NATIONAL CAPITAL REGION EXTREME HEAT TOOLKIT FOR TRANSPORTATION PLANNING

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National Capital Region
Transportation Planning Board

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ABOUT COG

The National Capital Region Transportation Planning Board (TPB) is the federally designated metropolitan planning organization (MPO) for metropolitan Washington. It is responsible for developing and carrying out a continuing, cooperative, and comprehensive transportation planning process in the metropolitan area. Members of the TPB include representatives of the transportation agencies of the states of Maryland and Virginia and the District of Columbia, local governments, the Washington Metropolitan Area Transit Authority, the Maryland and Virginia General Assemblies, and nonvoting members from the Metropolitan Washington Airports Authority and federal agencies. The TPB is staffed by the Department of Transportation Planning at the Metropolitan Washington Council of Governments (COG).

CREDITS

This report was prepared for the Metropolitan Washington Council of Governments (COG) Transportation Planning Board (TPB) by ICF and Rhodeside & Harwell, Incorporated (RHI). This project was led by Katherine Rainone and Pierre Gaunaurd from TPB. This report was prepared in close collaboration with TPB by individuals from ICF including Brenda Dix, Amanda Vargo, Emelia Suljic, Jasmyn Noel, Dasha Latvis, and D'Arcy Carlson and individuals from RHI including Sukirti Ghosh, Eric Feldman, and Benjamin Valente.

PHOTO CREDITS

BeyondDC/Flickr (MARC and Crystal City), Pierre Gaunaurd/COG (bus stop), Ted Eytan/Flickr (Georgetown)

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Introduction

The National Capital Region Transportation Planning Board (TPB) is committed to building system-wide resilience in the face of natural hazards and extreme weather. The National Capital Region Extreme Heat Toolkit for Transportation Planning is the latest in a series of transportation resilience resources to help member agencies identify and adapt to extreme heat risks. This toolkit includes the following resources:

- **Transit Impacts Assessment** of past, projected, and downstream impacts of extreme heat on rail operations and ridership to inform future resilience efforts. This resource includes an overview of the downstream impacts of extreme heat on the region's transit system as well as a quantitative assessment of lost fare revenue from changes in rail ridership during extreme heat and operational costs and travel time burdens from rail service slow orders.
- **Transportation Grants Database** of 20 funding opportunities applicable to extreme heat resilience planning and implementation projects. For each funding source, this database includes critical deadlines, evaluation criteria, applicant requirements, project requirements, and "win themes" to help member agencies write strong applications.
- **Transportation Design Guidance** for cooling solutions, with region-specific examples. This resource provides best practice design guidance considerations for implementing cooling strategies in streetscapes, bus station areas, and trailhead plazas.
- **Transportation Policy, Planning, and Design Applications** to help promote the use of cooling strategies. For each application, this resource includes suggestions for how to integrate extreme heat considerations into existing policies, planning efforts, and guidance documents and provides examples from other agencies and municipalities.

Toolkit Development Process

This toolkit builds directly on prior efforts in the region. In 2024, TPB conducted a [risk-based vulnerability assessment]() and developed a [Transportation Resilience Improvement Plan (TRIP)]() to identify priority resilience investments aligned with the region's adaptation and resilience goals. As part of the vulnerability assessment, TPB evaluated extreme heat vulnerability for several transit asset types, including bus stops, rail stations, and rail lines. The results indicated that public transit and active transportation are highly sensitive to extreme heat, which can cause infrastructure damage, operational impacts, and health and safety risks for outdoor workers and riders (Figure 2). For example, high temperatures can create heat kinks where rail tracks buckle, increasing the risk of derailment, and leading to slow orders and service delays. Additionally, transit riders walking to, or waiting at bus or rail stations as well as bikers and pedestrians traveling during a hot day can be sensitive to health risks, such as heat stroke.

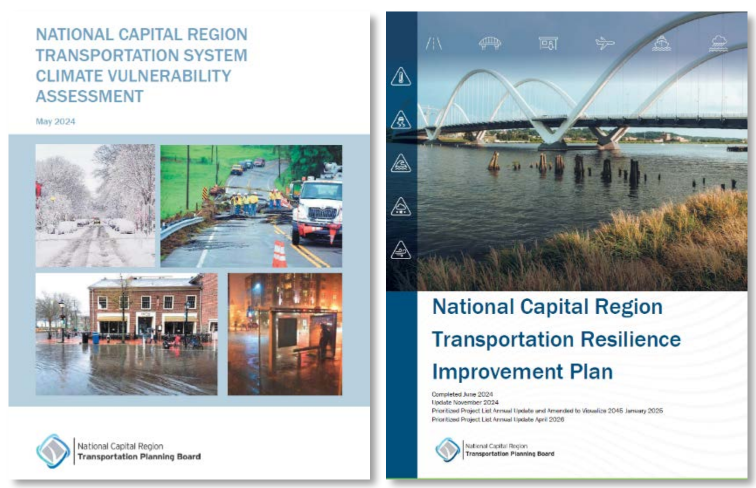


Figure 1. TPB's 2024 vulnerability assessment and transportation resilience improvement plan identified the need for a regional extreme heat toolkit.

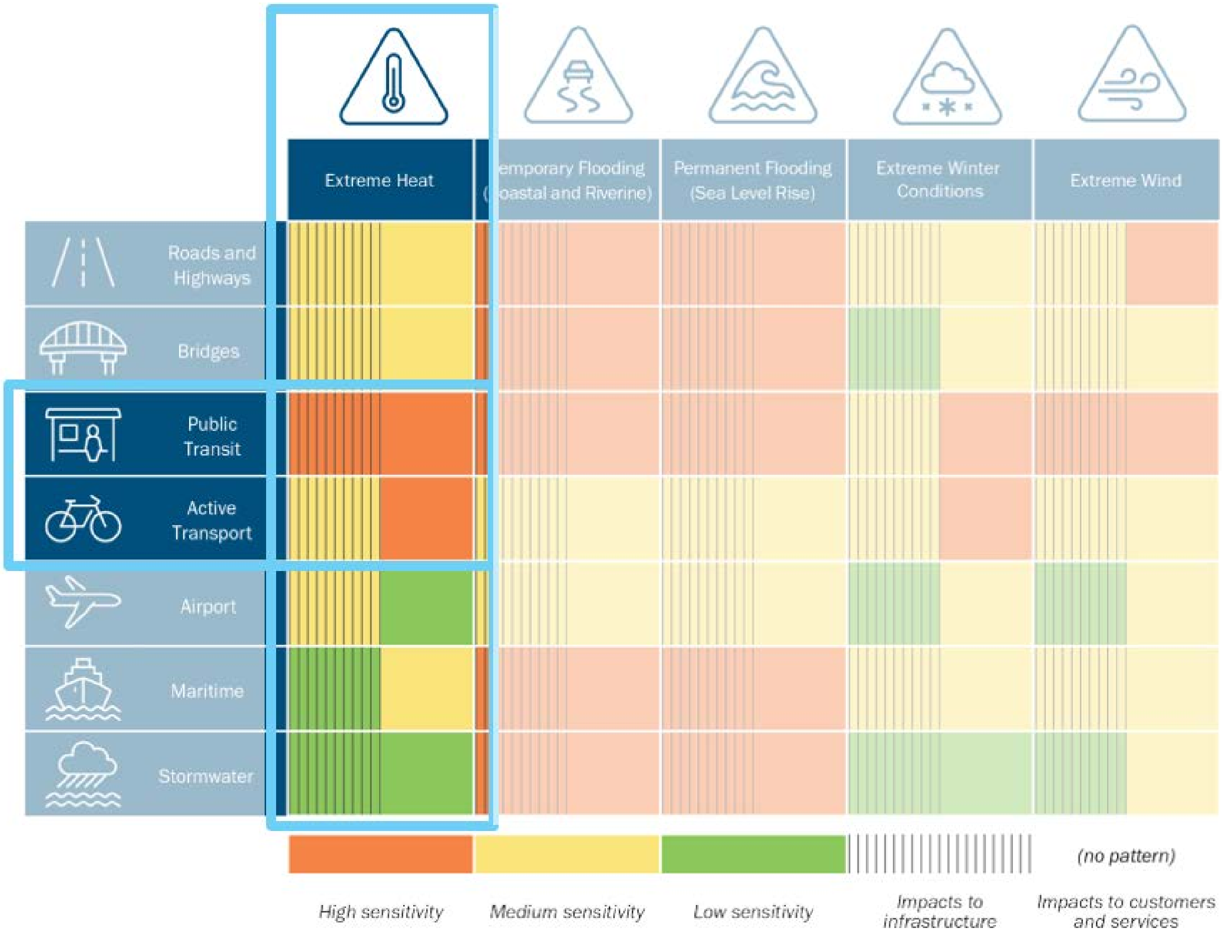
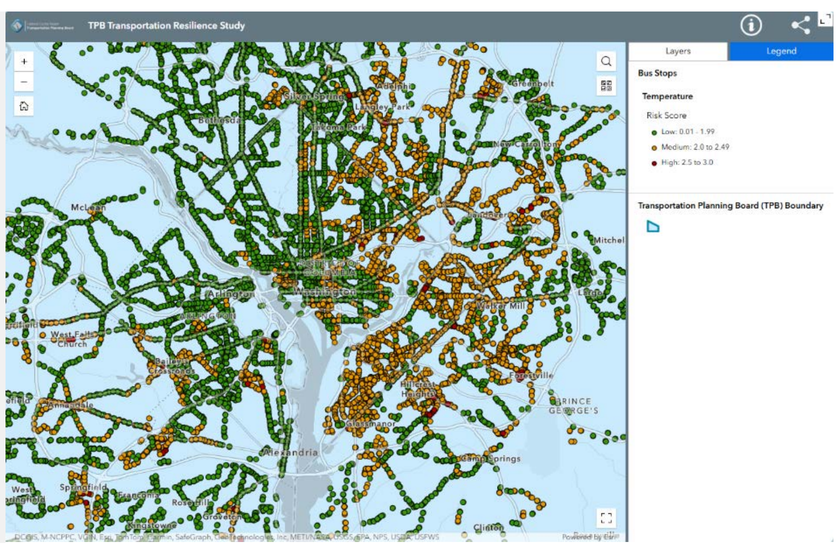


Figure 2. System-level analysis results from the National Capital Region Transportation System Climate Vulnerability Assessment (infrastructure impacts on left; service and customer impacts on right).

Geospatial Extreme Heat Data

Visit the [TPB Transportation Resilience Study Mapping Tool]() to view the asset-level extreme temperature vulnerability assessment results for bus stops, rail stops, and rail routes (bus stop results shown at right).

Median surface temperature and tree canopy coverage layers are also available in the tool to help support extreme heat planning.



Based on the vulnerability assessment results, the subsequent TRIP identified a need for additional analysis to better understand how extreme heat affects public transit riders, particularly those who rely heavily on transit or reside in urban heat islands.

Thus in 2025, TPB launched the development of the **National Capital Region Extreme Heat Toolkit for Transportation Planning** to dive deeper into extreme heat impacts and provide resources to member agencies to help kick-start their efforts to identify and adapt to heat risks. TPB engaged the Regional Transportation Resilience Subcommittee throughout the process to inform the selection and development of the toolkit components to ensure they provide value to the region. TPB also engaged the Washington Metropolitan Area Transit Authority (WMATA), the Virginia Railway Express (VRE), and the Maryland Area Regional Commuter (MARC) to better understand available data in the region related to slow orders and other heat impacts to shape the transit impacts assessment. TPB intends to continue to build on and refresh this toolkit as regional needs evolve and additional data becomes available.

Extreme Heat Primer

As discussed in the National Capital Region Transportation Climate Vulnerability Assessment,[1] temperatures in the region have been increasing over time and the number of heat waves have also increased. The number of extreme heat days each year (days where maximum temperature exceeds 95°F) has significantly increased since 1980 (Figure 3). Between 1943 and 1972, the National Capital Region experienced an average of 3.8 days per year where maximum temperature exceeded 95°F. From 1992 to 2025, there was an average of 8.4 days per year where temperature exceeded 95°F.[2]

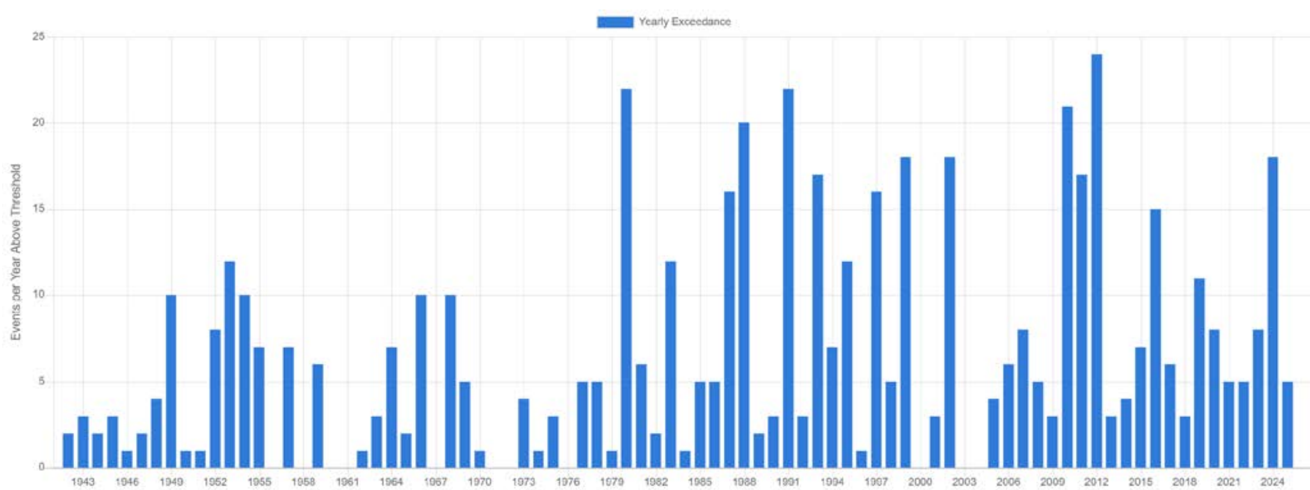


Figure 3. Time series of number of days where maximum temperature exceeds 95°F from 1942 to 2025. Source: NOAA Climate Explorer

Projections indicate that the number of days with extreme heat (days where maximum temperature exceeds 95°F) will continue to increase. From 1960-1990, there was an average of 4.4 days a year with temperatures above 95°F and zero days above 105°F. In 2050, climate models project that this will rise

[1] While the National Capital Region Transportation Climate Vulnerability Assessment focused on observed and projected days above 95°F, the impacts of extreme heat on transit and health can occur at lower temperatures. The Transit Impacts Assessment used days above 90°F, which is better aligned with the temperature thresholds at which transit agencies typically issue slow orders. This 90°F threshold is also generally regarded as the point at which heat poses an extreme risk to human health.
[2] NOAA Climate Explorer: Historical Weather Data. Accessed 2026. https://crt-climate-explorer.nemac.org/historical_weather_data/.

to 38.9 days with temperatures above 95°F and 2.3 days above 105°F. By 2100 these numbers will again rise to 77.4 days with temperatures above 95°F and 15.3 days above 105°F (Figure 4). For context, there are almost zero days in the historical record where temperatures pass 105°F. Perceived temperatures are likely to be even higher than this because the human body experiences temperatures to be hotter than they actually are when humidity is present.[3]

Days with Maximum Temperatures above 95°F in Washington, DC

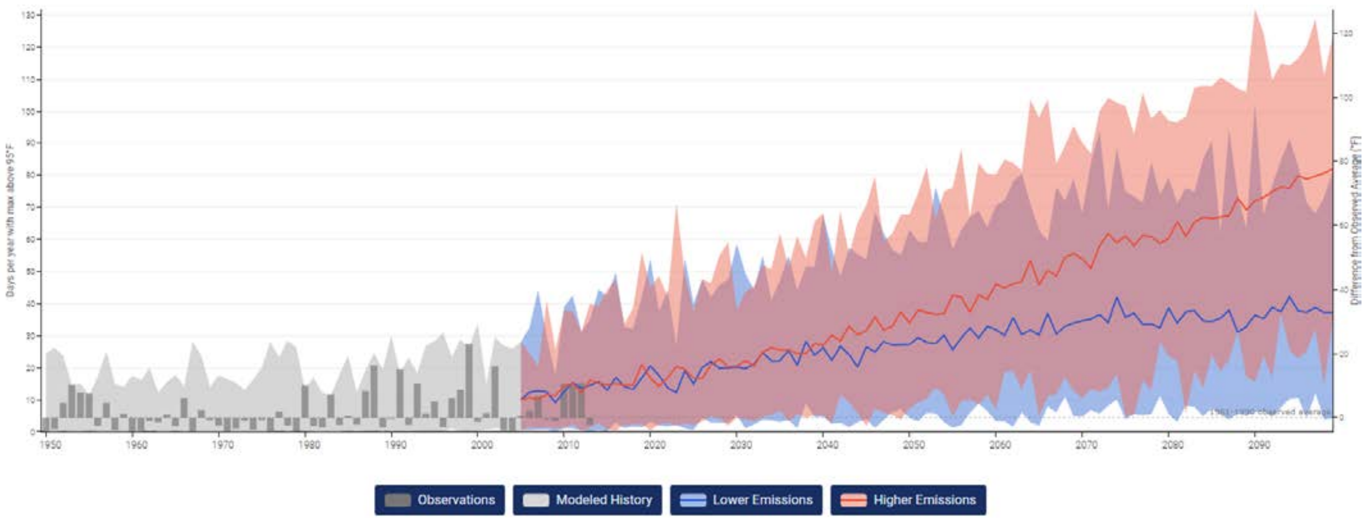


Figure 4. Days with extreme heat as identified by days with maximum temperatures above 95°F. Projections shown for both low and high emissions. Source: NOAA Climate Explorer

Urban Heat Islands and Extreme Heat

Urban heat islands (UHIs) are areas with temperatures that are higher than those otherwise found in the natural environment, due to the impact of urban development. Extreme heat refers to periods when temperatures exceed thresholds for human comfort and safety and can impact public health and the functioning of urban systems. Heat stress refers to the negative impacts of extreme heat on people.

Extreme heat is most common in the afternoon when daily temperatures are highest. Summer peak temperatures tend to cluster in urban centers and along major transportation corridors, occurring from 1:00PM to 5:00PM. This time period coincides with afternoon commute times, and for parts of the year, after school student travel.[4]

Impact on Transit and Active Transportation Users

Transportation users, particularly those traveling via transit or active transportation (walking and bicycling), can be exposed to extreme heat over the course of their journeys. This includes walking to and from transit stations, specifically during first- and last-mile connectivity from residences to transit stations and from transit stations to destinations.

[3] National Weather Service. What is the Heat Index? https://www.weather.gov/ama/heatindex
[4] Huiying Fan, "Network-Level Modeling of Transit Riders and Pedestrians' Thermal Comfort" (Dissertation, Georgia Institute of Technology, 2024).

The longer an individual is exposed to extreme heat, the higher the risk. Heat vulnerable populations face increased risk of health impacts on their transit journey potentially forcing them to select longer routes, alternate modes of travel, or cancel trips, to minimize their heat exposure and risk. Therefore, minimizing the impact of extreme heat on transit users and those traveling on foot or bicycle is important to protect public health and build resilience.

Heat Vulnerable Populations

- *Individuals with chronic health conditions*
- *Older adults and young children*
- *Outdoor workers and commuters*
- *Socially vulnerable populations*
- *Individuals without air conditioning or access to cooling spaces*
- *Individuals without a personal vehicle who may be more dependent on transit and active transportation modes*

Measuring Thermal Comfort and Heat Stress

Urban heat is not defined and measured equally, and it is important to focus specifically on the heat that affects human comfort. The two most common temperature measurements for urban analysis are land surface temperature and air temperature:

- **Land surface temperature (LST)** is the temperature of the ground in a given area. LST is more easily measured than air temperature but does not directly correlate to the comfort of an environment for humans and is not the most accurate and relevant metric to use to specifically target thermal comfort.[5] However, LST does allow you to see hot spots within the region that may benefit from interventions. TPB has a median land surface temperature map readily available to use as an input to help inform extreme heat planning (Figure 5; also available on the TPB Transportation Resilience Study Mapping Tool). This should be supplemented by other available data and local context as needed.
- **Air temperature** is the ambient temperature, usually measured 2 meters from the ground. It is more directly related to human thermal comfort than LST. As humans move through the environment, the air around them affects their thermal comfort and can cause heat stress. Different mitigation strategies may be favored when specifically designing for human thermal comfort.[6] Publicly available tools, such as

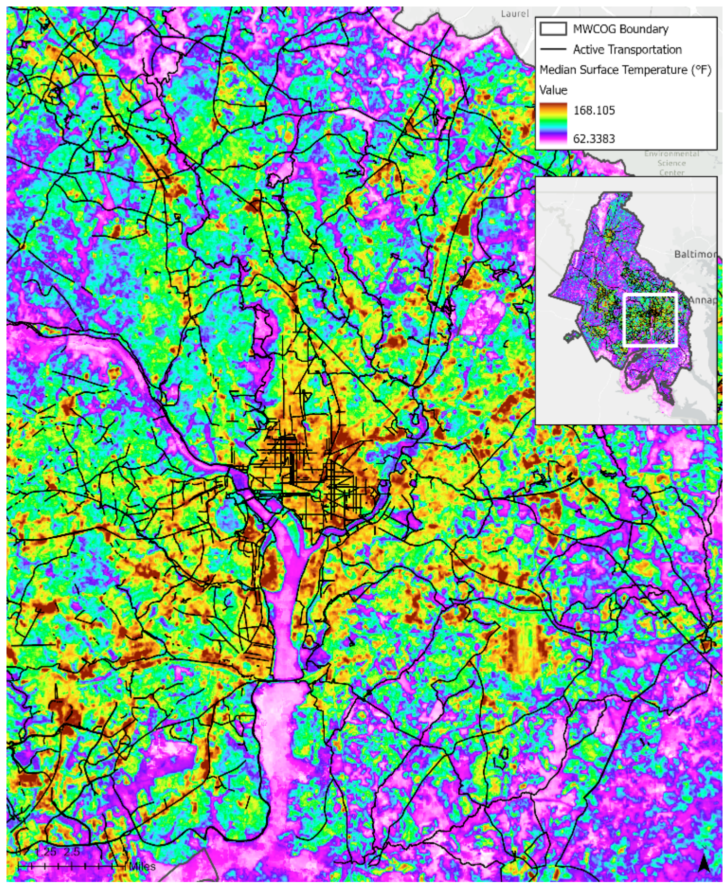


Figure 5. Median land surface temperature and regional bike route map. Source: National Capital Region Transportation Climate Vulnerability Assessment

[5] Leonidas G. Ioannou et al., "Indicators to Assess Physiological Heat Strain – Part 1: Systematic Review," *Temperature* 9, no. 3 (2022): 227–62, https://doi.org/10.1080/23328940.2022.2037376.
[6] Kevin Lanza et al., "Heat Stress Mitigation by Trees and Shelters at Bus Stops," *Transportation Research Part D: Transport and Environment* 140 (March 2025): 104653, https://doi.org/10.1016/j.trd.2025.104653.

the NOAA Climate Explorer used to produce Figure 4, provide projections for extreme heat (air temperature). However, the spatial resolution of climate models is much coarser than LST and is not able to provide block-by-block differences within a region that are helpful for identifying potential hot spots and targeted interventions.

How to Use this Toolkit

The following sections provide each component of the Extreme Heat Toolkit for Transportation Planning, which are designed for member agencies to help answer the following key questions. Each individual component is also available as a separate resource on TPB's website.

- **Transit Impacts Assessment:** What are the downstream impacts of extreme heat on transit operations? How does extreme heat affect ridership? What are some quantifiable economic impacts of extreme heat?
- **Transportation Grants Database:** What funding opportunities are available to support my agency's extreme heat planning and implementation projects? How can my agency write a winning grant application?
- **Transportation Design Guidance:** What are the key considerations and best practices for siting, designing, and implementing cooling solutions in streetscapes, bus station areas, and trailhead plazas?
- **Transportation Policy, Planning, and Design Applications:** What are possible avenues for mainstreaming extreme heat considerations into agency decision-making? What jurisdictions have already started to make these changes to help promote the use of cooling strategies?

Transit Impacts Assessment

The Transit Impacts Assessment presents a preliminary examination of the observed and projected extreme heat impacts on transit operations and ridership. The Transit Impacts Assessment includes two complementary assessments that characterize extreme heat impacts on transit services across the National Capital Region:

- A **qualitative overview of the downstream impacts** on health and access, service and operations, and economic outcomes.
- A **quantitative assessment of select extreme heat impacts** using WMATA and VRE data to approximate lost fare revenue from changes in rail ridership, as well as cascading operational costs and travel time burdens from slow orders.

Goals & Objectives

The Transit Impacts Assessment supports regional resilience efforts by:

I. Improving understanding of past and future extreme heat risk, including downstream impacts, to help inform future planning and resilience efforts.
II. Quantifying impacts to ridership and fare revenue.
III. Quantifying the impacts of slow orders on operating costs for transit agencies and travel time burden for transit riders.

Rail transit plays a critical role in regional mobility. According to TPB's 2025 State of the Commute survey, 21 percent of commuters rely on the train as their primary or secondary commute mode.[7] The region's rail system comprises three primary transit services:[8]

1. The **Washington Metropolitan Area Transit Authority's (WMATA) Metrorail** serves approximately four million people across the District of Columbia (D.C.), Virginia, and Maryland and is the third largest urban rail system in the country.
2. The **Virginia Railway Express (VRE)**, operated by the Northern Virginia Transportation Commission and the Potomac Rappahannock Transportation Commission, provides weekday commuter rail service along the I-66 and I-95 corridors and links suburban Virginia communities to downtown D.C.
3. The **Maryland Area Regional Commuter (MARC)** rail system, operated by Maryland's Transit Administration, provides commuter rail service in Maryland and into D.C. and parts of West Virginia.

The results of transit impact assessment are intended to inform future resilience planning and investment decisions. The assessment concludes with future enhancements that could further explore the impacts of extreme heat across transportation modes, including bus and active transportation, as additional data becomes available.

[7] TPB. 2026. 2025 State Of The Commute Technical Report. https://www.mwcog.org/documents/2026/01/21/state-of-the-commute-survey-report--carsharing-featured-publications-state-of-the-commute-telework-travel-surveys/
[8] TPB. 2026. State Of Public Transportation 2024 Report. https://www.mwcog.org/documents/2026/02/09/state-of-public-transportation-report-bus-rail-tpb-transit/

Extreme Heat Impacts for Transit Operations and Users

Rising temperatures in the National Capital Region pose significant challenges to the safety and reliability of the transportation network. The following sections provide an overview of three categories of extreme heat-related impacts to the region's transit system and its users (Figure 6).

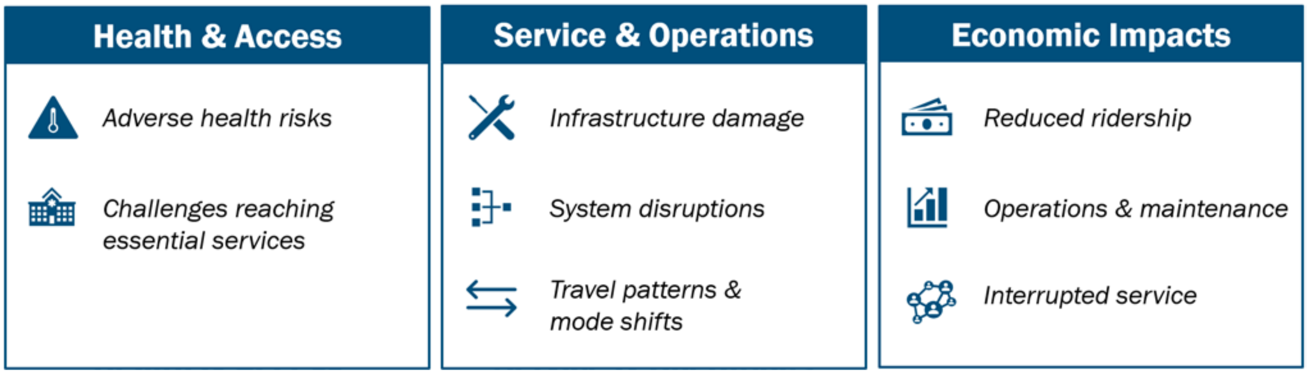


Figure 6. Overview of the major categories of heat-related impacts to the region's transit system and users.

HEALTH AND ACCESS

Extreme heat can result in adverse health effects for transit operators and riders, due either to direct exposure to the high temperatures or as a result of heat-related disruptions that complicate access to essential services.

Adverse Health Risks

Exposure to extreme heat places transit riders and workers at risk of heat-related illnesses such as heat stroke and heat exhaustion.[9] Vulnerable populations (see textbox) are at even higher risk of experiencing severe heat-related health outcomes.[10,11] High temperatures also worsen air quality.[12] Exposure to poor air quality can exacerbate existing health conditions such as asthma, cardiovascular disease, and other respiratory illnesses.

Commuters spend significant time outdoors while traveling to stops and stations, waiting on platforms, or transferring between services. These activities can result in prolonged exposure to high temperatures which makes transit users (especially those who lack the ability to mode shift during dangerous conditions) particularly vulnerable. Frontline

Heat Vulnerable Populations

- *Individuals with comorbid health conditions*
- *Older adults and young children*
- *Outdoor workers and commuters*
- *Socially vulnerable or isolated populations*
- *Individuals without air conditioning or access to cooling spaces*
- *Individuals without a personal vehicle who may be more dependent on transit and active transportation modes*

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[9] National Institute for Occupational Safety and Health (NIOSH). 2024. Heat-related Illnesses. https://www.cdc.gov/niosh/heat-stress/about/illnesses.html

[10] Milman, O. 2026. 'Woefully Unprepared': Extreme Heat Will Double US Hospitalizations by 2040, Study Finds. www.theguardian.com/environment/2026/jun/09/extreme-heat-double-hospitalizations-2040-study

[11] EPA. 2021. Climate Change and Social Vulnerability in The United States: A Focus on Six Impacts. https://www.epa.gov/system/files/documents/2021-09/climate-vulnerability_september-2021_508.pdf

[12] U.S. Environmental Protection Agency (EPA). 2021. Climate Change and Social Vulnerability in The United States: A Focus on Six Impacts. https://www.epa.gov/system/files/documents/2021-09/climate-vulnerability_september-2021_508.pdf

workers, including bus drivers, maintenance crews, and station staff, also face sustained exposure during heatwaves.

In 2025, WMATA analyzed heat severity and tree canopy around their Metrorail stations.[13] For each station, WMATA mapped its *Pedshed*, or area around a station where pedestrians are likely to be walking or biking on the sidewalk to and from the station and thus are most likely to be exposed to extreme heat. This [StoryMap](https://storymaps.arcgis.com/stories/e16e3fe110d2432ebcb0f2c0697931d8) provides insight into areas where commuters may face health risks due to high heat severity and lack of shade, such as around the Mount Vernon Sq 7th St - Convention Center station in downtown D.C (Figure 7).

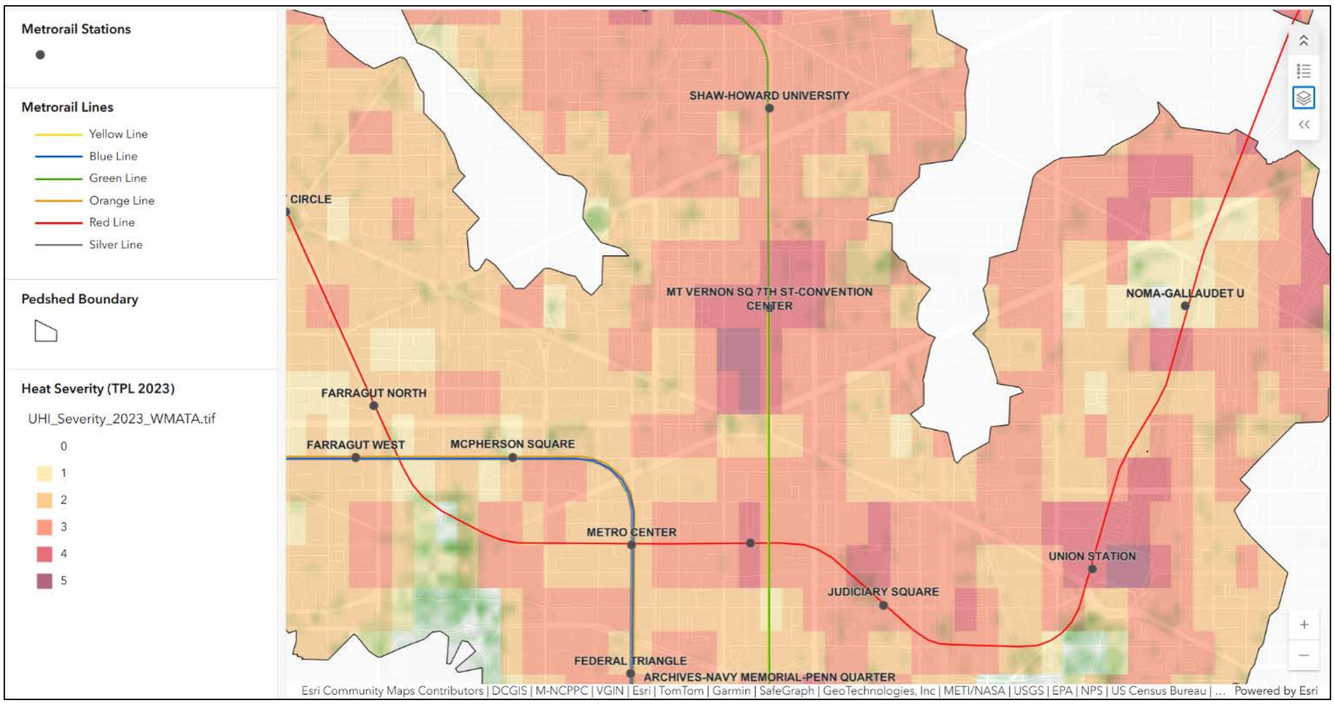

Figure 7. Screenshot of heat exposure near Metro lines and stations in downtown D.C from WMATA's Heat Exposure for Metro Riders StoryMap. Source: WMATA, 2025.

During extreme heat events, transit agencies may decrease or slow service to reduce strain and damage on assets, potentially leading to overcrowding from decreased service frequency, as well as longer waits in the heat. Packed buses or trains, especially those experiencing HVAC issues, can heighten health risks for riders.

Challenges Accessing Essential Services

Extreme heat events may also cause service disruptions or cancellations that prevent people from reaching critical goods and services such as cooling centers, emergency services, workplaces, healthcare or childcare facilities, and other vital resources. People without alternative forms of transportation, and those at risk of heat-related illnesses, are particularly affected. These cascading access barriers can deepen existing struggles for transit-dependent communities.

[13] WMATA. 2025. Heat Exposure for Metro Riders. https://storymaps.arcgis.com/stories/e16e3fe110d2432ebcb0f2c0697931d8

SERVICE AND OPERATIONS

Extreme heat increases the risk of transit infrastructure failure, prompting agencies to slow operations to protect equipment, which can cause system-wide disruptions and affect travel patterns. For specific examples of how some of these risks have impacted the region, refer to the analysis described in the **Quantified Impacts for Transit Owners and Users** section of this assessment.

Infrastructure Damage

Heat accelerates wear on transit infrastructure, prompting more frequent inspections, repairs, and replacements. For example, high temperatures can cause rail tracks to expand and deform, creating "sun kinks" or "heat kinks" that require immediate slow orders or single tracking to prevent derailments.[14] Agencies including VRE, WMATA, and MARC regularly issue or respond to slow orders on abnormally high temperature days or during rapid temperature fluctuations to proactively reduce risk where kinks may have formed but have not yet been identified. When sun kinks occur, affected track segments must be taken out of normal service until repairs are completed. Recent examples of heat-related transit disruptions include the following:

- In **July 2012**, 10 consecutive days of temperatures over 95°F caused a heat kink that led three railcars to derail in Prince George's County.[15]
- On **June 20, 2024**, rail temperatures exceeded 135°F (metal rails get hotter than air temperatures), prompting WMATA to limit all trains to a maximum speed of 35 mph.[16] VRE also implemented heat orders due to this event.
- On **July 14, 2024**, rail temperatures exceeded 135°F again, prompting systemwide speed restrictions on above-ground track segments for WMATA, MARC, and VRE service.[17] WMATA also implemented single tracking on the Blue and Yellow Lines after a heat kink formed near Crystal City (Figure 8).[18]
- WMATA implemented another heat order a year later due to high rail temperatures on **June 24, 2025.**[19] According to internal records, MARC and VRE also implemented heat orders due to this event.

Figure 8. Heat kink on WMATA's Blue and Yellow rail service line on July 14, 2024. Source: [DCNewsNow, 2024](https://www.dcnewsnow.com).

Extreme heat also places significant stress on onboard and station air-conditioning systems, increasing the likelihood of equipment failure. As described in the **Health and Access** section above, this creates dangerous conditions for riders. When cooling systems falter,

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[14] VRE. n.d. Blog - Train Delays. https://www.vre.org/blog-train-delays/

[15] Trautman, T. 2012. Metro says heat kink likely caused derailment. https://www.washingtonpost.com/blogs/dr-gridlock/post/metro-heat-kink-in-rail-likely-caused-derailment/2012/07/07/gJQAKJTEUW_blog.html

[16] Woolsey, A. 2024. NOW: Metro slows down trains due to high temperatures. https://www.ffxnow.com/2024/06/20/now-metro-slows-down-trains-due-to-high-temperatures/

[17] Tuss, T. 2024. Metrorail lowers train speeds as rail temps top 135°. https://www.nbcwashington.com/news/local/transportation/metrorail-lowers-train-speeds-as-rail-temps-top-135/3666284/

[18] Allen, G., & Farrell, B. 2024. Metro puts above-ground speed restriction into place due to heat. https://www.dcnewsnow.com/news/local-news/washington-dc/blue-yellow-lines-single-tracking-due-to-kink-from-extreme-heat/

[19] Failla, Z. 2024. Heat Wave Slows Metro Trains as Rail Temps Hit 135 Degrees In DC, Maryland, Virginia. https://dailyvoice.com/md/brooklyn-park/heat-wave-slows-metro-trains-as-rail-temps-hit-135-degrees-in-dc-maryland-virginia/

interior temperatures can rise rapidly, and commuters waiting on platforms or in enclosed stations can be exposed to even higher heat-stress.

Together, these infrastructure and equipment impacts increase operational and maintenance expenditures during extreme heat days and create broad systemic disruptions that can have resounding impacts throughout the region, especially for industries and people that depend upon functional transit.

System Disruptions

As discussed above, transit agencies slow service and reduce operations at certain ambient and rail temperature thresholds to minimize infrastructure damage. Because regional rail networks operate on tightly scheduled corridors with multiple operators, a heat-related delay due to slow orders on one line can cause cascading impacts across the system. Conflicts at stations, bottlenecks at junction points, and mismatched headways disrupt operations for multiple services and compounds delays for riders.

Rail Heat Order Delays in Virginia

The Virginia Passenger Rail Authority compared monthly heat-related delay minutes for Virginia rail with average daily high temperatures from February to October in 2022 and 2023. Results show a peak delay of 6,276 minutes in July 2023, representing a 53 percent increase from July 2022 and corresponding with an 8.1°F rise in temperature.

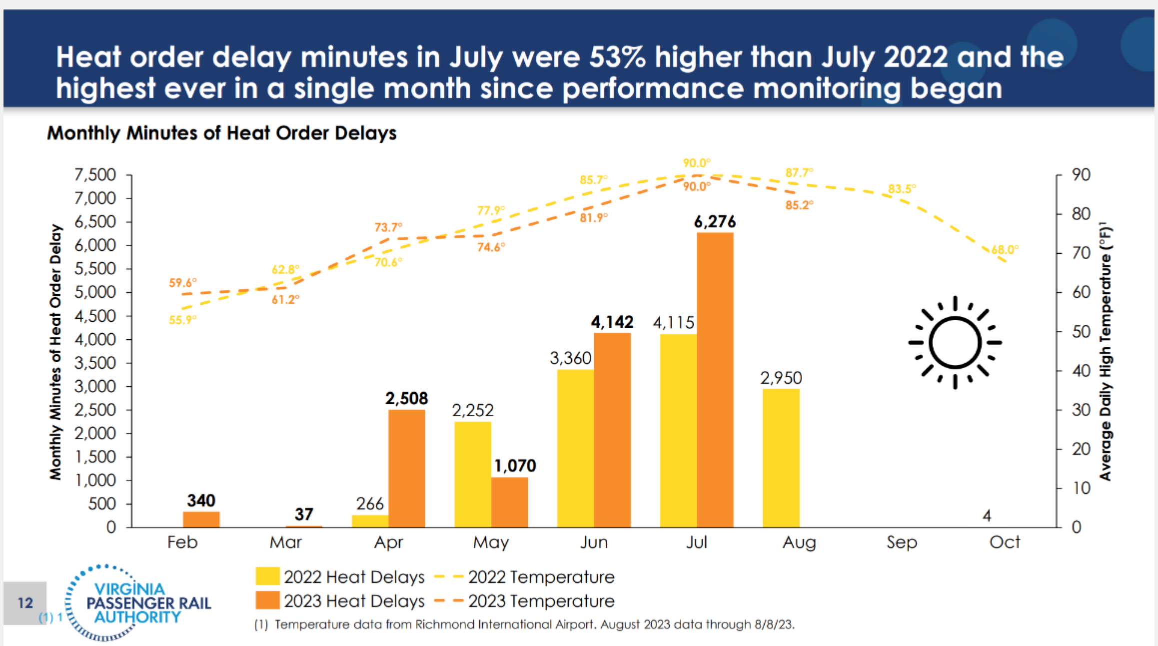

Figure 9. Chart showing the relationship between monthly Virginia rail heat order delay duration and average daily temperature in 2022 and 2023. Source: [Virginia Passenger Rail Authority, 2023](#).

Travel Patterns and Mode Shifts

Studies suggest that travel patterns and rider behavior shift during extreme heat conditions.[20] Ridership may decline on certain routes (particularly those that serve outdoor destinations or that rely on outdoor transit stations) while demand may increase for trips to cooling centers or indoor facilities.

Some travelers may also avoid active transportation modes during high heat. Walking and biking often serve as connections to and from transit stops, so high temperatures can make it harder for riders to access stations. Figure 10 illustrates this relationship by plotting Capital Bikeshare trips per day alongside average daily temperature in 2010 and 2011.[21] Ridership is generally low in the colder months and higher in the warmer months. However, there is a noticeable dip in ridership in July and August when temperatures are at their hottest (above 80°F). Due to these high temperatures, cyclists chose not to use Capital Bikeshare. This means they either chose not to travel, or they switched to alternative modes of transportation that might be more comfortable on a very hot day (i.e., cars, bus). As riders opt for air-conditioned travel alternatives such as personal vehicles or ride-hailing services, this may lead to increased roadway congestion.

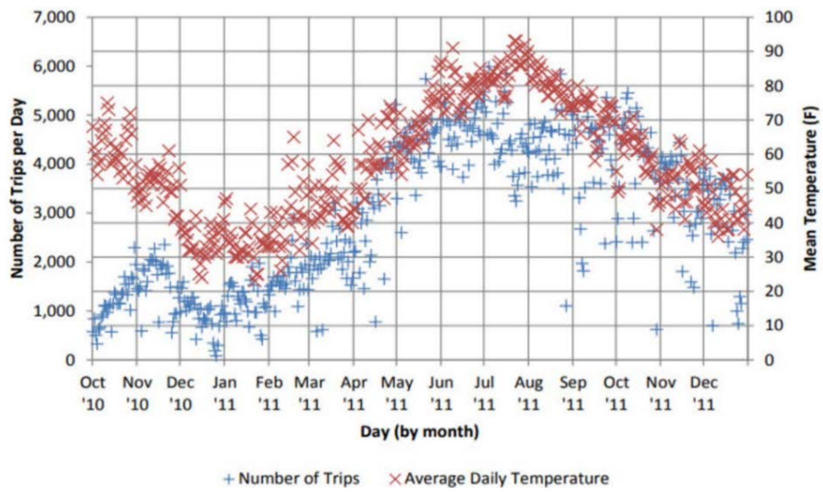

Figure 10. Total number of Capital Bikeshare trips per day compared to average temperature per day. Source: Gebhart and Noland, 2014.

ECONOMIC IMPACTS

The range of disruptions to transit operations and rider behavior described above all translate into economic losses for transit stakeholders, including travelers, transit agencies, regional businesses, and freight operators.

Cost of Reduced Ridership

When heat drives commuters to forgo trips or shift to alternative modes of service, transit ridership declines.[22] This translates into reduced fare revenue for transit owners. *Lost fare revenue due to reduced ridership is estimated in the* **Cost of Reduced Ridership** *section below.*

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[20] Ngo, N., & Bashar, S. 2024. The impacts of extreme weather events on U.S. Public transit ridership. https://www.sciencedirect.com/science/article/abs/pii/S1361920924004619

[21] Gebhart, K., & Noland, R. 2014. The impact of weather conditions on bikeshare trips in Washington, DC. https://link.springer.com/article/10.1007/s11116-014-9540-7

[22] Ngo, N., & Bashar, S. 2024. The impacts of extreme weather events on U.S. Public transit ridership. https://www.sciencedirect.com/science/article/abs/pii/S1361920924004619

Cost of Operations and Maintenance

The operations and maintenance demands associated with extreme heat translate into additional costs for transit agencies (e.g., fuel, depreciation, and labor costs).[23] For example, and as described above, high temperatures may require agencies to increase cooling in enclosed areas (i.e., stations, train cars, buses). Increased use of cooling infrastructure necessitates more frequent maintenance and emergency repairs, especially during heat-related infrastructure failures, as well an increased energy costs for running the equipment more. As another example, heat-related delays may increase the amount of fuel and labor required to keep transit running and transit owners ultimately bear this cost. *Delay-related owner costs are estimated in the* **Cost of Heat Delays** *section below.*

Cost of Interrupted Service

Heat-related slow orders affect both passenger and freight operations along shared corridors. Freight carriers may face delays and reduced throughput that leads to downstream supply chain complications and revenue loss. Local businesses that rely on foot traffic from transit riders may also experience lower customer volumes during slow orders or service disruptions. Disruptions also mean longer commutes and decreased productivity, the cost of which transit users ultimately bear. *Delay-related user costs are estimated in the* **Cost of Heat Delays** *section below.*

Analyzing the Cost of Inaction

TPB has conducted five benefit-cost analysis (BCA) case studies of transportation assets within the TPB service territory to demonstrate the cost of inaction, compare low-cost and high-cost solution options, and provide support for the benefits of proactive resilience investment. The transit case studies include:

- **Rail Stop:** Greenbelt station in Greenbelt, MD. This station is served by both MARC and WMATA and serves roughly 2,100 passengers per day during the summer.
- **Rail Line:** Silver Line between Loudoun Gateway and Washington Dulles International Airport. This section is served by WMATA and sees roughly 5,000 passengers per day through the Dulles Station.
- **Bus Stop:** Army Navy Drive & South Joyce Street westbound/southbound bus stop in Arlington, VA. This stop serves roughly 70 riders per day.

The case studies consider costs from both extreme heat and flood exposure. For extreme heat, the case studies quantify heat-related health costs for users through emergency department visits and hospitalizations. For more details, see TPB's Regional Transportation Resilience Economic Analysis.

[23] Office of the Secretary, U.S. Department of Transportation. 2025. Benefit-Cost Analysis Guidance for Discretionary Grant Programs. https://www.transportation.gov/sites/dot.gov/files/2025-05/Benefit%20Cost%20Analysis%20Guidance%202025%20Update%20II%20%28Final%29.pdf

Quantified Impacts for Transit Owners and Users

Extreme heat affects transit owners (operators) and users (riders) alike. It disrupts service which drives economic losses for transit operators, and it subjects riders to delays that may result in their prolonged (increasingly dangerous) exposure to the extreme heat conditions. For this assessment, TPB quantified a subset of specific costs to transit owners and users associated with these impacts to begin to understand the cascading impacts of extreme heat on both transit owners and riders. The specific costs included in this assessment were estimated using data made available by WMATA and VRE.[24] This assessment has two primary components:

- **Cost of Reduced Ridership:** Using WMATA and VRE historic and projected ridership data, TPB approximated the financial loss that transit owners may bear due to changes in this metric (i.e., changes in ridership driven by heat-related mode shift or users deciding to forego a discretionary trip).
- **Cost of Heat Delays:** In combination with industry-standard operating and value-for-time costs, TPB used VRE's historical database of slow orders to approximate the cost that the traveling public might bear due to these delays. This analysis does not quantify the broader impacts of heat for users, like heat-related threats to users' health.

These high-level analyses are a first step towards quantifying heat-related losses using available data.

COST OF REDUCED RIDERSHIP

This analysis uses historic and projected ridership data to determine how heat may impact transit ridership across the National Capital Region, and how these changes might translate into economic impacts for transit agencies.

Methodology

TPB developed a three-step quantitative methodology for this analysis. The approach integrates projected temperature data with observed ridership and operational data for WMATA Metrorail and VRE to quantify how extreme heat affects transit use and how those impacts may change in the future.

The methodology **(1)** approximates baseline ridership, **(2)** assesses how ridership has historically been impacted during extreme heat events, and **(3)** projects the extent of these heat-related impacts under future climate conditions.

STEP 1: SET A BASELINE

For both transit agencies, TPB identified three representative extreme heat events or "case studies" to evaluate how ridership may respond under high-temperature conditions. To isolate the impact of heat on any observed changes in ridership, each of these case studies reflects a period over which temperatures were distinctly high. In other words, these case studies do not reflect instances of extremely hot days during an already very hot period. They instead reflect abnormally high heat conditions during an otherwise normal period, to increase the likelihood that any changes in ridership might be attributed to the high heat conditions. TPB also verified that each selected case study resulted in known operational disruptions (i.e., slow orders) using publicly available sources, such as news articles and internal transit agency data, as

[24] TPB anticipates adding MARC to the transit impacts assessment as data becomes available later this year (2026).

available. TPB assessed several case studies and chose to include those that were representative of the standard ridership patterns and excluded those that were outliers driven by external factors.

For each case study, TPB defined "baseline ridership" by determining the average daily ridership for two weeks before and two weeks after the high heat event, on the equivalent days of the week.

Case Studies

Tuesday, September 5 – Friday, September 8, 2023

- VRE affected by slow orders
- 86.2°F average ambient temperature at Ronald Reagan National Airport
- Three consecutive days with highs above 95°F

Agencies Analyzed: VRE

Thursday, June 20 – Sunday, June 23, 2024

- WMATA and VRE affected by slow orders
- 86.1°F average ambient temperature at Ronald Reagan National Airport
- Three consecutive days with highs above 95°F; heat emergency activated
- Record-breaking temperatures, highest since August 2016
- Climatologically abnormal for time of year

Agencies Analyzed: VRE, metro

Saturday, July 13 – Wednesday, July 17, 2024

- WMATA, MARC, and VRE affected by slow orders
- 88.5°F average ambient temperature at Ronald Reagan National Airport
- Daily highs of 95°F to 103°F, high nighttime lows
- Excessive heat warning
- Record-breaking high temperatures

Agencies Analyzed: metro

Monday, June 23 – Thursday, June 26, 2025

- WMATA, MARC, and VRE affected by slow orders
- 86.8°F average ambient temperature at Ronald Reagan National Airport
- Four consecutive daily highs above 95°F; heat index exceeding 105°F
- Climatologically abnormal for time of year

Agencies Analyzed: VRE, metro

STEP 2: QUANTIFY OBSERVED IMPACTS

To quantify the observed impact of extreme heat on transit ridership, TPB compared the average daily ridership during each case study to its respective baseline ridership, as determined in Step 1. This produced an average percent change in ridership that could reasonably be attributed to the extreme heat conditions. TPB translated any change in ridership into economic impacts for transit operators by calculating the difference in average daily fare revenue earned during baseline versus high heat conditions. For this calculation, TPB used available fare data to create a proxy average trip fare for both transit agencies.

STEP 3: PROJECT FUTURE IMPACTS

This step offered an approximation of how impacts to future ridership and fare revenue might escalate as temperatures rise. TPB generated climate projections for the region to estimate the frequency of high heat days (i.e., days exceeding 90°F) in 2030 and 2050, based on a high emissions scenario (SSP5-8.5). TPB then used the observed relationship between extreme heat and ridership (determined in Step 2) to estimate the magnitude of these impacts under future climate conditions, based on the transit agencies' projections for ridership in 2030 and 2050. As an illustrative example of the projections that TPB generated, Figure 11 displays the projected high heat days in 2050 against WMATA Metrorail stations.

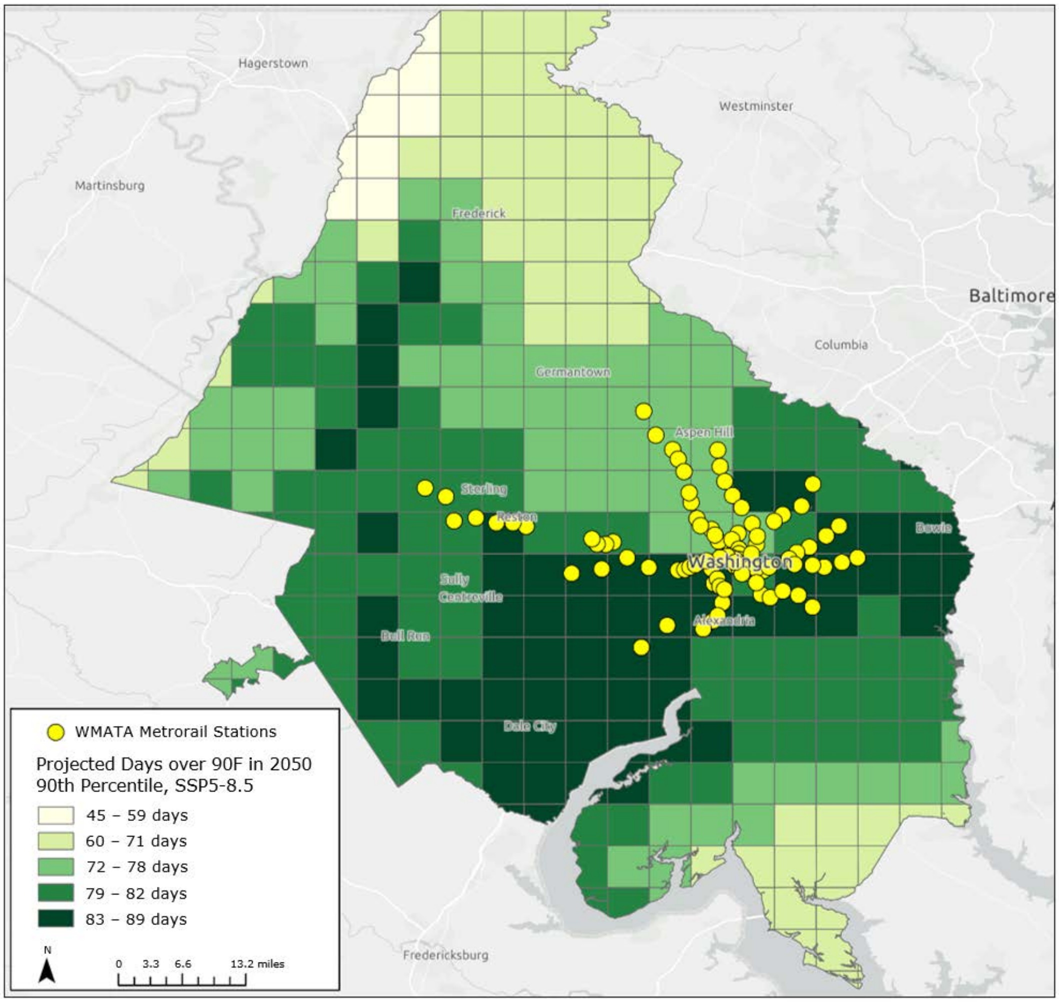


Figure 11. Map of projected days exceeding 90°F in 2050 under a high emissions scenario and WMATA Metrorail stations.

Results

The results of this Ridership Analysis offer an approximation of a direct cost that transit agencies ("Owners") may incur due to the impact of extreme heat on rail ridership, now and in the future.

WMATA

On average, TPB calculated an approximate 3.4 percent decrease in Metrorail ridership during the three high heat event case studies. Assuming an average fare of $3.18[25], this corresponds to an estimated $36,903 in lost fare revenue per day during extreme heat events. These impacts are likely driven by heat-related slow orders that reduce train frequency, as well as decreased rider willingness to walk to or wait for

[25] TPB assumed an average fare of $3.18 by averaging the peak, off peak, and weekend rates for 2025.

transit in extreme heat. Table 1 summarizes the observed ridership changes and estimated revenue losses, as described.[26]

Table 1. Observed Ridership and Estimated Revenue Impacts for WMATA Metrorail During Extreme Heat Events.

Heat Event	Average Baseline Daily Ridership	Average High Heat Daily Ridership	Percent Change in Ridership under High Heat Conditions	Estimated Daily Fare Revenue Lost due to Heat Event
Thursday, June 20 – Sunday, June 23, 2024	334,781	308,859	-7.7%	$82,518
Saturday, July 13 – Wednesday, July 17, 2024	336,554	329,728	-2.0%	$21,730
Monday, June 23 – Thursday, June 26, 2025	506,280	504,251	-0.4%	$6,460

While these results suggest that extreme heat reduces Metrorail ridership during individual events, overall demand for WMATA Metrorail service is projected to increase. As overall ridership increases, more transit users will be exposed to extreme heat conditions, particularly those who rely on transit for non-discretionary trips. In tandem, climate projections indicate that extreme heat conditions will become increasingly frequent and severe. Table 2 summarizes the projected changes in ridership, extreme heat exposure, and associated revenue impacts.

Table 2. Projected Changes in Ridership, Extreme Heat Exposure, and Estimated Revenue Impacts for WMATA Metrorail.

Metric	Observed	2030 Projection	2050 Projection
Annual Ridership Change (relative to 2025)	--	+2%	+23%
High Heat (>90°F) Days per Year	~32	66	88
Estimated Annual Fare Revenue Loss	$1.2M	$2.8M	$4.6M

VRE

TPB observed an approximate 3.6 percent decrease in VRE ridership across the September 2023 and June 2024 high heat events and a 3.56 percent increase in ridership during the June 2025 high heat event. Overall, this reflects an average ridership decrease of 1.21 percent across these case studies,

[26] The percent change in ridership varied widely by heat event, as shown Table 1. This variability likely reflects a combination of factors beyond temperature alone, including system changes over time, differences in service conditions, weekend versus weekday travel patterns, and broader demand shifts such as the federal return-to-office order in the Washington, DC region in early 2025. Similar variability is documented in the literature: studies of New York City subway ridership during extreme heat find declines that differ widely by time of day, location, and rider group, with larger reductions during off-peak periods and weekends (e.g., Zhao et al., 2026; Guo et al., 2026).

corresponding to an approximate $1,514 in fare revenue loss per day. The increase in ridership during the 2025 heat event may reflect external factors, like potential road closures or traffic that could encourage temporary mode shift to transit or the return to office mandate for federal government employees.[27] Table 3 summarizes the observed ridership changes and estimated revenue losses during extreme heat events, assuming an average fare of $7.10.

Table 3. Observed Ridership and Estimated Revenue Impacts for VRE During Extreme Heat Events.

Heat Event	Baseline Daily Ridership	High Heat Daily Ridership	Percent Change in Ridership under High Heat Conditions	Estimated Daily Fare Revenue Lost due to Heat Event
Tuesday, September 5th – Friday, September 8th, 2023	6,616	6,391	-3.4%	$1,601
Thursday, June 20 – Sunday, June 23, 2024	5,303	5,102	-3.79%	$1,427
Monday, June 23 – Thursday, June 26, 2025	10,773	11,156	(+) 3.56%	(+) $2,723

VRE ridership is expected to greatly increase over time due to planned expansions, contributing to greater exposure to extreme heat conditions. At the same time, extreme heat is projected to become more frequent across VRE's service area, increasing the likelihood of operational disruptions and associated rider impacts. Table 4 summarizes the projected changes in ridership, extreme heat exposure, as well as associated revenue impacts for the September 2023 and June 2024 high heat events.

Table 4. Projected Changes in Ridership, Extreme Heat Exposure, and Estimated Revenue Impacts for VRE.

Metric	Observed	2030 Projection	2050 Projection
Annual Ridership Change (relative to 2025)	—	+69%	+210%
High Heat (>90°F) Days per Year	~36	65	88
Estimated Annual Fare Revenue Loss	—	$250k	$617k

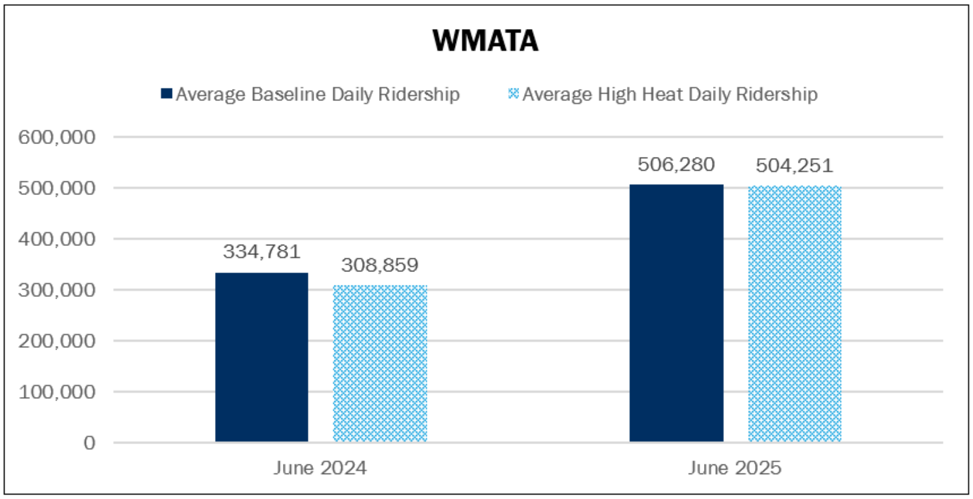
Key Takeaways

While ridership impacts vary by system and individual heat event, TPB observed that extreme heat is generally associated with decreased ridership across rail services (Figure 12). However, this change is significantly colored by external factors. The change in ridership is clearer and more significant for WMATA Metrorail likely because a larger proportion of Metrorail users take the train discretionarily. When taking the train is a choice, it is more likely that extreme temperatures may be a factor in riders' decision making.

[27] VRE. 2024. Annual Comprehensive Financial Report for Years Ended June 30, 2025 and 2024. https://www.vre.org/assets/1/6/Virginia_Railway_Express_06_30_2025_Annual_Comprehensive_Financial_Report_-_as_issued.pdf

VRE is a commuter rail and thus most trips on VRE lines are not discretionary.[28,29] In other words, users need to get to work, especially after the 2025 federal return to office order, and uncomfortable outdoor conditions are likely insufficient to drive behavioral changes. For this reason, the minimal observed changes in ridership for VRE are likely mode shifts, not discretionary travelers forgoing their planned trip due to inclement weather.

Overall, the results indicate that extreme heat has a moderate but observable impact on transit ridership and fare revenue as a result, and these impacts are expected to increase over time as extreme heat days become more frequent.



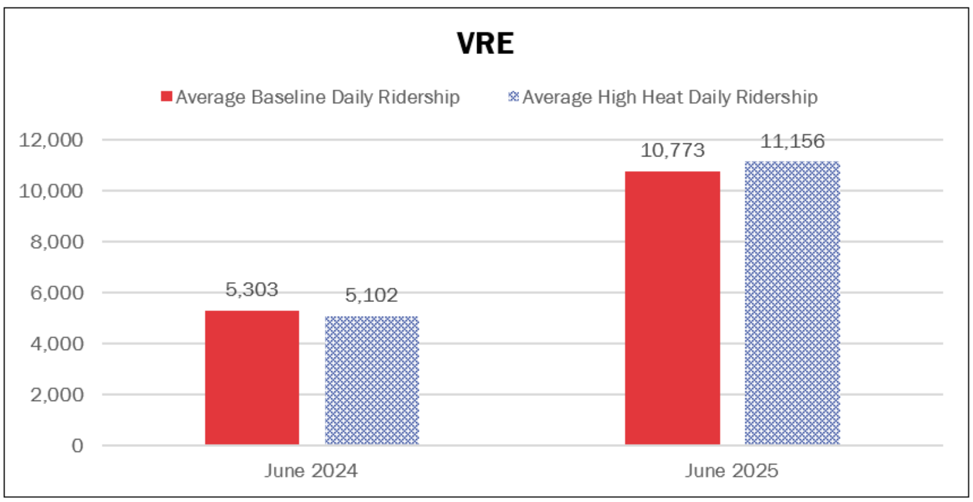


Figure 12. Comparison of baseline and high heat ridership during the June 2024 and June 2025 case study periods.

[28] TPB. 2026. State Of Public Transportation 2024 Report. https://www.mwcog.org/documents/2026/02/09/state-of-public-transportation-report-bus-rail-tpb-transit/

[29] VRE. 2025. 2025 Customer Opinion Survey Results. https://www.vre.org/assets/1/6/2025_CSS.pdf

COST OF HEAT DELAYS

Heat-related slow orders lead to compounding delays which increase operating costs for transit agencies and add travel time burden for riders. The following assessment begins to quantify these costs under current and future climate conditions.

Methodology

VRE provided TPB with a robust database that documents all rail disruptions from 2015 to 2025. This data enabled TPB to approximate select operational and value-for-time costs incurred by transit riders during heat-related delays on VRE rail lines over this period.

For this analysis, TPB followed an approach that **(1)** identifies the riders impacted by VRE's historical, heat-related delays, **(2)** defines low, average, and high impact delay scenarios based on the observed ridership and delay durations, **(3)** monetizes the impacts of those delay scenarios, and **(4)** projects the magnitude of those impacts under future climate conditions.

STEP 1: IDENTIFY IMPACTED RIDERS

TPB extracted events that specifically cited heat as a reason for the delay in the database. TPB then conducted an analysis to quantify how many riders were on the train at any given point during each specific heat-related delay—for each station, on each train, in each trip direction, and during each delay event—using station level on and offboarding data.

STEP 2: DEFINE LOW, AVERAGE, AND HIGH IMPACT DELAY SCENARIOS

Using the information gleaned in Step 1, TPB determined the low, average, and high number of riders impacted when a single VRE train was delayed by a heat-related slow order. TPB also determined the low, average, and high number of minutes that a single delay lasted. Delay duration was determined separately because shorter delays do not necessarily impact fewer riders. In other words, more people are impacted if a full train is delayed for one minute than if an empty train is delayed for any length of time. This allowed TPB to define a low, average, and high impact delay scenario (e.g., the low scenario assumes the lowest observed ridership and the lowest observed delay duration, etc.).

STEP 3: MONETIZE IMPACTS

TPB monetized each delay by applying standard values derived from the Federal Highway Administration's (FHWA) Benefit Cost Analysis Guidance 2025 Update II, adjusted to 2026 dollars. TPB approximated "Owner Cost" (i.e., the cost to the transit operator) using the standard value for operating costs incurred hourly for hauling commuter trains ($750.80 per hour of delay). Similarly, TPB approximated "User Cost" (i.e., the cost to the impacted transit riders) by applying the standard value of person-time per hour of personal travel and commuting ($21.20 per hour of person-time).

STEP 4: PROJECT FUTURE IMPACTS

According to the database, VRE lines experience an average of 20 days with heat-related slow orders per year. This is relatively similar to the historic baseline of approximately 36 high heat days per year at VRE stations, especially given the human error introduced by the slow order data collection process which involves train operators manually recording the details of the delays. To project the impacts of slow orders under future climate conditions, TPB assumed that VRE would experience one slow order per high heat day. Using climate projections of days exceeding 90°F (i.e., high heat days), TPB multiplied the calculated costs per delay by the anticipated number of heat-related delays that will occur in the year 2030 and 2050 to produce an annual cost for each of these time horizons.

Results

This approach produced the Owner and User Costs incurred per delay for one train. The sum of these components represents the total "*Cost per Train*" during a given delay. In practice, each slow order usually impacts multiple trains—according to VRE's historic data, anywhere from one to 11 trains are impacted by one slow order, with an average of approximately three trains impacted per delay. Based on this assumption, TPB multiplied the total "*Cost per Train*" by three to estimate the total "*Cost per Delay*." Finally, TPB calculated the annual cost of slow orders in the years 2030 and 2050 by multiplying the cost per delay by the frequency of high heat days in those years. Table 5 summarizes these results for the low, average, and high impact delay scenarios.

Table 5. Owner and User Costs per Train, Per Delay, and Per Year Under Future Climate Conditions.

Delay Scenario	Delay Duration	Riders Impacted	Owner Cost	User Cost	Cost per Train	Cost per Delay	Annual Cost, Observed	Annual Cost, 2030	Annual Cost, 2050
	(min)	(n)	$/train/delay			$/delay	$/year		
Low	1	4	$ 13	$ 90	$ 103	$ 308	$ 6k	$ 20k	$ 26k
Avg	10	431	$ 127	$ 9,143	$ 9,270	$ 27,810	$ 567k	$ 1.8M	$ 2.4M
High	47	1,229	$ 588	$ 26,050	$ 26,638	$ 79,914	$ 1.6M	$ 5.2M	$ 6.9M

Key Takeaways

As extreme heat events become more frequent and overall ridership continues to grow, the heat-related costs incurred by transit agencies and users alike will escalate. While discretionary transit users may have the flexibility to reduce their transit use during extreme heat conditions, this is not a choice that non-discretionary travelers can make. Those who rely upon the train to commute to work or access essential services remain exposed to extreme heat conditions and this analysis offers a preliminary look at the costs they might bear as a result.

Future Enhancements

The components of this assessment provide a narrow view into the broad landscape of heat-related losses. For example, with more data and further coordination with the regional transit agencies, TPB could complete a comprehensive cost assessment that quantifies each of the major impacts described in the first, qualitative section of this assessment. The combined results of the quantitative portion of this assessment highlight the importance of improving the transit system's resilience to extreme heat, for the benefit of transit operators and users alike. Future studies could include:

- Analyzing the impact of heat-related service disruption on access to emergency services, jobs, cooling centers, etc.
- Incorporating extreme heat data into TPB's Travel Demand Model (TDM) to better understand mode shifts during extreme heat events (e.g., shifts from active/public transit to personal vehicles or rideshares).
- Conducting a survey (or adding targeted questions to existing commuter surveys) to better understand the behavior and decisions that transit users make during extreme heat events.
- Quantifying the broader range of extreme heat impacts on the health and wellbeing of transit users, particularly those that use transit non-discretionarily (e.g., incorporating geographic and social drivers of transit use and heat vulnerability, like socioeconomic indicators or proximity to stations, to understand how some riders may be disproportionately vulnerable to heat).

- Expanding the quantitative ridership and cost assessment to include buses and bikeshare.
- Exploring extreme heat impacts at specific rail and bus stations in the region that have high heat exposure, which could also include evaluating the costs and benefits of implementing different cooling solution options at these specific locations.
- Characterizing the localized, heat-relevant risks and costs to transit users along their entire commute (e.g., walking to a specific transit stop, mid-commute mode switching).

Transportation Grants Database

The **Transportation Grants Database** compiles federal, state, and local funding opportunities relevant to transportation-related extreme heat resilience. It is designed to help transportation agencies, local governments, and partners identify grants and programs that support planning, design, and implementation of heat-related infrastructure and resilience projects. Each program entry includes information such as eligibility requirements, evaluation criteria, cost share details, funding timelines, and links to program webpages. Suggested "win themes" are also provided for each program to help member agencies craft winning grant applications.

> **Goals & Objectives**
>
> The Transportation Grants Database supports regional resilience efforts by identifying funding opportunities for heat-related planning, design, and implementation projects.

The Transportation Grants Database will be made available on [TPB's website.](#)

Example Grant Entry

As an example of the information provided in the database for each grant, below is the excerpted information for the **Building Resilient Infrastructure and Communities (BRIC) program.**

GENERAL PROGRAM INFORMATION

- **Opportunity Name:** Building Resilient Infrastructure and Communities (BRIC)
- **Funding Type:** Federal
- **Funding Agency:** Federal Emergency Management Agency (FEMA)
- **Program Overview:** BRIC provides pre-disaster funding for mitigation projects that reduce long-term risk to people and property from natural hazards and build community capacity and capability.
- **Max Award Amount:** No maximum award amount.
- **Submission Deadlines:** The FY 2024 & 2025 national application deadline is July 23, 2026. Subapplicant deadlines vary by state.
- **Funding Cycle Frequency:** Annually

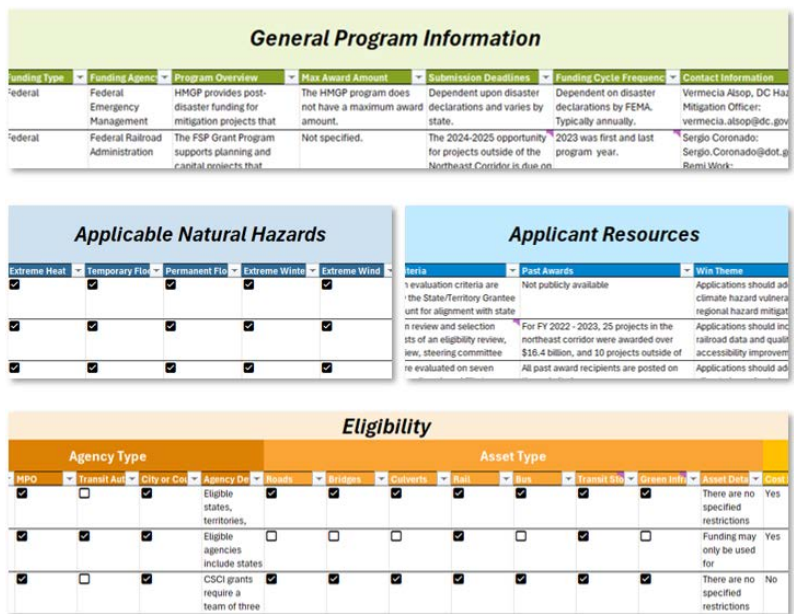


Figure 13. Example excerpts from the Transportation Grants Database.

- **Contact Information:** Vermecia Alsop, DC Hazard Mitigation Officer: vermecia.alsop@dc.gov; Katie Vugdalic, Virginia Hazard Mitigation Grants Manager: katie.vugdalic@vdem.virginia.gov; Maryland: mitigation.mdem@maryland.gov
- **Link:** https://www.fema.gov/grants/mitigation/learn/building-resilient-infrastructure-communities

ELIGIBILITY

- **Applicable Natural Hazards:** Extreme heat, flooding, extreme winter, extreme wind
- **State:** VA, MD, DC
- **Agency Type:** State, MPO, City or County
- **Agency Details:** Eligible states, territories, and federally recognized tribes can submit applications on behalf of subapplicants for BRIC funding. These eligible applicants host separate applications with varying eligibility requirements. Subapplicant agencies include communities, local governments, cities, townships, counties, special district governments, and tribal nations.
- **Asset Type:** Roads, Bridges, Culverts, Rail, Bus
- **Asset Details:** There are no specified restrictions on transportation asset eligibility.
- **Cost Share:** Yes
- **Cost Share Details:** The non-Federal cost share is 25%. Small, impoverished communities are eligible for lower cost shares down to 10%. For insular areas where the non-federal cost share for the entire award is under $200,000, the non-Federal cost share is 0%.
- **Eligible Activity:** Planning and Implementation
- **Eligible Activity Details:** Eligible activities include Capability and Capacity Building activities that directly support infrastructure resilience, such as the adoption, enforcement, and implementation of hazard-resistant building codes; Hazard Mitigation Projects that are cost-effective infrastructure and construction projects, and increase resilience and public safety, reduce injuries and loss of life; and reduce damage and destruction to property, critical services, facilities, and infrastructure (including natural systems) from natural hazards; and Management Costs, which provide financial assistance to reimburse recipients and subrecipients for eligible and reasonable indirect costs, direct administrative costs, and other administrative expenses associated with approved hazard mitigation measures or project subject to applicable cost share requirements. Hazard Mitigation Projects must have, at a minimum, a conceptual design.

APPLICANT RESOURCES

- **Evaluation Criteria:** Applications are evaluated using the following criteria: Infrastructure Project Construction Readiness; New Applicant or Subapplicant; Building Code Adoption and Enforcement; Small Impoverished Community; Risk Reduction; and Implementation Measures.
- **Past Awards:** All past award recipients are in the OpenFEMA dataset: https://www.fema.gov/openfema-data-page/hma-subapplications-v2

- **Win Themes (for Heat):** Ground the project in a FEMA approved Hazard Mitigation Plan priority and clearly define the hazard risk to infrastructure and show how the project measurably reduces that risk through eligible resilience improvements. Emphasize cost effectiveness using FEMA approved benefit cost methods (BCA ≥ 1.0) and a feasible implementation approach. Demonstrate building code adoption and enforcement in project location or community.

  Example Implementation Language: Based on TPB's resilience webmap, this project is located in an area of [high flood] and [high heat] risk. This project focuses on a critical asset [that provides access to emergency health services] and will involve collaboration with key partners such as TPB, [others specific to project location/needs].

Transportation Design Guidance

The Transportation Design Guidance provides best practice considerations for siting and designing effective cooling solutions to reduce heat exposure on people navigating the public realm, with a focus on first-last mile connections to transit and active transportation. Minimizing the impact of extreme heat on transit users and those traveling on foot or bicycle is important to protect public health and build resilience.

TPB identified three regional typologies to target for extreme heat mitigation and management (Figure 14):

- Streetscapes
- Bus Station Areas, and
- Trailhead Plazas

Goals & Objectives

The Transportation Design Guidance supports regional resilience efforts by:

I. Providing best practice considerations for siting and designing effective cooling solutions for streetscapes, bus station areas, and trailhead plazas.

II. Providing regional context and examples to help implement heat mitigation and heat management elements.

Streetscapes

Bus Station Areas

Trailhead Plazas

Figure 14. Regional typologies.

Regionally, multimodal streetscapes facilitate connections between homes, jobs, and transit, and contain many first and last mile trips. While rail transit stations are often enclosed or covered, many bus stops lack adequate facilities to protect riders from extreme heat while they wait for a vehicle. The National Capital Region also has a strong trail network, and many multimodal journeys include travel on bike routes and trail segments. Strategies for cooling the public realm should take these places into account as well.

Following a research process, which included a literature review of published research, case studies, and similar planning documents, TPB identified appropriate heat mitigation and management elements to consider for each regional typology. TPB prioritized elements that were applicable, effective, and contextually appropriate to each typology.

Figure 15 and Figure 16 list the heat mitigation and management elements discussed in this guidance. The list represents a diverse group of impactful elements but does not seek to be exhaustive of all considerations that may influence urban cooling and thermal comfort.

Figure 15. Heat mitigation elements.

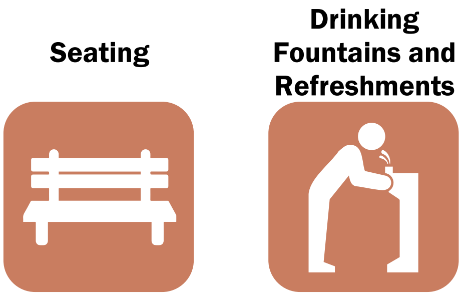


Figure 16. Heat management elements.

For each typology, this guidance examines specific extreme heat issues and considerations and provides guidance on the application of cooling elements in these contexts across the region. This guidance is organized into the following sections:

- **Regional Typologies:** Definition of each of the typologies, and specific guidance for each relevant mitigation and management element in context.
- **Heat Mitigation Elements:** Additional, detailed guidance and implementation best practices for trees, paving, groundcover and bioretention areas, shade structures, and water features.
- **Heat Management Elements:** Additional, detailed guidance and implementation best practices for seating and drinking fountains and refreshments.

Regional Typologies

STREETSCAPES

The streetscape covers the active portions of a journey, including routes to and from transit—commonly referred to as the first and last mile. Heat stress accumulates as people walk, cycle, and roll outside from place to place, with streets facilitating much of this travel. Streetscapes in urban areas tend to have high percentages of impervious surfaces, and the tree canopy cover along streetscapes is constrained by other land uses. Suburban streetscapes with transit routes tend to be arterial roads, with wide expanses of pavement and insufficient shade trees.

Figure 17 depicts a model streetscape scene, providing one example of how the different cooling elements relate to each other in a space. It can be used as a visual aid for interpreting the written guidance that follows.

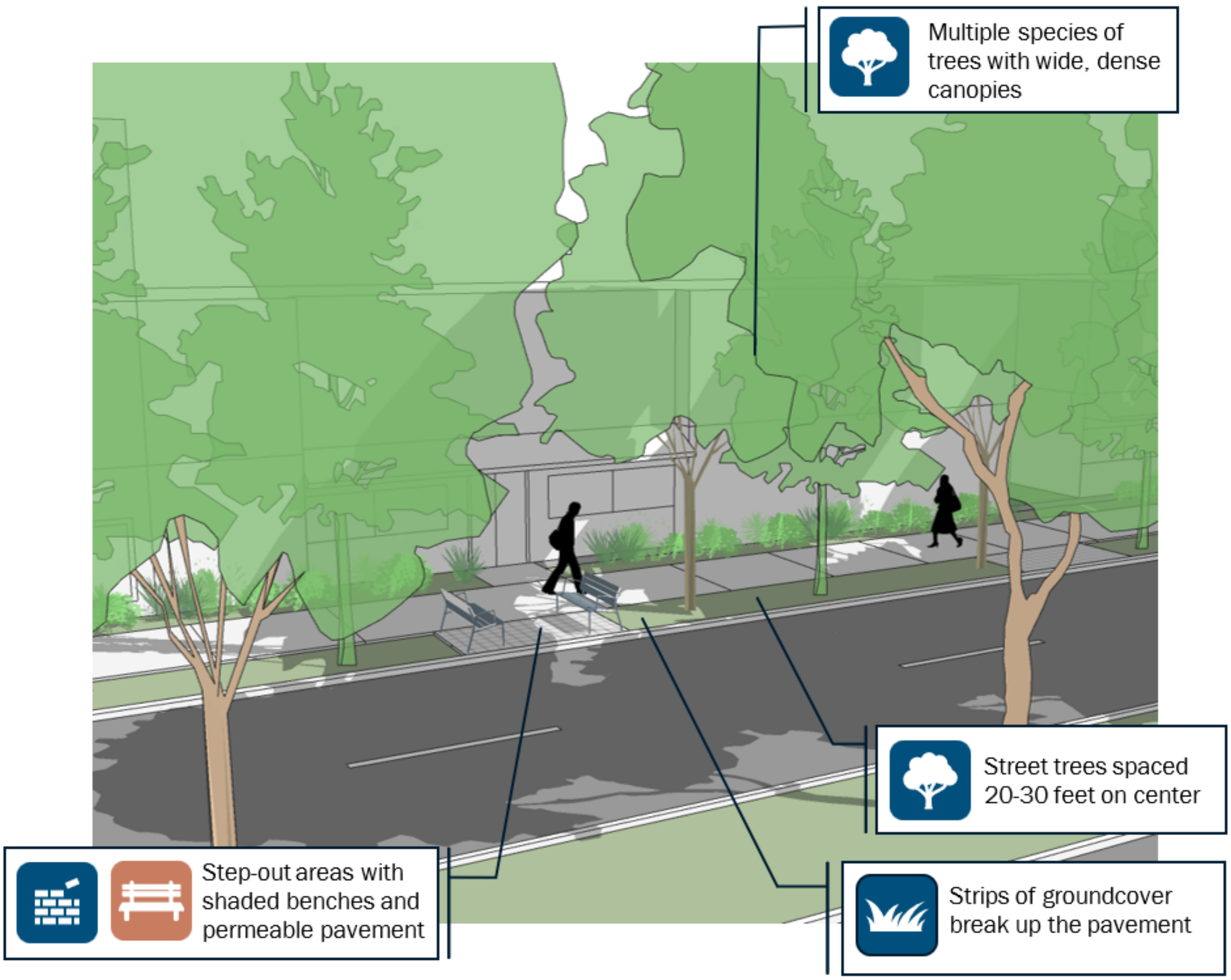


Figure 17. Model cool streetscape.

Elements in Context

Table 6 presents key guidance and considerations for the heat mitigation and management elements that are most important to consider in streetscapes: trees, paving, groundcover and bioretention areas, and seating.

Table 6. Streetscape Elements in Context.

TREES

Regularly spaced trees are the most effective cooling strategy for streetscapes. Spacing tree specimens to minimize canopy overlap will maximize shading potential.

Key Guidance

- **Spacing:** Plant trees 20 to 30 feet apart from each other, on center, minimizing overlap and gaps between canopies, to maximize their cooling potential.
- **Dense Canopies:** Select species with high leaf-area index scores to maximize shading and evaporative cooling potential.
- **Resilient Species:** Select trees expected to thrive in current and future climate conditions and plant a variety of species within a district to promote species diversity.

PAVING

Paving can be a secondary cooling strategy, best implemented with other elements including trees and groundcover. Intentional paving design can also directly support the success of trees.

Key Guidance

- **Application:** Paving must be functional, durable, and accessible to work in a streetscape setting. Portland cement and light-colored pavement are suitable for pedestrian through-zones. Permeable pavements can include permeable concrete or pavers that have gaps between units to enable infiltration and are best left for step-out areas and locations with lower travel.

GROUNDCOVER AND BIORETENTION AREAS

Groundcover along streetscapes is typically included in medians, tree planting beds, and landscape buffer strips. Specifically for groundcover patches with trees, minimum width of 5 feet of planting area is recommended for healthy tree growth. Small patches and strips of groundcover can break up pavement and help decrease LST and nighttime air temperatures.

Key Guidance

- **Application:** Encourage co-location of groundcover, bioretention, and trees to maximize cooling potential and co-benefits.
- **Species Selection:** Water-resilient grass and shrub species are required for bioretention areas that regularly swing between dry and saturated soil.
- **Connectivity:** Connected strips of groundcover provide more co-benefits to trees and can help reduce LST.

SEATING

Standalone benches are the main type of seating provided along streetscapes. They can be placed close to building facades, to take advantage of the shading from the structure, or under trees. Priority should be balanced between locations that will receive shade during summer afternoons and sun in the winter.

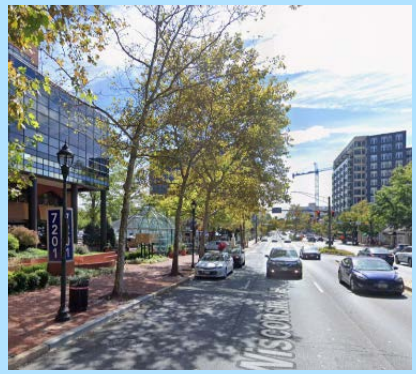
Key Guidance

- **Material:** Wood, stone, and concrete are naturally cooler materials and are more comfortable to sit on in the heat. Metal tends to be warmer to the touch and can be dangerously hot at times, but lighter colors and surface coatings can reduce this to an extent.
- **Orientation:** Benches should be oriented towards pedestrian activity whenever possible. Along building facades, seating should face the pedestrian through-zone. Within step-out areas and amenity zones along the curb, as space allows, seating should face perpendicular to the street to maintain visibility of both the sidewalk and the street.

Recommendations for Different Regional Contexts

Table 7 shows how implementation of the elements may change depending on actual site conditions and regional context. Given the size of the National Capital Region, what works in one place may not be suitable for another. The table bridges the gap between the model streetscape in Figure 17 and real sites across the National Capital Region. Representative examples of locations in the region, ranging from suburban to urban in context, are included to illustrate how conditions may vary in different contexts. Subsequent rows of the table detail typical applications of the elements within each context.

Table 7. Streetscape Recommendations for Different Regional Contexts.

	Suburban Arterial Road	Mixed-Use Arterial Road	Constrained Urban Street
Representative Regional Example	 Richmond Highway, Fairfax County, VA (Source: Google Maps)	 Wisconsin Avenue, Bethesda, MD (Source: Google Maps)	 Commonwealth Avenue, Alexandria VA (Source: Google Maps)
Trees	• Continuous landscape strips with shade trees planted on sides of streets and in medians	• Street trees spaced at projected full canopy distance, in continuous strips, individual tree planting beds, and bioretention areas as context allows	• Continuous landscape strips with shade trees on sides of streets with selective trees in medians where street cross-sections allow
Pavement	• Continuous light-colored concrete sidewalks	• Light-colored two-toned pavers • Permeable pavement step-out areas for street furniture and bus stops between tree planting beds	• Continuous light-colored concrete sidewalks • Permeable pavement step-out areas for street furniture and bus stops between tree planting beds
Groundcover	• Can be dictated by other project needs and goals	• Native grasses and low shrubs in tree planting beds and along building footprints	• Native grasses and low shrubs in tree planting beds and along building footprints
Seating	• Located regularly along streets, co-located with other heat mitigation and management elements	• Located regularly along streets, co-located with other heat mitigation and management elements	• Located regularly along streets, co-located with other heat mitigation and management elements

BUS STATION AREAS

Bus station areas are used as places to sit or stand in between stretches of walking or riding transit. Compared to streetscapes, they focus more on stationary rest rather than active movement. They vary significantly in size and composition based on location, intended level of service, and municipality. Shelters, furnishings, and amenities can expand waiting capacity, increase comfort, and even mitigate heat stress. The National Capital Region's bus network has many operators and types of service, from commuter buses to bus rapid transit (BRT). The heat mitigation and management strategies can vary greatly depending on location, service type, and available space.

Figure 18 depicts a model bus station scene, providing one example of how the different cooling elements relate to each other in a space. It can be used as a visual aid for interpreting the written guidance that follows.

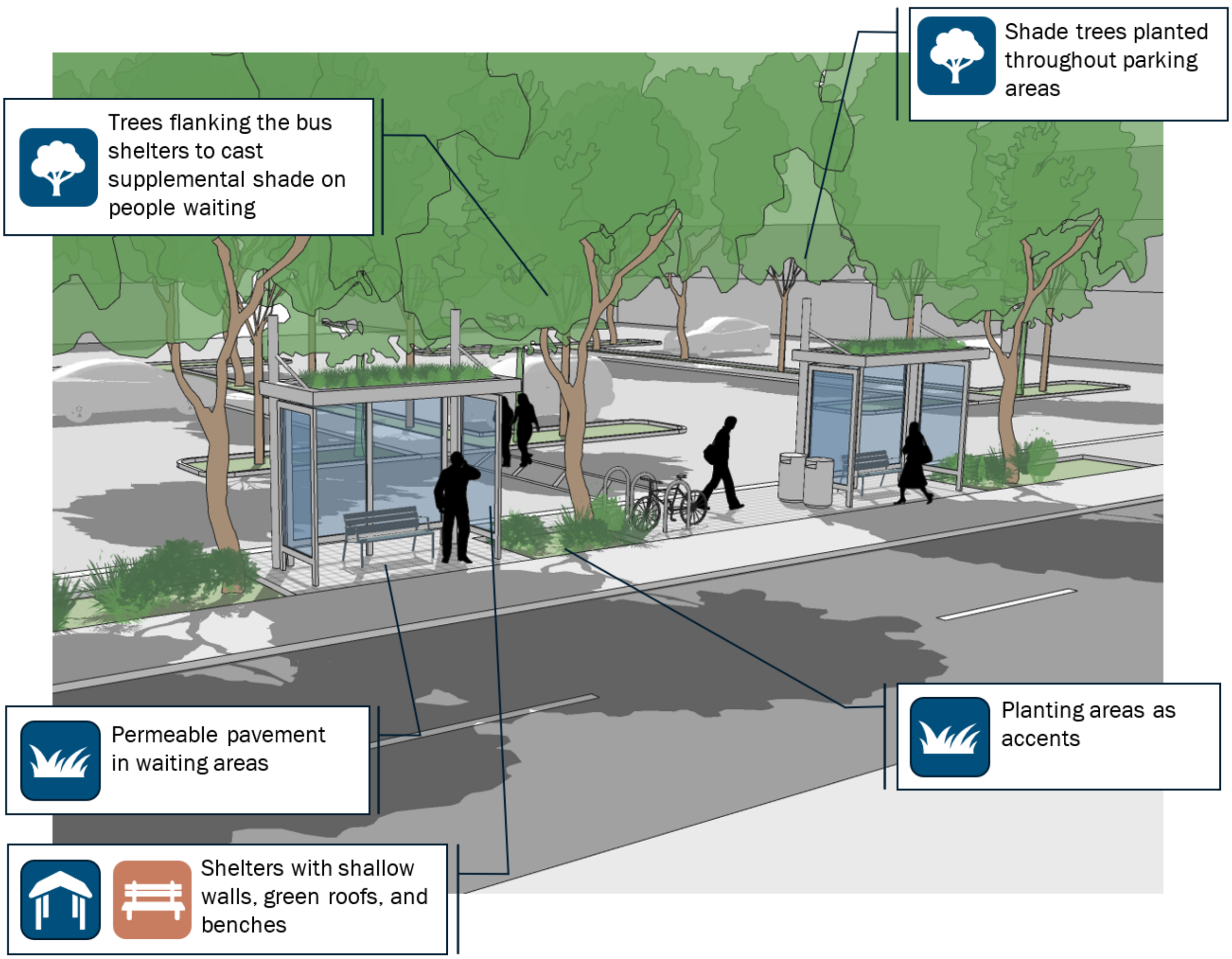


Figure 18. Model cool bus station area.

Elements in Context

Table 8 presents key guidance and considerations for the heat mitigation and management elements that are most important to consider in bus station areas: trees, groundcover and bioretention, shade structures and seating.

Table 8. Bus Station Area Elements in Context.

TREES

Trees should be placed to provide shade over and around bus waiting areas, both where shelters are present as well as where they are absent. Redundancy in shading from trees and shelters can improve cooling when shelters cannot adequately shade their interiors due to the angle of the sun, and minimize the thermal gain caused by shelter material choices.

Key Guidance

- **Spacing:** Plant 20 to 30 feet on center; minimizing overlap and gaps between canopies maximizes the efficiency of tree cooling. Where space allows, grids of trees can create large, shaded areas of continuous canopy when mature.
- **Tree Grates and Supported Pavement:** Areas surrounding bus stations have high foot traffic, which can cause soil compaction and root damage to exposed trees. Tree grates and supported pavement (including silva cells, pier-supported slabs, and structural soils) are recommended measures to support long-term tree health.

GROUNDCOVER AND BIORETENTION AREAS

Interspersing patches of groundcover in impervious areas helps to mediate overall surface temperatures, and longer, complex borders have been shown to facilitate more significant heat exchange between hard and soft surfaces.[30] Planting beds increase the overall greenspace of an area, contributing to the perception of coolness and comfort during the day and helping to cool the air more quickly in the evening.

Key Guidance

- **Siting:** Groundcover should not impede the need for bus station areas to facilitate orderly movement of people, especially at peak times. Greenspace should be located along edges of station areas and away from travel areas.
- **Maintenance and Upkeep:** High traffic bus station areas can be prone to litter accumulation. Installation of waste receptacles at bus stops and regular groundskeeping can minimize the accumulation of litter in planting areas.
- **Space Delineation:** Fence skirting delineates space and discourages walking and standing in planting areas, helping to preserve the greenspace in high-traffic areas.

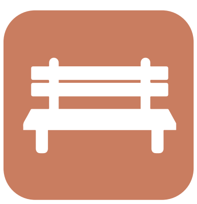
[30] Beele, E. et al. 2024. Spatial Configuration of Green Space Matters: Associations between Urban Land Cover and Air Temperature. *Landscape and Urban Planning* 249: 105121. https://doi.org/10.1016/j.landurbplan.2024.105121.

SHADE STRUCTURES

Transit shelters are shade structures designed specifically for waiting for a bus or train. Their purpose is to maximize comfort and capacity of a waiting area and to provide relief from the elements, including solar radiation. Transit shelters are the most visible infrastructure for active transportation apart from transit vehicles themselves and have co-benefits for transit ridership independent from comfort.

Key Guidance

- **Shelter Design:** Transit shelters typically feature acrylic or glass walls which protect from wind and rain while retaining clear sightlines. However, they can also trap warm air through the greenhouse effect. A study of bus shelters in Houston found that shelters without supplemental shade from trees could be hotter than a bus stop with trees but no shelter[31] and that shallower walls and those that permit airflow can minimize the greenhouse effect.
- **Overlapping Shade Sources:** The amount of solar radiation reaching people under and adjacent to bus shelters can be minimized by siting other shadow-casting elements close by. Buildings, canopy trees, and other types of shade structures can also shade people when the shelter's own roof does not fully protect them at different times of the day. Green roofs on bus shelters also offer great potential to cool bus stop areas in the future. This approach is currently being tested by communities around the United States, but green roofs have not yet been adopted widely.



SEATING

Benches provide a resting place while waiting for the bus and are effective at reducing heat stress for users. They can be installed in a shelter or standalone. Design factors influence the usefulness of a bench to manage extreme heat within a UHI.

Key Guidance

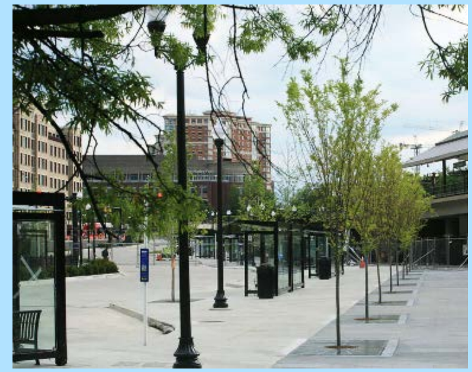
- **Material:** Wood, stone, and concrete are naturally cooler materials and are more comfortable to sit on in the heat. Metal tends to be warmer to the touch and can be dangerously hot at times, but lighter colors and surface coatings can reduce this to an extent.
- **Cooling Synergy:** Benches can be more effective at helping people to reduce their heat stress when located within a shelter or other shaded area. Where benches are proposed, also prioritize shelters and tree plantings.

[31] Lanza, K. et al. 2025. Heat Stress Mitigation by Trees and Shelters at Bus Stops. Transportation Research Part D: Transport and Environment 140: 104653. https://doi.org/10.1016/j.trd.2025.104653.

Recommendations for Different Regional Contexts

Table 9 shows how implementation of the elements may change depending on actual site conditions and regional context. Given the size of the National Capital Region, what works in one place may not be suitable for another. The table bridges the gap between the model bus station area in Figure 18 and real sites across the National Capital Region. Representative examples of locations in the region, ranging from suburban to urban in context, are included to illustrate how conditions may vary in different contexts. Subsequent rows of the table detail typical applications of the elements within each context.

Table 9. Bus Station Area Recommendations for Different Regional Contexts.

	Suburban Commuter Station	Roadside Constrained Stop	Urban Transfer Station
Representative Regional Example	 Horner Road Commuter Lot, Prince William County, VA (Source: Google Maps)	 Mall at Prince George's, Prince George's County, MD (Source: Google Maps)	 King St-Old Town Bus Loop, Alexandria, VA (Source: Google Maps)
Trees	• Trees planted on the bus stop island • Trees planted in the parking area medians and aisle caps	• Ideally provided as part of streetscape; can be planted otherwise	• Grid of trees as part of plaza • Smaller tree planting beds or tree grates recommended for high-traffic areas
Groundcover	• Small accents where practical and unobtrusive	• Provided as part of streetscape	• Minimal, as part of general landscape design
Shade Structures	• Highly prioritized	• Highly prioritized where ridership meets threshold	• Highly prioritized
Seating	• Highly prioritized	• Highly prioritized	• Highly prioritized

TRAILHEAD PLAZAS

The National Capital Region's trail network is used daily by commuters walking, cycling, and rolling—as full trips as well as parts of journeys to and from transit. The rise of shared mobility systems has further expanded the user groups making trips on trails. They are also recreational amenities, used for exercise and leisure. Trails include urban segments with high building and pavement cover, and more natural segments surrounded by groundcover and trees. Trails are used by people running, cycling, or rolling modes of transportation that require more exertion than walking, meaning that heat stress builds up more quickly and opportunities to cool down become more important. In addition, trails are separated from vehicular traffic and located within smaller, more constrained sites requiring different approaches to heat mitigation and management than those along streetscapes. This section focuses specifically on trailheads and plazas along trails that can serve as "cool zones" where amenities are clustered and people can rest.

Figure 19 depicts a model trailhead plaza scene, providing one example of how the different cooling elements relate to each other in a space. It can be used as a visual aid for interpreting the written guidance that follows.

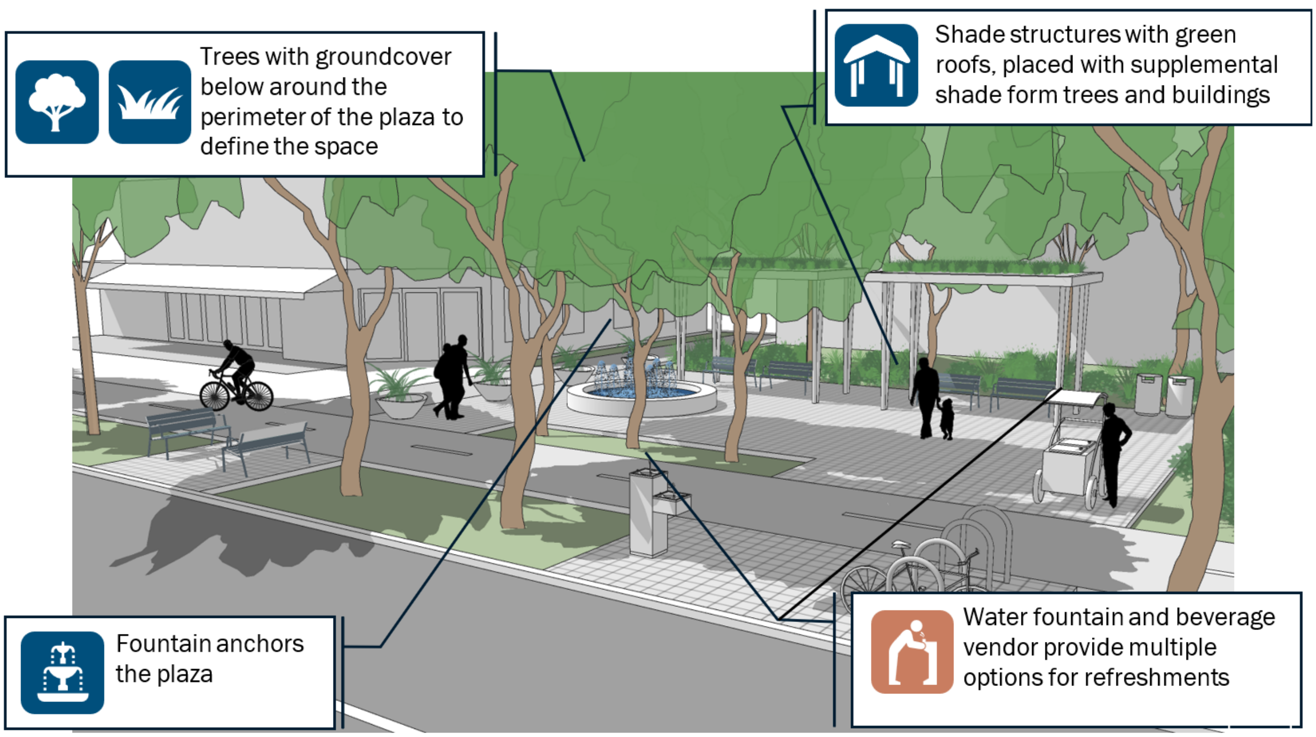


Figure 19. Model cool trailhead plaza.

Elements in Context

Table 10 presents key guidance and considerations for the heat mitigation and management elements that are most important to consider in trailhead plazas: trees, shade structures, water features, and drinking fountains and refreshments.

Table 10. Trailhead Plaza Elements in Context.

TREES

Many trails have existing tree cover along their routes. At trailheads and plazas along routes, surrounding forest tree cover may not provide sufficient functional shade to cool people resting on their journeys. Much like in the other regional typologies, the combination and configuration of elements is important to maximizing cooling potential.

Key Guidance

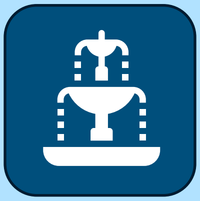
- **Spacing:** Plant 20 to 30 feet on center; minimizing overlap and gaps between canopies maximizes the efficiency of tree cooling. Where space allows, grids of trees, when mature, create large, shaded areas of continuous canopy where the air is most comfortable.
- **Orientation:** Shade studies can help to identify areas where additional trees could fill gaps and cool more evenly across the space.

SHADE STRUCTURES

Pavilions and shade sails provide shelter while allowing breezes to circulate and cool the air and skin, reducing heat stress. Both types of structure are frequently installed in parks and plazas where they can be pass-through or waiting spaces for active transportation users seeking refuge from heat and rain.

Key Guidance

- **Structure Selection:** The type of structure and design is highly dependent on the specific project location and should respond to municipal design standards and aesthetic context. Solid roofs cast the greatest shadows, but pergolas with slatted roofs allow for more airflow and have potential for plants to fill in between slats.
- **Co-location of Elements:** Shade structures are ideal places to install benches, tables, play equipment, bicycle racks, and other amenities as appropriate that improve the quality and experience of the space and create opportunities for respite.



WATER FEATURES

Typically installed as placemaking elements, fountains and water features cool their surroundings through evaporation. They can define spaces and create an inviting environment while lowering air temperatures. The edges of trailheads and plazas, often defined by buildings or continuous vegetation, filter and slow wind down, meaning that the air cooled by water features lingers longer before being carried away.

Key Guidance

- **Water Feature Design:** Water features cool through evapotranspiration, in which tiny droplets are dispersed and then evaporate. Because all water features with a fountain/spray element of similar volume will cool similarly, creative and engaging water features can maximize their placemaking and recreation potential. Splash pads, cascading fountains, decorative pools, and misting sculptures can fit into different contexts and fulfill a range of project needs.
- **Siting:** Water features cool most effectively in the sun, where heat can more easily evaporate water droplets. Sunny paved surfaces also minimize residual surface moisture which can otherwise lead moss and algae to grow, creating maintenance and safety issues.

DRINKING FOUNTAINS AND REFRESHMENTS

Trailhead plazas are ideal locations for drinking fountains. They can service trail users and others passing by.

Access to water and snacks helps people recover from heat stress and improves comfort. Public drinking fountains are the most equitable and permanent fixtures that meet this need, but vending areas for stalls, carts, and food/beverage trucks can also provide flexible access to food and drinks that help to manage heat stress.

Key Guidance

- **Abundance of Options:** Water fountains, vending machines, and staffed beverage and snack vendors all activate spaces and make them more welcoming. People are more likely to linger and return when they know they can stop to refresh themselves while travelling.
- **Siting:** Water fountains should be placed in accessible, prominent locations to incentivize their use. Commercial vendors should be permitted where space is intentionally designed for them, while not blocking travel paths. Seating, waste receptacles, and other amenities become more important to provide.

Recommendations for Different Regional Contexts

Table 11 shows how implementation of the elements may change depending on actual site conditions and regional context. Representative examples of trailhead plazas in a range of suburban to urban contexts are included for illustrative purposes. Compared to other typologies, application of trailhead plaza elements is less likely to vary across regional contexts.

Table 11. Trailhead Plaza Recommendations for Different Regional Contexts.

	High Traffic Urban Park	Mixed-Use Rail/Bike Plaza	Small Town Trailhead
Representative Regional Example	 Alethia Tanner Park, Washington, DC (Source: Google Maps)	 Riverdale Park Town Center, Prince George's County, MD (Source: Google Maps)	 W&OD Trailhead, Purcellville, VA (Source: Google Maps)
Trees	Recommendations consistent across contexts and scales. See general guidance for each element in previous section under "Elements in Context."		
Shade Structures			
Water Features			
Drinking Fountains and Refreshments			

Heat Mitigation Elements

The impacts of extreme heat on people can be reduced through heat mitigation elements. These are passive design choices that reduce the air and surface temperatures of a place. Each heat mitigation element is introduced and given context before specific design and implementation guidance is provided to help achieve the desired cooling effect and ensure long-term success.

TREES

Trees are highly effective at mitigating urban heat because they provide two forms of cooling. They reflect solar radiation and absorb less heat than harder surfaces, decreasing both LST and air temperature. They also release water from their leaves during the day, cooling the air through evapotranspiration. Planting trees in urban and suburban environments also has many co-benefits such as helping manage stormwater, providing habitat space, and dampening sound.

Cooling and Design Considerations

TREE SPECIES

Trees with denser canopies tend to cool more effectively than other species because there is more surface area of leaves to shade and cool. This metric is measured through Leaf Area Index (LAI), calculated as the ratio of total leaf area of a tree divided by ground surface area defined by the tree's extents.[32]

The District of Columbia Department of Transportation (DDOT) has studied the impacts of long-term shifts in climate on the District's urban forests and developed guidance to manage the impacts. Part of this effort included vetting suitable tree species for future planting based on factors such as climate and pest vulnerability. Many of the trees recommended for increased and sustained rates of planting in the District in the future have high LAIs, meaning there is ample opportunity to select for both resilience and cooling. For example, many species of oak trees (of the *Quercus* genus) score highly on the District's resilience criteria and have dense canopies, and are already some of the most common street trees found the District.[33] Note that the species listed below do not comprise a definitive, comprehensive list of tree species suitable for planting in the region, and collaboration with arborists and landscape architects will help to determine the ideal species to plant in different locations.

Figure 20. Fruitless Sweetgum Tree. Source: Hannele Lahti.

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[32] Alonzo, M. et al. 2025. Urban Trees and Cooling: A Review of the Recent Literature (2018 to 2024). *Arboriculture & Urban Forestry* 51 (5): 420–44. https://doi.org/10.48044/jauf.2025.023.

[33] District Department of Transportation. Urban Forest Climate Adaptation. https://climatereadyforests.dc.gov/.

High Leaf Density Species

DC Tree Planting List: Recommended to Increase Planting Frequency

- Liquidambar rotundiloba (Fruitless sweetgum)
- Platanus occidentalis (American sycamore)
- Gleditsia triacanthos var. inermis (Honey locust)
- Quercus lyrata (Overcup oak)
- Quercus bicolor (Swamp White oak)
- Quercus muehlenbergii (Chinquapin oak)

DC Tree Planting List: Recommended to Maintain Planting Frequency

- Aesculus hippocastanum (Horse chestnut)
- Liriodendron tulipifera (Tulip tree)
- Metasequoia glyptostroboides (Dawn redwood)
- Liquidambar styraciflua (American sweetgum)
- Tilia americana (American linden)

Figure 21. Row of American Sycamores. Source: Van Den Berk Nurseries.

For additional guidance on resilient tree species and planting, see Fairfax County's *Resilience of Trees in Fairfax County* guide.

TREE SPACING

To achieve maximum cooling potential, there should be no overlap between individual tree canopies, maximizing relative canopy cover. The optimal planting distance should be determined during project design, taking into consideration the species and amount of space available for planting.[34] The same number of trees dispersed across a space, rather than clustered together, can provide more shade over a greater area. Studies recommend that expanding tree canopy in built-up areas focus on dispersing trees across the space, forming complex shapes and minimizing shade overlap.[35]

SOLAR ORIENTATION

With shading being the primary cooling mechanism of trees, planting location in relation to the sun and other shade-casting structures is an important consideration in design. On the hottest days during summer, trees planted to the south, southwest, and southeast of buildings are shaded *the least* by surrounding structures compared to other relative orientations.[36] Generally, urban streets that run north/south are less shaded by buildings than streets that run east/west, meaning

Future Considerations

As temperatures in the National Capital Region rise and precipitation patterns change, certain tree species may be more vulnerable to disease, pests, and stress, resulting in shorter lifespans. Urban heat islands have higher temperatures than surrounding areas and can be more stressful on trees. Tree species selected specifically for cooling should be resilient to water availability and heat stress. Existing and future resources can help guide which species will be more resilient and suitable for planting in the future.

[34] Zhu, Y. and Kensek, K.M. 2024. MITIGATING THE URBAN HEAT ISLAND EFFECT: The Thermal Performance of Shade-Tree Planting in Downtown Los Angeles. *Sustainability* 16(20): 8768, https://doi.org/10.3390/su16208768.
[35] Beele, E. et al. 2024. Spatial Configuration of Green Space Matters: Associations between Urban Land Cover and Air Temperature. Landscape and Urban Planning 249: 105121. https://doi.org/10.1016/j.landurbplan.2024.105121.
[36] Zhu, Y. and Kensek, K.M. 2024. MITIGATING THE URBAN HEAT ISLAND EFFECT: The Thermal Performance of Shade-Tree Planting in Downtown Los Angeles. Sustainability 16(20): 8768, https://doi.org/10.3390/su16208768.

more trees are required to shade an equivalent amount of street space. Thus, trees should be prioritized for planting on north/south streets and southern block faces to balance this deficiency and have higher impact relative to other locations.

PLANTING BED SIZE

Trees grow healthier and more successfully when their roots have adequate space. Trees that reach their full size potential can cool more than those stunted by lack of space or water. Tree planting areas of 5 feet by 8 feet are recommended as a minimum, with continuous planting area strips between trees being ideal.[37] Continuous soil panels, where street trees can share soil volume beneath solid pavement, may be feasible where continuous landscaping or sufficiently wide planting beds are not. Silva cells, pier-supported slabs, or sand-based structural soils can all been used to provide more growing space and connect root systems. The chosen medium is then surfaced with permeable or conventional paving.

EARLY TREE MAINTENANCE

Trees require consistent maintenance in the first few years after planting to ensure survival and long-term cooling benefits. Survival rates are strongly influenced by the level of maintenance and stewardship provided, with newly planted trees especially vulnerable during this time.[38] Regular watering and basic care are essential to support healthy growth and canopy development, after which maintenance needs generally decline.[39]

PRIORITIZATION

Shading benefits from canopy trees can be more impactful in lower-income neighborhoods due to the correlation between higher temperatures and lower-income neighborhoods, and between lower-income neighborhoods and higher vulnerability and lower adaptive capacity to heat stress.[40]

PAVING

Pavement refers to open impervious surfaces in urban spaces, including asphalt, poured concrete, brick, and pavers of various materials. Paving material factors that impact heat are color and permeability. High albedo pavement can reflect solar radiation back into the atmosphere rather than absorbing it and radiating it back out, and pavement that holds moisture can help cool through transpiration.

Pavement composition and configuration have the largest influences on daytime LST and nighttime air temperature. During the day, pavement absorbs solar radiation, heating the surface and interior of the pavement. As the air cools in the evening, UHI shifts from being generated from direct solar radiation to radiative heat from the surface. This causes pavement to have a small impact on UHI severity during summer afternoons, when heat stress is most severe.[41]

[37] New York State Urban Forestry Council. 2023. The Urban Heat Island and Extreme Heat: Eight Guidelines for Trees in the Urban Landscape. https://nysufc.org/the-urban-heat-island-and-extreme-heat-eight-guidelines-for-trees-in-the-urban-landscape/2023/08/29/.

[38] Hilbert, D.R. et al. 2019. Urban Tree Mortality: A Literature Review. *Arboriculture & Urban Forestry* 45(5): 167-200. https://doi.org/10.48044/jauf.2019.015.

[39] U.S. Environmental Protection Agency. 2008. Trees and Vegetation. *Reducing Urban Heat Islands: Compendium of Strategies*. https://www.epa.gov/sites/default/files/2017-05/documents/reducing_urban_heat_islands_ch_2.pdf.

[40] Pickett, S.T.A. et al. 2019. Science for the Sustainable City: Empirical Insights from the Baltimore School of Urban Ecology. *Yale University Press*. https://doi.org/10.2307/j.ctvqc6gb7.

[41] Beele, E. et al. 2024. Spatial Configuration of Green Space Matters: Associations between Urban Land Cover and Air Temperature. Landscape and Urban Planning 249: 105121. https://doi.org/10.1016/j.landurbplan.2024.105121.

Cooling and Design Considerations

PAVEMENT COLOR

The color of paving materials affects its albedo, which impacts both LST and air temperature. Light-colored and reflective paving reflects less solar radiation than darker colored pavement. This reduces LST, as less heat is stored in the material and then radiated out in the evenings and nights. However, high albedo pavement positively correlates with heat stress because the reflected radiation can be absorbed by human skin and warm the body.[42] Specific reflective coatings should be limited in busier areas, as the heat stress during afternoon periods can outweigh the benefits to LST and air temperature in the evenings.

Figure 22. Two-tone Pavers in Boston, MA. Source: Landscape Perspectives.

While cool ground surfaces are not a strong strategy for reducing heat stress, green and cool roofs can be effective. This is because they reflect solar reflection above human height.

PERMEABLE PAVEMENT

Permeable pavement refers to a group of pavement types that have sufficient structure to walk, roll, or drive on while permitting water to infiltrate through the surface into a substrate or soil layer. Permeable pavement has potential to slightly cool near-surface air temperatures through evaporation and lower thermal mass, which improves thermal comfort.[43] Their cooling efficacy is tied closely to the amount of water available in the material to evaporate from its surface and will vary based on season and weather conditions. Coarse aggregate and capillary tubes to keep water close to the surface of the permeable pavement layer help to maximize the amount of water available to evaporate from the surface and cool the air.

Figure 23. Permeable Paver Step-out Areas. Source: MNLA.

PAVEMENT MAINTENANCE OVER TIME

Cool and reflective coatings on pavement and roofs rely on a clean, exposed surface to reflect solar radiation and, in the case of permeable pavement, to absorb water. Regular surface cleaning and refinishing over time will restore the cooling potential of light-colored pavement and roofs. Permeable pavement requires vacuuming of deposited sediment over time to maximize water infiltration performance.

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[42] Pigliautile, I. et al. 2020. Humans in the City: Representing Outdoor Thermal Comfort in Urban Canopy Models. *Renewable and Sustainable Energy Reviews* 133: 110103. https://doi.org/10.1016/j.rser.2020.110103.

[43] Li, H. et al. 2012. The Use of Reflective and Permeable Pavements as a Potential Practice for Heat Island Mitigation and Stormwater Management. *Environmental Research Letters* 8(1): 015023. https://doi.org/10.1088/1748-9326/8/1/015023.

Future Considerations

Retro-reflective surfaces

Current reflective pavement treatments are not effective treatments for reducing air temperature and heat stress in humans as the reflected solar radiation scatters onto skin and heats the body instead of the paved surface. A new generation of finishes, called retroreflective materials, can greatly increase the percentage of solar radiation that is reflected back into the atmosphere, rather than onto building facades and people. Application of these finishes on urban pavement can reduce air temperatures during the hottest parts of the day. Due to their novelty, real-world applications of these materials have been rare, and further study is required before implementing these treatments on a large scale. This intervention may become more technologically viable and economically feasible in the future and is worth investigating (Huang et al., 2024).

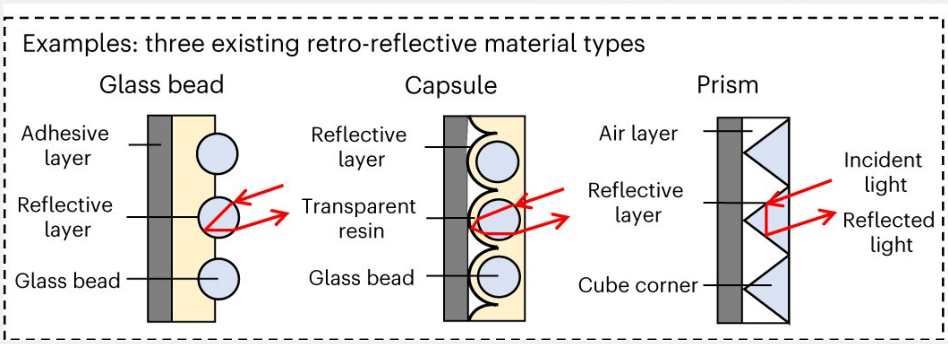

Figure 24. Types of Retroreflective Surfaces. Source: Colton Poore, Princeton University.

PLACEMENT BEST PRACTICES

Cool pavements with reflective treatments are best suited to areas away from high pedestrian activity. As cool pavement treatments have negligible effect on air temperature and heat stress, there is no significant negative impact from focusing their application in areas where LST reduction is the priority such as longer-term parking lots. Permeable pavement has more co-benefits alongside cooling and no negative impact on heat stress, and it is best suited for pedestrian areas with lower direct traffic.

GROUNDCOVER AND BIORETENTION AREAS

Groundcover refers to green, pervious land covers, such as grass and shrubs found in tree beds, medians, along roads, within parks, and on private lots. Groundcover has many co-benefits alongside cooling potential, such as stormwater management and recreation space. Bioretention areas, an increasingly popular type of blue-green infrastructure, are natural or structured pervious areas planted with trees and groundcover that divert and filter water before slowly releasing it into the soil or a stormwater system.

Cooling and Design Considerations

NIGHTTIME COOLING

Grasses and shrubs contribute relatively little to cooling the air doing the day; the rates of evapotranspiration and shading are not significant enough to meaningfully impact air temperature. They do provide value in quickly cooling the air in the evening when the source of heat shifts from direct solar radiation to the release of heat stored in surfaces and structures. After the sun goes down, the air above groundcover cools down much more quickly than pavement. In this context, groundcover is more effective than trees, which can actually trap heat in the evening and night, causing the air to cool more slowly. Groundcover therefore serves as a good complement to trees in urban and suburban areas to provide necessary cooling in the evening and at night.[44]

PERCEPTION OF TEMPERATURE

While groundcover and shrubs do not provide substantial daytime relief, greenery contributes to a psychological feeling of coolness. Physical and psychological factors both contribute to thermal comfort and stress. Aesthetic-minded planting areas can make the public realm more attractive and comfortable to linger in.[45]

Figure 25. Bioretention Area Along Streetscape. Source: Cape Code Green Infrastructure Guide.

BIORETENTION AND EVAPORATIVE COOLING

Studies suggest that blue-green infrastructure can effectively lower LST and air temperature through evapotranspiration and shading. They are most effective when trees and groundcover are planted together.[46] Small bioretention areas that are typically found along streets are likely to cool at the hyperlocal scale but lack sufficient aggregation to cool past the block level.

BREEZE-FRIENDLY PLANTING PATTERNS

A mix of grasses and shrub heights is recommended when planting for visual interest as the layers create movement and dimension. An important consideration for urban cooling is minimizing wind breaks. Low grasses and shrubs permit air to circulate throughout the area, moving warm air away from the surface. Tall, thick shrubs and hedges can channel the wind to exchange the warm air with cooler air.[47] Designing breaks into softscape and hardscape elements can minimize the impact of these factors and direct air into pedestrian areas.

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[44] Beele, E. et al. 2024. Spatial Configuration of Green Space Matters: Associations between Urban Land Cover and Air Temperature. Landscape and Urban Planning 249: 105121. https://doi.org/10.1016/j.landurbplan.2024.105121.

[45] Steinharter, L. et al. 2025. Hot Stops, Cool Looks: Aesthetic Solutions for Thermal Comfort at Transit Stops. *Urban Climate* 64: 102606. https://doi.org/10.1016/j.uclim.2025.102606.

[46] Budzik, G. et al. 2024. Understanding Urban Cooling of Blue–Green Infrastructure: A Review of Spatial Data and Sustainable Planning Optimization Methods for Mitigating Urban Heat Islands. *Sustainability* 17(1): 142. https://doi.org/10.3390/su17010142.

[47] Richards, D.R. et al. 2020. Differential Air Temperature Cooling Performance of Urban Vegetation Types in the Tropics. *Urban Forestry & Urban Greening* 50: 126651. https://doi.org/10.1016/j.ufug.2020.126651.

SHADE STRUCTURES

Shade structures can include permanent and temporary coverings that provide shelter and shield from the sun and rain. This is a diverse category that includes bus shelters, pavilions, fabric shade sails, pergolas, and awnings. They reduce LST and air temperature through shading. Shade structures are best suited for areas where trees would not grow well or where more complete shelter from the elements is necessary.

Cooling and Design Considerations

COOL AND GREEN ROOFS

Shade structures cool primarily through shading. Solar radiation is captured or reflected by the roof structure, preventing heat from reaching the air near the surface and increasing temperatures. Traditional roofs absorb most of the radiation and slowly releases it back into the air when temperatures start to cool in the evening. Low albedo surfaces reflect this radiation back into the air, reducing the embedded heat in the shade structure and the air.

Green roofs can increase the cooling capacity of shade structures by reflecting more solar radiation back into the atmosphere[48] like cool roofs, while also facilitating evapotranspiration from the vegetation and soil they hold. Pilot projects in U.S. cities[49] including Bladensburg, MD, and Boston, MA, have shown green roofs to be effective at reducing air temperatures and LST inside the shelters themselves, increasing thermal comfort. Regular irrigation is important while the vegetation establishes itself and during dry periods, as the thin soil layer is prone to drying out and its cooling potential relies in part on soil moisture to evaporate.

Figure 26. Green Bus Stop in Boston, MA. Source: City of Boston.

Figure 27. West Falls Church Bus Loop. Source: flickriver.com.

SHADE STRUCTURE WALLS

Shade structures, especially bus shelters, may have walls on their sides and backs to protect users from the elements while waiting. Clear materials are commonly used to increase transparency and environmental safety while reducing the impact of rain and wind on people inside them. This can create a warmer microclimate caused by solar radiation passing through the wall material. Perforations or gaps in the wall can reduce this severity. Trees should also be planted around shelters, wherever possible, to

[48] Li, D. et al. 2014. The Effectiveness of Cool and Green Roofs as Urban Heat Island Mitigation Strategies. *Environmental Research Letters* 9(5): 055002. https://doi.org/10.1088/1748-9326/9/5/055002.
[49] Balcoff, Z. 2025. How These Green Bus Stops Help Bees and Communities. *The Washington Post*. https://www.washingtonpost.com/climate-solutions/interactive/2025/green-bus-stops-shelters-bees-heat/.

minimize the amount of direct solar radiation the shelter areas receive.[50]

WATER FEATURES

Water features such as fountains, splash pads, and misters enliven spaces visually and sonically, while also helping to reduce heat stress in the public realm through evaporative cooling. They can be a defining placemaking element when integrated into spaces.

The air-cooling effect of water features is very localized, with strong impact directly within and adjacent to the feature. Benefits diminish further from the water source and are eventually negligible. One study of a ground-mounted spray fountain measured decreased air temperatures as far as 35 meters away. Cooling potential is dependent on local atmospheric factors such as air temperature, humidity, and wind velocity.

Cooling and Design Considerations

SYSTEM DESIGN

Water spray features and waterfall style fountains both lower local air temperatures, but water spray features are most effective because they distribute more fine mist particles in the air. A study investigated various nozzle sizes on spray features and found that smaller nozzles cool more effectively because they disperse more fine droplets through the air compared to larger fixtures. This means that water features that produce more mist will cool more than other types of features with the same volume of water flow.[51]

Figure 28. Sculptural Misting Installation in Alexandria, VA. Source: Site See Alexandria.

IMPACT OF WIND AND SUN

Wind direction and speed impact the cooling efficiency of water features. Low, steady breezes can distribute the fine mist across a space, but when wind speeds are too high, the cooling effect is effectively negated.[52] Sunlight also affects cooling efficiency as sufficient heat is necessary for evaporative cooling to take place. Taken together, the optimal environment for cooling water features are sunny areas with low to moderate wind.

Figure 29. Small Spray Fountain in Aspen, CO. Source: TripAdvisor.

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[50] Lanza, K. et al. 2025. Heat Stress Mitigation by Trees and Shelters at Bus Stops. Transportation Research Part D: Transport and Environment 140: 104653. https://doi.org/10.1016/j.trd.2025.104653.
[51] Nishimura, N. et al. 1998. NOVEL WATER FACILITIES FOR CREATION OF COMFORTABLE URBAN MICROMETEOROLOGY. *Solar Energy* 64(4): 197–207. https://doi.org/10.1016/S0038-092X(98)00116-9.
[52] Ulpiani, G. et al. 2020. Mist Cooling in Urban Spaces: Understanding the Key Factors behind the Mitigation Potential. *Applied Thermal Engineering* 178: 115644. https://doi.org/10.1016/j.applthermaleng.2020.115644.

Heat Management Elements

Heat management elements help people to cope with and recover from thermal stress and the related risks to health and wellbeing. While they do not directly cool the surface or air, they are essential to address extreme heat on transit and active transportation journeys. Each heat management element is introduced and given context before specific design and implementation guidance is provided to help achieve the desired cooling effect and ensure long-term success.

SEATING

Seating is a powerful placemaking element to create public spaces that are inviting and comfortable to linger in. It is especially suitable along active transportation and transit routes. Benches, chairs, and built-in seating arrangements help facilitate activities and interactions. They provide places of respite for sitting and reducing heat stress and can be co-located with heat mitigation elements for greater impact.

Cooling and Design Considerations

SEATING MATERIAL

Common seating materials have different thermal properties that can make them feel hotter or colder. Finish, density, and color all impact how much heat the material can absorb and transfer to the body. Concrete and wood have low thermal conductivity and transfer little heat when in contact with the body. Metal has a much higher thermal conductivity rate and will feel hotter regardless of temperature. This can be offset with coatings on the metal, which insulate it from skin. Wood benchtops and light-colored perforated metal increase air circulation within the bench structure and balance durability and thermal comfort.

Figure 30. Concrete Seat-bench with wooden seats. Source: Anston Architectural Products.

Cool Bench Materials

- Wood and composite wood
- Resin
- Concrete
- Light-colored perforated metal

PLACEMENT LOCATION

As a heat management strategy with no inherent cooling capacity, seating relies on other shading practices to be effective places to recover from heat stress. Studies have shown that shaded benches are better utilized than those in direct sunlight.[53] Seating should be placed in the shade and close to heat mitigation and management elements to maximize their potential. Solar radiation comes from the southwest during the hottest part of the day, casting shadows to the northeast. Seating placement should prioritize areas where structures and trees shade them during summer afternoons.

Figure 31. Wooden bench placed in building shadow, College Park, MD. Source: Google Maps.

[53] Lindley, S.J. 2025. Streetscapes and Heat Tolerance. *Nature Climate Change* 15(9): 919–20. https://doi.org/10.1038/s41558-025-02416-9.

MOVABLE SEATING

Flexible and movable seating can maximize shading in summer and sun exposure in the winter. Where appropriate, movable chairs, benches, and tables can be selected. This works best in spaces with active management and low risk of the furniture being removed from the intended area, such as fenced parks or surveilled public squares.

DRINKING FOUNTAINS AND REFRESHMENTS

Hydration and nutrition are important for the body to function and deal with heat stress. Multimodal journeys can be long, and during extreme heat events, taxing. Heat and movement cause sweating, depleting the body of water. Access to water and other refreshments is an important part of heat management in the public realm. Public drinking fountains are the most accessible and permanent fixtures that meet this need, but vending stalls, carts, and food/beverage trucks can also provide flexible access to food and drinks that help to manage heat stress.

Cooling and Design Considerations

SITING

Drinking fountains and vending areas should be placed in shaded locations—under trees, building overhangs, or shade structures. They should be located near natural breezeways when possible, improving perceived comfort and encouraging people to linger and hydrate and refresh themselves. Trails and walkways tend to channel breezes unobstructed, meaning co-locating these elements bring heat mitigation, management, and people traveling through public space all together.

Figure 32. Beverage vendor along Four Mile Run Trail, Arlington, VA. Source: Google Maps.

Transportation Policy, Planning, and Design Applications

The Transportation Policy, Planning, and Design Applications provides suggestions and examples for how to integrate extreme heat considerations into existing policies, planning efforts, and guidance documents to help promote the use of cooling strategies.

This resource lays out five use cases for extreme heat policy, planning, and guidance updates to help promote the use of cooling strategies in (re-)development projects and agency decision-making. Each use case is accompanied by examples from other agencies or municipalities.

The five use cases include:

1 **Goals and Vision Statements**
Integrating extreme heat preparedness language into resilience goals and vision statements.

2 **Land Use and Zoning Policies**
Developing language for land use and zoning policies that encourage preserving or expanding the tree canopy and other heat mitigation solutions.

3 **Cooling Design Standards**
Updating design standards and manuals to help mainstream the use of cooling strategies.

4 **Worker Safety Policy Language**
Updating worker safety policies and protocols to include extreme heat safety measures.

5 **Contract Language on Cooling Strategies**
Developing contracting and procurement language to encourage use of cooling strategies in project design and implementation.

Goals & Objectives

The Transportation Policy, Planning, and Design Applications supports regional resilience efforts by:

I. Helping mainstream extreme heat resilience considerations into existing policies, planning, and guidance.

II. Providing examples of successful implementation by other agencies and municipalities.

Use Case 1: Goals and Vision Statements

Integrating extreme heat preparedness language into goals and vision statements can help jurisdictions prioritize efforts that advance big-picture priorities.

Member agencies can embed extreme heat (or other key hazards of concern) into their decision-making and planning by adding clear heat preparedness and resilience vision statements and goals to planning documents, like comprehensive plans, land use plans, hazard mitigation plans, resilience plans, and climate action plans.

Vision statements articulate an overarching, long-term aspiration, such as creating a healthy, vibrant, and climate-resilient community. Even though visions are often high-level and non-regulatory, embedding heat resilience into vision language can elevate heat as a core community value and support cross-department coordination. Vision language could:

- Explicitly recognize extreme heat as a priority climate risk that affects public health, infrastructure, and mobility; and
- Articulate a long-term aspiration to create a safe, healthy, and resilient community.

Goals define more specific and measurable outcomes. Goals typically help clarify what success looks like, rather than prescribing specific implementation actions. Goal language could include:

- Near-term preparedness outcomes, such as increasing public awareness of heat safety and improving access to cooling resources; and
- Defining long-term resilience outcomes focused on reducing urban heat exposure, such as for transit users along bus routes.

Together, vision and goal language can help member agencies translate high-level aspirations into coordinated priorities that inform planning, projects, and investments. Having this language can also drive more consistent integration of shade, tree canopy, and heat-resilient materials across (re-)development and infrastructure projects, rather than treating heat as an ad hoc or secondary concern.

IMPLEMENTATION EXAMPLES

National Capital Region

- **Ivy City, Washington, DC:** The Ivy City Climate Resilience Strategy section 'Creating a Vision for Climate Resilience in Ivy City' provides an example of visioning language that ties climate hazards, including heat, to other community-wide challenges: "A Resilient Ivy City is an empowered, diverse, and equitable community equipped with tools to thrive in the face of current and future climate-related hazards. The District and the Ivy City community work collaboratively in the long-term stewardship of Ivy City, its most vulnerable residents, and community resilience" (p. 12). The section also

Figure 33. Ivy City's prioritized community input to shape the resilience vision and strategy. Source: D.C. Department of Energy and Environment, 2025.

provides the strategy's goals, including to "manage and reduce urban heat" (p. 13).

- **Washington, DC:** Keep Cool DC: The District of Columbia's Extreme Heat Adaptation Strategy establishes heat as a citywide risk requiring coordination action across sectors.

- **Montgomery County, MD:** Montgomery County's Climate Action Plan (CAP) – Fiscal Year 2025 Annual Report identifies an adaptation-focused CAP Vision 2035: "Montgomery County is equipped with the resources and infrastructure to withstand the impacts of climate change" (p. 20). The adaptation chapter describes ways to manage extreme heat and the urban heat island effect.

Other

- **City of Phoenix, AZ:** The City of Phoenix's planPHX, its citywide general plan for 2025, includes a Community Benefits vision, organized around Prosperity, Health and Well-being, and Environment (p. 32). This section identifies the establishment of the Office of Heat Response and Mitigation as a proactive resilience strategy, noting its primary goal "to enhance the city's resilience against heat-related threats and mitigate their adverse impacts in collaboration with all City departments and many external partners" (p. 42). The office recently developed its 2026 Heat Response Plan.

- **New York City, NY:** New York City's Cool Neighborhoods initiative establishes extreme heat as a core resilience issue, pairing neighborhood-scale cooling investments with citywide goals, including implementing NYC CoolRoofs. The initiative aims to help the city "reduce its contributions to rising temperatures, combat the UHI effect, and protect its residents from extreme heat events" (p. 9).

- **City of Medford, MA:** The City of Medford's Climate Action and Adaptation Plan establishes a vision to make Medford "a place where everyone can thrive, now and for generations to come, ensuring that our future is just and equitable, resilient, healthy, and carbon neutral" (p. 16). The plan outlines goals to ensure ecosystems can "grow and adapt even with climate change" while helping to "prevent flooding and keep temperatures cool" (p. 26). It also sets a goal (see Figure 34) to ensure "everyone has access to healthy neighborhoods, infrastructure, and sources that reduce health risks from climate change, pollution, and waste" (p. 30).

Figure 34. Example framing of public health goals. Source: City of Medford, 2022.

Use Case 2: Land Use and Zoning Policy

Land use and zoning policies that encourage preserving and expanding the tree canopy or other heat mitigation solutions can help make heat mitigation a routine consideration in (re-)development decision-making. This is particularly important in areas where the built environment and low canopy cover contribute significantly to urban heat island conditions.

MWCOG has made a strong step in this direction by developing the Regional Tree Canopy Subcommittee (RTCS) and adopting a regional goal to maintain a minimum tree canopy coverage of 50% across the metropolitan Washington region. MWCOG further supports local implementation by calling on jurisdictions to use Conserving Trees and Forests in Metropolitan Washington as a resource and guide to develop local tree canopy action plans.

Building on this foundation, member agencies can integrate extreme heat considerations into land use and zoning by establishing local tree canopy targets, native species requirements, or minimum planting standards. Transportation-relevant provisions could include shade requirements along bike and pedestrian corridors. In practice, this language can be inserted into various documents, like zoning ordinances and development codes, environmental and technical manuals, and development review checklists. Member agencies can also implement land use and zoning updates to encourage other types of heat mitigation strategies, such as passive cooling and permeable pavement. For example, policies could:

- Require preservation of existing trees and minimum tree planting standards for (re-)development;
- Update tree canopy or landscaping requirements tied to parcel size and land use type;
- Specify approved or preferred plant species lists, including native or climate-appropriate trees;
- Require shading along pedestrian and bicycle routes, such as street trees; and
- Encourage site designs that support heat mitigation, such as permeable, lighter colored surfaces.

IMPLEMENTATION EXAMPLES

National Capital Region

- **Falls Church, VA:** Falls Church updated its zoning code (Chapter 48) to require a minimum 10% tree canopy coverage for non-residential development sites, measured at 20-year maturity. The ordinance ensures canopy is provided on-site and strengthens the City's ability to require tree preservation and planning through site plan review, making it a consistent consideration in redevelopment.

- **Fairfax County, VA:** In 2024, Fairfax County adopted a Landscaping and Screening Zoning Ordinance Amendment to update requirements for parking lot landscaping and transitional screening (Figure 35). It introduces street frontage landscaping standards, which emphasize shade, pedestrian comfort, and the quality of the public realm along streets, rather than treating landscaping solely as a buffering tool.

Figure 35. Example tree planting area distribution for parking lots to achieve 10% canopy coverage. Source: County of Fairfax, 2023.

- **Prince George's County, MD:** Prince George's County's Climate Action Plan recommends revisions to County codes and ordinances related to tree canopy and tree protection (Priority Recommendation M-11, p. 186), including Revise Subtitle 25: Trees and Vegetation of the County Code of Ordinance and related Divisions to:
    - Calculate tree coverage requirements based on achieving a minimum of 52% tree coverage within each subwatershed, and with the goal of laying groundwork to increase county tree cover to 55% by 2050.
    - Prioritize preservation of urban remnant forests and specimen trees. Redefine the definition of forest to include urban remnant forest. Reduce threshold triggering Woodland Conservation regulations to include land disturbances starting at 3,000 sq. ft. for any subwatershed with more than 30% impervious land cover.
    - All fee-in-lieu paid must be utilized to plant trees within the same watershed.
- **Montgomery County, MD:** Montgomery County has taken steps to ensure any proposed changes to zoning and master plans are first screened to identify any positive or negative impacts on climate change in the County. This process is an outcome of Montgomery County's Bill 3-22, "Climate Assessments," which requires the Office of Legislative Oversight to conduct a climate assessment of introduced County bills and the Planning Board to conduct a climate assessment of proposed Zoning Text Amendments (ZTAs) and master plans.
    - The County developed a climate screening process for proposed ZTAs and master plans providing templates, checklists, and other tools to support the assessment. A Community Climate Resilience Checklist includes tree canopy-related sensitivity questions for whether the proposed ZTA or master plan amendment would result in "Change to forest cover" and "Change to non-forest tree canopy."

Does the ZTA/Master Plan concern any of the following factors: *(Indicate if there is no anticipated impact, or if an impact is indeterminate because you cannot say whether there will be an impact or not.)*			*If there is an anticipated impact, are changes to each factor expected to have a positive or negative impact, or both, on community resilience or adaptive capacity?* *(The assessment narrative should indicate minor, moderate, major, a combination, or a range of possible impacts based on the location and extent of potential changes that could occur under the ZTA or Master Plan.)*		
COMMUNITY CLIMATE RESILIENCE					
Exposure-Related Factors *(Change in the factor reduces (positive impact) or increases (negative impact) people or infrastructure experiencing a hazard)*	**No Impact**	**Indeter-minate**	**Positive Impact**	**Negative Impact**	**Comments**
Activity in flood risk areas	☐	☐	☐	☐	
Activity in urban heat island	☐	☐	☐	☐	
Exposure to other hazards (e.g., storms, wind, drought)	☐	☐	☐	☐	
Other: ______________	☐	☐	☐	☐	
Sensitivity-Related Factors *(Change in the factor reduces (positive impact) or increases (negative impact) impact severity)*	**No Impact**	**Indeter-minate**	**Positive Impact**	**Negative Impact**	**Comments**
Change to forest cover*	☐	☐	☐	☐	
Change to non-forest tree canopy*	☐	☐	☐	☐	

Figure 36. Excerpt from Montgomery County's Community checklist to help screen proposed ZTAs and master plans. Source: Montgomery County, 2026.

Other

- **Henrico County, VA:** Henrico County's Zoning Ordinance includes tree canopy percentage targets (Sec. 24-5308 - Minimum Tree Cover) and native species percentage requirements (Sec. 24-5304 - General Planting Requirements) for new development projects.

- **Salem, VA:** The City of Salem, Virginia Urban Forest Overlay District (Code of Ordinances §106-230) requires trees to be planted in interior parking lots and mandates tree planting at regular intervals along public streets adjacent to new or reconfigured parking lots. The Code lists required tree species.

- **Philadelphia, PA:** The Philadelphia Tree Plan outlines the City's goals to create a healthy and diverse tree canopy in Philadelphia. Its Landscape Design Guidelines, which consolidates the Zoning Code requirements and Planning Commission regulations, regulates tree removal and landscape planting for development. This includes mandatory tree replacement when healthy trees are removed; preservation requirements for heritage trees; standards for planting new yard, street, and parking lot trees; and detailed specifications on applicable species, soil volume, and spacing.

Use Case 3: Design Standards for Cooling Strategies

Updates and additions to design standards and manuals can support easier implementation of cooling strategies and help mainstream heat mitigation. Incorporating extreme heat considerations into design standards can help ensure that projects reduce heat exposure for multimodal users. Design guidance can include specific streetscape recommendations about tree spacing, transit stop shading, and permeable paving. Even modest updates to design guidance can significantly influence project outcomes by signaling that thermal comfort and heat resilience are valued design objectives.

Member agencies can incorporate this language into key implementation documents, including right-of-way (ROW) design manuals, roadway and streetscape standards, transit facility design criteria, construction specifications, public-space design guidelines, and related capital project manuals. Design standards can also be used to identify, review, and address conflicts where existing standards may unintentionally limit shading or greening—such as minimum clear zone widths or utility placement. Where appropriate, member agencies can update or supplement these standards with flexible or context-specific solutions to ensure effective and sustainable cooling outcomes (e.g., adjusted spacing, alternative species selection, or coordinated utility siting). For example, design standards and manuals could:

- Specify tree spacing, soil volumes, or planting zones within streetscapes to maximize shade;
- Identify appropriate locations for permeable or reflective paving;
- Include shading guidance for bus stops and train stations; and
- Highlight common design conflicts that affect tree viability and shade provision.

To support member jurisdictions in developing design guidelines and considering different heat mitigation options, TPB developed Transportation Design Guidance with heat mitigation and management elements for streetscapes, bus stations, and trailhead plazas. Each element includes key cooling and design considerations for successful implementation such as the optimal siting conditions and vegetation types and species.

IMPLEMENTATION EXAMPLES

National Capital Region

- **Arlington, VA:** Arlington's Design Standards & Guidelines integrate tree canopy and complete streets considerations. Part 5. Street-Space Standards intends to:
    - Create an environment that encourages and facilitates pedestrian activity, creating walkable streets that are comfortable, efficient, safe, and interesting.
    - Contribute to sustainability through requirements for trees and other landscape materials.

Figure 37. Streetscape elements in Pentagon City. Source: ICF.

- **Fairfax County, VA:** County of Fairfax Urban Design Guidelines include various cooling considerations. Street and streetscape design standards require and guide tree planting and removal, landscape panels, and coordination with infrastructure such as sidewalks and utilities. A tree planting appendix provides alternative compliance options for planting where standards cannot be met, including modified planting dimensions and soil volumes.

- **Silver Spring, MD:** The Downtown Silver Spring: Cool Streets Guidelines provide implementable streetscape elements—both nature-based and built environment—and guidance, such as street tree spacing, shade and evaporative cooling emphasis, and light-colored paving. The accompanying outdoor thermal comfort analysis evaluates design strategies and summarizes key takeaways about shade, evaporative cooling, and surface materials, including recommendations that can inform design standard concepts without drafting full specs (e.g., increased usage of open-grid paving system, solar reflectance targets, light-colored paving).

Other

- **Richmond, VA:** The City of Richmond's Richmond Cool Kit provides practical guidance on a range of cooling strategies, illustrating where different approaches can be applied and highlighting key design considerations to support effective heat mitigation. Cool strategies fall within urban greening, shade, smart surfaces, and depaving.

- **City of Cambridge, MA:** The City of Cambridge, Massachusetts Green Factor Standard is a performance-based standard that encourages heat mitigation by incorporating cool site and landscape designs. Using the Cool Score Sheet, a site's "Cool

Figure 38. Shading structure in Bellemeade Park. Source: City of Richmond.

Score" can be calculated with features including trees, green roofs, and cool pavements.

- **United States:** FTA's Transit Resilience Guidebook lists example heat adaptation measures, such as white paint on bus roofs, tinted windows, and energy-efficient air conditioning. Locally, **WMATA** is developing resilient design guidelines for its assets and is also currently piloting the use of white paint on rail line segments.

Use Case 4: Worker Heat Safety Policies

Extreme heat poses direct health and safety risks to workers involved in construction, maintenance, and outdoor operations. **Developing formal policy language for worker safety during extreme heat** can help jurisdictions move from informal practices to consistent protocols that reduce heat exposure and health impacts, limit project disruptions, and maintain continuity of critical transportation operations.

Member agencies can develop and implement worker heat safety policies, construction standards, operational manuals, and heat emergency plans. For example, policies could:

- Adjust working hours to limit outdoor labor during the hottest parts of the day;
- Allow for remote work where possible when extreme heat creates unsafe commuting conditions;
- Require shade, hydration, and rest breaks; and
- Integrate heat protocols into transportation agency maintenance and capital project delivery schedules.

IMPLEMENTATION EXAMPLES

- **Occupational Safety and Health Administration (OSHA)'s proposed Heat Injury and Illness Prevention in Outdoor and Indoor Work Settings** standard would require employers to create a plan to evaluate and control heat hazards in their workplace. It would more clearly set forth employer obligations and the measures necessary to effectively protect employees from hazardous heat. In the meantime, its **Heat Illness Prevention campaign** offers educational resources for employers and workers on heat hazards and solutions.

- In the absence of OSHA's proposed heat standard, many have put forward their own legislation:
    - **Maryland's Heat Stress Illness Prevention Standard**, COMAR 09.12.32, establishes minimum requirements for employers for both indoor and outdoor workplaces where there is employee exposure to a heat index at or above 80ºF (Figure 39). Heat index is what workers really feel due to a combination of temperature and relative humidity (Figure 40). The standard provides a document to guide employers in fulfilling the requirements.

Heat Index	Rest period
Above 90°F and below 100°F	Minimum of 10 minutes every 2 hours
Above 100°F	Minimum of 15 minutes every hour

Figure 39. Maryland's high heat procedures for employers. Source: Maryland Occupational Safety and Health, 2024.

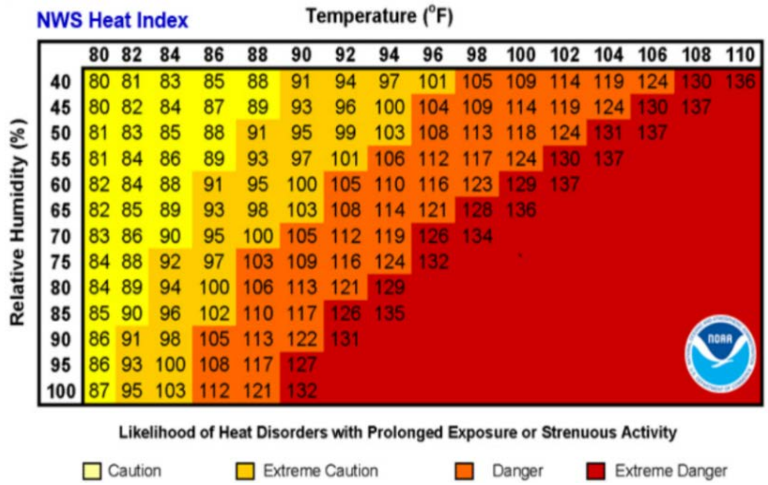

Figure 40. Likelihood of heat disorders based on heat index.
Source: [University of Maryland, 2025](#).

- **Virginia** recently passed **[heat illness legislation SB 288](#)**, which establishes enforceable heat safety standards for both indoor and outdoor workplaces. The legislation mandates that the new Virginia Occupational Safety and Health (VOSH) regulation must require employers to provide water, access to shade/climate-controlled environments, rest periods, acclimatization to working in heat, heat illness prevention trainings, and other requirements.
- The State of **California** has both **[Outdoor (T8CCR 3395) and Indoor (T8CCR 3396) Heat Illness Prevention Standards](#)** for employers to follow.
- The City of **Phoenix** **[Heat Worker Safety ordinance](#)** includes contractor requirements to develop a written heat safety plan.

- There are also numerous plans (not regulatory enforced but rather guidance) in place:
  - **Montgomery County's [Extreme Temperature Plan](#)** is activated during extreme heat events.
  - **Washington State's [Be Heat Smart!](#)** is the state's outdoor heat safety program, encompassing outdoor heat exposure regulations, training courses, and other resources.

Use Case 5: Contract Language to Maximize Use of Cooling Strategies

Cooling strategies are direct, localized strategies for reducing heat exposure and improving thermal comfort in outdoor environments. **Developing contracting and procurement language that encourages the use of cooling strategies** can ensure these features are prioritized and considered early in project planning and design. This language helps signal that reducing heat stress is a priority outcome alongside cost and feasibility. Member agencies can develop contracting language that sets clear expectations for incorporating cooling strategies and allows proposers to identify effective approaches to meet those goals. This contracting language could range from encouragement of creative heat mitigation approaches to requiring more prescriptive minimum or performance-based standards.

Examples of different types of contract language framing could include:

- Core requirement to consider heat mitigation without being overly prescriptive:
    - Proposers shall evaluate and incorporate shading and cooling strategies, as feasible, to reduce heat exposure and improve thermal comfort for users of the project area. Strategies may include, but are not limited to, tree canopy, engineered shade structures, material selection, and site design features that reduce direct solar exposure and heat absorption.
- Analysis-driven requirement:
    - Proposers shall assess existing and future heat exposure within the project area, including the availability and distribution of shade. The analysis shall inform recommended design solutions to mitigate heat exposure and enhance shade access, with particular attention to locations serving pedestrians, cyclists, transit users, and vulnerable populations. Where appropriate, proposers shall use GIS-based tools, shade modeling, or field observations to support findings.
- Design requirement:
    - The project shall consider pedestrian and user thermal comfort as a design objective. Proposers shall identify feasible opportunities to reduce exposure to extreme heat through the provision of shade and other cooling strategies within the project limits. This may include sidewalks, crossings, transit stops, and other areas of prolonged use or waiting. Where implemented, such features shall be designed to meet applicable safety, accessibility, structural, and maintenance requirements and be compatible with the surrounding right-of-way and utilities.
- Design requirement adhering to existing heat-related design standards:
    - All work performed under this contract shall be consistent with applicable City, County, and regional design standards and guidance related to pedestrian comfort, heat mitigation, and shade, as adopted or amended. Proposers are responsible for demonstrating how proposed designs align with these standards.
- Performance-based requirement:
    - Where feasible, proposed shading and cooling strategies shall aim to achieve City or County targets (e.g., a tree canopy percentage target for new development projects) to reduce heat exposure for users during hot-weather conditions. Proposers may qualitatively or quantitatively describe expected benefits, consistent with the level of project development.

In practice, this language can be incorporated into RFPs evaluation criteria, required design considerations within scopes of work, or standard provisions. Member agencies can also develop checklists for the contractor that include cooling strategy requirements. These provisions can complement broader canopy, green infrastructure, heat preparedness, and resilience goals already established in existing plans and policy by reinforcing them at the project design and delivery stage.

National Capital Region
Transportation Planning Board

Metropolitan Washington Council of Governments
777 North Capitol Street NE, Suite 300
Washington, DC 20002

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