more predictable set of climate conditions. The expected life of a project can also determine whether a more incremental or longer-term solution is warranted.

LOCATION

While some climate indicators are consistent across the District, such as anticipated changes in precipitation and increased temperature, each project location has its own unique set of climate risks. This is especially important for flood-prone locations or those with an increased urban heat-island effect.

The diagram below summarizes the steps to develop a Resilience Profile, as outlined in this chapter. In addition, the checklist provided in Appendix D can be used to document findings at each step.

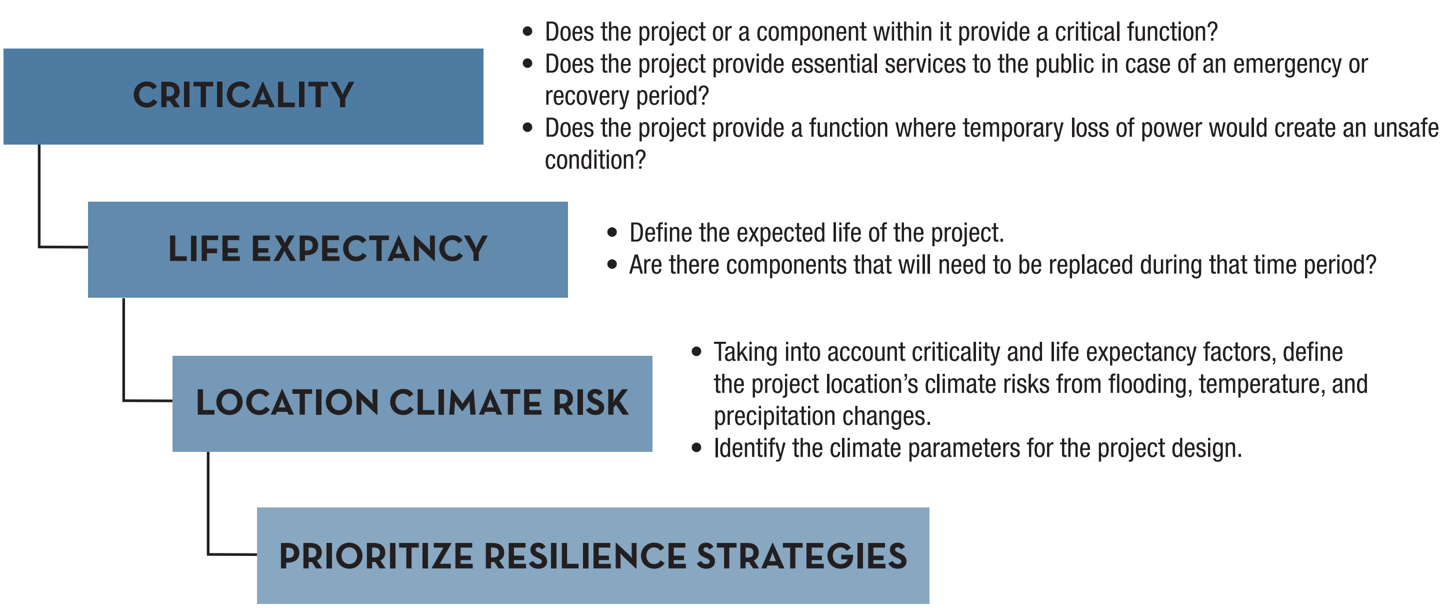


Figure 4: Steps to create a Resilience Profile for a project.

DEFINING CRITICALITY

Some facilities and components are more critical than others and must be protected to a higher standard. As defined by FEMA, a facility is considered critical if damage to that structure would present an immediate threat to life, public health, and safety.[10] DOEE's proposed updated District Flood Hazard Rules consider a "critical facility" to be a building intended to remain operational in an extreme event that contains essential equipment, houses services necessary for emergency response and recovery, or would pose a substantial risk or significant disruption in the event of disruption or damage by flooding.[11] This document draws on DOEE's proposed rules to identify critical uses.

The proposed District Flood Hazard Rules[12] and Section 3.1.6 of HSEMA's District Preparedness Framework[13] list a broad range of critical facility types. This includes:

- Hospitals and healthcare facilities having surgery or emergency treatment facilities;
- Fire, rescue, ambulance, and police stations, and emergency vehicle garages;
- Designated emergency shelters;
- Designated emergency preparedness, communication, and operation centers and other facilities required for emergency response;
- Power generating stations and other public utility facilities required in emergencies;
- Critical aviation facilities such as control towers, air traffic control centers, and hangars for aircraft used in emergency response;
- Ancillary structures such as communication towers, electrical substations, fuel or water storage tanks, or other structures necessary to allow continued functioning of a critical facility during and after an emergency;
- Jails, correctional facilities, and detention facilities;
- Care facilities where residents have limited mobility or ability, including nursing homes but not including care facilities for five or fewer persons;
- Housing owned or operated by the DC Housing Authority;
- Shelters and short-term family housing facilities for individuals experiencing homelessness;
- Elementary schools, secondary schools, and buildings with college or adult education classrooms;
- Preschool and childcare facilities not located in one- and two-family dwellings;
- Hazardous materials facilities;
- Telecommunication towers;
- Data Centers;
- Military bases;
- Memorials and historic landmarks;
- Mass transit, bus, and rail facilities; and
- Water Treatment and wastewater facilities.

OTHER CRITICAL FACILITY CONSIDERATIONS

In addition to those facilities identified as critical by the District, there are other facility types that contribute to emergency operations, provide essential services, or are fundamental to community wellbeing during extreme events. These building types should also be considered high priority for enhanced resilience:[14]

- Embassies and consulate offices
- Nursing Homes
- Blood and organ banks
- Resilience Hubs
- Libraries
- Community Centers
- Pharmacies
- Convenience stores
- Grocery stores and facilities with significant stocks of refrigerated items
- ATMs
- Gas stations

Projects should also consider whether loss of power for any reason over multiple days could create unsafe conditions for occupants. For projects that are part of a connected network, such as a school system, consider whether the individual project might support the larger system if one or more loses power. Examples include:

- Multi-family housing
- Schools
- University housing
- Homeless shelters

Some projects may include critical components that are essential to the project's functionality or may be expensive to replace, such as mechanical and electrical equipment, elevators, and back-up generators. Special care should be taken to protect these. (See Section 4.)

In general, the more critical the facility, the more conservative the design parameter—so the high emissions scenario should be used. The high emissions scenario assumes more extreme impacts from climate change. In most cases, it is unwise to depend on climate change being curbed to ensure that a critical facility will continue to operate into the future. Therefore, designing for the high emissions scenario reduces risk.

Some project teams may want to pursue a fairly nuanced analysis, assessing the criticality of different systems and setting different design parameters accordingly. For example, a school might decide that while its classrooms and cafeteria are critical, its athletic facilities are not. In this case, the school might use the low emissions scenario design parameters for the athletic facilities but the high emissions scenario design parameters for everything else.

As a general rule, these guidelines recommend that critical facilities use high emissions scenarios to design for the following:

- Extreme heat, regardless of whether—but especially if—the project is located within an urban heat island.
- Increased precipitation if there are location-based factors that make flooding from precipitation a concern (see defining climate risks by location).
- Sea level rise if the facility is located within the flood hazard area, adjacent to flood hazard area, or near the waterfront (see defining climate risks by location).

Projects that are not defined as critical may still want to use high emissions scenarios to set design parameters after weighing the next two factors: life expectancy and location risks.

DEFINING LIFE EXPECTANCY

The expected life of a project or component will drive core decisions about how to design for a changing climate.[15] A facility that will last for 30 years should address climate concerns that are reasonably expected over that time horizon.

The life expectancy can also inform whether to use an incremental approach or a longer-term strategy. For example, elevating a new building with a long-life expectancy is significantly cheaper than elevating it after it has been built and occupied for several decades. In other cases, it may be more sensible to build in flexibility for future modifications. Incremental approaches are also an important way of dealing with challenges in existing buildings. For example, if a larger retrofit is not currently an option, consider relocating critical equipment out of the basement to avoid flood damage.

The climate projections in Section 2 include decadal climate projections for the 2020s, 2050s, and 2080s.[xi] Projects should choose the decadal projection closest to the project's expected end-of-life. For example, a project built in 2020 and expected to have a 25-year lifespan would choose the 2050s decadal projection. Table 5 summarizes this.

Table 5: Decadal Climate Projections

DECADAL PROJECTION	EXPECTED END-OF-LIFE
2020s	Present to 2039
2050s	2040-2069
2080s	2070-2099

xi. This methodology mirrors that of the New York City (NYC) Mayors Office of Resilience and Recovery (ORR) Climate Resiliency Design Guideline (March 2019, version 3.0).

Discuss expected lifespan with the project owner. Table 6, adapted from the New York City Climate Resiliency Design Guidelines, provides some guidance for typical life expectancies by project type or component.

Table 6: Facilities and Components and Associated Climate Change Projections[16]

CLIMATE CHANGE PROJECTIONS	EXAMPLES OF BUILDING, INFRASTRUCTURE, LANDSCAPE AND COMPONENTS BY TYPICAL USEFUL LIFE
2020s (present to 2039)	*Temporary or rapidly replaced components and interior finishes, such as drywall and wallcoverings:* *Interim and deployable flood protection measures* • Asphalt pavement, pavers, and other right of way finishings • Green infrastructure • Street furniture • Temporary building structures • Storage facilities • Emergent technology components (e.g., telecommunications equipment, batteries, solar photovoltaics, fuel cells)
2050s (2040-2069)	*Facility improvements, and components on a regular replacement cycle* • Electrical, HVAC, and mechanical components • Most building retrofits (substantial improvements) • Concrete paving • Infrastructural mechanical components (e.g., compressors, lifts, pumps) • Outdoor recreational facilities • On-site energy equipment (e.g., fuel tanks, conduit, emergency generators) • Stormwater detention systems
2080s (2070-2099)	*Long-lifespan buildings and infrastructure* • Most buildings (e.g., public, office, residential) • Piers, wharfs, and bulkheads • Plazas • Retaining walls • Culverts • On-site energy generation/co-generation plants

Facilities or components with longer life expectancies should generally use more conservative design parameters. Climate projections for the 2080s will typically call for more stringent design parameters than the 2050s. However, climate projections for far into the future also have higher levels of uncertainty. If wide ranges of uncertainty pose too much risk, consider switching to a high emissions scenario rather than –or in addition to –choosing the 2080s climate projection.

DEFINING CLIMATE RISKS BY LOCATION

In combination with life expectancy and criticality, the project location plays a pivotal role in setting the climate resilience parameters. The following factors are framed in the context of analyzing a single project site. However, for facilities that are part of a connected network, consider the location risks of all facilities in the network and determine if the current project may play a role in supporting the entire system during a disruption. For example, while a specific school in the DC Public School system may not be in a flood hazard zone, it may serve as a temporary facility for nearby schools that are impacted by flooding.

This step can also help prioritize which resilient design strategies to implement. For instance, project teams with building sites near flood hazard areas should reference the flood strategies in Section 4. Projects near the waterfront should reference the site and landscape portions of Section 4.

EXTREME HEAT

Given the District's building typology, demographics, and climate zone (defined by the U.S. Department of Energy as "hot-humid"), extreme heat is particularly important to address, especially for longer-term projects or those with major system upgrades. All projects should consider heat related risks. However, this is especially important in projects that are in the areas most impacted by the urban heat island.

In choosing which temperature ranges to use as design parameters, projects that are in a significant urban heat island area of the District should use the high-emissions scenario to define temperature variables and prioritize heat resilience strategies. Refer to the Urban Heat Island map to determine if the project is sited within an urban heat island.[17] Urban heat islands are indicated by the color red, with deeper red signifying a more severe urban heat island effect.

FLOODING

If the project is in a flood-prone area, near a river, or in a waterfront area, use the DC Flood Risk Tool to identify whether the project is wholly or partially within an identified flood zone.

If the project is within the 100-year and 500-year floodplain, steps should be taken to minimize risks. These guidelines recommend that building projects avoid such zones if possible. If relocation out of the flood zone is not possible, use the tables and recommendations under Sea Level Rise in Section 2 to determine the sea level rise adjusted design flood elevation for your project. Note that there are four climate projections for the sea level rise table (Table 1), rather than just "high" and "low." This is because sea level rise depends on ocean warming and ice sheet loss, which are estimated using different climate models.[18, 19] For projects in the floodplain, use the "High" scenario. Other scenarios are provided for reference and demonstrates this recommendation is neither the most conservative nor the most optimistic approach.[xii]

Note that the proposed updated DC Flood Hazard Rules prohibit new or substantially improved critical facilities in 500-year or 100-year flood hazard areas without a variance or alternatives analysis and stringent protective measures. A Design Flood Elevation (DFE) of two (2) feet above the high flood elevation is required for such facilities. The proposed updated DC Flood Hazard Rules allow construction of new buildings that are not critical facilities in flood hazard areas as long as they meet stringent standards for flood protection. However, to account for the increased precipitation or sea level rise expected due to climate change, projects should consider exceeding regulations based on these flood zones.

For properties adjacent to, but currently outside of, an official flood hazard area, projects should consider including flood control measures in the project design to address changing climate conditions not reflected in the current flood zone maps.

For projects that are not near a floodplain or waterfront area, teams must assess whether the site may still be vulnerable to increases in extreme precipitation. Projects should be considered high risk if any of the following conditions are met:

- There is a history of flooding or storm sewer overflow
- It requires hydrologic engineering
- There is over 50% impermeable surface on the site[20]
- It is located in a low-lying area where water can pool
- A below-grade basement is planned

In summary, the following location factors increase a project's vulnerability to climate change and should weigh in favor of preferring high emissions scenarios when selecting design parameters:

- Location within an urban heat island
- Location within an identified flood hazard area
- Sites with a history of flooding or in need of hydrologic engineering
- Sites within low-lying areas

xii. Though the extreme scenario (global mean sea level rise of 2.5 meters by 2100) is considered unlikely, scientists note that it is increasingly plausible, based on recent research suggesting some parts of the Antarctic ice sheet may begin to collapse sooner than previously anticipated. Extreme scenarios are generally reserved for the most sensitive infrastructure such as nuclear power plants. The High scenario (2 m) assumes the maximum possible glacier and ice sheet loss. Intermediate-high (1.5 m) is based on an average of the high end of semi-empirical, global SLR projections. Intermediate (1 m) is based on risk primarily from ocean warming.

EXAMPLE: DEFINING A RESILIENCE PROFILE

As an example, consider a hypothetical new building replacing the current RFK Stadium (2400 Capitol St. SE). In this example, the project is a new data center on the same site as the existing structure.

STEPS 1 AND 2: DEFINE CRITICALITY AND LIFE EXPECTANCY

Per the District definition, the project is considered a critical facility. It has an anticipated lifespan of 60 years, so falls into the 2080 projection.

STEP 3: IDENTIFY CLIMATE RISKS BY LOCATION

SEA LEVEL RISE

Although the existing building is not within the current 100- or 500-year floodplain, its critical nature, long life expectancy and adjacency to the 500-year floodplain warrant incorporating flood control measures. In addition, access roads and surrounding areas are in the floodplain, so access to the site should be taken into consideration.

The project team would calculate the sea level rise adjusted design flood elevation:

A. Use the [DC Flood Insurance Study] to identify the Base Flood Elevation (1% Annual Chance Flood) of 13.3 feet and the High Flood Elevation (0.2% Annual Chance Flood) of 15.0 feet (page 48).

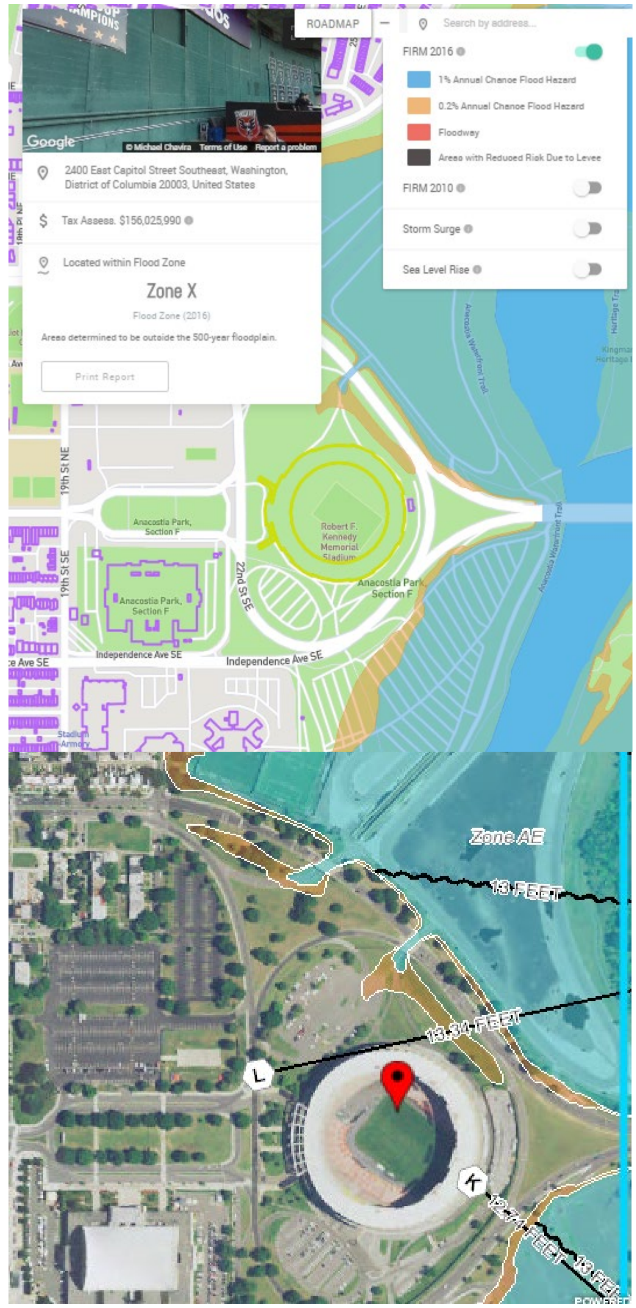


Figure 5: Screenshots from DC Flood Risk Tool showing the stadium is just outside of the floodplain, while the surrounding parking lots and access roads are within it.

B. Compare the base flood elevation plus 2 feet of freeboard (15.3 feet) to the high flood elevation (15.0 feet). Since the former is higher, select this value for the Design Flood Elevation (DFE). As the project is not located within a regulated floodplain, the project team could also choose to select a lower value based on a less cautious approach.

C. Consult the sea level rise table (Table 1), using the 2080 row, and select high emissions scenario column since this is a critical facility. Based on this, 6.07 ft. should be chosen.

Table 1: Sea Level Rise Design Values for the District

TIMEFRAME	DESIGN / PARAMETER VALUES (INCREASE FROM MEAN SEA LEVEL)			
	INTERMEDIATE	INTERMEDIATE-HIGH	HIGH	EXTREME
2020	0.56 ft	0.72 ft	0.85 ft	0.92 ft
2050	1.61 ft	2.23 ft	2.92 ft	3.31 ft
2080	3.05 ft	4.46 ft	6.07 ft	7.32 ft

SEA LEVEL RISE ADJUSTED FLOOD ELEVATION				
Design Flood Elevation	+	Expected relative sea level rise at the end of the asset's useful life	=	Sea Level Rise Adjusted Flood Elevation
EXAMPLE CASE				
15.3 feet	+	6.07 feet	=	21.37

PRECIPITATION

Increased precipitation must be considered, especially since the project is in a low-lying area of the District. Using the precipitation table (Table 2), the project team would use the 2080 row and the high-emission scenario. Based on this, the project team should set design parameters to anticipate 14.6 days with a precipitation accumulation above one inch. Similarly, this project should be designed to expect a 15-year storm with a 24-hour accumulation of 8.4 inches and a 100-year storm with a 24-hour accumulation of 13.6 inches.

Table 2: Changes in Precipitation for the District

HAZARD	TIMEFRAME	LOW EMISSIONS SCENARIO		HIGH EMISSIONS SCENARIO	
		MEAN	RANGE	MEAN	RANGE
Days per year with precipitation accumulation > 1 inch	Historical	9.8 days/year			
	2020s	12.5	8.8 to 16.3	12.3	8.5 to 16.0
	2050s	13.7	9.4 to 18.0	13.2	9.1 to 17.2
	2080s	13.5	9.3 to 17.7	14.6	11.0 to 18.2
15-year 24-hour Design Storm Accumulation (inches)	Historical	5.2 inches			
	2020s	6.3	5.3 to 7.3	6.9	5.6 to 8.3
	2050s	6.8	5.6 to 7.9	6.5	5.7 to 7.4
	2080s	6.4	5.5 to 7.3	8.4	7.2 to 9.6
100-year 24-hour Design Storm Accumulation (inches)	Historical	8.3 inches			
	2020s	11.0	7.4 to 14.6	12.1	8.8 to 15.5
	2050s	11.1	8.1 to 14.2	9.9	7.9 to 12.0
	2080s	13.1	10.4 to 15.9	13.6	11.1 to 16.2

HEAT

All projects in the District should consider increased heat exposure. Even if the hypothetical new building were not a critical facility, the project should still consider using the high-emissions scenario for heat, as it is impacted by the urban heat island (see image of urban heat island map). Using the heat table (Table 3), the project team would determine that the project should be designed assuming that it will see 72.4 days a year of above 95°F dry-bulb temperatures and 106.4 days with a heat index above 95°F. Systems should be designed to adapt over time to projected additional Cooling Degree Days (Table 4) during the building's useful life (1,522).

Table 3: Extreme Heat Design Projections for the District

HAZARD	TIMEFRAME	LOW EMISSIONS SCENARIO		HIGH EMISSIONS SCENARIO	
		MEAN	RANGE	MEAN	RANGE
Days per year with precipitation accumulation > 1 inch	2000s	13.1 days/year			
	2020s	18.3	6.7 to 29.9	20.3	6.8 to 33.9
	2050s	31.8	12.4 to 51.2	46.5	23.2 to 69.9
	2080s	41.2	17.8 to 64.6	72.4	39.2 to 105.6
15-year 24-hour Design Storm Accumulation (inches)	2000s	29.1 days/year			
	2020s	48.8	34.7 to 62.9	51.7	37.0 to 66.3
	2050s	68.2	48.8 to 87.6	80.3	60.7 to 99.8
	2080s	76.5	56.4 to 96.6	106.4	82.3 to 130.5

Table 4: Annual Cooling Degree Day projections, using 72°F as base temperature

PROJECTED CHANGE IN COOLING DEGREE DAYS OVER HISTORICAL VALUES		
PERIOD	LOW EMISSIONS SCENARIO	HIGH EMISSIONS SCENARIO
2020s	416	434
2050s	701	904
2080s	888	1522

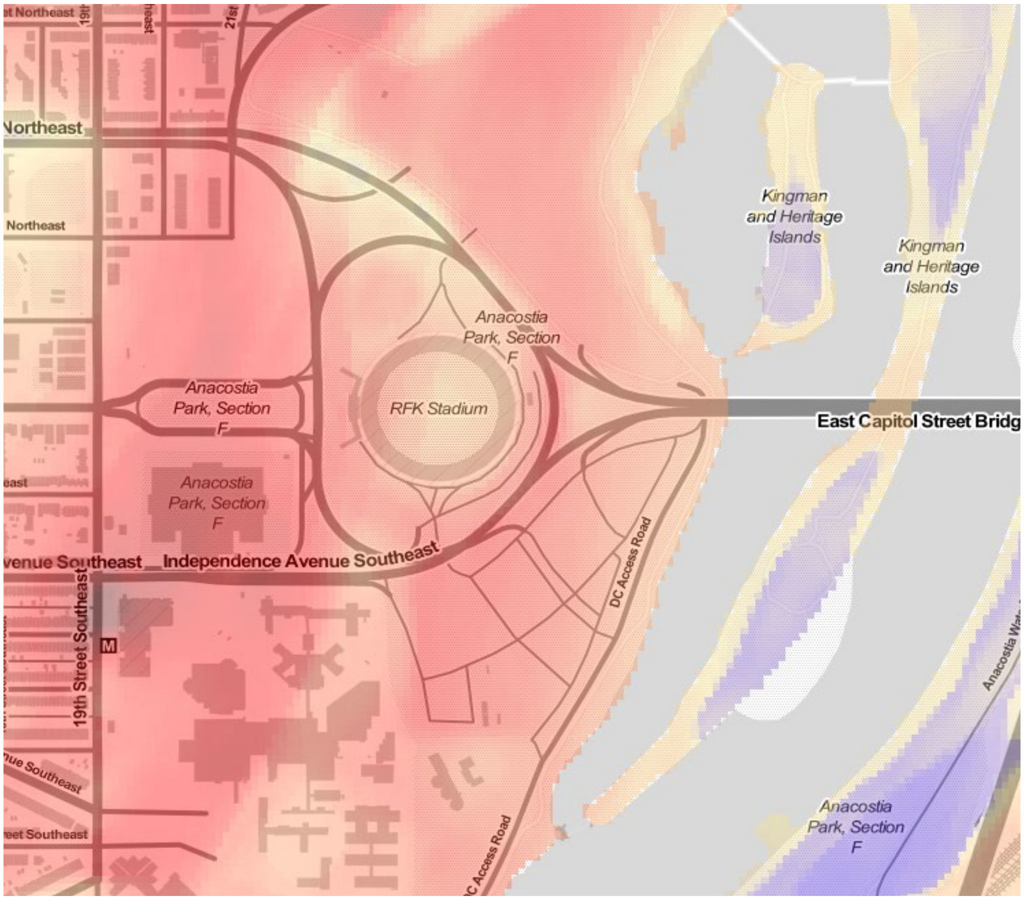


Figure 6: Screenshot from the Urban Heat Island map showing that the stadium is located within an urban heat island.
Source: ClimateScope Online tool

STEP 4: IDENTIFY RESILIENCE PRIORITIES

Based on this analysis, the design team should identify potential strategies for addressing sea level rise, increased precipitation, and heat using the strategies in Section 4 as a starting point. The design requirements should target the identified climate projections.

SECTION 4: RESILIENT DESIGN STRATEGIES

The District of Columbia's climate is changing, putting our buildings, roads, critical infrastructure, and people at risk. While codes and standards are typically designed to incorporate historic weather, these may no longer be sufficient to meet the demands of higher temperatures, more intense precipitation, and increased flooding along our riverways. As part of the District Government's implementation of the Climate Ready DC (CRDC) Plan, these guidelines provide a path to incorporate future climate conditions into District planning.

The strategies outlined are intended for project teams that are interested in exceeding baseline requirements to enhance the project's climate readiness. Projects should still comply with all applicable codes and regulations.

RESILIENT DESIGN STRATEGIES

Once climate risks are defined, the project team can begin to identify design solutions. This section of the Resilient Design Guidelines outlines various strategies to address climate risks in projects in the District. The section begins with overarching considerations that should be considered for all projects, followed by the specific resilient design strategies organized into two categories: *Buildings and Site & Landscape*.

The resilient design strategies presented in these guidelines are not intended to be a comprehensive list of every strategy that could be incorporated into a project. Rather, they are intended to spur thinking by the design teams on how to incorporate climate change resilience into any new construction projects, renovations (modernizations), and even the operation of existing facilities.

There are many other opportunities related to resilience not covered in this document. Design teams should not feel constrained to only the strategies outlined in this document, but instead should use this guidance as a starting point when addressing resiliency.

4.1 OVERARCHING CONSIDERATIONS

The strategies presented below are intentionally general and broadly applicable to many kinds of projects. While focused on resilience, these strategies reflect the need for striving toward goals of sustainability, boosting energy efficiency, minimizing operating costs, and respecting the historical character of the District's buildings.

IDENTIFY OPPORTUNITIES FOR RESILIENCE THROUGHOUT A PROJECT LIFECYCLE

There are opportunities to integrate resilience during every phase of project delivery—from initiation to close out. Even if no construction is currently planned, the resilience of the facility should be continually monitored, so that better choices can be made if rebuilding or retrofitting becomes necessary in the future.

- If the project is already built, include climate risk vulnerability assessments in property condition assessments to influence future renovations. For example, the Department of General Services (DGS) conducts Facility Condition Assessments (FCAs) across its portfolio on a periodic basis (especially for schools).[21]
- Continuously monitor climate risks by paying attention to how the facility responds to minor disruptions, such as power outages or strong storms.

LEVERAGE OTHER SUSTAINABILITY PROJECTS

Project owners should identify opportunities to integrate resilience into sustainability and energy reduction efforts. Many design strategies help to prepare buildings for the impacts of climate change while also working to reduce associated carbon emissions contributing to climate change. There are opportunities to leverage these guidelines to support multiple goals in tandem with the District's adoption of the "Clean Energy DC Act," which establishes a goal to achieve 100% renewable energy by 2032.[22]

- Identify corresponding (and often overlapping) opportunities to make projects more energy efficient and sustainable to maximize value and impact.

DESIGN FOR CHANGING NEEDS

An important aspect of resilience is the ability of a structure to adapt to other uses as needs, demographics, or other circumstances change. Repurposing an older building for a new use typically costs less, has significantly lower environmental impact, and takes less time than building new.

Where feasible, features should be incorporated in the design or modernization of new buildings that would simplify future conversions. For example, a residential area may transition to commercial if a demographic change causes the number of school-aged children to shrink. If the neighborhood school has extra structural support members in the school's gymnasium, an intermediate floor could be added, enabling the school to more easily be transformed into an office or commercial building.

- Incorporate easily modifiable conduit for electrical and data cabling.
- Provide oversized utility chases to allow for the addition of heating, ventilation and air conditioning (HVAC) equipment.
- Avoid interior bearing walls to allow for maximum flexibility over time.

INTEGRATE COMMUNITY SPACES

Resilience is about far more than a building itself; it also involves community and social interaction. Community spaces in and around public buildings, within multifamily spaces, or in the public realm offer places for neighbors to get together and build bonds that could become critically important during natural disasters. For example, public schools can include community spaces that are used actively in the evenings. Police and fire stations can include gathering rooms for community activities. Municipal office buildings can include outdoor courtyards and gathering spaces where employees and residents can enjoy lunch together.

"Your next-door neighbor is your first responder" is a phrase often heard in emergency management. When good design creates opportunities for neighbors to get to know one another, community resilience is enhanced.

- During design development for public facility projects, consider how and where community spaces can be incorporated—both indoors and outdoors. Incorporate that functionality in the design scope.
- Seek community input in planning for any new facility or major renovation.

CELEBRATE AND RETAIN THE HISTORIC CHARACTER OF OLDER BUILDINGS

Older or historic buildings add tremendous character to the District, and that character should be respected and honored in any modernization work that is undertaken.

- Work with historic preservation committees or agencies in the District to develop plans that serve both the goals of functionality and historic preservation.
- Restore any passive design features that may have been relied on prior to the advent of central HVAC systems. By doing so, it may be possible to create a more energy-efficient and resilient building, even as modern air conditioning is added or upgraded. For example, removing drop ceilings to expose full-height windows could save energy through daylighting and passive solar heating. Or reopening natural ventilation shafts could provide resilient natural ventilation. All projects must still adhere to contemporary fire or life safety codes.

ENSURE PROJECT DURABILITY

Resilience is partly about building durability. Building modernizations, as well as new buildings, should be designed to maximize longevity and adaptability to changing needs. One aspect of durability is aesthetics and historic character; buildings that are loved by their communities are more likely to be cared for and property maintained over time.

- Ensure that firms hired to design renovations, additions, and new buildings are fully aware of aesthetic and historic preservation design priorities.
- Employ best building science practices for siting, massing, and building geometry, transitions between old and new building elements, and construction details. Look for design teams that include building science consultants.

CONSIDER THE OPERATIONS AND MAINTENANCE IMPLICATIONS OF RESILIENCE MEASURES

Many of the measures described in this guide have operations and maintenance (O&M) implications that should be taken into account during planning and design. O&M considerations are noted throughout the strategies.

- Consider the costs of ongoing operations and maintenance of each strategy, in addition to the first costs of resilience measures.
- Update Operational Plans to address resilience, as needed.
- Train key custodial and landscape employees or contractors on specific resilience aspects of their work.

MINIMIZE OPERATING COSTS

Resilience measures are not intended to function alone and should be pursued in concert with measures that serve to reduce operating costs and ongoing environmental impacts. This should include strategies for minimizing heating, cooling, water heating, lighting, and ventilation loads; for decreasing maintenance costs; and for reducing outdoor landscaping costs. These efforts will also contribute to Sustainable DC goals.

- Establish rigorous targets for energy performance, such as setting an Energy Use Intensity (EUI) goal.
- Rely on passive energy design strategies to the extent possible, to minimize dependence on mechanical systems; this will enhance resilience, particularly during power outages (see *Design to Achieve Passive Survivability*).
- Ensure that design teams consider ease of cleaning and maintenance. Track-off mats at entryways, for example, will reduce ongoing cleaning costs. In new construction, measures that limit the need for exterior painting, such as installing rainscreens behind siding, have the potential to generate significant savings in avoided costs over the coming decades.
- Daylighting strategies that reduce the need for electric lighting during daytime hours will save operating costs and reduce electrical use.

DESIGN FOR NET-ZERO ENERGY PERFORMANCE

Designing for passive survivability and installing solar-electric systems on a project can result in net-zero-energy performance. Net-zero-energy performance means that energy loads are low enough that a rooftop solar array may provide enough electricity that, on an annual basis, the building generates as much energy as it consumes.[23] Such performance is well-aligned with the Clean Energy DC plan[24] and the Sustainable DC plan.[25]

- Use an integrated design team to target net-zero energy.
- Consider expanding the scope of net-zero-energy design to include backup power with islanding capability so that reasonable functionality and emergency operations can be maintained during power outages.

PROTECT STREETSCAPE VIBRANCY

Resilience measures should enhance rather than harm associated streets and public spaces, especially when coupled with flood protection measures. Elevating structures to reduce flooding risk can create spaces with a few amenities at the pedestrian level. Achieving the proper balance between flood resilience and vibrant streetscapes and community spaces requires careful design. In most cases, adding shading to a streetscape (by planting shade trees) will enhance the streetscape.

- For larger nonresidential and multifamily buildings, create a spacious, floodproofed building lobby or exhibition space at grade, with interior access to floors above the *Sea Level Rise Adjusted Flood Elevation*, rather than exterior stairs and ramps that may create a visual and spatial disconnect.
- For buildings near the property line, façade articulation at the base of the building combined with plantings and screenings can help break up the monotony of an elevated façade.
- For buildings that are set further back from the street, consider elements such as plantings, stairs, porches, temporary seating areas for outdoor cafes, public art, and changes in grade to maintain a more dynamic streetscape.
- Consider the impact of shade structures to mitigate extreme heat on the streetscape. While awnings and constructed shade features could negatively impact the streetscape, planting shade trees typically enhances the streetscape.

Figure 7: This project along McCoys Creek in Jacksonville, FL raises the street level to protect from flooding, but provides a new amenity in the form of a plaza connected to trails.
Photo courtesy of Groundwork Jacksonville

INTEGRATE EDUCATIONAL SIGNAGE

Most buildings, as well as site and landscape features, can educate visitors through effective use of signage. This way, facilities can help further resilient and sustainable practices throughout the District.

- Identify features in a modernization or new facility that can be implemented widely by District residents and businesses, then provide signage to highlight these features and describe their benefits.
- In schools, consider working with teachers to create educational signage and other materials to explain the function and benefits of impactful resilience features.
- Provide a modest budget to pay for interpretive materials.

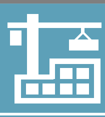
Figure 8: Energy dashboard signage at Discovery Elementary School, a net zero school in Arlington, VA.
Photo courtesy of Lincoln Barbour Studio

RESILIENT DESIGN STRATEGIES MATRIX

#	BUILDING STRATEGIES
	DESIGN FOR FLOODING
1	Avoid Development in Flood Hazard Areas
2	Keep Occupied Spaces Above the Sea Level Rise Adjusted Flood Elevation
3	Integrate Exterior Dry Floodproofing Techniques
4	Improve Drainage Control and Prevent Intrusion into Buildings
5	Use Wettable Systems/Finishes At and Below the Lowest Occupiable Floor
6	Provide Rainscreen Detail for Siding/Cladding
7	Reinforce Building Corners and Exteriors
8	Specify a Resilient Elevator
9	Protect Mechanical and Electrical Equipment from Flooding
10	Install Sewer Backflow Preventers
11	Consider a Vegetative (Green) Roof
	DESIGN FOR EXTREME HEAT
12	Building Form and Envelope
13	Continuous Air Barrier
14	Design for Increased Termites
15	Disease Carrying Insects
16	Mechanical Systems of The Future
17	Vegetated Facade
18	Cool or Reflective Roofs
	DESIGN FOR POWER OUTAGES
19	Achieve Passive Survivability
20	Design for Natural Daylighting
21	Provide Backup Power with Islanding Capability
22	Wire Building so that Critical Loads Are on Separate Circuits
23	Target 100% Building Electrification
24	Install Solar Electric System

#	SITE/LANDSCAPE STRATEGIES
	DESIGN FOR FLOODING
25	Implement Project Setbacks
26	Minimize Channelization of Stormwater
27	Design for Stormwater Infiltration
28	Incorporate Green Infrastructure
29	Install Permeable Pavement
30	Protect Critical Assets with Barriers
31	Plan for Controlled Flooding
	SPECIAL CONSIDERATIONS FOR WATERFRONT AREAS
32	Increase Setbacks From Waterfront
33	Design Waterfront Areas for Inundation
34	Incorporate Living Shorelines
35	Protect Floating Docks and Marina Assets
36	Design Waterfront Boating Access to Accommodate Change
	DESIGN FOR EXTREME HEAT
37	Provide Vegetative Shading
38	Install Drought-Tolerant Landscaping
39	Use Reflective Materials in Paved Patios, Parking Lots, and Sidewalks
40	Provide Shaded Outdoor Gathering Spaces

STRATEGY DESCRIPTIONS & LEGEND

DESIGN CONSIDERATION THEMES	
	**Flooding**
	**Extreme Heat**
	**Power Outages**
	**Waterfront Considerations**
APPLICABLE PROJECT TYPE	
	**New Construction**
	**Existing Building**
RELATIVE COST CONSIDERATIONS[xiii]	
	**Low**
	**Medium**
	**High**
O&M IMPACT	
Scale of low, medium, and high	**Amount/level of operations and maintenance required to implement the strategy.** ***(Note that while some strategies require extra maintenance, others reduce maintenance costs. Such instances are noted in O&M section.)***
RELATED RESOURCES AND REGULATIONS	
2017 District Building Code	***This section supports project teams with initial resources and a means to compare the guidelines to what is required by regulation. It is not intended to be comprehensive.***

xiii. Assessments of relative cost is not based on a rigorous cost analysis, but rather the observations and experience of the authors who have seen such strategies applied on projects.

4.2 BUILDINGS STRATEGIES

A fundamental purpose of buildings is to shelter occupants from the elements, keeping them safe during storms and other disturbances—a key aspect of resilience. The guidance in Section 4.2 of the Resilient Design Guidelines addresses resilience measures specifically for buildings.

Much of the work being undertaken by the District is with existing, rather than new buildings. Though many of the strategies included in the guidelines may appear to be best suited for new construction, the considerations are largely the same when an addition is planned for an existing building, such as when a wall is taken down to the original structural shell (for a gut-rehab). Therefore, the guidance offered here should be considered for all new construction, as well as additions and major renovations.

The strategies that follow are roughly organized by the order in which an issue would be addressed in the planning, design, and construction of a building.

4.2.1 - BUILDING DESIGN FOR FLOODING

Increasing precipitation and sea level rise require that project teams address flooding risks as buildings are constructed or modernized. The overall goal of the strategies in this section is to protect buildings and their occupants from flood damage. In very general terms, the priority for flood protection is, first, to avoid places that are vulnerable to flooding; second, to elevate buildings or functions within a building to minimize flood damage; and third, to protect building components and equipment within a building to minimize flood damage.

Strategies should be pursued in tandem wherever possible, especially where projects are most vulnerable to flooding and sea level rise.

By avoiding or minimizing flood damage, these strategies will extend the useful life of buildings, save money needed for repairs and renovations, and reduce the environmental impacts of repairs due to flooding.

BUILDINGS - FLOODING

1. AVOID DEVELOPMENT IN FLOOD HAZARD AREAS

APPLICABILITY & COST CONSIDERATIONS

OPERATIONS & MAINTENANCE IMPACTS

LOW

RELATED RESOURCES & REGULATIONS

DC Flood Risk Tool

District Flood Hazard Rules

2017 District Building Code – Appendix G

Keeping new buildings out of flood hazard areas will eliminate or reduce the costs and environmental impacts of repairs and renovations resulting from flooding. FEMA defines both 100-year and 500-year flood zones. Areas that are 100-year flood zones are modeled to have a 1% chance of flooding in any particular year; 500-year flood zones are modeled to have a 0.2% chance of flooding in any year. However, FEMA's flood modeling does not take into account increased precipitation or sea level rise expected due to climate change.[26]

GUIDANCE

All new development of critical facilities should be kept out of both 100- and 500-year flood zones if possible (see Section 3 for definition of critical facilities).

Construction of new buildings that are not critical facilities within the 500-year flood zone should be undertaken only with extreme care; avoiding such zones is far preferable. Note that the District's proposed updated Flood Hazard Rules incorporate both the 500-year and 100-year floodplain into a single regulated area known as the Flood Hazard Zone. Within this area, new non-critical projects must meet stringent performance standards for flood protection.

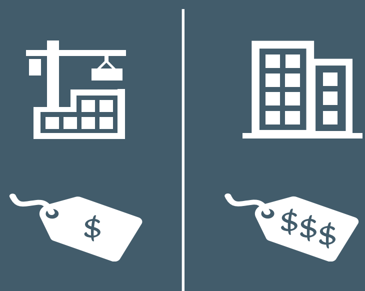
For existing buildings within a 500-year flood zone, weigh the feasibility of relocating or consider how the space can be reconfigured to minimize damage during floods. There should be no impact on operations and maintenance, though projects outside of these flood zones should require less flood-related repair.

OPERATIONS & MAINTENANCE

There should be little to no impact on operations and maintenance, though projects outside of these flood zones should require less flood-related repair.

2. KEEP OCCUPIED SPACES ABOVE THE SEA LEVEL RISE ADJUSTED FLOOD ELEVATION

APPLICABILITY & COST CONSIDERATIONS



OPERATIONS & MAINTENANCE IMPACTS

RELATED RESOURCES & REGULATIONS

District Flood Hazard Rules

FEMA P-348, Protecting Building Utility Systems From Flood Damage

2017 District Building Code – Appendix G

Damage to occupied spaces as a result of flooding is far more costly, dangerous to occupants, and carries a greater environmental impact than damage to unoccupied spaces. The Sea Level Rise Adjusted Flood Elevation provides a greater margin of safety than the *Base Flood Elevation*, which is defined by FEMA to be the 100-year flood elevation.

GUIDANCE

Elevate new construction so that the bottom structure of the lowest occupiable floor is above the Sea Level Rise Adjusted Flood Elevation. (Refer to *Section 2* to calculate).

Elevate critical equipment, such as mechanical systems, above the Sea Level Rise Adjusted Flood Elevation. (Refer to *Section 3* for information on what is considered critical equipment.) Alternatively, install outdoor-rated equipment (e.g., telecom, HVAC, and other mechanical equipment) on the roof.

Protect utility infrastructure that cannot be elevated from flood damage. For specific guidance, please see FEMA's guidance on protecting utilities.

OPERATIONS & MAINTENANCE

Maintenance and repair costs should be reduced if flooding is less likely. These savings should increase over time as sea level rise advances and flooding becomes more common.

3. INTEGRATE EXTERIOR DRY FLOODPROOFING TECHNIQUES

APPLICABILITY & COST CONSIDERATIONS

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OPERATIONS & MAINTENANCE IMPACTS

HIGH

RELATED RESOURCES & REGULATIONS

NYC Retrofitting Buildings for Flood Risk

2017 District Building Code

FEMA P-936, Floodproofing Non-Residential Buildings

District Flood Hazard Rules

Dry floodproofing is the practice of keeping floodwater out of a building by erecting flood barriers, watertight hatches, and other components to keep water out. Dry floodproofing aims to keep floodable spaces entirely dry, eliminating the need for costly cleanup and dewatering following floods. Another benefit is that it helps maintain neighborhood character by keeping windows, crawlspaces, entrances, and retail floor space at the pedestrian level.

GUIDANCE

Assess flooding risk at the site scale, both from coastal storm surge and inland flooding of rivers and streams—now and in the future.

Where flooding is or will be possible, evaluate the addition of flood barriers on exterior doors and windows that can be deployed in advance of threatened flooding.

If considering dry floodproofing, carry out a structural evaluation of any walls that would be exposed to elevated hydrostatic forces during flooding.

When such flood barriers are installed, provide clear instruction on when and how to deploy them.

Waterproof coatings can be used for exterior walls, windows, doors and around utility equipment.

All utility conduits, sanitary, sewer and stormwater infrastructure and other utility equipment should be sealed to prevent water damage.

Backflow prevention devices or tidal check valves can be used to assist with water management. (*See Install Sewer Backflow Preventers.*)

3. INTEGRATE EXTERIOR DRY FLOODPROOFING TECHNIQUES

OPERATIONS & MAINTENANCE

Dry floodproofing components, including flood barriers and watertight hatches, must be maintained to ensure proper functioning during flood events, and some products require significant labor with pre-flood installation and post-flood removal. Facilities staff must be fully trained in the operation of these systems, and clear procedures must be provided for deployment in advance of predicted floods.

SPECIAL CONSIDERATIONS FOR DRY FLOODPROOFING:

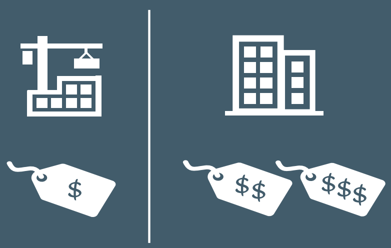
Because dry floodproofing can create significant hydrostatic pressure, this strategy can only be used for floodwaters that are a few inches to slightly over a foot deep in existing buildings. For deeper water, walls, floors, and interior columns and beams must be specifically engineered to resist expected pressures. Therefore, dry floodproofing is mostly pertinent to new construction and rarely allowed for residential buildings—except for mixed-use buildings that include commercial space, storage, or community facilities on ground floors or basement spaces.

Figure 9: Track for demountable flood barrier that can be deployed in advance of a possible flood event. This retrofit of a 19th Century mill building converted into commercial office space in Providence, RI will protect against about a foot of flooding.

Photo: Alex Wilson, Resilient Design Institute

4. IMPROVE DRAINAGE CONTROL AND PREVENT INTRUSION INTO BUILDINGS

APPLICABILITY & COST CONSIDERATIONS



OPERATIONS & MAINTENANCE IMPACTS

RELATED RESOURCES & REGULATIONS

2017 District Building Code

2020 DOEE Stormwater Management Guidebook

External water may enter a building through its foundation, either as bulk water entering through cracks and gaps or as water vapor evaporating on the building interior. That moisture can cause damage directly (for example, to surface finishes) and indirectly by increasing humidity levels in the building.

Keeping bulk water away from the foundation exterior can reduce the risk of flooding, as well as unwanted indoor humidity from water diffusing through foundation walls or floor slabs.

GUIDANCE

Grade the ground surface around a building, providing a minimum grade of 2% (inch per foot) away from the building.

Consider a relatively impervious (high-clay) layer sloping away from the building several inches below ground.

Provide onsite infiltration, but keep infiltration areas at least 10 feet from the building exterior. If space is limited, engage a civil engineer or landscape architect to explore infiltration trenches or other features to infiltrate water closer to the building.

For new construction and additions coat foundation walls on the exterior with a damp proofing layer.

Additionally, for new construction and additions install drainage tile at the wall footings (ideally draining to daylight) and provide a free-draining aggregate or drainage layer on the exterior of the wall; that drainage layer should be protected with a filter fabric/geotextile.

The drainage measures noted above are far easier to achieve with new construction, but it may be possible to retrofit existing buildings. If not, sump pumps should be installed to manage bulk water.

4. IMPROVE DRAINAGE CONTROL AND PREVENT INTRUSION INTO BUILDINGS

OPERATIONS & MAINTENANCE

These drainage measures, if property implemented, should require little, if any, ongoing maintenance. If certain systems are used, such as perimeter drain discharge pipes, it may be necessary to periodically inspect and clear clogging. To maintain surface runoff away from buildings, removing vegetation may be necessary, as roots may compromise surface drainage.

BUILDINGS - FLOODING

5. USE WETTABLE SYSTEMS/FINISHES AT AND BELOW THE LOWEST OCCUPIABLE FLOOR

APPLICABILITY & COST CONSIDERATIONS

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OPERATIONS & MAINTENANCE IMPACTS

LOW

RELATED RESOURCES & REGULATIONS

2017 District Building Code – Appendix G

FEMA Technical Bulletin 7-93, Wet Floodproofing Requirements

Using materials that are resistant to water damage can help avoid the expense and environmental impacts from flooding. Such materials are also usually far less prone to mold growth, offering an additional health benefit.

Even a building that is appropriately elevated, or that is not in a floodplain, can experience water damage from burst pipes or leaking roofs. As a precaution, use wettable finishes on the lowest occupiable floor as well as any unoccupied floors below that, such as a basement.

GUIDANCE

In any space that could be flooded, including—but not limited to—spaces below the Sea Level Rise Adjusted Elevation, use only materials that can get wet and then dry out again without damage.

This applies both to structural materials and finishes.

Avoid paper-faced drywall materials, cellulostic ceiling tiles, and wooden floors.

For schools and many other commercial and institutional buildings, commonly used painted concrete masonry unit (CMU) walls are highly resistant to water damage, as are tile surfaces. For floors, consider polished concrete, which can be finished with decorative pigments and aggregates (creating Terrazzo-like surfaces).

OPERATIONS & MAINTENANCE

Most wettable finishes (and structural materials that serve as finishes)—such as tile, decorative block walls, and polished concrete—are more durable than standard finishes, easier to clean, and will require less maintenance. There may be exceptions, however; consult manufacturer instructions for maintenance requirements.

6. PROVIDE RAINSCREEN DETAIL FOR SIDING/CLADDING

APPLICABILITY & COST CONSIDERATIONS

OPERATIONS & MAINTENANCE IMPACTS

RELATED RESOURCES & REGULATIONS

2017 District Building Code – Appendix G

2017 District Property Maintenance Code

Effective moisture management—both of precipitation and internally generated water vapor—is key for durability as rainfall events become more extreme. Vented rainscreens that allow moisture to escape from a wall system enhance durability and help prevent mold growth.

A rainscreen is a construction detail in which an air space is provided between the exterior cladding of a building (which could include brick veneer, stucco, terra cotta, wood, and other materials) and the structural wall system. This allows cladding (or siding) to dry out between precipitation events, blocks the vapor drive of moisture through cladding materials (such as brick), and allows water vapor from inside the building to escape without causing the walls to degrade or grow mold.

GUIDANCE

Ensure that the design team includes expertise in building science; this is particularly important when existing buildings are being modernized for energy conservation—which may affect moisture dynamics.

With rainscreen details, provide screening to exclude insects from the air cavity.

OPERATIONS & MAINTENANCE

Rainscreen detailing for a building should require little or no ongoing maintenance, though it is advisable to periodically inspect any screening that is used to keep insects out of the rainscreen cavity. A damaged screen should be repaired.

6. PROVIDE RAINSCREEN DETAIL FOR SIDING/CLADDING

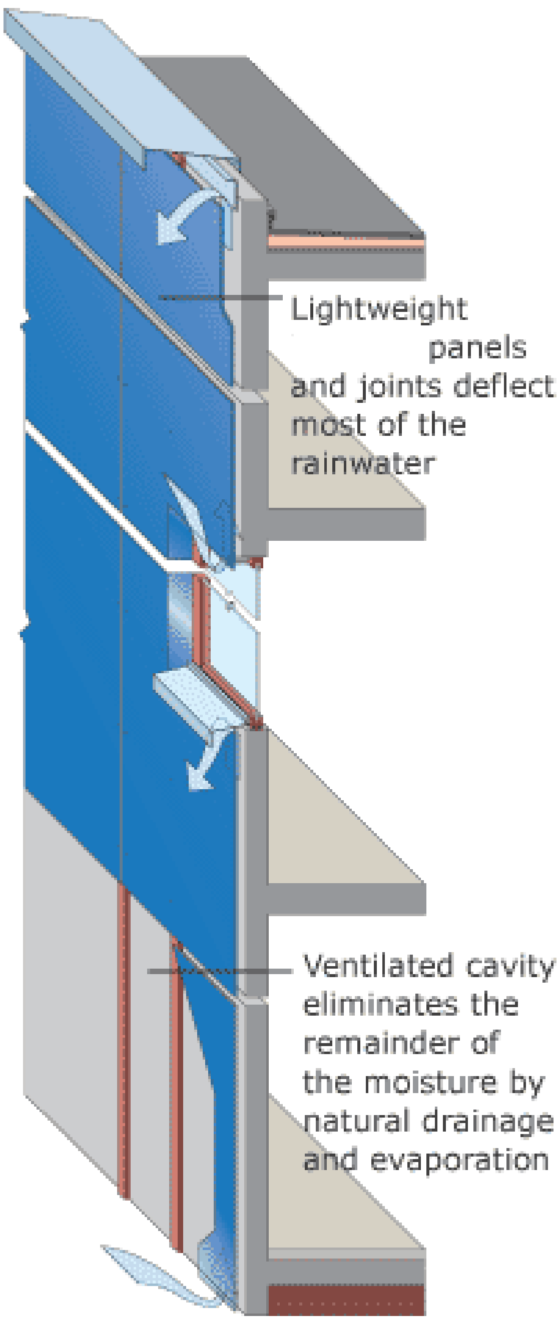

Figure 10: Example of a rainscreen detail that helps the cladding dry out between precipitation events.
Source: DavidWPI

7. REINFORCE BUILDING CORNERS AND EXTERIORS

APPLICABILITY & COST CONSIDERATIONS

OPERATIONS & MAINTENANCE IMPACTS

LOW

RELATED RESOURCES & REGULATIONS

No associated resources and regulations for this strategy.

During floods, particularly inland flood events in which streams or rivers overflow their banks, floating debris may collide with buildings and cause damage. Planning for such impacts and installing features to protect buildings from floating debris is a simple measure that can offer significant resilience and environmental benefits.

GUIDANCE

Along rivers, streams, and other locations where flooding may occur, assess potential debris sources upstream from the building; the shape and weight of expected debris can inform what kinds of protective measures are needed.

Install bollards or other features at building corners and along walls, particularly on the upstream side, to deflect floating logs and other materials during flood conditions. These protective features are important even if the building itself is designed to withstand flooding.

OPERATIONS & MAINTENANCE

There should be little to no ongoing operations or maintenance requirements for structures installed to protect buildings from floating debris. However, because the purpose of such structures may not be obvious, be sure that they are not removed or altered in a way that renders them ineffective.

8. SPECIFY A RESILIENT ELEVATOR

APPLICABILITY & COST CONSIDERATIONS

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OPERATIONS & MAINTENANCE IMPACTS

LOW

RELATED RESOURCES & REGULATIONS

FEMA Technical Bulletin 4, Elevator Installation for Buildings Located in Special Hazard Areas

Elevators can be the most expensive mechanical system installed in a building, and the design of certain types of elevators make them particularly prone to damage during flooding. Specifying the proper type of elevator in a flood-prone location can significantly reduce costs from flood damage, as well as prevent environmental contamination from spilled hydraulic fluid. Guidance is provided for both hydraulic and traction elevators.

GUIDANCE

Avoid basement machine rooms and elevator pits, thus protecting crucial machinery from flood damage.

With hydraulic elevators (commonly used for low-rise buildings), specify "holeless" designs that do not require an elevator pit in a basement and instead use cylinders and direct-acting pistons located higher in the building (where they are fully protected from flood damage).

With traction elevators, typical in taller buildings, specify advanced, energy-efficient models that do not require machine rooms and have controls high in the building or on the roof. These are typically the most energy-efficient elevators available today.

OPERATIONS & MAINTENANCE

Newer elevators that are protected against damage from flooding should require fewer repairs following flood events. Ongoing maintenance requirements and operating costs are highly dependent on the specific product; review these with the manufacturer. Note that some hydraulic elevators require keeping hydraulic fluid warm—which can be a significant share of total energy consumption in a highly energy-efficient building.

9. PROTECT MECHANICAL AND ELECTRICAL EQUIPMENT FROM FLOODING

APPLICABILITY & COST CONSIDERATIONS

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OPERATIONS & MAINTENANCE IMPACTS

MEDIUM

RELATED RESOURCES & REGULATIONS

2017 District Building Code – Appendix G

2017 District Mechanical Code

FEMA P-348, Protecting Building Utility Systems From Flood Damage

Protecting equipment from flooding avoids both the expense and environmental impacts of repairs or replacement while reducing interruptions in service. Basements, where mechanical and electrical equipment are commonly installed, are particularly flood prone.

GUIDANCE

When possible, keep mechanical equipment, including boilers, furnaces, water heaters, and pumps out of basements.

In new construction, highly efficient building design may allow mechanical equipment to be significantly downsized and fossil-fuel-fired equipment to be replaced with more efficient electrical equipment (such as air-source heat pumps). These changes may make placing an equipment room higher in the building more feasible.

In existing buildings, when equipment cannot be moved out of a basement, it should be elevated on concrete pads to minimize flood damage in a modest flood.

Install sump pumps to dewater flooded basements and avoid (or minimize) damage.

Install all wiring and electric panels in basement high on walls to minimize risk of flood damage.

See preceding strategy for special considerations for elevators.

OPERATIONS & MAINTENANCE

Accessibility to mechanical and electrical equipment may be affected, if such equipment would have previously been located in a basement with separate entrance. This may affect security protocols for occupied space.

9. PROTECT MECHANICAL AND ELECTRICAL EQUIPMENT FROM FLOODING

Figure 11: Elevating mechanical equipment in Carolina Beach, NC to protect against coastal flooding.
Photo: Dave Saville, FEMA

10. INSTALL SEWER BACKFLOW PREVENTERS

APPLICABILITY & COST CONSIDERATIONS

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OPERATIONS & MAINTENANCE IMPACTS

MEDIUM

RELATED RESOURCES & REGULATIONS

DC Water Backflow Prevention Guidance

District of Columbia Municipal Regulation Chapter 21-54

2017 District Plumbing Code

During flood conditions, water pressure in sewer lines can result in the backflow of sewage into a building. This most commonly occurs when the building's sewer connection is situated below the highest manhole cover in the sewer system, but it can also be caused by blockages. Installing relatively simple, passive, sewer backflow valves (or backwater valves) can prevent sewage backflow that can cause water damage, contamination, and health risks.

GUIDANCE

Determine whether the project is in a flood hazard area or a part of the District with combined sanitary and storm sewers—areas where having a backwater valve is particularly important.

Contact the DC Water and Sewer Authority for information on sewer backwater valves.

Use only a licensed plumber with experience in backflow valve installation in the District.

Install backflow valves on the street side of the building's sewer trap; there should be at least 2 feet of unbranched sewer pipe upstream of the backwater valve at a minimum 2% pitch.

Provide an access hatch to the backwater valve for cleaning and maintenance.

Install a sewer backflow alarm to notify the building manager of a sewer backflow event (Figure 11).

Brass backflow valves are more resistant to corrosion than cast-iron products, though cost is higher.

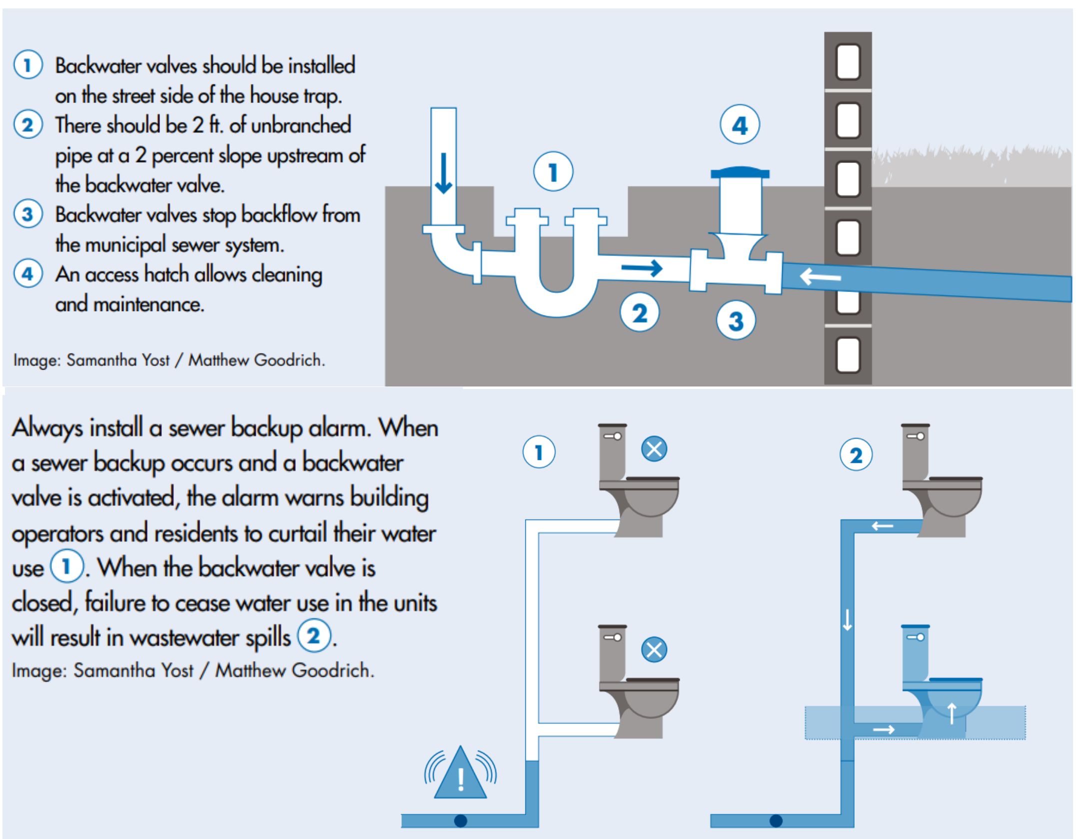
10. INSTALL SEWER BACKFLOW PREVENTERS

GUIDANCE (CONTINUED)

Instruct the building manager on proper operation of backflow valves. When the backflow valve is activated, water use in the building should be reduced or stopped, as sewage can start flowing back through plumbing fixtures when sewage cannot exit the building (see Figure 12).

OPERATIONS & MAINTENANCE

There are specific operations and maintenance requirements for most sewer backflow preventers. Some backflow valves may require periodic cleaning. There may also be specific operational requirements when backflow preventers are in use during flood events, such as avoiding flushing toilets. The plumbing contractor who installs a sewer backflow preventer should provide detailed instructions for operations and maintenance.



Figures 12 and 13: Backflow preventers need to be installed properly and emergency procedures need to be put in place when they are in use to ensure proper operation.

Source: Ready to Respond: Strategies for Multifamily Building Resilience, Enterprise Community Partners, 2015.

11. CONSIDER A VEGETATIVE (GREEN) ROOF

APPLICABILITY & COST CONSIDERATIONS

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OPERATIONS & MAINTENANCE IMPACTS

HIGH

RELATED RESOURCES & REGULATIONS

2020 DOEE Stormwater Management Guidebook

2017 DOEE Green Area Ratio Guidebook

2017 District Building Code

2017 District Fire Code

Vegetative, or green, roofs provide two primary benefits: capturing and retaining stormwater during rain events and reducing the urban heat island effect in urban areas (see sidebar for a more complete list of benefits). Green roofs are divided into two types: intensive green roofs include a fairly thick growing media layer that can support taller plantings and even trees in some cases; extensive green roofs are thinner, much lighter-weight, and typically planted with sedums or grasses. Both types must be carefully designed and built to prevent leakage and other difficulties. Modular green roof systems can often be installed directly on existing low-slope roof surfaces. Green roofs can help projects comply with the DC Stormwater Management and Green Area Ratio requirements.

GUIDANCE

For existing buildings, carry out a thorough structural assessment of the roof and building structure to determine if a green roof is feasible. Not all low-slope roofs can structurally support the weight of a green roof, and some roofs may be too filled with mechanical equipment to permit a green roof installation. There may also be concerns relative to roof access and safety of those who will be on the roof maintaining the plantings; for example, fencing may need to be installed at the roof perimeter.

Given the complexity of green roof systems, it is frequently beneficial to bring a specialized green roof consultant and/or contractor onto the design team.

Design a green roof so that it will be able to retain at least one inch of rainfall, assuming that the roof is relatively dry at the onset of precipitation.

11. CONSIDER A VEGETATIVE (GREEN) ROOF

GUIDANCE (CONTINUED)

Ensure that protection is installed at edges, roof transitions, and penetrations (chimneys, vents, pipes) to limit the chance of plants compromising the building envelope.

Consider plantings for a green roof that can help increase the District's biodiversity, including plants that support pollinator insects. Drought-tolerant plantings are preferred due to the hot, dry conditions found on roofs. An irrigation system can often be avoided for green roofs planted with common sedums.

OPERATIONS & MAINTENANCE

Vegetative or green roofs have significant ongoing maintenance requirements to keep plantings healthy, so do not consider this system unless there is a solid plan for the ongoing landscaping requirements. Depending on the plantings, irrigation may be required during dry periods. Safety of maintenance personnel is of utmost importance, so be sure that suitable protections are in place and that training has been provided. If maintenance is contracted out, make sure that the company providing it is suitably trained and bonded.

BENEFITS OF VEGETATED ROOFS[27]

- Capture an initial portion of the rainfall during precipitation events, thus reducing the contributions to stormwater runoff, flooding, and (where applicable) combined sewer overflow (CSO) events.
- Reduce urban heat islands because green roofs do not heat up as much as typical commercial roofs.
- May contribute insulation to roof systems, helping to reduce heat loss and save energy—or insulation can be added at the time the green roof is installed.
- Offer excellent acoustic benefits, which can be especially important near airports.
- Can support biodiversity by providing habitat to populations of insects, birds, and other species.
- Protect the roof membrane, increasing durability of that material.

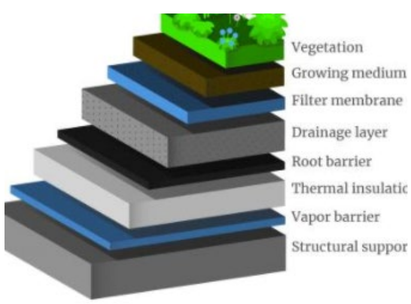


Figure 14: Common Green Roof Layers
Source: Environmental Protection Agency: Using Green Roofs to Reduce Heat Islands

4.2.2 - BUILDING DESIGN FOR EXTREME HEAT

The goal of the strategies presented in this section is to lessen the intensity and impact of extreme heat at the building scale. This will keep residents safer during disasters that may result in interruptions in power, and can reduce the cost and environmental impacts of air conditioning—which are expected to increase dramatically as the climate warms over the coming decades.

These strategies address: keeping unwanted heat out of buildings, planning for wood-destroying and disease-carrying insects extending their ranges north, and planning for greater cooling loads in buildings. Various site- and landscape-scale strategies to address heat are covered later in these guidelines.

Many of these strategies can be pursued at little or no additional cost and are particularly important for areas of the District most prone to excessive heat due to the *urban heat island effect*. Extreme heat is particularly important to address on projects that have more than a 30-year projected service life or may see major system upgrades before service life ends. (See *Design Mechanical Systems for Future Conditions.*)

Project developers should include design components that address and minimize the impacts of future climate related extreme heat by evaluating the following:

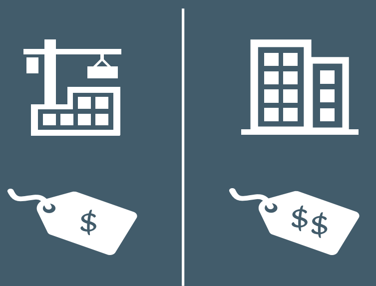
- How the project increases or reduces the urban heat island effect for the surrounding area; and
- The impact that rising average temperatures and increased frequency of extreme heat days will have on the physical building components or the operations of the facility.

The *urban heat island effect* is exacerbated by high densities of impermeable and dark materials that absorb and retain heat. The design interventions provided below address the urban heat island while offering benefits to the community and the facility by reducing energy costs.

12. DESIGN BUILDING FORM AND ENVELOPE FOR FUTURE CLIMATE CONDITIONS

From early stages in design, parameters are set to maintain occupant comfort based on design temperatures (reasonably expected minimum and maximum temperatures). These are typically based on historic climate data. With climate change, both winter and summer design temperatures are expected to rise. Setting overall building design parameters based on warmer temperatures will optimize long-term economic value, functionality, and comfort without primarily relying on mechanical systems. (See Appendix B Tables 3-7.)

APPLICABILITY & COST CONSIDERATIONS



OPERATIONS & MAINTENANCE IMPACTS

RELATED RESOURCES & REGULATIONS

No associated resources and regulations for this strategy

GUIDANCE

In early design stages, use future climate conditions to set an Energy Use Intensity (EUI) goal to define building massing and orientation, shading, and window-to-wall ratios. The goal is to both reduce energy consumption while maintaining long term comfort.

Ensure that design teams are using *predictive weather data* when setting building envelope *U and R values*.

Employ passive strategies to minimize reliance on mechanical systems and develop an integrated building systems approach. These might include adding insulation, upgrading windows, or—for buildings with high-pitched attic spaces—incorporating a radiant barrier.

For buildings with a long-term function, such as schools and civic buildings, consider how the building envelope can adapt to changing conditions over time and incorporate those potential adaptations into the initial design. This could include future additions of shading, "plug and play" building envelope elements, or additional roof insulation.

12. DESIGN BUILDING FORM AND ENVELOPE FOR FUTURE CLIMATE CONDITIONS

OPERATIONS & MAINTENANCE

There should be little to no impacts to operations and maintenance through enhanced envelope building design solutions.

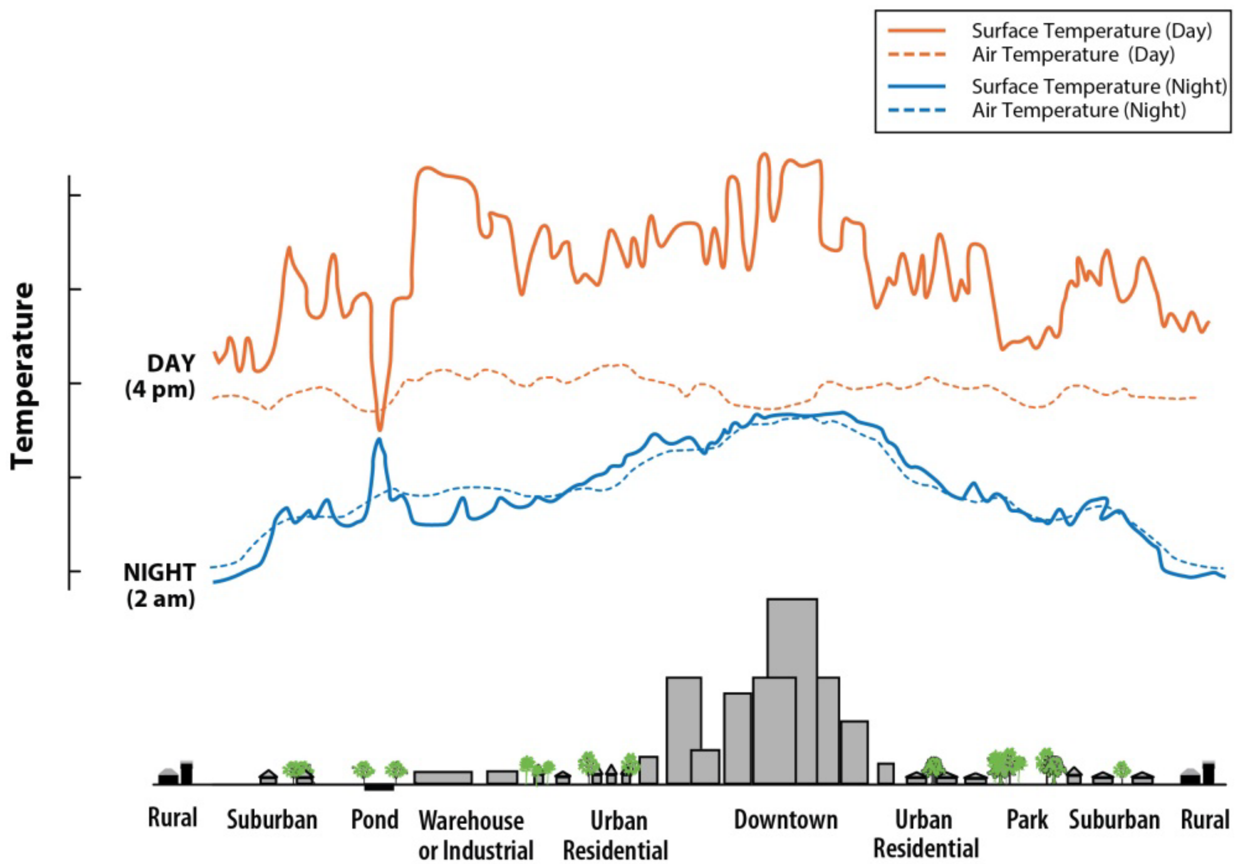


Figure 15: Urban areas are hotter during the day than rural areas, and don't cool down as much at night, resulting in what is called the urban heat island effect.
Source: US Geological Survey, EPA

13. PROVIDE A CONTINUOUS AIR BARRIER IN THE BUILDING ENVELOPE

APPLICABILITY & COST CONSIDERATIONS

OPERATIONS & MAINTENANCE IMPACTS

LOW

RELATED RESOURCES & REGULATIONS

[2017 District Energy Conservation Code, Commercial Provisions]

A continuous air barrier in the building envelope will help ensure good energy performance, avoid moisture problems in a building, and enhance long-term durability. An air barrier is the system of materials that separates the indoor, conditioned air from outdoor, unconditioned air. Air barrier systems are continuous if there is some material impermeable to air flow over the entire building enclosure, including tricky transitions, such as foundation-to-wall or wall-to-roof. With rising temperatures and potentially higher precipitation in the future, the control of air and moisture flow into the building envelope is particularly important to ensure building durability.

GUIDANCE

Hire a design team that includes expertise in building science. With additions and new construction, ask the architect to show the continuous air barrier path in envelope cross-sections.

With modernizations of existing buildings, ask the design team to demonstrate how air and moisture flow will be minimized and potential problems mitigated through the envelope design.

OPERATIONS & MAINTENANCE

This measure should have little to no impact on operations or maintenance.

14. DESIGN FOR INCREASED TERMITE PRESSURE

APPLICABILITY & COST CONSIDERATIONS

OPERATIONS & MAINTENANCE IMPACTS

LOW

RELATED RESOURCES & REGULATIONS

No associated resources and regulations for this strategy

As the climate warms, our buildings need to be made more resistant to wood-boring insects, whose ranges are extending northward. This includes Formosan termites, *Coptotermes formosanus*, an invasive species of termite introduced from southern China and Taiwan.[28] Protecting against infestations of termites, carpenter ants, and other wood-boring insects will require more diligent efforts than what has been needed to-date.

GUIDANCE

Provide termite-proof barrier materials in the foundation system and the connections between foundation and above-ground structure.

Install a termite shield between the foundation and above-ground portions of the building.

Provide an "inspection area" at the top of the foundation wall so that termite mud tubes will be visible (subterranean termites cannot be exposed to the air, so they often build mud tubes that extend over impenetrable materials, such as concrete).

Keep the area immediately around a building free of plantings and brush, as this may increase the likelihood of insect infestations.

If termites are found in a building, use termite bait controls rather than blanket insecticide treatments to avoid danger to humans and the ecosystem.

14. DESIGN FOR INCREASED TERMITE PRESSURE

OPERATIONS & MAINTENANCE

Once installed, termite shields, screens, and other physical barriers require little, if any, maintenance. However, building foundations should be inspected at least annually to identify mud tubes that subterranean termites may have built to access the building. Some ongoing maintenance is also advisable to remove vegetation immediately around a building (within three or four feet).

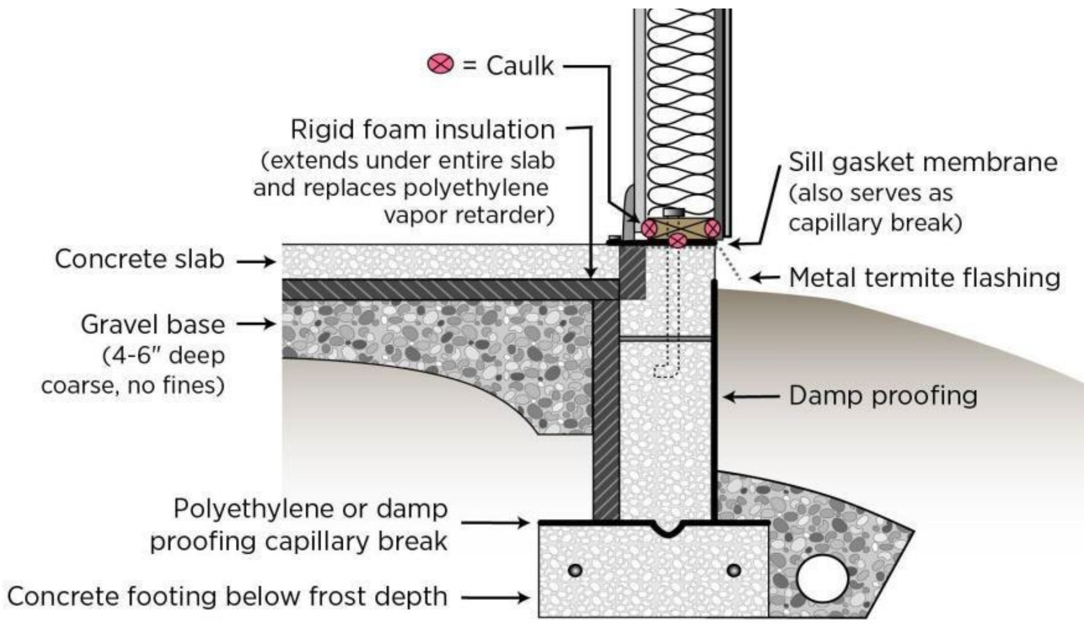


Figure 16: An example of termite flashing in a typical construction detail.
Source: Pacific Northwest National Laboratory, Building America Program.

15. PROTECT AGAINST ENTRY OF DISEASE-CARRYING INSECTS

As the climate warms, mosquitoes and other disease-carrying insects' ranges are extending northward.[29] As such, more diligent efforts to exclude flying insects may be required to protect building occupants.

GUIDANCE

Provide quality screening on operable windows; evaluate durability and convenience of screen systems.

Provide insect screening on HVAC air intakes to exclude flying insects.

OPERATIONS & MAINTENANCE

Window screens typically require seasonal installation and removal by facilities staff, though some screening is installed by the user when windows are opened and closed. Insect screening on HVAC air intakes should be inspected and cleaned annually to ensure that airflow is not being impeded.

APPLICABILITY & COST CONSIDERATIONS

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OPERATIONS & MAINTENANCE IMPACTS

MEDIUM

RELATED RESOURCES & REGULATIONS

2017 District Property Maintenance Code

16. DESIGN MECHANICAL SYSTEMS FOR FUTURE CLIMATE CONDITIONS

APPLICABILITY & COST CONSIDERATIONS

OPERATIONS & MAINTENANCE IMPACTS

LOW

RELATED RESOURCES & REGULATIONS

WeatherShift

The Climate Explorer

2017 District Energy Conservation Code, Commercial Provisions

Mechanical heating and cooling systems are sized to maintain comfort based on *design temperatures* (reasonably expected minimum and maximum temperatures). Both winter and summer design temperatures are expected to rise, and thus mechanical systems should be designed to accommodate these changes.[xiv] Even for buildings that are not heavily used during the peak summer months, such as schools, air conditioning has become increasingly necessary during spring and fall months. By fully understanding the changing conditions, design teams can optimize mechanical system sizing, resulting in energy savings and improved comfort.

GUIDANCE

Employ passive strategies for mitigating heat gain first, then evaluate whether to size up mechanical systems. (See strategies including: *Design Building Form and Envelope for Future Conditions, Install a Reflective or Cool Roof, Provide Vegetative Shading, and Achieve Passive Survivability*)

Ensure that design teams are using *predictive weather data* when sizing mechanical equipment for buildings (see Section 2).

For facilities that are not currently being mechanically cooled (such as those with little summertime use), consider providing for the addition of cooling in the future. With facilities that do not have air conditioning, incorporate air conditioning during modernizations.

xiv. See Tables 4-7 in Appendix B.

16. DESIGN MECHANICAL SYSTEMS FOR FUTURE CLIMATE CONDITIONS

GUIDANCE (CONTINUED)

Design flexibility into mechanical systems. For example, given the *Clean Energy DC Plan*, the District is expecting a shift from fossil-fuel-fired systems to electric heat pump technology that can be powered with renewable energy. Provision for such future modifications should be planned for and opportunities for integrated new technologies assessed at least every five years.

Ensure that mechanical equipment can be easily accessed for future modifications as conditions require.

For facilities with a long-expected service life, design for 100% electrification of all equipment.

OPERATIONS & MAINTENANCE

Giving forethought to future modifications of mechanical equipment should improve access for servicing and ongoing maintenance.

17. CONSIDER A VEGETATED FAÇADE

APPLICABILITY & COST CONSIDERATIONS

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OPERATIONS & MAINTENANCE IMPACTS

HIGH

RELATED RESOURCES & REGULATIONS

2020 DOEE Stormwater Management Guidebook

2017 DOEE Green Area Ratio Guidebook

2017 District Building Code

2017 District Fire Code

Vegetated facades reduce temperatures of a building by directly shading heat-absorbing surfaces and through direct cooling via evapotranspiration; however, they can be difficult to maintain and an eyesore if the plants die. (See also *Design for a Vegetated Roof.)*

GUIDANCE

Investigate the added structural load of a vegetated façade before proceeding.

Choose plants that can handle the varying light levels at different heights of the building façade and the amount of wind present at the location. In selecting plants, work with a landscape contractor who has experience in establishing and maintaining a vegetated façade.

Beware of planting self-clinging climber plants, such as English ivy, on facades where the cladding is in poor condition or may be damaged. These climbers may hide damage under leaf cover.

Consider installing a support system that keeps plants away from the building facade; this support structure must be securely fastened to the wall.

Install an irrigation system, especially if pursuing a façade with vertical plantings. Controlling water pressure will be important, as well as maintaining any sensors that govern automated watering cycles.

17. CONSIDER A VEGETATED FAÇADE

OPERATIONS & MAINTENANCE

Giving forethought to future modifications of mechanical equipment should improve access for servicing and ongoing maintenance.

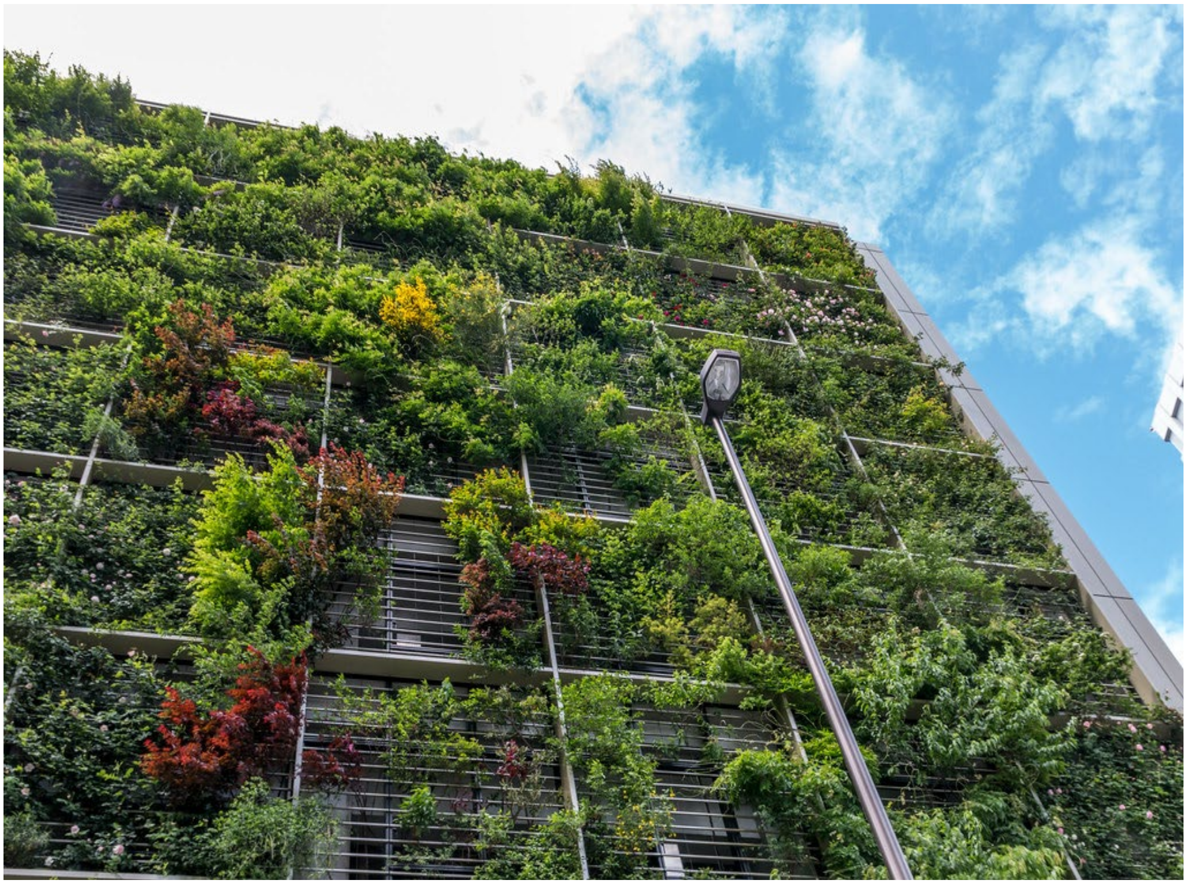

Figure 17: Vegetated Façade
Source: “Tokyo” by leander.kirsteinheine is licensed under CC BY-NC-SA 2.0

BUILDINGS - EXTREME HEAT

18. INSTALL REFLECTIVE OR COOL ROOFS

APPLICABILITY & COST CONSIDERATIONS

$ $$ | $ $$

OPERATIONS & MAINTENANCE IMPACTS

LOW

RELATED RESOURCES & REGULATIONS

Cool Roofs Rating Council

2017 District Energy Conservation Code, Commercial Provisions

A reflective (high-albedo) roof surface reduces cooling loads in the building and mitigates the urban heat island effect.[30] Heat loads in the building are reduced by slowing conductive heat transfer through the roof, and this reduction in energy consumption reduces the building's contribution to greenhouse gas emissions and global warming. Minimizing *urban heat islands*—localized warming that is experienced in urban neighborhoods—has District-wide benefits. Additionally, cool roofs have been shown to enhance the performance of rooftop solar systems; some studies have attributed a 5-10% improvement in generation when coupled with cool roof applications.[31]

GUIDANCE

Cool roofs are required within the District's code for new or replacement roofs (R908).

Install reflective roofs when re-roofing or with new construction. Cool roofs are feasible with both low-slope and pitched roofs by following guidance of the EPA's Energy Star Roof Program.

Specify reflective roof products certified by the Cool Roofs Rating Council.

Consider retrofitting with a reflective elastomeric coating when existing low-slope roofs are in reasonably good shape. Along with providing reflectivity, this can increase the roof life by protecting the older roof surface.

Blue roofs (e.g., roof systems that are explicitly intended to capture rainfall) coupled with light colored roofing material, can provide stormwater management as well as rooftop cooling. Investigate structural capacity before proceeding.

18. INSTALL REFLECTIVE OR COOL ROOFS

OPERATIONS & MAINTENANCE

Reflective roofing typically requires little to no ongoing maintenance once installed. In fact, retrofit installations (reflective elastomeric coatings on existing roofs) should increase the life of the existing roof and may reduce the need for roof repairs. Annual power-washing of reflective roofing will improve energy performance (reflectivity), especially in locations exposed to significant particulate pollution.

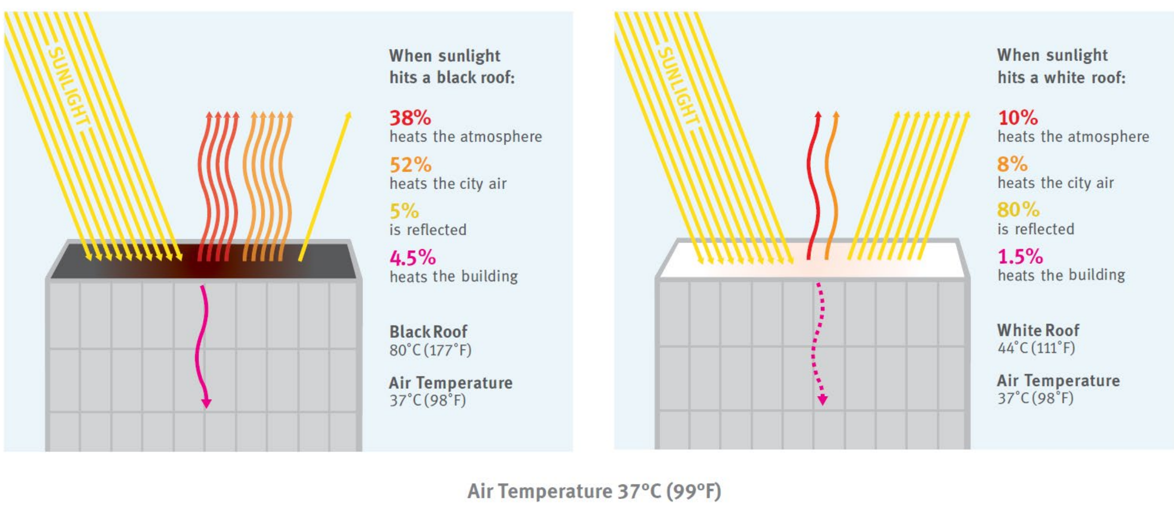

Figure 18: Reflective roofing: Difference in heat dispersal on a black versus white roof.
Source: Lawrence Berkeley National Lab

4.2.3 - BUILDING DESIGN FOR POWER OUTAGES

A wide variety of natural and man-made disasters can result in extended power outages. Without electricity, the vast majority of heating, cooling, ventilation, and in some cases, critical life support systems cannot function—putting building occupants, visitors, or those seeking emergency refuge at risk.

The goal of the strategies described in this section is to keep building occupants safe during and after disasters and other disturbances that may result in extended power outages. Secondary goals of these strategies include: reducing the operating costs of buildings during normal (non-emergency) operation and reducing environmental impacts through reduced fossil fuel use. These goals can be achieved through energy-efficient building design, design for passive heating and cooling, natural daylighting, and backup power systems.

Strategies should be pursued together whenever possible, especially where projects are most vulnerable to loss of critical function from power outages.

19. ACHIEVE PASSIVE SURVIVABILITY

APPLICABILITY & COST CONSIDERATIONS

$$

$$$

OPERATIONS & MAINTENANCE IMPACTS

LOW

RELATED RESOURCES & REGULATIONS

LEED Pilot Credit, Passive Survivability and Back-up Power During Disruptions

Passive House Institute, PHIUS+ Certification

Power outages are expected to become more common as a result of more intense storms and flooding. A building designed to achieve *passive survivability* will maintain temperature conditions that keep occupants reasonably safe during extended power outages. Design features that enable a building to achieve passive survivability will also dramatically reduce operating energy use and greenhouse gas emissions.

GUIDANCE

Establish a passive survivability performance goal for the project. The intent should be to maintain habitable conditions during an extended power outage. Design features may include:

- Highly insulated building envelope
- High-performance windows (multiple glazing layers, low-e coatings, low-conductivity gas fill)
- Passive solar heating
- Cooling-load-avoidance features (building siting and geometry that limits afternoon sun, reflective roofing, louvered shades on windows, etc.)
- Vegetative shading
- Reliance on natural ventilation
- Manual controls to change shading and temperature, such operable windows, pull-down shades, and vents.

Particularly for critical use facilities, comply with the Passive Survivability requirements of LEED Pilot Credit, "Passive Survivability and Access to Back-Up Power During Disruptions."[32]

19. ACHIEVE PASSIVE SURVIVABILITY

OPERATIONS & MAINTENANCE

There is a wide range of measures that, in aggregate, enable a building to achieve passive survivability. Some of these specific measures will have minor maintenance requirements, such as periodically cleaning south-facing windows relied on for passive solar heating or pruning trees that provide summertime shade, but most such measures will have little to no maintenance requirements. From an operational standpoint, these features will significantly reduce energy consumption and cost.

20. DESIGN FOR NATURAL DAYLIGHTING

APPLICABILITY & COST CONSIDERATIONS

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$$$

OPERATIONS & MAINTENANCE IMPACTS

MEDIUM

RELATED RESOURCES & REGULATIONS

LEED Daylight Credit

2017 District Energy Conservation Code, Commercial Provisions

Natural daylighting offers energy savings[33] and productivity benefits[34] in classrooms and other occupied spaces, and also provides important resilience benefits in the event of power outages. For schools and office buildings used predominantly during the day, significant reliance on daylight, as opposed to electric lighting, will allow continued functioning during power outages and/or fuel savings when using backup generators. Daylighting involves solar apertures that bring natural light deep into building interiors. Specialized design features can enhance daylighting, and advanced controls achieve commensurate energy savings through reduced electric lighting.

GUIDANCE

Specify glazing that optimizes visible light transmittance (VLT), even when long-wavelength, heat radiation is selectively blocked.

Provide *light shelves* with reflective upper surfaces that transmit natural light deeply into building interiors.

Consider adding tubular skylights or specialized fiber-optic daylighting systems that can deliver daylight to spaces without full access to windows.

In older buildings including schools, evaluate whether drop ceilings that block the top of existing windows can be removed. Restoring original ceiling height will enhance daylighting.

In modernization projects, restore original transom windows (if they have been closed off) to bring natural light into corridors.

Achieve LEED requirements for daylighting whether or not LEED certification is being sought; there are various paths to compliance.

Replace older light controls with advanced controls that automatically reduce electric lighting levels when adequate daylighting is available.

20. DESIGN FOR NATURAL DAYLIGHTING

OPERATIONS & MAINTENANCE

Maintaining optimal daylighting requires some ongoing maintenance, including periodic window washing, cleaning light shelves (which reflect daylight deeper into rooms), and cleaning daylight and occupancy sensors that turn off or dim electric lights when natural daylight is adequate. Depending on the design, there may also be some daily operation of window blinds or other window coverings required.

Figure 19: A dropped ceiling at the Capitol Hill Montessori School near Union Station, showing how daylighting is still able to enter the room. In some situations, drop ceilings from previous modernizations can be removed to allow full ceiling height to be restored, further improving daylight distribution.
Photo: Alex Wilson, Resilient Design Institute

BUILDINGS - POWER OUTAGES

21. PROVIDE BACKUP POWER

APPLICABILITY & COST CONSIDERATIONS

$$$ $$$

OPERATIONS & MAINTENANCE IMPACTS

MEDIUM

RELATED RESOURCES & REGULATIONS

LEED Pilot Credit, Passive Survivability and Back-up Power During Disruptions

Climate Ready DC

A source of backup power keeps critical systems operational when the regional power grid is down. Backup power can be provided by a fuel-fired generator or a battery system and can either serve the entire building or just critical loads. A primary advantage of a battery system is that it can be charged by a grid power or renewable energy system. A *microgrid* that serves a neighborhood or campus and can operate in an *islanding* mode would also provide this functionality by maintaining power when the regional grid is down. Design projects to comply with the LEED Backup Power requirements.[35]

GUIDANCE

Consider a renewable energy system with battery backup, rather than a fossil-fuel-fired generator to avoid greenhouse gas and other air emissions as well as fuel supply issues.

For highly critical facilities with fuel-based back-up power, develop a plan for quickly replacing equipment in the event of a primary backup failure.

Configure wiring so that backup power can be provided to only the building's critical loads. (See *Wire Buildings so that Critical Loads are on Separate Circuits.*)

Provide access and clearances that allow for an off-site emergency generator to be brought in should the on-site generator fail.

Investigate with the utility company the feasibility of establishing a microgrid that would allow the delivery of power even when the regional grid is down; this will be most feasible for campuses and clusters of buildings that are served by their own power plants.

21. PROVIDE BACKUP POWER

OPERATIONS & MAINTENANCE

Backup generators should be tested semi-annually or annually, depending on the manufacturer's recommendations. Long-term storage of liquid fuel (diesel or gasoline) can be problematic; in such situations there should be a plan in place to either add fuel conditioners to increase the lifetime, or use the stored fuel and replace it with fresh fuel. O&M staff should be trained on sourcing fuel, testing, and deployment, as well as restart and automation override procedures.

BUILDINGS - POWER OUTAGES

22. WIRE BUILDINGS SO THAT CRITICAL LOADS ARE ON SEPARATE CIRCUITS

In most situations, backup power does not need to be provided for a building's entire electrical load; ensuring emergency backup power is available for critical loads within the building will usually suffice. For this strategy, create a separate critical-load circuit so that backup power can be supplied only for that load and not the entire building. This will allow for a smaller, more affordable, battery system or less fuel to be stored onsite.

GUIDANCE

Identify critical loads for new buildings or those undergoing a major renovations or modernizations. The critical loads for a building will vary considerably based on the type of building and expected uses.

Critical loads could include—but are not limited to—the following:

- Electrical components of fuel-fired heating systems;
- Minimal ambient lighting throughout the building and within 10 feet of building entrances on the building exterior. A minimum of 3 foot-candles (32 lux) is recommended for low-level ambient light;
- At least one location for every 500 square feet of floor area for occupied buildings that provides a minimum of 30 foot-candles (320 lux) measured 30 inches above the floor;
- A minimum of one outlet (receptacle) per 250 square feet of occupied space throughout an occupied building (for cell phone charging and other critical plug loads);
- Cable modems, wireless routers, and other components required for Internet communications;
- Ceiling fans and other low-energy fans that can be used when refrigerant-cycle air conditioning is not available;
- Pumps, if needed, to distribute potable water throughout building;

APPLICABILITY & COST CONSIDERATIONS

$ $$ | $$ $$$

OPERATIONS & MAINTENANCE IMPACTS

LOW

RELATED RESOURCES & REGULATIONS

2017 District Electrical Code

22. WIRE BUILDINGS SO THAT CRITICAL LOADS ARE ON SEPARATE CIRCUITS

GUIDANCE (CONTINUED)

- Powered components of wastewater conveyance or treatment systems (if present); and
- Powered access-control systems for entrance doors and other doors for which security is required.

Provide electrical connections and switches that function either automatically or manually, to deliver battery or backup generator power to identified critical loads.

OPERATIONS & MAINTENANCE

Once this measure is implemented there should be little to no ongoing operations or maintenance.

23. INSTALL SOLAR ELECTRIC SYSTEM WITH ISLANDING CAPABILITY

APPLICABILITY & COST CONSIDERATIONS

$$$ $$$

OPERATIONS & MAINTENANCE IMPACTS

HIGH

RELATED RESOURCES & REGULATIONS

DC Solar Map

DOE Tax Credits, Rebates & Savings

DC Sustainable Energy Utility

PSC Net-metering Rules

At the building scale, photovoltaic (solar-electric) systems offer one of the best options for renewable energy. When coupled with at least some battery storage and an ability to draw power during power outages (islanding capability), solar-electric systems can provide back-up power in the event of an outage. However, even when battery storage is provided, few solar-electric systems will be sufficient to power the entire building.

GUIDANCE

Carry out a solar assessment to determine whether a solar-electric system is feasible and cost-effective. The DC solar map provides a high-level assessment for your facility.

Include battery storage as an option in bid documents for any solar installation, and evaluate the extra cost of battery backup against the cost of a solar system without battery backup plus the cost of a stand-alone backup generator.

Clarify the net-metering rules for solar-electric systems in the District with Pepco, the utility. The DC Public Service Commission has ensured net-metering rules are attractive for both residential and commercial customers.

Look into any special utility incentives that may exist for battery storage—especially a battery system that enables the utility company to use it for demand management. In other words, the utility company may be interested in subsidizing a battery storage system if it can use the system to manage peak demand in the power grid.

Select quality solar modules and inverters for solar-electric systems. Look for a good performance guarantee and equipment warranty on solar modules and UL ratings on both modules and inverters. Performance should be guaranteed to maintain at least 90% of rated

23. INSTALL SOLAR ELECTRIC SYSTEM WITH ISLANDING CAPABILITY

GUIDANCE (CONTINUED)

output for 10 years and 80% for 25 years. Modules should be warrantied to perform for at least 10 years without problems. Inverters should be warrantied for at least 10 years.

Except in locations where partial shading of the solar array is significant, specify string inverters (inverters that are separate from the modules, with multiple modules feeding into each inverter), as these are typically more durable than *microinverters* (separate inverters built into each module) and easier to replace when they fail.

OPERATIONS & MAINTENANCE

Solar-electric systems may require periodic cleaning of solar modules and monitoring to ensure proper operation. Over the long term, inverters, which convert direct-current (DC) electricity into alternating-current (AC) that can be used in buildings and fed into the grid, need to be periodically replaced as well. In general, a 25-to 40-year life can be expected for modules, while 10 to 15 years is more typical for inverters. Battery systems may require special maintenance.

24. TARGET 100% BUILDING ELECTRIFICATION

APPLICABILITY & COST CONSIDERATIONS

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$$ $$$

OPERATIONS & MAINTENANCE IMPACTS

LOW

RELATED RESOURCES & REGULATIONS

2017 District Energy

Conservation Code, Commercial Provisions

By pursuing 100% electrification, all building systems will more easily adapt to onsite or grid-delivered renewable energy and therefore will be more prepared to continue functioning during power outages. Also, building electrification contributes to the reduction of greenhouse gas emissions and provides safety and health benefits to building occupants by removing on-site fossil fuel combustion.

GUIDANCE

For new construction: Specify only electrically powered, high-efficiency mechanical and electrical equipment and appliances.

For modernizations: Replace older, fossil-fuel-fired heating and water heating equipment with high-efficiency, electric equipment. The lack of flue pipes may make it easier to locate equipment on upper floors, avoiding flood-prone basements.

Specify ENERGY STAR air-source heat pumps as an alternative to gas- or oil-fired furnaces or boilers for space heating and window air conditioners for cooling.

OPERATIONS & MAINTENANCE

Operating cost impacts of switching from natural gas or fuel oil to electricity will depend on how the electricity is used (heat pump technology vs. electric-resistance heat) and what fuel is being replaced. Given the high coefficient of performance of heat pumps, there may be an immediate operating cost savings by switching from propane or heating oil. A longer payback is likely when converting from natural gas. The expected lifespan of heat pumps is comparable to or slightly shorter than that of fossil-fuel-fired heating equipment, but annual cleaning and maintenance requirements are usually lower.

4.3 SITE AND LANDSCAPE STRATEGIES

Although buildings are where people typically shelter, shared public spaces and the landscapes around buildings cannot be forgotten. This is where some of the most effective resilience strategies can be implemented, such as stormwater control features, plantings for heat island mitigation, temporary flood barriers, and seawalls. The guidance in this section addresses resilience measures at the site and landscape level.

At the site level, water infiltration projects can relieve stress on aging stormwater management systems, and modest landscape design decisions can lessen the urban heat island effect. Measures implemented at the site and in the landscape can mitigate the severity of storms and heat waves and reinforce building-scale measures that are being implemented.

Site and landscape strategies may require design teams to include a civil engineer or landscape architect on the project team, though there are many site and landscape strategies that can be implemented without specialized design team members.

4.3.1 - BUILDING DESIGN FOR FLOODING

Strategies covered in this section focus on capturing and infiltrating stormwater, avoiding or managing stormwater flows, and keeping floodwaters at bay. Such measures tend to have little, if any, negative impact on appearance or functionality of a landscape. In fact, they have the potential to enhance those aspects of the area, while also improving resilience.

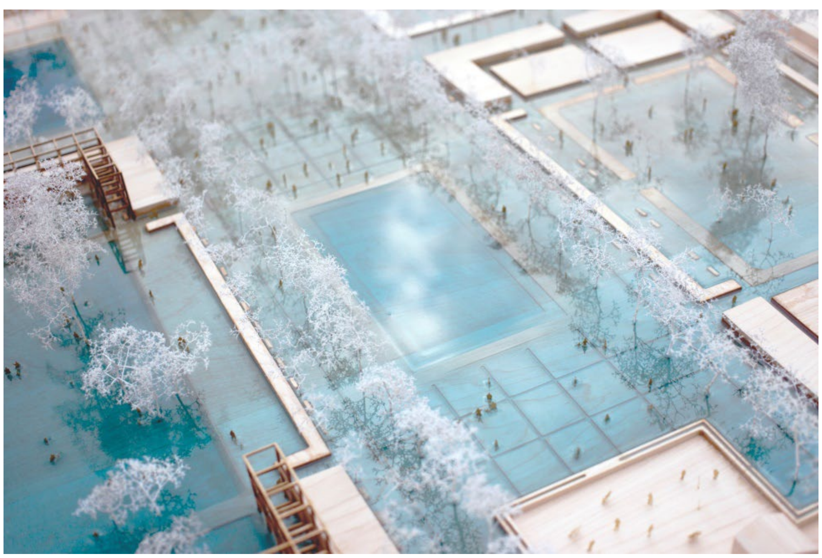


Figure 20: The plazas and open fields of Enghaveparken Climate Park in Copenhagen, Denmark are currently being renovated to be floodable spaces during extreme rain events.
Source: THIRD NATURE

SITE & LANDSCAPE - FLOODING

25. IMPLEMENT PROJECT SETBACKS

Setting structures and site features back and out of regularly inundated areas offers the highest level of structural protection. Additionally, setbacks can create space to restore wetlands or invest in green space that can provide protection and environmental benefits.

COST CONSIDERATIONS

GUIDANCE

Design teams should try to keep structures, especially critical structures, outside of the 100-year or 500-year floodplains. For an even greater margin of safety, site projects at Sea Level Rise Adjusted Flood Elevations. (See Section 2 to calculate.)

Employ site-wide elevation or grading changes to meet target elevation if the space allows.

If a setback is not feasible, use a partial setback from higher-frequency flood zones combined with alternative flood risk reduction strategies outlined in these guidelines.

OPERATIONS & MAINTENANCE IMPACTS

LOW

OPERATIONS & MAINTENANCE

Other than reducing the need for repairs due to flooding, siting should have little to no operations or maintenance implications.

RELATED RESOURCES & REGULATIONS

2017 DOEE Green Area Ratio Guidebook

District Flood Hazard Rules

26. MINIMIZE CHANNELIZATION OF STORMWATER

Curbs along roadways and driveways typically channel stormwater to storm sewers, carrying stormwater away from the site and into nearby surface waters. In this capacity, curbing plays an important role in localized stormwater management. However, in situations where that stormwater can be infiltrated onsite, rather than being carried away in storm sewers, the impact on regional flooding can be reduced and local ecosystems can be enhanced.

COST CONSIDERATIONS

$

OPERATIONS & MAINTENANCE IMPACTS

LOW

RELATED RESOURCES & REGULATIONS

2019 DDOT Design and Engineering Manual

GUIDANCE

Engage a civil engineer or landscape architect to advise on stormwater management practices.

When slope and soil conditions permit, avoid use of raised curbs altogether—though in some cases curbs will be required to prevent erosion.

Without curbs, sheet runoff from crowned roadways and driveways should be allowed to flow into vegetated buffers and swales along those paved areas. (See *Incorporate Green Infrastructure.*)

Shed surface water away from buildings and other structures in the landscape.

26. MINIMIZE CHANNELIZATION OF STORMWATER

OPERATIONS & MAINTENANCE

When curbs and storm sewers are not used for stormwater conveyance, there is usually less need for ongoing maintenance—like clearing debris and unclogging storm sewer drains. When sheet runoff from paved surfaces is used instead, there may be increased risk of erosion, requiring repairs. Furthermore, grassy swales used for capturing and infiltrating sheet runoff will need ongoing mowing and other turf maintenance.

Figure 21: A raised curb has been removed and sheet runoff runs directly into an infiltration trench and bioswale.

Source: Minnesota Pollution Control Agency, Minnesota Stormwater Manual

27. DESIGN FOR STORMWATER INFILTRATION

COST CONSIDERATIONS

$ — $$$

OPERATIONS & MAINTENANCE IMPACTS

MEDIUM

RELATED RESOURCES & REGULATIONS

2020 DOEE Stormwater Management Guidebook

Extreme precipitation events cause significant stormwater runoff, which contributes to downstream flooding and can result in *combined sewer overflow* (CSO) events in areas with older sewer systems. Infiltrating a significant portion of the rainfall onsite can reduce flooding and the environmental impacts of CSO events.

GUIDANCE

Commission a stormwater plan that includes provisions for enhanced infiltration for any new building project or major modernization project in which the site will be modified.

Incorporate stormwater features that will allow a 2 inches storm event in 24 hours to be infiltrated onsite, to the extent possible.

Account for projections of increasing storm intensity as a result of climate change. Use the latest data from the District in creating stormwater management plans. (See Section 3.)

Minimize or avoid contiguous impermeable surfaces in the landscape.

Install stormwater filtration systems to treat stormwater runoff from parking lots and other impervious surfaces with significant pollutant loading.

Consider the specific stormwater infiltration measures that are described in accompanying text on Green Infrastructure (#28).

27. DESIGN FOR STORMWATER INFILTRATION

OPERATIONS & MAINTENANCE

When curbs and storm sewers are not used for stormwater conveyance, there is usually less need for ongoing maintenance—like clearing debris and unclogging storm sewer drains. When sheet runoff from paved surfaces is used instead, there may be increased risk of erosion, requiring repairs. Furthermore, grassy swales used for capturing and infiltrating sheet runoff will need ongoing mowing and other turf maintenance.

28. INCORPORATE GREEN INFRASTRUCTURE

Designers should consider landscape and site features that can absorb and manage extreme precipitation events without impacting water quality. Typically, above-ground approaches like retention ponds can manage regular precipitation and provide a buffer for extreme rain events. These options are often implemented in conjunction with below-ground stormwater conveyance and storage systems. Green infrastructure strategies that infiltrate, evaporate, or reuse rainwater improve water quality, and reduce stormwater volume, downstream flooding, and CSO events (where combined sanitary and storm sewers exist).

GUIDANCE

Incorporate green infrastructure, such as bioswales and rain gardens, to capture and infiltrate stormwater.

Use open space such as parks, playgrounds and permeable parking areas to improve detention and infiltration of excess stormwater that results from flooding events. For small-area planning purposes, consider how a network of open spaces and detention areas can address flood risk.

For areas that do not have space for bioswales and other nature-based solutions, use permeable surfaces and subsurface detention.

Implement engineered streams, ponds, and wetlands to convey stormwater and provide longer-term retention.

Install stormwater infiltration, detention, and storage (e.g., bioswales, green roofs, blue roofs, and other blue or green infrastructure; storage basins or tanks).

Explore interventions to protect underground utility and telecommunications infrastructure from water damage.

COST CONSIDERATIONS

$$ – $$$

OPERATIONS & MAINTENANCE IMPACTS

MEDIUM

RELATED RESOURCES & REGULATIONS

2020 DOEE Stormwater Management Guidebook

District Blue Green Infrastructure Report

DOEE RiverSmart Program

OPERATIONS & MAINTENANCE

Many green infrastructure features require regular maintenance. For example, rain gardens and bioswales may require hand-weeding to remove invasive species. Autumn leaf removal from infiltration basins may be required to avoid clogging. Plants may need to be replaced, especially within the first few seasons. Some vegetated areas may require irrigation during droughts. A landscape contractor should be able to advise on ongoing maintenance needs.

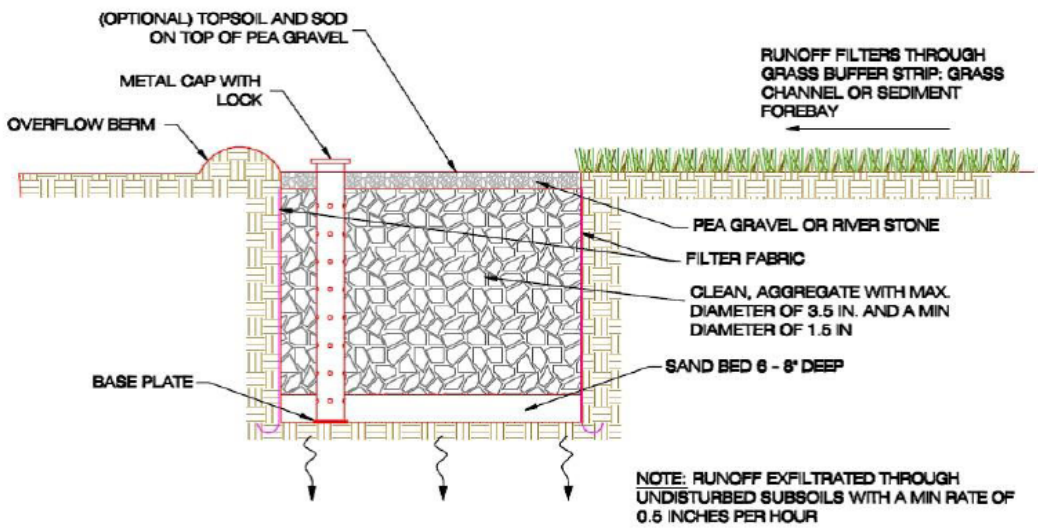


Figure 22: This diagram shows the elements of a stormwater infiltration trench.
Source: Stormwater Management Guidebook, DOEE, 2020

29. INSTALL PERMEABLE PAVEMENT

Properly designed and installed permeable pavement can reduce flooding pressure by absorbing precipitation without creating stormwater flows. (The terms porous asphalt, pervious concrete, and permeable pavers are all used to describe such approaches, but this usage is not always consistent; the term permeable pavement is used here when referring to all three of these options.) Surfaces planted with turf (grass pavement) can also be permeable, though a matrix to prevent compaction is typically required. A permeable pavement system can sometimes reduce the size of—or even eliminate—storm sewers and other stormwater infrastructure, such as detention ponds, significantly reducing construction costs for a new facility or an addition.

COST CONSIDERATIONS

$$

OPERATIONS & MAINTENANCE IMPACTS

HIGH

RELATED RESOURCES & REGULATIONS

2020 DOEE Stormwater Management Guidebook

GUIDANCE

Engage a civil engineer or landscape architect to design a permeable pavement system.

Consider standard pavement for more heavily traveled roads and driveways, with permeable pavement for parking areas.

Permeable pavement can be made with asphalt pavement, concrete pavement, or modular pavers. With asphalt and concrete pavement, make sure that the supplier has had experience with permeable mixes. With pavers, it is the space between the pavers that typically provides the permeability; the pavers themselves may or may not be permeable.

Ensure that there is a well-designed base to a permeable pavement system—this should include a properly sized layer of free-draining, tamped, aggregate that can serve as a storage reservoir and a geotextile filter fabric to keep silt out of the drainage layer.

29. INSTALL PERMEABLE PAVEMENT

GUIDANCE (CONTINUED)

Establish winter maintenance practices so that the pore structure in the pavement does not become clogged. Winter sanding should generally be avoided on pervious pavement.

In seasons other than winter, regular vacuum sweeping may be required to maintain permeability, and edges may need to be detailed to limit movement of debris across the paved surface.

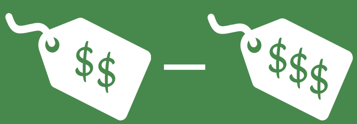
OPERATIONS & MAINTENANCE

Permeable pavement systems typically require different winter maintenance needs than standard pavement. Winter sanding for ice can clog the pores in porous asphalt and pervious concrete. Plowing snow on grass-paved systems may require special shoes on snowplows to avoid digging into the support matrix. Periodic vacuum-sweeping of most types of permeable pavement may be needed to maintain permeability.

SITE & LANDSCAPE - FLOODING

30. PROTECT CRITICAL ASSETS WITH BARRIERS

COST CONSIDERATIONS



OPERATIONS & MAINTENANCE IMPACTS

HIGH

RELATED RESOURCES & REGULATIONS

No associated resources and regulations for this strategy.

Temporary or permanent flood barriers can protect important landscape features, buildings, roadways, bridges, and other elements that are expected to flood yet impractical to elevate. Permanent barriers include sea walls and levees. Temporary barriers include sandbags, barriers that can be inflated with water or air, and temporary (demountable) flood walls and gates.

GUIDANCE

Install temporary barriers in critical areas expected to receive flooding in extreme weather events or to route water flow away from key facilities.

Consider permanent flood barriers to protect landscape features, roadways, and buildings that are expected to receive routine flooding and size them to meet expected flood levels. (See Section 3.)

In planning removable (demountable) flood barriers that fit into permanently installed tracks, consider the permanent components that must be installed, as well as the covered, easily accessible storage that will be required for storing flood barriers when not deployed.

Engage a structural or civil engineer—or rely on the expertise from the manufacturer of a temporary flood barrier system—to assess the acceptable height of the barrier system, and make sure that the structure is suitable for the application.

30. PROTECT CRITICAL ASSETS WITH BARRIERS

OPERATIONS & MAINTENANCE

Staff should be trained on how to properly store, deploy, and dismount temporary flood barriers, given that they are erected in advance of a storm, then dismantled and stored. Equipment may require modest maintenance to ensure proper operation when needed. For panel-type flood barrier systems that get inserted into pre-installed channels, periodic cleaning may be required to remove accumulated detritus, and nearby trees and other vegetation may need to be removed to prevent roots from buckling the flood barrier channels. Levees should be inspected periodically for erosion and repaired as needed. Reusable inflatable barriers and sandbags should be inspected periodically and repaired or replaced as needed.

Figure 23: Streetlight bases at the edge of a park form supports into which removable flood barriers slot in.

Source: Amec Foster Wheeler West Riverfront Park Development, Metro Nashville Parks Department

SITE & LANDSCAPE - FLOODING

31. PLAN FOR CONTROLLED FLOODING

COST CONSIDERATIONS

$ — $$

OPERATIONS & MAINTENANCE IMPACTS

HIGH

RELATED RESOURCES & REGULATIONS

No associated resources and regulations for this strategy.

Not all projects need to be fully functional during a flood event. Designing some landscape elements to allow flooding (both routine and catastrophic) to happen in a controlled manner directs flooding to where it will result in minimal damage. Identifying those features, such as parks or plazas that could be designed for temporary inundation during an event, can protect more vulnerable buildings or landscape features.

GUIDANCE

Identify parks, plazas, or other open spaces that can be flooded during storm events with little damage.

When the floodable area may include significant pollution sources or litter, install filtration or pollutant-removal systems to clean stormwater when it drains.

Develop a plan and clear signage to protect the public during flood conditions—keeping people out of areas designed to receive floodwater. Temporary barriers may be needed.

Electrical panels and critical equipment in public park and plaza areas should be raised above expected flood stage elevations.

Make use of sophisticated weather forecasting to provide advance warning of likely flood inundation, so that temporary barricades and signage can be deployed. Put a plan in place to ensure community safety and provide a clear chain of authority in the District for emergency management of public spaces, including possible evacuation, during flood events.

31. PLAN FOR CONTROLLED FLOODING

OPERATIONS & MAINTENANCE

Stormwater filtration or pollutant removal systems may be needed when parking lots or plaza areas that may contain significant pollutants or litter are designated as floodable areas. Those systems must be property maintained, as per the manufacturers' instructions, to ensure effective operation. For areas designed for inundation during flood events, clear signage must be maintained, and damaged or missing signs replaced. Crews must be properly trained and available to correctly deploy barricades and temporary signs, as needed, in advance of predicted flood events.

Figure 24: Rotterdam's Benthemplein water square is used as an amphitheater, basketball court, or skateboarding rink in good weather. When a cloud burst hits it transforms into a series of collection ponds.

Source: De Urbanisten

4.3.2 - SPECIAL CONSIDERATIONS FOR WATERFRONT AREAS

Areas of the District along the Potomac and Anacostia Rivers, and their associated tidal basins and bays, call for special consideration relative to flooding. Specific strategies for these waterfront areas are described in this section.

Figure 25: Waterfront properties, like those along the Anacostia River, require enhanced measures to protect from flooding.
Source: DC Department of Energy & Environment

32. INCREASE SETBACKS FROM WATERFRONT TO ACCOUNT FOR SEA LEVEL RISE AND STORM SURGE

As of April 2020, the current setback requirement in the District for Waterfront areas is 75 feet, with certain exceptions noted in the regulations.[36] This requirement applies not only to buildings, but also landscape features. These setback requirements should be considered a minimum; in most cases, increasing the setback will make sense due to sea level rise. Setting back structures from hazard areas to keep them out of floodways, regularly inundated areas, and floodplains offers the highest level of structural protection.

GUIDANCE

Setbacks can create space to restore wetlands or invest in green space that can provide protection and environmental benefits.

Land within the setback zone should be used for walking and bicycle paths; in fact, the District's regulations specifically call for 25 feet of the setback to be reserved for such pedestrian and bicycle trails.

OPERATIONS & MAINTENANCE

There should be little to no operations and maintenance implications associated with this strategy.

COST CONSIDERATIONS

$

OPERATIONS & MAINTENANCE IMPACTS

LOW

RELATED RESOURCES & REGULATIONS

2016 District Zoning Regulations, General Rules Chapter 11

Anacostia Waterfront Environmental Standards Amendment Act of 2012

SITE & LANDSCAPE - WATERFRONT AREAS

33. DESIGN WATERFRONT AREAS FOR INUNDATION

Waterfront development is particularly susceptible to climate risks from flooding. Landscape features and other development in waterfront areas should be able to withstand and recover quickly from flood inundation while also providing for vibrant community spaces.

COST CONSIDERATIONS

$ — $$$

OPERATIONS & MAINTENANCE IMPACTS

LOW

RELATED RESOURCES & REGULATIONS

Flood Inundation Mapping Tool

GUIDANCE

Landscape features and other development in waterfront areas should include strengthened foundations, structural design to resist hydrostatic forces, hydrodynamic loads, and buoyant forces that may be experienced during flooding.

Through careful grading and landscape elements like berms and levees, design waterfront sites to divert floodwater around structures and other features that require protection.

Identify opportunities to create valuable community amenities when designing landscape features to provide flood protection in inundation areas. For example, berms may be turned into hillside seating for outdoor performance spaces.

OPERATIONS & MAINTENANCE

Designing features for inundation should significantly reduce future repair costs. There should be few negative impacts on operations and maintenance beyond typical landscape management.

Figure 26: This floodwall is successfully keeping floodwaters away from a pedestrian path.

Photo Courtesy of Fairfax County, VA

34. INCORPORATE LIVING SHORELINES

COST CONSIDERATIONS

$ — $$

OPERATIONS & MAINTENANCE IMPACTS

MEDIUM

RELATED RESOURCES & REGULATIONS

2020 District Wetland Conservation Plan

Fisheries and Wildlife Omnibus Amendment Act of 2016

Living shorelines use vegetation or other natural elements, sometimes in combination with traditional construction materials, as a shoreline stabilization technique that provides significant ecosystem benefits. This practice is sometimes referred to as *ecological engineering* or *blue/green infrastructure*. In some cases, living shorelines also serve to reduce the potential for erosion and to attenuate waves.

GUIDANCE

Stabilize banks or shorelines using natural materials and native vegetation; while protecting these areas, important wildlife habitat is created and biodiversity enhanced.

Work with an ecological engineering consultant to determine the most appropriate type of living shoreline for the environmental conditions at the site. The preferred strategy often includes a mix of green and gray options.

Consider incorporating construction materials that include native vegetation, coir (coconut-fiber) mats or logs as edging, along with other natural stabilization materials such as stones. Specify biodegradable netting to hold such erosion-control materials together, rather than the more common, non-biodegradable, polypropylene netting.

Incorporate native vegetation into stabilization and adaptation strategies to provide aesthetically attractive, ecologically responsible, and practical value to a project site. Vegetation can mitigate storm surge, allow flood waters to filter into the subgrade, and prevent erosion by stabilizing the soil through its root system.

34. INCORPORATE LIVING SHORELINES

OPERATIONS & MAINTENANCE

When properly designed and executed, living shorelines should improve in both strength and durability over time, but there may be some ongoing maintenance requirements, such as removal of invasive vegetation or replacement of lost trees in exceptional storm events.

More on Living Shorelines:

Because they also create habitat and promote biodiversity, living shorelines are a preferred strategy for shoreline stabilization by most environmental regulators, compared with hardened structures such as riprap revetments or bulkheads. These natural protections also tend to improve in performance over time, while riprap and other engineered solutions tend to become less effective over time as they erode.

Living shoreline techniques have successfully been applied along river and stream banks where they can be an important adaptation strategy to combat erosion due to storm surge and boating wakes.

35. PROTECT FLOATING DOCKS, BOARDWALKS, AND OTHER MARINA ASSETS

COST CONSIDERATIONS

$ – $$$

OPERATIONS & MAINTENANCE IMPACTS

HIGH

RELATED RESOURCES & REGULATIONS

No associated resources and regulations for this strategy.

Docks, boardwalks, and marina features are often damaged during severe storms and storm surges—impacts that will increase as the impacts of climate change are increasingly felt. Various strategies can help protect these waterfront features during flooding—thus reducing the costs and environmental impacts of repairs. Floating docks are typically attached to piers and have ramps or ladders for access from the shore. These structures provide direct access to the water and adapt to changing water levels, but they may still be vulnerable to severe conditions.

GUIDANCE

When siting a boat launch, consider accessibility to navigable waters at both low and high tides and take into account future storm surge and sea level rise impacts.

Consider designing boat and slip areas to position smaller boats in the shallow areas and larger boats in deeper portions of a marina area.

Strengthen existing dockage by evaluating and strengthening connection points between marina infrastructure and dock areas. This is typically the weakest point in a waterfront and dock design.

Consider installing or leveraging breakwaters, wave attenuators, or natural features to protect boats and waterfront assets from current and future wave action and periodic flooding.

- Boat launches designed for public programs should have adequate setbacks on the adjacent shoreline to allow for staging of participants and maneuvering room for moving boats to and from storage.
- Specify ramp hinges and associated equipment that can accommodate future loading and impacts.

35. PROTECT FLOATING DOCKS, BOARDWALKS, AND OTHER MARINA ASSETS

GUIDANCE (CONTINUED)

- Consider installing storm drains in dock structures to facilitate drainage during flooding and promote quicker asset recovery and return to operation.
- Dock ramps should be designed without turns, if possible, to promote accessibility.
- Design docks and associated marina features with traction materials that can withstand heat and salt exposure, and with vertical sides, if possible, to promote accessibility.
- If possible, docks and boat launch areas should be protected from potentially damaging wakes, waves, and currents, and they should be able to accommodate predicted future storm surge and sea level rise.
- Design deck connections to lift off supports during high water events. If fixed docks are specified because of cost or logistical reasons, consider using a multi-level dock adjust system to allow the structure to be raised over time or in advance of future storms.
- Consider designing docks and marina infrastructure to allow removal and storage seasonally and in advance of predicted extreme weather events.

OPERATIONS & MAINTENANCE

Permeable pavement systems typically require different winter maintenance needs than standard pavement. Winter sanding for ice can clog the pores in porous asphalt and pervious concrete. Plowing snow on grass-paved systems may require special shoes on snowplows to avoid digging into the support matrix. Periodic vacuum-sweeping of most types of permeable pavement may be needed to maintain permeability.

36. DESIGN WATERFRONT BOATING ACCESS TO ACCOMMODATE CHANGE

COST CONSIDERATIONS

$ – $$

OPERATIONS & MAINTENANCE IMPACTS

HIGH

RELATED RESOURCES & REGULATIONS

No associated resources and regulations for this strategy.

Project design teams should consider docking orientation and adjust the layout to minimize the impact marine traffic may have on the waterfront, including on nearby public boating access facilities. The impact of boating wakes can be magnified in tidal rivers when storm surges occur.

GUIDANCE

Design gangways to accommodate quick loading and unloading of watercraft.

Use non-slip surfaces and materials on all walkways and provide shelter from the elements for passengers.

Provide pedestrian and bicycle wayfinding to and from upland connections and provide bike access and parking or short-term bike rentals, as applicable.

Elevate structures above the future mean high-water line (seasonal high tide mark) using the relevant sea level rise projections from Section 3 of these guidelines.

Design to withstand uplift from flooding and lateral forces from wave/wake action and ice, if applicable, and allow for adaptability in design. For example, floatable boardwalk sections can adjust to surge and a wide tidal range, though these should be positioned away from sensitive habitat.

Use materials resistant to rot, corrosion, or fracturing, and avoid or limit construction and foundation structures in unconsolidated soils or in areas of high erodibility and vulnerability to storm surge.

Piles should be built to withstand floating debris collision, storm surge, regular wave action, and prevailing current forces.

36. DESIGN WATERFRONT BOATING ACCESS TO ACCOMMODATE CHANGE

GUIDANCE (CONTINUED)

Shoreline improvements that minimize boating wakes or reduce boating speeds should improve resiliency of water transport.

Consider modular dock and boardwalk designs that allow rapid disassembly and safe storage in advance of predicted extreme storms as well as seasonally.

OPERATIONS & MAINTENANCE

Elevated shoreline features, such as boardwalks and docks, require regular maintenance, and some docks and floating platforms require seasonal removal or winterizing—and may require removal in advance of major storms.

4.3.3 - SITE AND LANDSCAPE DESIGN FOR EXTREME HEAT

The strategies included in this section help to moderate outdoor temperatures—compensating for some of the warming that is occurring with climate change and reducing the intensity of the urban heat island effect (localized warming that occurs in urban areas due to the significant area of pavement and dark roof surfaces). Issues related to drought are also covered in this section.

37. PROVIDE VEGETATIVE SHADING

COST CONSIDERATIONS

$ – $$

OPERATIONS & MAINTENANCE IMPACTS

HIGH

RELATED RESOURCES & REGULATIONS

2020 DOEE Stormwater Management Guidebook, primarily Section 3.14 (pages 241-252)

Strategic use of shade trees and other forms of vegetative shading on, or directly adjacent to, buildings can reduce the need for air conditioning, enhance comfort, and lessen contributions to urban heat islands. Trees and vegetation are most useful as a mitigation strategy when planted in strategic locations around buildings.

Researchers have found that planting deciduous trees or vines to the west is typically most effective for cooling a building, especially if they shade windows, part of the building's roof, or the area near the fresh air intake. This is because the reduced site temperature means mechanical systems work less hard to provide cooling. Shade trees and arbors that support vines are also effective for creating comfortable outdoor spaces.

GUIDANCE

Include a landscape architect with experience in vegetative shading strategies and locally appropriate tree selection onto the design team.

Select and locate shade trees to maximize shading benefits while reducing risk of wind damage. Select tree species that are very sturdy and not prone to limb loss or uprooting during storms, especially as storms become higher in frequency and greater in intensity due to climate change.

When planting, consider the orientation of major limbs, considering whether falling limbs in a wind storm several decades down-the-road would cause damage; position trees so that the largest limbs face away from the building.

For optimal shading while still allowing wintertime sun penetration, plant deciduous trees on the south side of a building that will grow tall with minimal lower branches so that the low-angle winter sun can penetrate while the high-angle summer sun is blocked by leaves.

37. PROVIDE VEGETATIVE SHADING

OPERATIONS & MAINTENANCE

The maintenance requirements for trees and other vegetation for shading should not be underestimated. To ensure a long healthy life, plantings must be actively maintained for at least a year after planting, including regular irrigation. More established trees and vines typically require periodic pruning and, depending on the species, may require leaf collection in the fall and sweeping up fruit in the summer. Facilities staff should be apprised on ongoing maintenance needs at the time plantings go in.

38. INSTALL DROUGHT-TOLERANT LANDSCAPING

Future climate models predict more intense heat waves as well as more variable precipitation patterns, including more frequent or longer-duration droughts. The use of drought-tolerant, native landscaping can dramatically reduce the need for irrigation, increase survival rate of plantings, and reduce ongoing landscape maintenance costs.

COST CONSIDERATIONS

OPERATIONS & MAINTENANCE IMPACTS

MEDIUM

RELATED RESOURCES & REGULATIONS

2014 DDOT Green Infrastructure Standards Plant List

DOEE Native Plants Resources

2017 District Green Construction Code

GUIDANCE

Install turf areas only where necessary for aesthetic reasons, stormwater infiltration (e.g., grassy swales), and recreation (e.g., playing fields); otherwise consider other landscape treatments.

With lawn areas, specify drought-tolerant turf grasses to minimize irrigation requirements.

Plant native trees and shrubs that are adapted to the local climate and will require minimal irrigation, fertilizer, and care.

OPERATIONS & MAINTENANCE

Drought-tolerant landscaping with native plantings should require less ongoing care and maintenance than standard landscaping—especially regarding irrigation—but all plantings will require some ongoing care (especially for the first few years of establishment).

39. USE REFLECTIVE MATERIALS

COST CONSIDERATIONS

OPERATIONS & MAINTENANCE IMPACTS

LOW

RELATED RESOURCES & REGULATIONS

Reducing Urban Heat Islands: A Compendium of Strategies, U.S. EPA (Ch. on Cool Pavements)

Cool pavements that use lighter-colored, more reflective materials can reduce the intensity of urban heat islands on outdoor spaces like parking lots, sidewalks, and other hard surfaces, making surrounding areas more comfortable.

GUIDANCE

Use light-colored pavement materials, such as concrete, permeable pavers, chip-seal, crushed stone, and other aggregates. Some of these materials' reflectivity (i.e., albedo) are more than twice as high as standard asphalt or concrete pavement.

Where feasible, consider grass pavers or concrete grid pavers that are planted with grass for locations with minimal vehicle traffic.

Shade parking lots, sidewalks, and other paved surfaces with trees or constructed canopies (which can house solar PV modules for power generation).

OPERATIONS & MAINTENANCE

There should be little to no added operations and maintenance cost impacts with this strategy.

40. PROVIDE SHADED OUTDOOR GATHERING PLACES

COST CONSIDERATIONS

$ — $$$

OPERATIONS & MAINTENANCE IMPACTS

MEDIUM

RELATED RESOURCES & REGULATIONS

RiverSmart Homes, Shade Tree Planting

Providing shade for outdoor gathering spaces will improve comfort during summer months and can be especially important for residents without access to air conditioning in their apartments or houses. Shaded outdoor spaces are crucial during power outages when most air conditioning systems are nonoperational.

GUIDANCE

Provide vegetative shading of outdoor spaces so that those spaces can remain reasonably comfortable even during power outages.

Consider shade structures that will also provide cover during rainstorms. Such structures can be designed to hold solar panels on the roof.

Provide attractive, comfortable, safe outdoor landscapes that will encourage use of these spaces.

OPERATIONS & MAINTENANCE

Shade trees require ongoing maintenance, and additional care during the first few years after planting. If well-designed and well-built, shade structures should require little maintenance, though photovoltaic modules on solar canopies may require periodic cleaning to maintain optimal energy production.

APPENDICES

A. GLOSSARY

B. REFERENCED AND SUPPLEMENTAL CLIMATE TABLES

C. CLIMATE RISKS AND VULNERABILITY DESIGN PARAMETERS BACKGROUND

D. PROJECT RESILIENT DESIGN CHECKLIST

C. STRATEGY SUMMARY TABLES

APPENDIX A: GLOSSARY

- **100-Year floodplain** – The boundary of a flood that has a 1% chance (or 1 in 100 chance) of occurring or being exceeded in a given year. Also known as the Base Flood Elevation. FEMA Flood Insurance Rate Maps delineate the horizontal extent of the Base Flood, along with its corresponding Base Flood Elevations. Also referred to as Special Flood Hazard Areas (SFHA) on FEMA Flood Insurance Rate Maps. (Source: Boston Climate Resiliency Guidelines)
- **500-Year flood plain** – Area that historically has a 0.2% chance (or 1 in 500 chance) of flooding in a given year. (Source: USGS Flood and Recurrence Intervals - Climate Ready DC Strategic Roadmap)
- **Adaptation** – The process of adjusting to new (climate) conditions in order to reduce risks to valued assets. (Source: US Climate Resilience Toolkit)
- **Backup power** – Electricity that is provided during a power outage when power from the utility grid is not available.
- **Base flood elevation (BFE)** – The elevation of the base (100-year) flood, including wave height, relative to the National Geodetic Vertical Datum (NGVD), North America Vertical Datum (NAVD) or other datum specified on the Flood Insurance Rate Map (FIRM). (Source: District's Proposed Updated Flood Hazard Rules 2021)
- **Bioswale** – Vegetated, mulched, or xeriscaped channels that provide treatment and retention as they move stormwater from one place to another. (Source: EPA)
- **Blue-green infrastructure** – Infrastructure that is designed to control or prevent urban flooding (aka cloudburst or interior flooding) by using green infrastructure concepts. This may include streets or parks that are designed to flood, and conveyance infrastructure such as bioswales or pipes. Blue-green infrastructure also delivers water quality benefits as well as other environmental, social, and economic benefits. (Source: Climate Ready DC Strategic Roadmap)
- **Continuous air barrier system** – The air barrier layer or layers prevent the unwanted entry of outside air and escape of inside air. The air barrier can consist of any durable solid material that blocks air flow between conditioned space and unconditioned space. Code often requires, and best practice dictates, that the thermal layer of insulation be in full continuous contact with the continuous air barrier. (Source: DOE)
- **Combined sewer overflows** – Combined sewer systems are designed to collect rainwater runoff, domestic sewage, and industrial wastewater in the same pipe. Most of the time, combined sewer systems transport all wastewater to a sewage treatment plant, where it is treated and discharged to a water body. (Source: EPA - Climate Ready DC Strategic Roadmap)

APPENDIX A: GLOSSARY

- **Cool or reflective roof** – A roof that has been designed to reflect more sunlight and absorb less heat than a standard roof. A high solar reflectance—or albedo—is the most important characteristic of a reflective roof as it helps to reflect sunlight and heat away from a building, reducing roof temperatures. (Source: DOE)
- **Critical loads** – Electrical loads that are deemed essential; a building's wiring may be configured so that critical loads are on a circuit that can be served by a backup power source.
- **Daylighting** – The utilization of natural light in a building, allowing use of electric lighting to be minimized during daytime hours.
- **Design flood elevation (DFE)** – The high flood elevation, or the base flood elevation plus a freeboard safety factor of two feet (2 ft.), whichever is higher. (Source: District's Proposed Updated Flood Hazard Rules, 2021)
- **Dry floodproofing** – The practice of keeping floodwater out of a building by erecting flood barriers, watertight hatches, and other components to keep water out.
- **Energy use intensity (EUI)** – An expression of the annual energy used or calculated to be used by a building or building space per unit of gross floor area. Expressed in MBtu/ft2·yr (watts-hours/m2·yr). (Source: ASHRAE)
- **ENERGY STAR** – A program that provides certification to buildings and consumer products that meet certain standards of energy efficiency. (Source: DOE)
- **Flood barrier** – A protective barrier erected to keep floodwater out of a building or a larger area; flood barriers can be deployed in advance of a storm event.
- **Flood Insurance Rate Map (FIRM)** – An official map of a community, on which the Federal Insurance Administrator has delineated both the special hazard areas and the risk premium zones applicable to the community. (Source: District's Flood Hazard Rules, 2019)
- **Flood Hazard Area (FHA)** – Land in the floodplain within the community subject to a 0.2-percent (0.2%) chance or greater chance of flooding in any given year. (Source: District's Proposed Updated Flood Hazard Rules 2021)
- **Flood Insurance Study (FIS)** – An official report including a Flood Insurance Rate Map by the Federal Insurance Administrator evaluating flood hazards and containing flood profiles and water surface elevations of the base flood. (Source: District's Flood Hazard Rules, 2019)
- **Floodproofing** – Any combination of structural and non-structural additions, changes, or adjustments to structures that reduce or eliminate flood damage to real estate or improved real property, water and sanitary facilities, structures and their contents. (Source: FEMA)

APPENDIX A: GLOSSARY

- **Freeboard** – A factor of safety usually expressed in feet above a flood level for purposes of floodplain management. "Freeboard" tends to compensate for the many unknown factors that could contribute to flood heights greater than the height calculated for a selected size flood and floodway conditions, such as wave action, bridge openings, and the hydrological effect of urbanization of the watershed. (Source: District's Proposed Updated Flood Hazard Rules, 2021)
- **Global sea level rise (GSLR)** – Global Sea Level Rise refers to the increase currently observed in the average Global Sea Level Trend, which is primarily attributed to changes in ocean volume due to two factors: ice melt and thermal expansion. (Source: NOAA)
- **Green roof** – An extension of a roof that involves, at a minimum, high quality water-proofing, root repellent system, drainage system, filter cloth, a lightweight growing medium, and plants. (Source: Green Roofs for Healthy Cities)
- **Heat waves** – A series of dangerously hot days in a row. (CRDC - Climate Ready DC Strategic Roadmap)
- **High flood elevation** – The elevation of the high (500-year) flood, including wave height, relative to the National Geodetic Vertical Datum (NGVD), North America Vertical Datum (NAVD) or other datum specified on the Flood Insurance Rate Map (FIRM). (Source: District's Proposed Updated Flood Hazard Rules 2021)
- **Hydrostatic forces** – The pressure exerted by a fluid at rest due to the force of gravity on a submerged object, such as a flood dam.
- **Impermeable surface** – Solid surfaces that prevent rainwater from infiltrating the ground; urban areas with a high percentage of impermeable surface can contribute to flooding concerns.
- **Infiltration (stormwater)** – The process of rainwater or snowmelt soaking into the ground and replenishing the aquifer rather than leading to stormwater runoff.
- **Islanding capability** – The ability of a power system to function if isolated from the regional power grid.
- **Living shoreline** – A green infrastructure technique using native vegetation alone or in combination with low sills to stabilize the shoreline. Living shorelines use plants or other natural elements — sometimes in combination with harder shoreline structures — to stabilize estuarine coasts, bays, and tributaries. (Source: NOAA)
- **Microgrid** – A group of interconnected loads and distributed energy within a given electrical boundary that acts as a single controllable entity and can be connected to and disconnected from the grid, enabling it to operate as part of the grid or as an island. (Source: DOE - Climate Ready DC Strategic Roadmap)

APPENDIX A: GLOSSARY

- **Mitigation** – Processes that can reduce the amount and speed of future climate change by reducing emissions of heat-trapping gases or removing them from the atmosphere. (Source: US Climate Resilience Toolkit)
- **Net-zero energy building** – An energy-efficient building where, on a source energy basis, the actual annual delivered energy is less than or equal to the on-site renewable exported energy. (Source: DOE)
- **Passive design** – Using layout, fabric and form to reduce or remove mechanical cooling, heating, ventilation and lighting demand. Examples of passive design include optimizing spatial planning and orientation to control solar gains and maximize daylighting, manipulating the building form and fabric to facilitate natural ventilation strategies, and making effective use of thermal mass to help reduce peak internal temperatures. (Source: British Research Establishment)
- **Passive survivability** – The ability of a building to maintain habitable temperatures if it loses power or heating fuel for an extended period of time. (Source: Resilient Design Institute)
- **Permeable pavement** – A porous urban surface composed of open pore pavers, concrete, or asphalt with an underlying stone reservoir. Permeable pavement catches precipitation and surface runoff, storing it in the reservoir while slowly allowing it to infiltrate into the soil below or discharge via a drain tile. (Source: USGS)
- **Radiant barrier** – A surface of low emissivity (less than 0.1) placed inside an attic or roof space above (but not touching) the distribution system to reduce radiant heat transfer. (Source: ASHRAE)
- **Rain garden** – A garden of native shrubs, perennials, and flowers planted in a small depression. It is designed to temporarily hold and soak in rain water runoff and typically holds water only during and following a rainfall event. (Source: Groundwater Foundation)
- **Rainscreen** – An exterior wall detail where the siding (wall cladding) stands off from the moisture-resistant surface of an air barrier applied to the sheathing to create a capillary break and to allow drainage and evaporation.
- **Relative sea level rise (RSL)** – A combination of the sea level rise and the local vertical land motion. (Source: NOAA)
- **Resilience** – The capacity of individuals, communities, institutions, businesses, and urban systems to survive, adapt, and thrive, no matter what kinds of chronic stresses and acute shocks they experience. (Source: Resilient DC)
- **R-value** – A measure of resistance to the flow of heat through a given thickness of a material (such as insulation) with higher numbers indicating better insulating properties. (Source: Miriam Webster Dictionary)

APPENDIX A: GLOSSARY

- **Sea Level Rise Adjusted Flood Elevation** – The Design Flood Elevation plus the anticipated relative Sea Level Rise.
- **Sewer backflow preventer** – A specialized valve that prevents floodwater from entering a building through the sewer line; sewage backflow is a health hazard that often occurs during flood events.
- **Stormwater** – Runoff that results from a rainstorm or other precipitation event.
- **Streetscape** – The appearance of a street, including natural features like shade trees and the built elements on the street like buildings, sidewalks, and art installations.
- **Sump pump** – A pump that removes water from a basement or other low area, particularly during flood events.
- **Vegetated façade** – Plantings that create a "living wall" on a building exterior; these can be vines trained to cover a wall or plantings in specialized containers incorporated into the exterior facade.
- **Wet floodproofing** – Wet Floodproofing includes permanent or contingent measures applied to a structure or its contents that prevent or provide resistance to damage from flooding while allowing floodwaters to enter the structure or area. Generally, this includes properly anchoring the structure, using flood resistant materials below the Base Flood Elevation (BFE), protection of mechanical and utility equipment, and use of openings or breakaway walls. (Source FEMA)
- **Urban heat island (UHI)** – Developed areas, with high amounts of paved or manmade surfaces that are hotter than nearby rural or more forested areas. (Source: EPA - Climate Ready DC Strategic Roadmap)
- **U-value:** Heat transmission in unit time through unit area of a material or construction and the boundary air films, induced by unit temperature difference between the environments on each side. Note: this heat transmission rate is also called the overall coefficient of heat transfer. U, in Btu/h·ft2·°F (W/[m2·K]). Thermal transmittance is sometimes called the overall coefficient of heat transfer or U-factor. Thermal transmittance includes surface film conductance. (Source ASHRAE)
- **Wettable material** – A material that can get wet and dry out again without damage or loss of functionality.

APPENDIX B: REFERENCED AND SUPPLEMENTAL CLIMATE TABLES

Table 1: Sea Level Rise Design Values for the District

TIMEFRAME	DESIGN / PARAMETER VALUES (INCREASE FROM MEAN SEA LEVEL)			
	INTERMEDIATE	INTERMEDIATE-HIGH	HIGH	EXTREME
2020	0.56 ft	0.72 ft	0.85 ft	0.92 ft
2050	0.56 ft	2.23 ft	2.92 ft	3.31 ft
2080	3.05 ft	4.46 ft	6.07 ft	7.32 ft

Table 2: Changes in Precipitation for the District

HAZARD	TIMEFRAME	LOW EMISSIONS SCENARIO		HIGH EMISSIONS SCENARIO	
		MEAN	RANGE	MEAN	RANGE
Days per year with precipitation accumulation > 1 inch	Historical	9.8 days/year			
	2020s	12.5	8.8 to 16.3	12.3	8.5 to 16.0
	2050s	13.7	9.4 to 18.0	13.2	9.1 to 17.2
	2080s	13.5	9.3 to 17.7	14.6	11.0 to 18.2
15-year 24-hour Design Storm Accumulation (inches)	Historical	5.2 inches			
	2020s	6.3	5.3 to 7.3	6.9	5.6 to 8.3
	2050s	6.8	5.6 to 7.9	6.5	5.7 to 7.4
	2080s	6.4	5.5 to 7.3	8.4	7.2 to 9.6
100-year 24-hour Design Storm Accumulation (inches)	Historical	8.3 inches			
	2020s	11.0	7.4 to 14.6	12.1	8.8 to 15.5
	2050s	11.1	8.1 to 14.2	9.9	7.9 to 12.0
	2080s	13.1	10.4 to 15.9	13.6	11.1 to 16.2

APPENDIX B: REFERENCED AND SUPPLEMENTAL CLIMATE TABLES

Table 3: Extreme Heat Design Projections for the District

HAZARD	TIMEFRAME	LOW EMISSIONS SCENARIO		HIGH EMISSIONS SCENARIO	
		MEAN	RANGE	MEAN	RANGE
Days per year with Maximum Temperature >95°F*	2000s	13.1 days/year			
	2020s	18.3	6.7 to 29.9	20.3	6.8 to 33.9
	2050s	31.8	12.4 to 51.2	46.5	23.2 to 69.9
	2080s	41.2	17.8 to 64.6	72.4	39.2 to 105.6
Days per year with Maximum Heat Index >95°F**	2000s	29.1 days/year			
	2020s	48.8	34.7 to 62.9	51.7	37.0 to 66.3
	2050s	68.2	48.8 to 87.6	80.3	60.7 to 99.8
	2080s	76.5	56.4 to 96.6	106.4	82.3 to 130.5

* As measured in the shade. ** Accounts for humidity *** Values in table represent low and high emissions scenarios respectively. See Section 2 for definition and description of RCP values.

APPENDIX B: REFERENCED AND SUPPLEMENTAL CLIMATE TABLES

Table 4: Annual Cooling Degree Day projections, Using 72°F as Base Temperature

PROJECTED CHANGE IN COOLING DEGREE DAYS OVER HISTORICAL VALUES		
PERIOD	LOW EMISSIONS SCENARIO	HIGH EMISSIONS SCENARIO
2020s	416	434
2050s	701	904
2080s	888	1522

* Temperature projections sourced from The Climate Explorer (available at climate-explorer3-prod.nemac.org). ** CDD calculated based on ensemble mean monthly temperature projections for the respective timeframes.

Table 5: Annual Heating Degree Day Projections, Using 72°F as Base Temperature

PROJECTED CHANGE IN COOLING DEGREE DAYS OVER HISTORICAL VALUES		
PERIOD	LOW EMISSIONS SCENARIO	HIGH EMISSIONS SCENARIO
2020s	-547	-567
2050s	-827	-969
2080s	-977	-1346

* Temperature projections sourced from The Climate Explorer (available at climate-explorer3-prod.nemac.org). ** HDD calculated based on ensemble mean monthly temperature projections for the respective timeframes.

APPENDIX B: REFERENCED AND SUPPLEMENTAL CLIMATE TABLES

Table 6: Annual Cooling Degree Day Projections, Using 65°F as Base Temperature

PROJECTED CHANGE IN CDD		
PERIOD	LOW GHG	HIGH GHG
2020s	572	599
2050s	905	1129
2080s	1119	1789

* Temperature projections sourced from The Climate Explorer (available at climate-explorer3-prod.nemac.org). ** CDD calculated based on ensemble mean monthly temperature projections for the respective timeframes.

Table 7: Annual Heating Degree Day Projections, Using 65°F as Base Temperature

PROJECTED CHANGE IN CDD		
PERIOD	LOW GHG	HIGH GHG
2020s	-391	-401
2050s	-623	-744
2080s	-746	-1079

* Temperature projections sourced from The Climate Explorer (available at climate-explorer3-prod.nemac.org). ** HDD calculated based on ensemble mean monthly temperature projections for the respective timeframes.

APPENDIX B: REFERENCED AND SUPPLEMENTAL CLIMATE TABLES

Table 8: Projected Precipitation Changes in 24 Hour Period

PROJECTED INCREASE IN 24-HOUR DESIGN STORMS						
DESIGN STORM	1yr	2yr	15yr	25yr	100yr	200yr
2020s	4%	8%	26%	27%	38%	44%
2050s	6%	16%	27%	27%	29%	31%
2080s	13%	29%	42%	59%	67%	73%

APPENDIX C: CLIMATE RISKS AND VULNERABILITY DESIGN PARAMETERS BACKGROUND

CLIMATE RISKS AND VULNERABILITY DESIGN PARAMETERS

It is well established in the scientific community that no single climate model produces an ideal simulation of all climate variables and their various statistics. A single projection represents only one of many possible realizations of the future climate; however, this is not robust as it does not capture the primary sources of climate projections uncertainty. As each global climate model (GCM) provides a slightly different conceptualization of the earth-atmosphere system, the Intergovernmental Panel on Climate Change (IPCC) and others recommend using a multi-model ensemble approach (i.e., a collection of various climate projections). Ensembles often include multiple greenhouse gas (GHG) emissions scenarios, such as RCP 8.5 (a high GHG, business-as-usual scenario) and RCP 4.5 (a more moderate scenario resulting from significant global GHG mitigation efforts). An ensemble approach, including multiple GHG scenarios, was used to estimate the design datums in the tables below. Additional details are provided in the accompanying discussion. All climate projections have been downscaled from GCMs for analysis specific to the District.

SEA LEVEL RISE

Global sea level rise (SLR) is driven primarily by the thermal expansion of the ocean as it warms as well as the addition of water from melting icecaps and glaciers. SLR in any specific location is additionally influenced by other processes, such as changes in ocean circulation and land subsidence or rebound. This section outlines the projected SLR for the District, taking into consideration as many of these processes as possible.

The projected SLR in Table 1 is with respect to baseline observations of local mean sea levels (MSL) from the 1983 to 2001 National Tidal Datum Epoch ("Historical" in Table 1). NOAA's 2017 Technical Report NOS CO-OPS 083 indicates that increases to MSL lead to proportional increases in high tidal levels (including Mean High Water and Mean Higher High Water) and worsen the impacts of storm surge, high tides, riverine flooding and wave action.

The CRDC data presents global mean sea level rise (SLR) while accounting for local changes in land subsidence. However, as previously noted, there are other major processes contributing to SLR that also warrant consideration. The projected slowing of the Gulf Stream is expected to contribute significantly to SLR on the eastern seaboard, while changes in earth's gravitational field due to the redistribution of mass from melting ice are also a factor. The NOAA analysis accounts for such processes (resulting in higher SLR projections) and it is these projections which are presented in Table 1.

Corroborating this approach is a recent study published in the Proceedings of the National Academy of Sciences that indicates that new understanding and uncertainty in ice sheet dynamics suggest that global mean SLR may exceed 60 feet by the end of the century, under a high GHG scenario (keeping in mind that SLR in the District is expected to exceed the global mean). NOAA's online visualization tool shows the extent to which mean SLR (in increments of one foot) will contribute to coastal flooding.

This can be used as a starting point for vulnerability discussions and to identify the highest risk regions within the District. Additional modeling would need to be conducted to investigate the impact of SLR on high-impact coastal flooding mechanisms, such as storm surge.

TEMPERATURE

Global mean temperature has been increasing for decades and is projected to continue in the coming decades and beyond. Table 3 presents projections for the number of days per year where the maximum daily temperature and maximum heat index (which also factors in humidity) exceed 95°F, for RCP 4.5 and RCP 8.5. These values were drawn directly from CRDC analysis[1] and estimated from 20-year averages of the ensemble mean, representative of the timeframes in Table 3 (i.e., 2000s is the average of observations from 1991-2010, 2020s is the average of the 2015-2034 ensemble mean projections, 2050s is the average of 2045-2064, and 2080s the average of 2075-2094).

These projections represent an average for three locations (Dalecarlia Reservoir, National Arboretum, and Reagan National Airport) and should be interpreted as the average projected change for the District. There will be local micro-climates within the District that experience more severe or more moderate changes as well as years within the respective timeframes that experience more or fewer hot days.

The uncertainty range, as represented by the range column in Tables 2 and 3, is the ensemble mean plus or minus the standard deviation of the ensemble member projections. This is a measure of the ensemble spread, or the degree to which the climate model projections agree with each other. A tighter spread implies higher confidence in the projections, while a larger range indicates greater uncertainty. As one might expect, the uncertainty ranges tend to increase as the timeframe extends further into the future.

In order to account for multiple possible future emissions scenarios, the Intergovernmental Panel on Climate Change (IPCC) developed four *Representative Concentration Pathways (RCP)* as part of a new initiative for the fifth Assessment Report, AR5. RCP 2.6, 4.5, 6.0 and 8.5 reflect various levels of climate change mitigation efforts (RCP 4.5, resulting in an increase of 4.5 W/m^2 in radiative forcing to the global climate system) and business-as-usual GHG emissions continuing (RCP 8.5, an increase of 8.5 W/m^2).

PRECIPITATION

Changes in the hydrologic cycle are expected to accompany projected temperature increases. In general, warmer air holds more water vapor, increasing the potential for more frequent, high-intensity precipitation events. Table 2 presents projections for the number of days per year that see more than one inch of rain, as well as the 24-hour 15-year and 100-year design storms.

Similar to the heat indices above, projected precipitation parameters are representative of the 20-year periods surrounding the respective timeframes (e.g., 2020 is 2015-2034, etc.). The historical period for precipitation days >1” is 1990 (1981-2000), as opposed to the 2000 for heat indices, due to data availability reasons. The historical values for the respective design storms are based on NOAA Atlas 14, which includes a much longer historical period (contributing to higher confidence than would be found with a 20-year observation record).

The range of uncertainty is presented in square brackets and was determined using the same method as with the heat indices. In general, there tends to be more uncertainty associated with precipitation projections than temperature projections due to the coarse resolution of climate models relative to rainfall mechanisms, such as convection (i.e., thunderstorms), micro-physical processes (e.g., water droplet formation and growth) and the influence of local geography (including topography and coastlines).

RECOMMENDATIONS

When deciding which of the projected values to use as the basis for design and planning, NOAA's Technical Report NOS CO-OPS 083 recommends selecting a scientifically plausible upper-bound (or worst-case) scenario as a "guide for overall system risk and long-term adaptation strategies," while using a mode mid-range scenario as the baseline for shorter term planning (e.g., initial adaptation plans for the next two decades). While this recommendation was intended specifically for SLR, the concept can be applied to heat and precipitation projections as well, keeping in mind the variables discussed above will continue to evolve and change beyond 2080. In light of evolving variables, other cities on the east coast, such, as Boston and New York City have committed to evaluating their climate projections through their research advisory councils every two and five years, respectively. New York City has produced updates in five-year increments. Though Boston initially expressed interest in completing two-year updates, the projections have not been formally updated since 2016, suggesting that two years may be too short of a duration to manage the update process. The climate projections should be considered along with the consequences of failure/disruption of the asset or system in question. For example, the consequences of disruption would be more severe for a hospital than for a recreational facility, so a more conservative value (i.e., often RCP 8.5, or the higher end of the uncertainty range) should be applied. This must be balanced with the cost and benefit of potential adaptation measures. It is rarely possible (or advisable) to plan and design for the worst-case scenario. The most notable exceptions to this being nuclear facilities and dams, where the consequences of failure could be catastrophic.

APPENDIX D: PROJECT RESILIENT DESIGN CHECKLIST

Introduction: The purpose of this checklist is to enable teams to identify the resilience requirements and prioritize resilient strategies for a landscape, site, or building design project in Washington, DC. While primarily intended for use on public projects, the checklist can also be used as a resource for private development. It is intended for use in the initiation, planning and early design phases.

The checklist consists of three parts: The first covers fundamental project information, the second provides an overview of the steps to assess a project's resilience profile, and the third lists potential resilience strategies for teams to pursue further based on the analysis. The checklist is intended to be used in conjunction with the Resilience Design Guidelines, which includes additional framing, resources, climate information and guidance.

BASELINE PROJECT INFORMATION

Date:		Reviewed by:	
Completed by:		Additional regulations to comply with:	
Project Name:			
Anticipated Initiation Date:		Anticipated Completion Date:	
Minimum Construction Cost:		Project Square Footage:	
Project Type:	☐ New Construction ☐ Major Equipment Replacement	☐ Substantial Renovation ☐ Other (explain)______________	
Project Description:			
Phase:	☐ Initiation ☐ Planning ☐ Concept Design ☐ Schematic Design		

APPENDIX D: PROJECT RESILIENT DESIGN CHECKLIST

1) PROJECT CRITICALITY

a) Will the project or a component within it provide a defined critical function in the District?

See "Defining Criticality" Section 3 here.

☐ Yes ☐ No ☐ Unsure

b) Will the project provide essential services to the public in case of an emergency or recovery period?

Refer to "Other Critical Facility Considerations" here.

☐ Yes ☐ No ☐ Unsure

c) Will the project provide a function where loss of power over multiple days would create an unsafe condition?

Refer to "Other Critical Facility Considerations" here.

☐ Yes ☐ No ☐ Unsure

d) Will the project temporarily provide critical functions for a connected network of facilities, such as an office park or school district?

☐ Yes ☐ No ☐ Unsure

e) Based on the above analysis, will the project be considered critical in determining resilience goals?

☐ Yes ☐ No ☐ Unsure

2) CONSIDERATIONS FOR CRITICAL COMPONENTS

In addition to the project as a whole, are there any critical components within the project that need to be prioritized above and beyond the project resilience considerations? Indicate below:

Component 1 ________________________________

Component 2 ________________________________

Component 3 ________________________________

Component 4 ________________________________

APPENDIX D: PROJECT RESILIENT DESIGN CHECKLIST

3) PROJECT LIFE EXPECTANCY

What is the anticipated lifespan for the project?

____

Note: see Table 5 for typical life expectancy by project type.

4) PROJECT CLIMATE DESIGN CONDITIONS

Indicate the project climate design parameters:

See following pages for design conditions table.

RESILIENCE PROFILE

This section is intended to provide a high-level assessment of the key resilience factors that could impact a project to inform the climate vulnerabilities to be addressed.

APPENDIX D: PROJECT RESILIENT DESIGN CHECKLIST

<table>
<tr><th colspan="2">QUESTION</th><th>PROJECT RESPONSE</th><th colspan="3">GUIDANCE</th></tr>
<tr><td colspan="6">a) Flooding: Sea Level Rise/Storm Surge/Inland Flooding</td></tr>
<tr><td colspan="2">i. Will the project be in an identified 100- or 500-year flood hazard zone?</td><td>☐ Yes
☐ No</td><td colspan="3">See the DC Flood Risk Tool for your project site. Note that this tool is based on historical data, not taking into account future projections which are higher. The guidelines recommend that no buildings be located in a flood hazard zone. If building in the flood hazard zone is unavoidable, design to a sea level rise adjusted flood elevation and prioritize flood control measures. See formula below.</td></tr>
<tr><td colspan="2">ii. Will the project, a building, or a component be identified as critical per above criteria?</td><td>☐ Yes
☐ No</td><td colspan="3">If yes, the building would not be allowed to be built in a 100- or 500-year flood hazard zone per the proposed updated District Flood Hazard Regulations without a variance or comprehensive evaluation. The guidelines recommend no buildings be located in a flood hazard zone</td></tr>
<tr><td colspan="2">iii. Will the project be on the waterfront?</td><td>☐ Yes
☐ No</td><td colspan="3">If yes, projects should prioritize design interventions for waterfronts based on adjusted sea level rise adjusted flood elevation. See formula below.</td></tr>
<tr><td colspan="6">(Calculate if answered “yes” to questions 3-5 above.)
Sea Level Rise Adjusted Flood Elevation

The variables used to calculate a climate-adjusted flood elevation, can be found in the following locations:
Base Flood Elevation (100-year or 1% annual chance of flood) can be found at OpenData.dc.gov or at the FEMA Map Service Center. High flood elevation (500 year or .2% annual chance flood) can be found in the flood profile section of the DC Flood Insurance Study. The 2017 DC Construction Codes set the design flood elevation at 2 feet above the Base Flood Elevation, or at the 500-year flood elevation, whichever is higher.
Expected sea level rise see Table 1 (see additional guidance in Section 3 for choosing design parameters based on lifespan and criticality)</td></tr>
<tr><td>Design Flood Elevation [Compare the 500-year flood elevation with the 100-year flood elevation + 2 feet and select the highest]</td><td>+</td><td>Expected sea level rise</td><td>=</td><td>Sea level rise adjusted flood elevation</td><td></td></tr>
</table>

APPENDIX D: PROJECT RESILIENT DESIGN CHECKLIST

QUESTION	PROJECT RESPONSE	GUIDANCE
b) Flooding: Increased Precipitation		
i. Is there a history of flooding or storm sewer overflows in the site?	☐ Yes ☐ No	If yes, the site is considered high risk for flooding and should use the climate adjusted precipitation Table 2 to set design parameters. Select values based on life expectancy.
ii. Will the project require hydrologic engineering using a design storm?	☐ Yes ☐ No	
iii. Will the project be in a location with over 50% of impermeable surfaces?	☐ Yes ☐ No	
iv. Will it be in a low elevation, or have a below-grade basement?	☐ Yes ☐ No	
Indicate here: Days per year with precipitation accumulation > 1 inch: ___________		
15-year 24-hour design storm accumulation (inches): ___________		
100-year 24-hour design storm accumulation (inches): __________		

APPENDIX D: PROJECT RESILIENT DESIGN CHECKLIST

QUESTION	PROJECT RESPONSE	GUIDANCE
c) Extreme Heat		
i. Will the project include a building or a component that is defined as critical, per above criteria?	☐ Yes ☐ No	If yes, use the high emissions scenario for design values in designing for heat. See Table 3.
ii. Will the project be within an urban heat island area?	☐ Yes ☐ No	Urban heat island (UHI) locations are shown on the Urban Heat Island map, indicated by red. Deeper red signifies a more severe urban heat island area. If yes, use the high emissions scenario for design values. See Table 3-5. *Denser urban areas generally have more pavement and buildings that absorb sunlight, compared to less developed areas, resulting in what is called the urban heat island (UHI) effect.*
iii. For all other projects, determine if the project will use a low or high emissions scenario for design values.	☐ Yes ☐ No	The guidelines recommend high emissions values for projects with a long-term life expectancy. *See Section 2 for further explanation of low and high emissions scenarios.*
Indicate the selected temperature parameters for the project using Table 3: Extreme Heat Design Projections. Select values based on criticality and life expectancy.		
Days per year with Maximum Temperature >95°F:		
Days per year with Maximum Heat Index >95°F:		
Use Cooling and Heating Degree Day Tables in Appendix (link) based on project's baseline temperature to indicate:		

Cooling Degree Days:	Baseline temperature:
Heating Degree Days:	Baseline temperature:

APPENDIX D: PROJECT RESILIENT DESIGN CHECKLIST

5) CONSIDERATIONS FOR RENOVATION PROJECTS

Does the project have existing attributes that address the identified climate vulnerabilities above?

☐ Yes ☐ No

If yes, briefly describe the existing conditions that could be integrated into the renovation for flooding, precipitation, and temperature extremes (e.g., operable windows, high floor to floors, raised mechanical, etc.)

____

____

____

IDENTIFICATION OF POTENTIAL RESILIENT DESIGN STRATEGIES

Summary of Climate Vulnerabilities

Indicate all climate vulnerabilities identified in the Resilience Profile above:

☐ Flooding: Sea Level Rise/Storm Surge/Inland Flooding

☐ Flooding: Increased Precipitation

☐ Waterfront Area

☐ Extreme Heat

☐ Power Loss

Use the list on the following pages to select the resilient design strategies you are planning to investigate for the project or for critical components. Incorporate these efforts into the project integrated design process.

APPENDIX D: PROJECT RESILIENT DESIGN CHECKLIST

	DESIGN FOR FLOODING	✔	COMMENTS
1	Avoid Development in Flood Hazard Areas	☐	
2	Keep Occupied Spaces Above the Sea Level Rise Adjusted Flood Elevation	☐	
3	Integrate Exterior Dry Floodproofing Techniques	☐	
4	Improve Drainage Control and Prevent Intrusion into Buildings	☐	
5	Use Wettable Systems/Finishes At and Below the Lowest Occupiable Floor	☐	
6	Provide Rainscreen Detail for Siding/Cladding	☐	
7	Reinforce Building Corners and Exteriors	☐	
8	Specify a Resilient Elevator	☐	
9	Protect Mechanical and Electrical Equipment from Flooding	☐	
10	Install Sewer Backflow Preventers	☐	
11	Consider a Vegetative (Green) Roof	☐	

	DESIGN FOR FLOODING	✔	COMMENTS
25	Implement Project Setbacks	☐	
26	Minimize Channelization of Stormwater	☐	
27	Design for Stormwater Infiltration	☐	
28	Incorporate Green Infrastructure	☐	
29	Install Permeable Pavement	☐	
30	Protect Critical Assets with Barriers	☐	
31	Plan for Controlled Flooding	☐	

APPENDIX D: PROJECT RESILIENT DESIGN CHECKLIST

	SPECIAL CONSIDERATIONS FOR WATERFRONT AREAS	✔	COMMENTS
32	Increase Setbacks From Waterfront	☐	
33	Design Waterfront Areas for Inundation	☐	
34	Incorporate Living Shorelines	☐	
35	Protect Floating Docks and Marina Assets	☐	
36	Design Waterfront Boating Access to Accommodate Change	☐	

	DESIGN FOR EXTREME HEAT	✔	COMMENTS
12	Building Form and Envelope	☐	
13	Continuous Air Barrier	☐	
14	Design for Increased Termites	☐	
15	Disease Carrying Insects	☐	
16	Mechanical Systems of the Future	☐	
17	Vegetated Facade	☐	
18	Cool or Reflective Roofs	☐	

	DESIGN FOR EXTREME HEAT	✔	COMMENTS
37	Provide Vegetative Shading	☐	
38	Install Drought-tolderant Landscaping	☐	
39	Install Sewer Backflow Preventers	☐	
40	Consider a Vegetative (Green) Roof	☐	

APPENDIX D: PROJECT RESILIENT DESIGN CHECKLIST

	DESIGN FOR POWER OUTAGES	✔	COMMENTS
19	Achieve Passive Survivability	☐	
20	Design for Natural Daylighting	☐	
21	Provide Backup Power with Islanding Capability	☐	
22	Wire Building so that Critical Loads Are on Separate Circuits	☐	
23	Target 100% Building Electrification	☐	
24	Install Solar Electric System	☐	

APPENDIX E: STRATEGY SUMMARY TABLES

The tables in this section summarize key information for each strategy. These tables can be used in conjunction with the Project Resilient Design Checklist (Appendix D) to review all 40 strategies for applicability at a glance.

A legend that outlines how to read the strategy tables follows below.

LEGEND		COSTS	O&M IMPACT
$	Low	Cost required to implement the strategy	Amount/level of operations and maintenance required to implement the strategy
$$	Medium		
$$$	High		
	New Construction		
	Existing Building		
O&M	Operations and Maintenance Impacts		

RESILIENT DESIGN STRATEGIES MATRIX		COST CONSIDERATIONS		O+M	BENEFITS							
BUILDING STRATEGIES				Impact	Benefit Description	Reduce Economic Impact	Reduce Environmental Impact	Enhance Durability	Reduce Damage	Reduce UHI	Promote Continued Operation	Enhance Wellness
DESIGN FOR EXTREME HEAT												
1	Avoid Development in Flood Hazard Areas	$		Low	Keeping new buildings out of flood hazard areas will eliminate or reduce the costs and environmental impacts of repairs and renovations resulting from flooding.	x	x	x	x		x	x
2	Keep Occupied Spaces Above the Sea Level Rise Adjusted Flood Elevation	$	$$$	Low	Damage to occupied spaces as a result of flooding is far more costly, dangerous to occupants, and carries a greater environmental impact than damage to unoccupied spaces.	x	x	x	x		x	x
3	Integrate Exterior Dry Floodproofing Techniques	$$ - $$$		High	Dry floodproofing aims to keep floodable spaces entirely dry, eliminating the need for costly cleanup and dewatering following floods.	x		x	x		x	x
4	Improve Drainage Control and Prevent Intrusion into Buildings	$	$$ - $$$	Low	Keeping bulk water away from the foundation exterior can reduce the risk of flooding, as well as unwanted indoor humidity from water diffusing through foundation walls or floor slabs.	x		x	x		x	x
5	Use Wettable Systems/ Finishes At and Below the Lowest Occupiable Floor	$	$$	Low	Using materials that are resistant to water damage can help avoid the expense and environmental impacts from flooding. Such materials are also usually far less prone to mold growth, offering a health benefit.	x	x	x	x		x	x
6	Provide Rainscreen Detail for Siding/ Cladding	$ - $$	$$ - $$$	Low	Vented rainscreen construction details enhance durability and help prevent mold growth.	x		x	x			x
7	Reinforce Building Corners and Exteriors	$	$	Low	Installing features to protect buildings from floating debris is a simple measure that can offer significant resilience and environmental benefits.	x		x	x		x	
8	Specify a Resilient Elevator	$$	$$$	Low	Specifying the proper type of elevator in a flood-prone location can significantly reduce costs from flood damage, as well as prevent environmental contamination from spilled hydraulic fluid.	x	x	x	x		x	
9	Protect Mechanical and Electrical Equipment from Flooding	$	$$	Medium	Protecting equipment from flooding avoids both the expense and environmental impacts of repairs or replacement while reducing interruptions in service.	x	x	x	x		x	x
10	Install Sewer Backflow Preventers	$ - $$	$ - $$	Medium	Installing relatively simple, passive, sewer backflow valves (or backwater valves) can prevent sewage Sewage backflow that can cause water damage, contamination, and health risks.	x	x	x	x		x	x
11	Consider a Vegetative (Green) Roof	$$	$$$	High	Vegetative, or green, roofs provide two primary benefits: capturing and retaining stormwater during rain events and reducing the urban heat island effect in urban areas.		x	x		x		

RESILIENT DESIGN STRATEGIES MATRIX		COST CONSIDERATIONS		O+M	BENEFITS							
BUILDING STRATEGIES				Impact	Benefit Description	Reduce Economic Impact	Reduce Environmental Impact	Enhance Durability	Reduce Damage	Reduce UHI	Promote Continued Operation	Enhance Wellness
DESIGN FOR EXTREME HEAT												
12	Design Building Form and Envelope for Future Climate Conditions	$	$$	Low	Setting overall building design parameters based on warmer temperatures will optimize long-term economic value, functionality, and comfort without primarily relying on mechanical systems.	x		x		x	x	x
13	Provide a Continuous Air Barrier in the Building Envelope	$		Low	A continuous air barrier in the building envelope will help ensure good energy performance, avoid moisture problems in a building, and enhance long-term durability.	x		x	x			x
14	Design for Increased Termite Pressure	$		Low	As the climate warms, our buildings need to be made more resistant to wood-boring insects, whose ranges are extending northward.	x	x	x	x			x
15	Protect Against Entry of Disease-Carrying Insects	$	$	Medium	More diligent efforts to exclude flying insects protect building occupants from disease-carrying insects.							x
16	Design Mechanical Systems for Future Climate Conditions	$	$ - $$	Low	Both winter and summer design temperatures are expected to rise, and thus mechanical systems should be designed to accommodate these changes.			x			x	
17	Consider Vegetated Façade	$$	$$$	High	Vegetated facades reduce temperatures of a building by directly shading heat-absorbing surfaces and through direct cooling via evapo-transpiration.		x			x		
18	Install Reflective or Cool Roofs	$ - $$	$ - $$	Low	A reflective (high-albedo) roof surface reduces cooling loads in the building and ameliorates local perceptions of the urban heat island effect.	x	x	x		x		
DESIGN FOR POWER OUTAGES												
19	Achieve Passive Survivability	$$	$$$	Low	A building designed to achieve passive survivability will maintain temperature conditions that keep occupants reasonably safe during extended power outages.	x	x			x	x	x
20	Design for Natural Daylighting	$$	$$$	Medium	For schools and office buildings used predominantly during the day, significant reliance on daylight, as opposed to electric lighting, will allow continued functioning during power outages and/or fuel savings when using backup generators.	x	x				x	x
21	Provide Backup Power	$$$	$$$	Medium	A source of backup power keeps critical systems operational when the regional power grid is down.						x	
22	Wire Building so that Critical Loads are on Separate Circuits	$ - $$	$$ - $$$	Low	In most situations, backup power does not need to be provided for a building's entire electrical load; ensuring emergency backup power is available for critical loads within the building will usually suffice.						x	
23	Install Solar Electric System with Islanding Capability	$$$	$$$	High	When coupled with at least some battery storage and an ability to draw power during power outages (islanding capability), solar-electric systems can provide back-up power in the event of an outage.	x	x				x	
24	Target 100% Building Electrification	$	$$ - $$$	Low	By pursuing 100% electrification, all building systems will more easily adapt to onsite or grid-delivered renewable energy and will therefore be more prepared to continue functioning during power outages.	x	x				x	

RESILIENT DESIGN STRATEGIES MATRIX		COST CONSIDERATIONS	O+M	BENEFITS							
SITE & LANDSCAPE STRATEGIES			Impact	Benefit Description	Reduce Economic Impact	Reduce Environmental Impact	Enhance Durability	Reduce Damage	Reduce UHI	Promote Continued Operation	Enhance Wellness
DESIGN FOR FLOODING											
25	Implement Project Setbacks	$	Low	Setting back structures and site features to keep them out of regularly inundated areas offers the highest level of structural protection.	x	x	x	x		x	x
26	Minimize Channelization of Stormwater	$	Low	In situations where that stormwater can be infiltrated onsite, rather than being carried away in storm sewers, the impact on regional flooding can be reduced and local ecosystems can be enhanced.	x	x	x	x	x		
27	Design for Stormwater Infiltration	$ - $$$	Medium	Infiltrating a significant portion of the rainfall onsite can reduce flooding and the environmental impacts of CSO events.	x	x	x	x	x		
28	Incorporate Green Infrastructure	$$ - $$$	Medium	Green infrastructure strategies that infiltrate, evaporate, or reuse rainwater improve water quality, and reduce stormwater volume, downstream flooding, and CSO events (where combined sanitary and storm sewers exist).		x	x	x	x		
29	Install Permeable Pavement	$$	High	Properly designed and installed permeable pavement can reduce flooding pressure by absorbing precipitation without creating stormwater flows.		x	x	x			
30	Protect Critical Assets with Barriers	$$ - $$$	High	Temporary or permanent flood barriers can protect important landscape features, buildings, roadways, bridges, and other elements that are expected to flood yet impractical to elevate.	x	x	x	x		x	
31	Plan for Controlled Flooding	$ - $$	High	Designing some landscape elements to allow flooding (both routine and catastrophic) to happen in a controlled manner directs flooding to where it will result in minimal damage.	x	x	x	x		x	

RESILIENT DESIGN STRATEGIES MATRIX		COST CONSIDERATIONS	O+M	BENEFITS							
SITE & LANDSCAPE STRATEGIES			Impact	Benefit Description	Reduce Economic Impact	Reduce Environmental Impact	Enhance Durability	Reduce Damage	Reduce UHI	Promote Continued Operation	Enhance Wellness
DESIGN FOR FLOODING											
32	Increase Setbacks From Waterfront	$	Low	Setting back structures from hazard areas to keep them out of floodways, regularly inundated areas, and floodplains offers the highest level of structural protection.	x	x	x	x		x	x
33	Design Waterfront Areas for Inundation	$ - $$$	Low	Landscape features and other development in waterfront areas should be able to withstand and recover quickly from flood inundation while also providing for vibrant community spaces.			x	x		x	
34	Incorporate Living Shorelines	$ - $$	Medium	Living shorelines use vegetation or other natural elements, sometimes in combination with traditional construction materials, as a shoreline stabilization technique that provides significant ecosystem benefits.		x	x	x	x	x	
35	Protect Floating Docks and Marina Assets	$ - $$$	High	Various strategies can help protect these waterfront features during flooding—thus reducing the costs and environmental impacts of repairs.	x	x	x	x		x	
36	Design Waterfront Boating Access to Accommodate Change	$ - $$	High	Adjusting layout to minimizes the impact that marine traffic may have on the waterfront, including on nearby public boating access facilities.	x	x	x	x		x	
DESIGN FOR FLOODING											
37	Provide Vegetative Shading	$ - $$	High	Strategic use of shade trees and other forms of vegetative shading on, or directly adjacent to, buildings can reduce the need for air conditioning, enhance comfort, and lessen contributions to urban heat islands.	x	x			x	x	x
38	Install Drought-Tolerant Landscaping	$$	Medium	The use of drought-tolerant, native landscaping can dramatically reduce the need for irrigation, increase survival rate of plantings, and reduce ongoing landscape maintenance costs.	x	x	x		x		
39	Use Reflective Materials in Paved Patios, Parking Lots, and Sidewalks	$$$	Low	Cool pavements that use lighter-colored, more reflective materials can reduce the intensity of urban heat islands on outdoor spaces like parking lots, sidewalks, and other hard surfaces, making surrounding areas more comfortable.		x	x		x		x
40	Provide Shaded Outdoor Gathering Spaces	$ - $$$	Medium	Providing shade for outdoor gathering spaces will improve comfort during summer months.		x				x	x

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