Urban Heat Island in Cold Climates

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Urban Heat

In the US, heat is the most fatal weather event, surpassing floods, hurricanes, and tornadoes, and over four times more fatal than cold temperatures.[1] In cities, heat and its impacts are exacerbated by the Urban Heat Island (UHI) effect, which causes urban areas to be significantly warmer than their surrounding rural landscapes. As buildings and infrastructure replace vegetation, cities lose much of the cooling that nature facilitates, as urban surfaces absorb more of the sun's energy. This raises city temperatures by about 5–9°F compared to surrounding rural areas.[2]

Hotter communities often pay more for electricity, are more vulnerable to heat-related health issues, experience infrastructure failures more often, and have poorer air quality. Within urban areas, low-income neighborhoods and communities of color that were historically marginalized are at a higher risk of hazardous heat due to characteristics of the built environment, such as extensive paved areas, industry sites, and a lack of tree canopy and green space.[3,4]

Typical approaches to urban development contribute substantially to the UHI effect. Abundant pavements, dense building layouts, and reduced vegetation inhibit cities' abilities to dissipate heat, causing urban materials to absorb and retain solar energy and heat. Darker, low albedo (absorptive of heat rather than reflective), and impervious surfaces exacerbate this effect by

1 National Weather Service
2 Urban Heat Hot Spots: Climate Central
3 Modification of the PM2.5- and extreme heat-mortality relationships by historical redlining
4 Discrimination has Trapped People of Color in Unhealthy Urban Heat Islands

raising temperatures in the air around them as well as inside buildings they surround. As cooling demand rises in response to increasing temperatures, the additional energy use contributes to added emissions, further warms the surrounding environment, and contributes to straining of the energy grid, reinforcing the cycle.

Cold Climate Cities

The UHI effect is not limited to cities in warm climates. In fact, UHI has been observed in almost all urban areas, including in colder climates.[5] Several cities in cold climates still overheat and face dangerous conditions during heatwaves and in the summer months. Many of these cities may be less prepared for UHI mitigation because they have historically focused on dealing with cold conditions.

In acknowledgement of this trend, many cities located in cool and cold climates are planning and implementing UHI mitigation strategies to reduce excessive summer temperatures. However, UHI mitigation strategies have winter-time implications of which cold-climate cities need to be aware. Wintertime UHIs can play a protective role during extreme cold events in US cities. A study analyzing twelve cities across diverse climates found that UHIs increase and provide protective heating during cold waves, especially at night.[6] In the wintertime, a substantial share of this heating results from heat released by building heating systems. This can act as a “cold-wave shield,” reducing exposure to dangerous cold. Because of this, some argue that UHI mitigation strategies implemented in cold climate cities could unintentionally weaken this protective effect. Climate-specific approaches that are tailored to particular seasons and regions are therefore warranted for UHI mitigation efforts in cold climate cities.

This Resource

This resource identifies strategies that policymakers, planners, designers, developers, and others can pursue to reduce the UHI effect. These strategies are tailored specifically to the needs of cities located in mixed to very cold climates and have year-round benefits.

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5 Dual Impact of Urban Overheating
6 Should Cities Embrace Their Heat Islands as Shields from Extreme Cold?

Overview of Strategies and Key Recommendations

UHI mitigation strategies are not “one-size-fits-all.” Strategies should be selected based on climate zones, seasonal temperature patterns, and associated risks. Cold-climate cities should prioritize measures that cool in the summer without eroding the benefits of wintertime UHI impacts. These cities also need to select strategies that can withstand extreme conditions on both ends of the temperature spectrum.

This document covers the top 5 strategies for mitigating the UHI effect in cold-climate cities and presents design, implementation, and policy strategies honed for the particular considerations that cold-climate cities warrant. The strategies are summarized below.

Cooling Strategy	Cold Climate Considerations	Sample Policy Approaches
Green Infrastructure (GI)	Infrastructure and landscaping strategies are able to capture water, mitigate flood risk, and reduce UHI. They offer storm inundation mitigation benefits that can be helpful during winter storms.	• Complete streets policies and street design standards • Impervious coverage limits • Planning standards and guidelines
Trees and Greening	Vegetation strategies provide summer cooling with minimal or no winter downside. Native species can tolerate a city’s unique climatic conditions. Deciduous trees can offer significant passive energy benefits by providing shade in the summer and allowing for solar gain in the winter.	• Climate plans and UHI mitigation plans • Municipal ordinances • Landscaping requirements and guidelines • Intragovernmental and public-private partnerships and funding
Streets and Paving	Pervious and reflective pavements can reduce summer surface temperatures and reduce water that freeze on the surface of pavements. Cold-climate cities may benefit more from permeable pavements; light-to-medium albedo pavements; or shaded pavements. Infrastructure must be able to withstand winter conditions. Temporary and removable shading devices such as fabric shades can also cool the building when the weather necessitates it.	• Pavement pilot programs • Permeable paving codes • Complete streets policies and street design standards
Cool and Green Roofs	Cool roofs generally offer net annual energy savings in cold climates, but may contribute slightly more wintertime heating demand due to lower solar heat gain. Winter heating penalties are often limited due to multiple factors. Green roofs typically do not incur a winter penalty because they provide added insulation. Consider high-albedo roofs only in areas of a city that experience the most UHI effect.	• City ordinances, zoning and overlays • Building and energy code updates • Cool roof programs
Building Envelope Design	Passive design strategies like insulation and air tightness are useful in cold climates to protect indoor environments from extreme weather conditions (both cold and heat). Incorporation of thermal mass on the interior of the building can lessen indoor temperature swings. Temporary and removable shading devices such as fabric shades can also cool the building when the weather necessitates it.	• Building, energy, and green codes • Weatherization programs • Financial incentives

Green Infrastructure

Green Infrastructure (GI) refers to a large range of strategies that can reduce UHI as well as capture stormwater to mitigate flood risk. Removing heat-absorbing pavements and planting vegetation in their place can cool and shade urban neighborhoods and mitigate smog during hotter months. Increasing green spaces and landscaping can also cool areas down by pulling moisture from the ground and diffusing it into the air.

GI is also useful in colder climates that face extreme winter storms and inundation because it integrates vegetation, soil, and engineered systems to absorb and filter water runoff. Effective elements include stormwater planters or rain gardens, trees and tree trenches (trees connected to one underground trench), permeable pavements, green gutters (landscaped strips along sidewalks and curbs), and bioswales. GI is often designed to mimic natural processes to capture and reuse stormwater, using tools such as rain gardens, green roofs bioswales, greenways and parks to increase permeable surface area that may collect, store, and clean stormwater as well as mitigate combined sewer overflow events and decrease surface air pollution. GI also offers a host of other benefits, including improving air quality, sequestering carbon, conserving biodiversity, and improving neighborhood aesthetics.[7]

Many individual strategies that fall under GI are addressed in other sections of this resource, but cities may also promote GI more comprehensively through the implementation models described in this section.

[7] Land Use Changes in Philadelphia Following GI Policies

Implementation Models

Complete Streets Policies and Street Design Standards

Streets and sidewalks alone cover about 25% of city surface area in US cities and serve not only mobility purposes but also act as hubs for economic and social activity.[8] Given their large land coverage, streets can significantly reduce UHI effects and enhance community resilience during extreme weather events, including by incorporating comprehensive GI principles through landscape integration; maximizing permeable surfaces; and using resilient materials to withstand heat and flood impacts. Standardizing this approach at the city level can effectively help in UHI reduction and strengthen year-round resilience.[9] The complete streets concept emphasizes a move away from car-centric street designs to those that equally prioritize the needs, convenience, comfort, and safety of all users of varying physical capabilities, including pedestrians and cyclists as well as drivers and riders of public transit. Typically, complete streets incorporate clearly marked bicycle lanes with separation from vehicular traffic; sidewalks that are wide, well-maintained, and adequately lit; ample and visible crosswalks; and transit stops with sheltered seating for riders to wait comfortably. These policies can incorporate landscaping and permeable material requirements to provide GI. Incorporating green elements helps with mitigating the impacts of extreme heat: removing heat-absorbing pavement and planting vegetation in its place can cool and shade urban neighborhoods and mitigate smog during hotter months. In winter months, these green pathways can offer storm and flood mitigation benefits.

Spotlight: Trenton, New Jersey (Climate Zone 5A)

Trenton, New Jersey adopted a Complete and Green Street Policy, which requires the incorporation of smart surface strategies including permeable pavements, green stormwater infrastructure practices, shade trees and other vegetation, as well as green infrastructure interventions that support traffic calming.[10] The policy's goals are to improve air quality, reduce the UHI effect, provide shade, strengthen storm resilience, and improve traffic circulation.

8 Parking Lots Cause More Heat and Flooding
9 NYC Street Design Policy
10 City of Trenton Green and Complete Streets Policy

Spotlight: Boston, Massachusetts (Climate Zone 5A)

Boston's Streets Green Infrastructure (GI) Policy makes green infrastructure a standard practice for public rights-of-way, parking lots, and maintenance yards. The policy requires capital projects to integrate stormwater-managing landscape features, which has the benefit of expanding the urban tree canopy. The city has embedded GI into its routine street design and reconstruction, representing a systematic approach to incorporating stormwater and heat mitigation assets across the city.[11] The policy also introduces standardized GI design templates, establishes maintenance contracts and volunteer stewardship programs.[12]

Impervious Coverage Limits

Municipal ordinances can reduce urban heat by limiting impervious surfaces, encouraging the use of shaded or reflective materials, and requiring green space in dense areas. Impervious coverage limits are one tool that can play a meaningful role in mitigating UHI by capping the percentage of a lot that can be paved or built upon, reducing the area of hard surfaces like asphalt and concrete that absorb and re-radiate solar radiation as heat. This also forces the incorporation of trees and natural ground cover, improving an area's capacity to counter UHI by enabling evapotranspiration. If deciduous trees are used, there is less disruption of beneficial heating during cold weather. These policy mechanisms also encourage green roofs and permeable paving alternatives that may count or receive credit toward achieving the status of "pervious." Permeable paving is addressed in more detail in the Streets and Paving section of this report.

Spotlight: Philadelphia, Pennsylvania (Climate Zone 4A)

Philadelphia's "Green City, Clean Waters" program aims to increase the overall permeability of the urban landscape and introduce more stormwater storage and filtration infrastructure, as well as UHI mitigation benefits, in connection with green spaces. It is a 25-year plan to manage stormwater runoff and improve the overall quality of the city's waterways by way of introducing and updating sustainable green areas and infrastructure. The primary goal of the plan is to reduce the impact of contaminated water that overflows, untreated, into the city's rivers during flood events. Ultimately, the city determined that each greened acre of city land could treat the first inch of runoff from an acre of impervious cover.[13,14]

Planning Standards and Guidelines

[11] City of Boston Green Infrastructure Policy
[12] City of Boston Green Infrastructure Planning and Design Resources
[13] Green City Clean Waters
[14] GSI Investment

Standards and guidelines for neighborhood and city planning play a critical role in maintaining the quality and consistency of design interventions while providing a structured framework to address a city's specific social, demographic, economic, and environmental needs. Integrating UHI mitigation requirements within these frameworks establishes heat reduction strategies as core requirements rather than treating them as optional design features. Providing minimum criteria around tree canopy targets, cool roof and pavement specifications, shading requirements, green infrastructure integration, impervious surface coverage, and other qualities can systematically regulate the surface and ambient temperatures. Such standards and guidelines strengthen climate resilience, support public health, and advance long-term sustainability objectives.

Spotlight: Belfast, Maine (Climate Zone 6)

The Climate Action Plan of the City of Belfast highlights actions to maintain thermal comfort year-round. These strategies include sending out heat and cold emergency warnings; instituting public shelters; promoting efficient heating and cooling installations in public and private buildings; pursuing building code adoptions; and conducting energy audits and weatherization techniques.

Spotlight: Omaha, Nebraska (Climate Zone 5A)

The Omaha Master Plan highlights urban forestry and sustainable neighborhood design for climate resilience. It offers a consolidated design manual focused on uplifting the role of interconnected natural systems in delivering benefits of trees for stormwater management, air quality, energy conservation, and wildlife habitat.[15] This manual emphasizes the role of interconnected natural systems in urban planning, highlighting the benefits of trees for stormwater management, air quality, energy conservation, and wildlife habitat. The plan prescribes a range of concrete design strategies to achieve those goals.

[15] Omaha Master Plan

Trees and Greening

In the US, an average of 40 percent of urban areas is covered by trees, but that number is declining. Impervious surfaces, meanwhile, are expanding. In many cities, the geographic divide between areas with and without tree cover mirrors demographic lines, namely race and income, contributing to hotter conditions in historically disinvested neighborhoods.[16,17]

City trees and greening help regulate a city's microclimate and alleviate the UHI effect by providing shade and cooling from evapotranspiration, and reducing the heat absorbed by manmade surfaces and buildings. In fact, urban surfaces shaded by trees can be up to 20–45°F cooler than unshaded ones in the summer. [18,19] By capturing carbon and storing it in their biomass, trees also help to control urban greenhouse gas emissions; in the US, urban forests offset climate pollution equivalent to the emissions of about 10 million cars.

Introducing new landscaping and preserving existing green spaces throughout a city offers multiple benefits, in addition to reducing summer temperatures. These include increased biodiversity; carbon sequestration; reduced pollution; decreased winter wind speeds; and positive effects on human health.

When increasing urban tree canopy, native and climate adaptive species should be chosen to tolerate a city's unique climatic conditions. In cold climates, deciduous trees in particular can offer significant passive energy benefits by providing shade in the summer and allowing for solar gain in the winter. This offers passive benefits to buildings, decreasing energy needs and associated costs. Planting deciduous trees on south- and west-facing facades of buildings can block radiant heat in the summer and then allow sunlight to warm the building envelope during the winter, once the leaves are lost.[20] In fact, trees can help conventional houses reach up to 20

16 Tree Equity
17 Residential Housing Segregation and Urban Tree Canopy in 37 US Cities
18 The little-known physical and mental health benefits of urban trees
19 EPA: Using Trees and Vegetation to Reduce Heat Islands
20 DOE: Landscaping for Shade

to 25 percent of their energy use compared to the same home in unshaded conditions on an annual basis.[21] In a changing climate, some native species may be less likely to survive long into the future, might be overrepresented in a tree canopy, or may be less resistant to pests or diseases. Climate adaptive trees that are native to warmer regions may therefore better thrive in some cold climate cities in the future.

Vegetation can be introduced along transportation routes, on public lands, or on private lands. Urban pockets of vegetation, including parks, have the capacity to generate urban cooling islands: areas of a city that are significantly cooler than their surrounding built-up areas. Landscaped areas do not need to be particularly large to generate this effect: one study observed that a vegetated island spanning around 200 square meters could generate a cooling effect within a 330-foot radius; this phenomenon can grow exponentially as the vegetated space gets larger.[22]

Ongoing tree care is also key to maintaining a healthy canopy. This can include identifying and treating trees against diseases and invasive species; planting and pruning; installing watering devices; and identifying and dealing with trees of concern.

Implementation Models

Climate Plans and Urban Heat Island Mitigation Plans

Climate Action Plans and Urban Heat Island Mitigation Plans provide strategic frameworks for a city's tree planting and urban forestry work. Establishing clear objectives for UHI mitigation and canopy thresholds sets the direction for all activities taken by local governments, utilities, developers, and community partners. These documents are also essential for identifying the highest impact strategies to achieve the goals set out by the plan, including defining canopy targets, integrating trees into street design standards, identifying priority areas for planning, and prescribing climate-appropriate species selection.

Spotlight: Montreal, Canada (Climate Zone 6A)

Montreal's Urban Heat Island Mitigation Plan identifies tree planting as an essential strategy for mitigating UHI.[23] The plan identifies planting deciduous foliage to reduce shade in non-summer seasons, when solar gain is needed, which reduces the impact of shade on solar heating demand. The plan calls for mature trees to filter 60 percent of solar radiation and to be planted a maximum distance of between one-and-a-half times to twice the height of mature trees between building façades and the trees. This maximizes the capacity of the trees to shade buildings in the summer and block wind in the winter. The plan also identifies characteristics of species that should be avoided, including those that produce allergens or emit volatile organic compounds.

[21] USDA: Energy Savings with Trees
[22] Vegetation as a Climatic Component in the Design of an Urban Street
[23] Quebec UHI Mitigation Strategies

Municipal Ordinances

Municipal ordinances can take a range of approaches, including regulating land use and lot coverage; setting standards that protect existing trees and encourage increased planting; and guiding development on private land and along public rights-of-way. Ordinances may mandate tree planting in new developments, along streets, and in public spaces, and can specify minimum planting standards, soil requirements, and species designations to ensure long-term canopy health and maximize UHI mitigation potential.

> **Spotlight: Saint Michael, Minnesota (Climate Zone 6A)**
>
> Saint Michael, Minnesota adopted an ordinance with the purpose of controlling UHI by discouraging the unnecessary removal or disturbance of significant trees when developing.[24] If more than 40 percent of significant tree cover is removed from a development, the developer must replant at a rate of “one for one” by diameter-inch. The ordinance also offers density bonuses if preservation exceeds this threshold. The city also offers incentives to assist developers in meeting or surpassing these requirements, including a density bonus of 10%; omission of the tree survey requirement; variants for right-of-way, width of paving, length of cul-de-sac and increased street grades; and permissions for shared driveways and building setbacks.[25]

Landscaping Requirements and Guidelines

Municipal landscaping requirements and guidelines operate through a range of regulatory mechanisms, but often through zoning or development codes, which establish baseline landscaping standards as conditions of development approval. This may constitute specifying minimum canopy coverage percentages, parking lot-to-tree ratios, street tree planting requirements, or other provisions. Similar to street tree programs, these regulations may reference approved species lists or planting specifications but would apply to private development. These specifications and guidelines typically constitute landscaping types that have been pre-vetted by a municipality for use on public or private development. Comprehensive forestry policies can simultaneously address tree protection, strategic planting, species selection, and the need for adequate soil conditions and species diversity at a citywide scale. In cooler climates, these requirements create a framework for maintaining a city’s natural cooling infrastructure while supporting climate adaptation and ensuring strong performance throughout the winter months.

[24] Saint Michael Code of Ordinances
[25] Saint Michael Incentives

Spotlight: Minneapolis, Minnesota (Climate Zone 5A)

The City of Minneapolis and the Minneapolis Park & Recreation Board (MPRB) adopted a comprehensive urban forestry policy to identify the standards and guidelines that would be necessary to protect, maintain, and grow the city's urban forest. The policy focuses on Minneapolis' parks and trees located along public roadways. The standards and guidelines highlight the appropriate places for municipal policies to adopt provisions related to tree specifications; boulevard paving; hardscape design; engineered root space; construction protection; site plan review; and permits and enforcement. The policy also introduces the role of a Forestry Preservation Coordinator (FPC), who is responsible for, among other things, determining the appropriate tree species.

Spotlight: St. Louis Park, Minnesota (Climate Zone 6A)

The City of St. Louis Park's forestry team maintains a tree list that guides municipal planting, tree sale options, recommendations to residents, and trees eligible for reimbursement. The tree list makes distinctions between native and adapted tree species, as well as trees for particular spatial contexts.

Intergovernmental and Public-Private Partnerships and Funding

Some cities lack the staff or financial resources to plant trees, instead relying on partnerships with private landowners, organized community groups, nonprofits, or even assistance from state and federal governments.[26] The US Forest Service (USFS), for example, allocates funds to local governments, states, territories, and community groups working to increase and maintain urban forests in disadvantaged communities through its Urban and Community Forestry Program.[27]

Spotlight: Detroit, Michigan (Climate Zone 5A)

The Greening of Detroit is one organization supported by USFS that utilizes urban greening and tree planting programs to promote youth employment and training as well as adult workforce development. Prior to the program's inception in 1989, the city suffered a dramatic loss of its tree canopy due to urbanization and associated disease and neglect. In the three decades since its founding, the program has planted 135,000 trees in the city, primarily in streets but also in parks, schools, and other vacant lots.

Spotlight: Minnesota (Climate Zones 5–7)

The Minnesota Tree Steward Community Volunteer Program, backed by University of Minnesota research and education, municipal leadership, and environmentally-conscious volunteers, trains volunteers in proper tree planting, pruning, watering and installation of watering devices, identifying common tree diseases and pests, and reporting trees of concern.[28]

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26 USDA Climate Change Resource Center
27 USDA Urban and Community Forestry Program
28 Minnesota Tree Steward Community Volunteer Program

Streets and Paving

By area, streets constitute some of the largest continuous surfaces and public spaces in a city. When designed thoughtfully, they can function as adaptable, multi-purpose environments that meet the diverse needs of the people who use them. Beyond mobility, streets can play a critical role in bolstering a city's resilience to environmental hazards.

Cool and permeable pavements reflect solar energy and enhance water evaporation, which contribute to cooling impacts on the cityscape.[29] In cooler climates, these benefits are welcome in the summer, but the same infrastructure must also be able to withstand harsh winter conditions.

The materials and design choices that make up streets directly influence how much they absorb, store, and release heat. Reflective, high-albedo and permeable pavement can significantly reduce surface and air temperatures. Reflective pavements are designed to reduce heat absorption by reflecting solar radiation.[30] Light-colored materials reflect more sunlight and reduce the amount of heat absorbed and reradiated by sun-exposed surfaces. Reflectivity can be achieved by choosing lighter materials, such as concrete or lighter binders and aggregates. Coating or overlaying surfaces with lighter colored materials has also become a common and lower-cost way to prevent heat buildup. Replacing dark surfaces with lighter-colored ones can reduce surface temperatures by up to 20°F during warmer months.[31] White surfaces can reflect between 30–80 percent of incoming sunlight back into the atmosphere, compared to fresh asphalt, which reflects only about 4–12 percent. In acknowledgement of this impact, many cities, including New York and Chicago, have begun programs to coat roofs and road surfaces

[29] EPA: Using Cool Pavements to Reduce Heat Islands
[30] Urban Heat: Can White Roofs Help Cool World's Warming Cities?
[31] Performance of Cool Pavements for UHI Mitigation

with white or lighter materials.[32,33] Reflective pavements can reduce greenhouse gas emissions year-round through a process called negative radiative forcing, or global cooling. A proportion of the solar energy cool pavements reflect travels back into the atmosphere and into space. This process shifts the Earth's energy balance and effectively offsets some of the radiation trapped by greenhouse gases. The MIT Concrete Sustainability Hub found that roughly a third of the annual CO_2-equivalent emissions reductions from the radiative forcing effects of cool pavements occur in the fall and winter.[34] There is limited research on the impacts of cold climate-specific freezing temperatures combined with de-icing salts on coating performance, but reflective coating durability is typically sensitive to environmental exposure and will likely need more frequent recoating under extreme conditions.

On high-volume traffic roads, the largest benefit of cool pavements is not due to their UHI mitigation potential, but rather due to their impact on road longevity and vehicle fuel consumption. Permeable surfaces also undergo less thermal expansion compared to impermeable and darker alternatives, leading to longer service lives. Over the lifetime of a pavement, these fuel savings can add up, often offsetting the higher initial cost and impact of paving with more durable materials appropriate for high-traffic roads. Cool pavement alternatives that minimize fuel consumption can continue to cut GHG emissions in winter, assuming traffic is constant.

Permeable and porous pavements can retain water in the system when wet, which can cool the pavement surface and near-surface air temperatures through evaporative cooling to reduce UHI impacts. The relatively open structure of these types of paving allows them to absorb and store less heat, ultimately reducing the amount of radiation released into the air and reducing local temperatures in the summer.[35] In colder climates, permeable pavements offer mixed results. These pavements have the benefit of improving stormwater quality and reducing flood risk.[36] A University of Minnesota study on permeable pavements found that these materials can still perform well in cold regions, if installed with proper base layers and drainage.[37] Water on the surface can infiltrate into the soil below the pavement, where temperatures are warmer. This means that water will not pool, freeze, or refreeze on the surface, a common problem on impermeable pavements that leads to dangerous ice patches. Sediment-laden runoff tends to clog the pores and percolation pathways: this requires a strong commitment to maintaining these surfaces. However, air voids located in permeable pavement can act as insulation from the warmer soil below, meaning that snow and ice that are frozen tend to last longer on the surface compared to impermeable pavements.[38] If water can fully infiltrate, ice formation is reduced and the need for road salt is minimized. Permeable pavements often work best over subgrades that are non-compacted. Permeable pavements also require maintenance through pressure washing or vacuuming to prevent clogging and restore water infiltration rates and capacity. In general, sand is not recommended to be used on permeable pavement, and road

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32 NYC CoolRoofs
33 Chicago Cool Roofs Program
34 How Cool Pavements Can Mitigate Climate Change
35 Guidance on Permeable Pavements in Cold Climates
36 Cool Roadways Fact Sheet
37 Guidance on Permeable Pavements in Cold Climates
38 University of Minnesota: Permeable Pavements, Environmental Benefits, and Safety Risks

salt should be reduced. In general, salt has been identified as a substance that should be reduced on all road surfaces due to the impact that they have on water sources and the environment.[39] Saltless water softening systems are one technology that can serve the same purpose as salt with fewer environmental impacts.[40]

Placement of reflective pavements is an important consideration. Recent research has shown that walking on cool pavements can lead to higher temperatures and discomfort for pedestrians, as surface temperature is being reflected. A few studies, for example, found that people standing on reflective pavements on hot, dry days could feel over 7°F hotter compared to standing on uncoated asphalt.[41] This is in large part due to the glare that reflective coatings cause. This issue can be resolved by coating pavements that pedestrians do not directly stand on: treating roadways instead of sidewalks, or treating only shaded sidewalks, can lead to a reduced experience of heating for pedestrians.[42]

In general, management plans for permeable pavements are useful resources for understanding maintenance requirements, including directions on short-term and ongoing maintenance as well as placement opportunities and considerations. EPA, for example, published best practices for siting, designing, installing, and maintaining permeable pavements, which is available here.[43]

Available Product Performance

The table and material descriptions below describe how different paving options perform in both summer heat and winter conditions.

Alternative Asphalt Mixes (Reflective Aggregates and Polymer-Modified Binders)

The typical dark color of asphalt tends to absorb solar radiation, contributing to the UHI effect. Modifications can be made to asphalt mixes to enable them to withstand both heat and cold. Studies show that roads with solar-reflective aggregate, for example, can reduce surface temperatures by up to 20°F.[44] Polymer-modified asphalt, polymer-based binders, and nano-additives like nano-clay or nano-silica can also raise the softening point of the mixture and improve high-temperature stability, helping pavements better withstand extreme heat. Reflective pavements may reduce heat absorption during winter, which can be counterproductive when pavement warming is needed to support snowmelt and reduce icing. However, polymer-modified asphalt is excellent at resisting fracturing or micro-cracks in cold climates compared to asphalt.

Porous Asphalt

Porous asphalt is plowable, with some precautions, and can provide adequate skid resistance. When it is properly designed for freeze–thaw conditions, it can last about 10–15

[39] Impact of Road Salt on the Environment
[40] Minnesota Environmental Partnership: Salt on Roads
[41] The Hottest Urban Heat Solution Comes with a Glaring Tradeoff
[42] UNEP: Beating the Heat: A Sustainable Cooling Handbook for Cities
[43] EPA Guidance on Permeable Pavements
[44] Cool pavements help relieve urban heat islands, ASCE

years under suitable traffic loads; by contrast, conventional asphalt paved roads typically last between 15–25 years.[45] Like porous concrete, it requires relatively intensive maintenance to keep its voids from clogging, including regular vacuum sweeping, periodic high-pressure washing, limiting access by heavy vehicles, avoiding the use of sand and minimizing the use of de-icing chemicals, and following a strict sediment-control plan for adjacent areas. However, porous asphalt is not as effective in reducing daytime temperatures during the summertime compared to other high-albedo alternatives; it does, however, perform well during the nighttime compared to other impermeable asphalt or concrete pavements with a similar or higher albedo due to the high air void content of porous asphalt.[46]

Concrete with Additives

Different types of concrete mixes offer different structural properties and lifespans that can minimize the excess fuel consumption of vehicles caused by road quality; concrete can also naturally offer a high solar reflectance that benefits UHI mitigation. In cold regions, concrete should be able to balance solar reflectivity (albedo) in summer and heat retention in winter. Using light-colored concrete or reflective coatings can increase solar reflectance by about 30–50 percent, reducing surface temperatures in the summer.[47] Concrete mixes can also be improved by adding materials such as vermiculite, perlite, or crushed glass, which lower thermal conductivity and reduce daily temperature swings.[48] In addition, phase-change materials (PCMs) can be incorporated to absorb heat when temperatures rise and release it when temperatures fall, helping to stabilize surface temperatures throughout the year.[49]

Pervious Concrete

Permeable concrete contains large, connected pores, allowing water to drain through and reducing pavement temperatures by storing and evaporating moisture in its void spaces when wet. Permeable concrete is typically used in lightly trafficked areas like sidewalks, parking lots, and rest areas.[50] Permeable concrete pavements are plowable, with some precautions. When properly designed for freeze–thaw conditions, can last 20–30 years. They require relatively high maintenance because their pores can clog with sand and fine sediment, which reduces infiltration and treatment performance. Their longevity and function can be improved by regular vacuum sweeping, periodic high-pressure washing, limiting access by heavy vehicles, minimizing the use of sand and de-icing chemicals, and implementing a sediment control plan to keep fines off the surface.

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[45] How Long Should Asphalt Last?
[46] Porous Asphalt Pavement Temperature Effects for Urban Heat Island Analysis
[47] International Society for Concrete Pavements
[48] Mitigating Urban Heat Island Effects Through Thermally Efficient Concrete Paver Blocks for Sustainable Infrastructure, MDPI
[49] Reviewing the Potential of Phase Change Materials in Concrete Pavements for Anti-Freezing Capabilities and Urban Heat Island Mitigation, MDPI
[50] Permeable Concrete: Global Center on Adaptation

Permeable Resin Bound Paving

Permeable resin bound paving significantly mitigates UHI impacts and provides added benefits of filtering rainwater naturally into the ground.[51,52,53] It is a slip resistant, fully trafficable if built as such, and frost-resistant surface can endure freeze–thaw cycles. Its porous design allows water to drain through, preventing puddles and reducing ice buildup in cold weather. Its flexible composition of resin and aggregate allows expansion and contraction without cracking in frosty weather. It requires routine maintenance such as sweeping and shoveling with a plastic shovel to keep pores open, with normal winter salting and light de-icing in cold weathers.[54,55,56]

Permeable Blocks, Pavers, and Grid Systems

Permeable pavers and blocks perform better than porous asphalt and porous concrete due to their different system designs. When it comes to infiltration capacity during winter rain and melt events, permeable pavers tend to experience slower freeze and faster thaw times, meaning there were fewer days below freezing and higher temperatures on melt days.[57] Permeable pavers should be light colored and aid in a permeable system to mitigate UHI effects and manage stormwater runoff at the same time. In cold climates, including a de-icing system for freeze-thaw cycles is crucial for long-term durability. Because pavers are individual units, they are durable as well as easy to maintain, repair, and replace, which can reduce long-term operational impacts. They can be installed in permeable or on-permeable systems. Permeable systems include open grid systems that are filled with sand, gravel, or vegetation. Pavers are commonly manufactured from concrete, fired-clay brick, natural stone, or durable materials.[58] Options for permeable pavers include the following.[59,60]

- *Permeable articulating concrete blocks (P-ACBs):* Use high-albedo P-ACBs to increase reflectivity and infiltration. When installed over an open-grade base, P-ACBs have good resistance to frost heave and cracking, and the open joint openings give ice room to expand and melt.[61]
- *Grass pavers:* Cellular grids filled with turf create a drivable, plowable, and skid-resistant surface for low-traffic areas such as overflow parking and fire lanes. With proper soil, drainage, and turf care, they tolerate freeze-thaw cycles reasonably well; de-icing salts should be used sparingly to protect vegetation, and service lives of roughly 25–30 years are reported in practice.
- *Gravel-filled plastic grid pavers:* Plastic reinforcement grids filled with gravel provide a plowable, skid-resistant surface with good infiltration and relatively low maintenance needs. When underlain by a well-drained base, they experience fewer freeze-thaw

51 The Science Behind Permeable Resin Driveways
52 Epoxy Resin-Based Permeable Concrete Containing Ceramsite
53 Permeable Resin Bound Paving
54 Weather Resilience: How Resin Driveways Perform in Wet & Cold Climates
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61 Permeable Articulating Concrete Blocks for Stormwater Management

problems than traditional asphalt, can be used with de-icing salts, and commonly last up to 20 years or more under light traffic.

- *Unit concrete or brick pavers:* Conventional interlocking concrete or clay brick pavers are durable in cold climates, and their light-colored version can slightly reduce surface temperatures compared with asphalt. When laid in a permeable pavement system, they handle freeze-thaw cycles well, can be plowed, and provide service lives around 30 years in pedestrian and light traffic settings. Heavy duty pavers can also be used in permeable pavements that are designed for heavy (road) traffic.

High Solar Reflectance and Heat-Reflective Coatings

Coatings can be applied to asphalt or concrete to increase albedo and reduce heat gain without replacing the underlying pavement. These products include light-colored acrylic coatings that add reflectivity and resist discoloration under high temperatures. Transparent epoxy coatings can provide chemical, skid, and solvent resistance.[62,63] One peer-reviewed study by Altostratus Inc. of the Cool Community Project in the Pacoima neighborhood of Los Angeles, California found that application of solar reflective coatings on pavement reduced ambient air temperature by up to 3.5°F during extreme heat events, resulting in a 25–50 percent reduction in local UHI intensity during peak temperatures.[64] Heat-reflective coatings reflect solar radiation across UV, visible, and infrared wavelengths and can reduce asphalt surface temperatures by up to 10–20°F, depending on climate and product type.[65]

Photocatalytic TiO_2-based coatings are heat-reducing, self-cleaning surfaces, which can degrade harmful pollutants from vehicles, including nitrogen oxides (NO_x), microplastics, and total volatile organic compounds (TVOCs) while maintaining surface brightness for UHI mitigation.[66] IR-reflective (NIR/IR) coatings contain pigments that reflect near-infrared and mid-infrared wavelengths, enabling up to 18–22°F surface cooling, even under intense heat exposure.[67] In cold climates, low-emissivity (low-e) materials that allow useful solar heat gain can reflect solar heat in the summer and retain heat in the winter.[68] In such cases, thermochromic coatings may offer a better solution. These coatings change color based on ambient temperature, becoming lighter in warm conditions to reflect more sunlight and increase albedo if the surface temperature exceeds certain threshold, and darker in cold conditions to absorb more heat.[69] Thermoelectric asphalt pavements reduce surface temperatures by 8–9°F in the summer and can generate electricity.[70, 71]

62 Epoxy Coating
63 Materials to Mitigate the Urban Heat Island Effect for Cool Pavement: A Brief Review
64 Peer-reviewed Study on GAF and Climate Resolve Initiative Demonstrates Effectiveness of Cool Pavement Coatings in Mitigating Extreme
65 Comparison and analysis on heat reflective coating for asphalt pavement based on cooling effect and anti-skid performance
66 Evaluation of photocatalytic efficiency of TiO_2 applied over cement plaster for mitigating urban air pollutant: TVOC
67 Evaluating the performance of cool pavements for urban heat island mitigation under realistic conditions: A systematic review and meta-analysis
68 Guide to Low-e Coatings: Choosing the Right One for Your High-Efficiency Windows
69 Adaptive measures for mitigating urban heat islands: The potential of thermochromic materials to control roofing energy balance, ScienceDirect
70 Thermoelectric Asphalt Pavements
71 Optical and Mechanical Properties of Innovative Multifunctional Thermochromic Asphalt Binders

TABLE 1: AVAILABLE PAVING PRODUCTS AND THEIR UHI AND WINTERTIME PERFORMANCE

Product Type	UHI Performance	Cold Weather Performance
High-Solar Reflectance and Heat-Reflective Coatings	• Reflective coatings can reduce surface temperatures by up to 20°F.[72] • Cooling effect can improve performance of asphalt mixtures in the field. • Reflects solar radiation and reduces heat gain without structural or material modification. • Some reflect solar radiation across UV, visible, and IR wavelengths, • Successful at reducing ambient air temperature. • Some constitute flexible films that expand and contract with temperature changes, reducing cracking.	• Reflective sealcoats reduce heat absorption and hinder snowmelt during winter. • Thermochromic coatings offer an option: change color based on ambient temperature. • Low-emissivity (low-e) materials allow useful solar heat gain in the winter. • Emerging technologies, such as temperature-adaptive radiative coatings (TARC) at ambient temperatures below 59°F to reduce heat loss and increase to a high emittance (~0.90) at ambient temperatures above 86°F to enhance heat dissipation. • There is limited research on the impacts of cold climate-specific freezing temperatures combined with de-icing salts on coating performance, but reflective coating durability is typically sensitive to environmental exposure and will likely need more frequent recoating under extreme conditions.
Porous Asphalt	• Performs poorly in reducing daytime temperatures compared to high albedo pavements. • Performs well in reducing nighttime temperatures compared to other impermeable asphalt and concrete pavements with a similar or higher albedo due to high air void content.	• Plowable and can provide skid resistance when designed for freeze-thaw conditions • Can last 10–15 years • Requires relatively high maintenance because pores can clog with sand and fine sediment, reducing infiltration and treatment performance. •
Concrete with Additives	• Naturally offers solar reflectance levels that benefit UHI mitigation. • Some additives (vermiculite, perlite, crushed glass) reduce thermal conductivity and daily temperature swings. • Reduces heat retention.	• Durable in cold climates. • Can handle freeze-thaw cycles and plowing. • Additives improve resilience, longevity, and thermal stability. • Phase-change materials (PCMs) can stabilize surface temperatures throughout the year.
Pervious Concrete	• Higher solar reflectance mitigates UHI when compared to conventional pavements with low solar reflectance. • Stores moisture in its void spaces when wet and as water evaporates, it cools (through evaporative cooling), mitigation UHI.	• Effective for stormwater management in lightly trafficked areas. • Plowable and can last 20–30 years when properly designed for freeze-thaw conditions. • Requires relatively high maintenance because pores can clog with sand and fine sediment, reducing infiltration and treatment performance. • Can reduce the amount of salt and de-icing products needed.
Permeable Resin Bound Paving	• Can significantly lower UHI impact when a light color is selected.	• Frost-resistant surfaces can endure freeze-thaw cycles.

[72] Arizona State University Parking Lot Study

Product Type	UHI Performance	Cold Weather Performance
	• Evaporative cooling when wet can mitigate UHI.	• Porous design allows water to drain and reduces ice build-up. • Expands and contracts without cracking in frosty conditions. • Requires routine low maintenance and light de-icing to keep pores open.
Permeable Articulating Concrete Blocks (P-ACBs)	• High solar reflectance can mitigate UHI impacts when compared to conventional asphalt pavement. • Evaporative cooling when wet can mitigate UHI.	• Can handle freeze-thaw cycles and plowing. • Sealing of blocks is required to protect from damage caused by road alt. • Requires routine vacuum maintenance.
Permeable Interlocking Concrete Pavers (PICPs) and Clay Brick Pavers	• Light-colored pavers can increase reflectivity. • Evaporative cooling when wet can mitigate UHI.	• When over an open-grade base, good resistance to freeze heave and cracking. • Joint openings allow ice expansion and melting. • Can handle freeze-thaw cycles and plowing.
Grass Pavers	• Absorb less heat than conventional paving. • Evapotranspiration cools surfaces better than other permeable pavement types.[73] • Must be maintained and irrigated.	• Can tolerate freeze-thaw cycles with proper drainage. • De-icing salts should be limited in order to protect vegetation.
Gravel-Filled Concrete Grid System	• Gravel pavers store less heat than asphalt. • Light-colored pavers and gravel absorb less heat than asphalt. • Open-grid structure reduces heat retention.	• Plowable and skid resistant. • Fewer freeze-thaw issues with a well-drained base. • Compatible with de-icing salts.

Implementation Models

Pavement Pilot Programs

These pilot programs are municipal initiatives that can be designed to implement, test, monitor, and scale pavement treatments and technologies that stay cooler than conventional paving. These are often instituted on municipally owned streets, alleys, parking lots, and schoolyards. Some programs incorporate pilot testing phases that install multiple pavement types, measure relative performance, and document findings for future use. These findings can be used to expand the most promising installations where the benefits can be felt the most.

[73] Effects on evaporation rates from different water-permeable pavement designs

Spotlight: Minnesota Permeable Pavements in Cold Climates Studies (Climate Zones 5–7)

The Minnesota Department of Transportation and University of Minnesota conducted a series of pilots and released an associated report studying case studies on the performance of permeable pavements in cold climates, focusing on surface and subsurface temperatures; freeze-thaw durability; winter infiltration performance; de-icing salt behavior; and integrity under snowplow operations.[74] The Minnesota Department of Transportation conducted monitoring of test roads composed of porous concrete and asphalt for two years to come to a series of lessons learned on best practices and considerations for smart design, siting, use, placement, and maintenance of these alternative pavements.

Permeable Paving Codes

Permeable paving codes may be adopted by cities to regulate the location, use, and conditions under which permeable pavements can be installed. Some cities permit these surfaces, while others amplify them as preferred. Permeable paving codes may include specific performance requirements for particular materials; approved materials lists; infiltration testing requirements, such as through ASTM C1701 or C1781; runoff treatment provisions; or maintenance instructions.

Spotlight: Milwaukee Permeable Paving Code (Climate Zone 6A)

The Milwaukee Code of Ordinances includes a permeable paving code, which allows all roads, lots, spaces, and other areas to have permeable paving in any location that is not subject to the risk of hazardous liquids being absorbed into the soil.[75] The code also contains a green stormwater infrastructure substitution section, which provides exemptions to tree planting requirements for green infrastructure, such as permeable paving, rain gardens, and bioswales.[76] These strategies are part of a larger Green Infrastructure strategy, which has included a baseline inventory effort; a GI plan; a Green Streets Stormwater Management Plan; and a Sustainable Municipal Water Management Public Evaluation Report.[77] The Green Streets Stormwater Management Plan in particular provides important information about short-term and ongoing maintenance as well as placement opportunities and considerations.

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[74] Minnesota Permeable Pavements in Cold Climates Pilot Program
[75] Milwaukee Permeable Paving Code
[76] Milwaukee GSI Code of Ordinances
[77] Milwaukee Green Infrastructure Strategy

Cool and Green Roofs

In some cities, roofs can account for 20–25 percent of the total urban surface. Cool and green roofs replace the impermeable and dark surface area taken up by buildings and can reduce the amount of heat they absorb, reducing buildings' reliance on air conditioning. In cooler climates, pairing cool roofs with roof insulation upgrades can maximize energy conservation benefits in the winter and improve net annual energy consumption, however, a thorough moisture and energy analysis should be undertaken before retrofitting a roof.

Installing cool roofs is one of the most cost-effective passive strategies for reducing cooling loads, which saves energy and money while also reducing peak electricity loads during heat waves. Cool surfaces reflect sunlight and efficiently radiate heat away from the roof surface. Installing cool roofs reduces the conduction of heat into the building, reducing the need for air-conditioning in conditioned spaces. This saves energy and money, and the decreased load helps to moderate peak grid demand during heat waves and very hot summer afternoons, thereby reducing the risk of power outages.[78]

Winter Heating Penalty

In colder climates, there is often concern about a winter heating penalty[79] from cool roofs, or a potential increase in the need for heating, and associated energy cost and demand, in the winter. However, a 2015 study from Lawrence Berkeley National Lab (LBNL) found that cool roofs offer net annual energy savings in cold climates in the US because they reduce summer cooling costs more than they increase winter heating.[80] The magnitude of the heating penalty in cooler climates tends to vary but is often small or realizes annual net benefits for building stock that has sufficient insulation. As the climate shifts toward warmer temperatures, longer heat seasons, and a greater demand for cooling, cool roofs will become increasingly cost-effective.

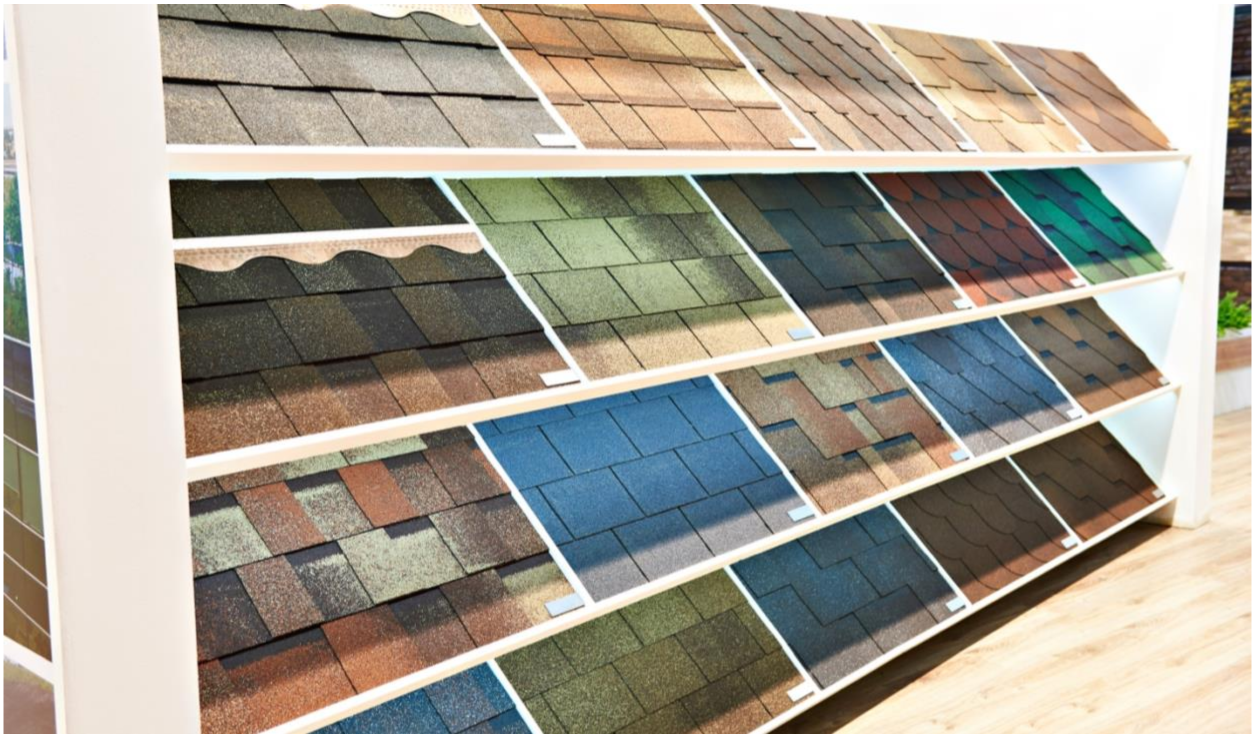
[78] Lawrence Berkeley National Lab Heat Island Group
[79] LBNL Heat Island Group: Cool Science

Another factor that minimizes the winter heating penalty is the lower angle of the sun in winter months, which reduces the impact of roof type on solar gain during the winter.[81] Additionally, cities that experience snowfall see an increase in albedo in the wintertime regardless of roof types, as these roofs are white when covered.[82] Energy simulations for Minneapolis and Montreal have shown that, in addition to snow cover masking roof color, heating penalties are minimized by high insulation levels in modern buildings, resulting in annual net energy savings, which range depending on location in building type. For example, a cool roof placed on an old retail building in Montreal can save up to $62/100 m^2. On a new, medium-sized office building with electric cooling and natural gas as heating fuel, a cool roof would save "$4/100 m^2 in Montreal, $14/100 m^2 in Milwaukee and Anchorage, and $10/100 m2 in Toronto. Cool roof also saves maximum of $37/100 m^2 for a retail store building in Toronto."[83]

Green—or landscaped—roofs are effective in colder climates because they reduce the amount of heat that buildings absorb in the summer, relieving their reliance on energy-intensive cooling techniques like air conditioning. In the wintertime, these same structures provide insulation, reducing heating need and improving energy efficiency. One study found that, "[o]f all the types of roof covering (traditional, reflective coating, plant), the green roof achieves the most cooling. A dark roof exposed to the sun can reach 80 degrees C, a white roof, 45 degrees C, and a green roof, 29 degrees C."[84] Energy consumption in buildings equipped with green roofs was lower than that for non-green roofs and could even be enhanced through natural ventilation during the summer. When it comes to specifying green roofs, dry soil in the winter can increase heat storage and thermal insulation in the winter.[85]

When applied at the city scale, cool and green surfaces can amplify neighborhood-level cooling. For optimal UHI mitigation, prioritize Cool Roof Rating Council (CRRC)-listed pavements or coatings with high Solar Reflectance Index (SRI) values over standard dark roof materials. Solar Reflectance (SR) refers to the percentage of sunlight a material reflects back into the atmosphere. A Solar Reflectance Index (SRI) is a value that combines solar reflectance and thermal emittance, or the capacity of a surface to absorb heat. SRI values typically fall between 0 and 100.

81 Why We Need Cool Roofs and What to Consider When Planning to Install Them
82 A Practical Guide to Cool Roofs and Cool Pavements
83 Cool Roofs Savings and Penalties in Cold Climates
84 Quebec: Urban Heat Island Mitigation Strategies
85 Green Roofs and Facades: A Comprehensive Review



Available Product Performance

A summary of typical roof types and their relative performance levels under extreme heat and wildfire conditions is provided below.

Asphalt Shingles

Asphalt shingles make up a majority of residential roof market share due to their combination of durability, cost-effectiveness, and aesthetic appeal. Conventional dark shingles usually have a low Solar Reflectance Index (SRI); however, "cool" asphalt shingle options are also available.[86] In colder climates, asphalt shingles perform reliably and are widely chosen for their insulation, snow and ice management, moisture resistance, and freeze-thaw durability.[87]

Metal Roofing

Metal roofing, most commonly used on steep slope buildings, offers high durability and a long service life. It typically has relatively a high SRI, and, when paired with appropriate surface finishes or when adding a white or reflective coating, can further increase SRI, helping the roof stay cooler.[88] Metal roofing is most commonly applied in sheets with standing seams, however, metal shingles are also available and can mimic the style of asphalt shingles while providing the performance benefits of a metal roof. Because metal is highly conductive, a reflective metal roof cools rapidly when solar input drops, which can limit unwanted heat gain in summer, in particular at nighttime. In cold climates, cool metal shingles can assist with snow melt and UHI

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[86] Reducing Urban Heat Islands: Compendium of Strategies Cool Roofs
[87] Asphalt Shingles in Cold Climates
[88] A Practical Guide to Cool Roofs and Cool Pavements

mitigation by running warmer than the ambient air when the sun is shining yet still reflecting more solar energy than dark asphalt shingles.

Concrete or Clay Tile

Concrete and clay tile roofs offer strong benefits for heat resilience. Their mass and thickness offer thermal mass benefits, slowing heat transfer to underlying decking and spaces. Sub-tile venting with roof tiles also can have a significant impact on heat transfer. Products are also available in light-color or reflective formulations. In cold climates, these options perform well in snow, ice, and freeze-thaw climates, and have low moisture absorption.[89] Clay tiles are highly resistant to freeze-thaw, while concrete tiles can be engineered for cold climates. The thermal mass that these materials offer also helps retain indoor cooling during the summer and heating during the winter.

Wood Shake or Cedar Shingle

Wood is naturally cool and has a moderate reflectance, meaning that its performance can vary.[90] However, air gaps between shingles can trap and re-radiate heat at the surface level, which limits this materials' ability to contribute significantly to UHI mitigation. They also do not have high emissivity, meaning they cannot shed absorbed heat back to the atmosphere. These materials do perform well under cold climate winter conditions, offering natural insulating properties and a high ability to handle freeze-thaw cycles when properly installed. However, they can be vulnerable to moisture retention and can be susceptible to moisture intrusion when snow or ice lingers on the surface.

Coatings

Cool roof coatings can cost-effectively, quickly, and easily convert most non-cool low-slope roofs to cool roofs for near-immediate heat mitigation and energy efficiency benefits. Coatings are thick, paint-like surface treatments mostly used for low-slope roofs. They are engineered to improve adhesion, durability, biological resistance, corrosion, and dirt shedding, while also functioning as a low-cost cool retrofit when a light-colored coating is applied on existing roof materials. Coatings can be cementitious, elastomeric, or silicone or acrylic paints, and can provide high initial solar reflectance and thermal emittance.[91] They can be applied over an existing roofing system to provide life extension and protection against heat, moisture, standing water, hail, ultraviolet radiation, and physical damage. Elastomeric coatings have elastic properties, allowing them to expand in hot summer conditions and then return to their original shape without cracking, which is why they are widely used in roof applications.[92] Applying cool roof coatings can increase a roof's SRI, help lower surface temperatures, and contribute to reducing urban heat island effects.[93] Emerging technologies, such as temperature-adaptive radiative coatings (TARC) can automatically adjust thermal emittance based on surface temperature changes.[94] It maintains a low emittance (around 0.20) at ambient temperatures

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89 Roof Tile Winter Performance
90 DOE: Cool Roofs
91 Reducing Urban Heat Islands: Compendium of Strategies Cool Roofs
92 A Practical Guide to Cool Roofs and Cool Pavements
93 Reducing Urban Heat Islands: Compendium of Strategies Cool Roofs
94 Temperature-adaptive radiative coating for all-season household thermal regulation

below 59°F to reduce heat loss and increases to a high emittance (around 0.90) at ambient temperatures above 86°F to enhance heat dissipation.

Single-Ply Membranes

Single-ply membranes are prefabricated sheets installed in a single layer on low-slope roofs. They are typically adhered or mechanically fastened across the roof surface, with seams sealed using tape, adhesives, or welding. They are also used for extensive repair of existing buildings. Many manufacturers produce them with reflective "cool roof" options that absorb less solar radiation. These options may slightly increase winter heating demand in cold climates; overall energy impacts depend on the building's insulation level and climate.[95,96] Common types of single-ply membranes include:

- EPDM (ethylene propylene diene monomer): A synthetic rubber membrane with seams that are typically glued or taped together.
- CSPE (chlorosulfonated polyethylene): A polymer-based membrane with seams that can be heat-welded.
- PVC (polyvinyl chloride), TPO (thermoplastic olefin), and KEE (ketone ethylene ester): Thermoplastic membranes with seams that are welded to form durable, watertight joints.[97]

Film or Panels with Film

Films are thin polymer sheets that are adhered or laminated to a substrate and can be engineered to modify the thermal behavior of a roof assembly.[98] Their composition and configuration vary according to functional objectives and climatic conditions. For instance, films developed for UHI mitigation are formulated to enhance surface solar reflectance and thermal emittance, which may include retroreflective (RR) materials or polyvinyl fluoride (PVF)-based films.[99,100,101] These can become significantly more brittle and prone to cracking under harsh winter conditions, as many plastics lose flexibility at lower temperatures and when exposed to freeze-thaw cycling. However, high-performance films are available and engineered specifically to retain flexibility and dimensional stability at sub-zero temperatures.

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95 Single-Ply Roofing: The Quick Guide
96 Single-Ply Roof Membrane Types and Comparison
97 Reducing Urban Heat Islands: Compendium of Strategies Cool Roofs
98 Roofing Films, AM Stabilizers
99 Retro-reflective surfaces for mitigating urban overheating: application, evaluation, and optimization
100 Radiative cooling improvement by retro-reflective materials
101 Tedlar® PVF Film

TABLE 2: SUMMARY OF AVAILABLE ROOFING PRODUCTS AND THEIR UHI AND WINTERTIME PERFORMANCE

Product Type	UHI Performance	Cold Weather Performance
Asphalt Shingles	• Conventional dark shingles have low Solar Reflectance Index (SRI). • Some cool asphalt shingles with higher solar reflectance are available, but many do not go over 0.3 SR.	• Perform reliably in colder climates and are widely chosen for their insulation, snow and ice management, moisture resistance, and freeze-thaw durability.
Metal Roofing	• Relative high SRI and thermal emittance. • Adding a white or other reflective coating can further increase SRI and emittance.	• Cool metal roofing can assist with snow melt by running warmer than the ambient air when the sun is shining yet still reflecting more solar energy than dark asphalt shingles.
Concrete or Clay Tile	• High thermal mass can reduce heat transfer. • Light-colored options available.	• High thermal mass can retain heating in the winter. • Performs well in snow, ice, and freeze-thaw climates, and have low moisture absorption.
Wood Shake or Cedar Shingle	• Naturally cool material though reflectance may vary. • Air gaps between shingles can trap and re-radiate heat at the surface level. • Do not have high emissivity. • Do not maintain high reflectance in initial vs. aged ratings.[102]	• Offers insulating properties and a high ability to handle freeze-thaw cycles when properly installed. • Can be vulnerable to moisture retention and susceptible to moisture intrusion when snow or ice lingers on the surface.
Coatings	• Typically cementitious, elastomeric, and silicone coatings or acrylic paints, both offering high initial solar reflectance and thermal emittance, which helps keep roofs cooler.	• Coatings can protect against moisture, standing water, hail, ultraviolet radiation, physical damage.
Single-Ply Membrane	• Many manufacturers produce them with reflective “cool roof” surfaces.	• May slightly increase winter heating demand in cold climates, but extent depends on the building’s insulation level and climate.
Film or Panels with Film	• Films can be developed for UHI mitigation by enhancing surface solar reflectance and thermal emittance.	• Can become significantly more brittle and prone to cracking under harsh winter conditions, as many plastics lose flexibility at lower temperatures and when exposed to freeze-thaw cycling. • High-performance films available to retain flexibility and dimensional stability at sub-zero temperatures.

[102] CCRC Intial vs. Aged Ratings

Implementation Models

City Ordinances, Zoning and Overlays

City and zoning codes and ordinances serve as a foundational regulatory mechanism for defining and managing land use and building performance within specific districts—such as residential, commercial, industrial, market, historic, or financial zones—tailored to local urban context and planning objectives. These codes establish standardized criteria for reviewing development proposals, ensuring consistent implementation of design, safety, and operational standards that support energy efficiency, standard quality of building stock, livability, and hazard mitigation. Integrating provisions for UHI mitigation, climate resilience, energy efficiency, and sustainability measures within these regulations can enhance environmental performance, strengthen adaptive capacity, and promote the long-term social and ecological resilience of the city.

A legislative body, such as a city council, can enact an ordinance that becomes law, enforceable within the city's boundary. Ordinances can take many forms that guide development and infrastructure interventions, including zoning or building code amendments and the establishment of overlays. For example, an ordinance may require all city-funded projects to incorporate cool roofs.

Zoning codes allow jurisdictions to implement extreme heat—as well as stormwater—mitigation strategies on a neighborhood or citywide scale. Overlay zones that acknowledge hazard potential may be established in areas particularly prone to environmental risk, including UHI and extreme heat. Within an overlay zone, regulations may be adjusted to address the particular circumstances of the area. For example, jurisdictions can use zoning and overlay provisions to identify hot spots for introducing additional landscaping and reflectivity. Some jurisdictions outline expectations, requirements, or incentives for cool and green roofs into zoning overlays. For example, zoning overlays for specific districts such as waterfront zones, downtown cores, or areas with high impervious surface coverage, benefit more substantially from sustainable roof interventions and therefore may constitute priority areas for cities to focus this promotion. Some jurisdictions do not mandate but rather incentivize cool roofs through such mechanisms as density or floor area ratio (FAR) bonuses, expedited permitting, or fee credits and tax abatements.

Spotlight: Casper, Wyoming (Climate Zone 6B)

Casper's zoning code highly encourages the use of green roofs, explicitly mentioning the purpose of reducing UHI, minimizing building energy consumption, and facilitating stormwater management within the Old Yellowstone District and South Poplar Street Corridor.[103] The code defines green roofs as building roof systems designed to reduce rainwater runoff, heat, and glare, with the benefit of reducing energy consumption. The definition further prescribes the use of open place and living vegetation as the "primary exterior material."

Spotlight: Laramie, Wyoming (Climate Zone 6B)

Laramie's code of ordinances also encourages sustainable roofs, which can be cool or vegetative roofs. Developments may receive a waived or reduced requirement for onsite parking in exchange for utilizing cool or vegetative roofs. Cool roofs must comprise 75 percent of the roof's surface air and have an SRI of 78 or higher for flat roofs and 29 or higher for sloped roofs. Vegetative roofs must comprise 50 percent of the total roof area and be populated with plants from the city's planting list.

Building and Energy Code Updates

Building and energy codes have become an increasingly prominent tool for promoting cool and green roofs. The International Energy Conservation Code (IECC) and ASHRAE 90.1 is a model energy standard which acts as the basis for many state and local energy codes. Over time, these codes have introduced and tightened roof reflectance requirements, though these have primarily focused on warmer climate zones. However, this has not stopped jurisdictions located in colder climates from adopting cool and green roof requirements into their codes, in acknowledgement of the multitude of benefits they can deliver. The Cool Roof Rating Council (CCRC) maintains a list of codes, standards, and voluntary programs that promote cool roofs, which may be accessed here.

[103] Casper Code of Ordinances

Spotlight: Chicago, Illinois (Climate Zone 5A)

The Chicago Energy Transformation Code and Chicago Building Code include requirements for commercial and residential buildings to meet minimum solar reflectance values.[104] Rooftop walking surfaces, vegetative roofs, and solar panels are exempt. The code incorporates solar reflectance and thermal emittance values, with product specifications submitted at plan review. In addition to its energy code strategy to promote reflectivity, Chicago has also used other policy mechanisms to push green roofs. Its Green Permit Program, for example, offers expedited plan review for projects incorporating qualifying sustainable features, including green roofs. It also offers FAR and density bonuses for green roof installations in certain districts including the downtown.

Cool Roof Programs

Cool roof programs can operate through a range of mechanisms including utility rebates, direct installation, and contractor certification and training. Utility rebate programs can subsidize the incremental cost difference between conventional and qualifying reflective roofing products, making cool roofs more cost-effective for building owners. These programs are often funded through ratepayer charges or state energy efficiency financing. Direct installation programs deploy cool roof installations to heat-vulnerable populations who are least able to finance upgrades. Contractor certification and training programs focus on building workforce capacity to specify, procure, and install cool roofs. Many cities, including New York, Chicago, and Los Angeles have also begun programs to paint roofs and road surfaces with white or lighter paint.

[104] Chicago Construction Codes

Spotlight: Cambridge, Massachusetts (Climate Zone 5A)

The City of Cambridge's Community Development Department conducted a mapping exercise to inform heat mitigation policies.[105] The city measured the roof reflectivity of all buildings in 2018 and 2021. The maps also noted roof shapes, helping the city to identify the lowest hanging fruit from a heat mitigation perspective: flat and low-slope roofs are more easily coated with high SRI materials at a lower cost compared to pitched roofs. The city also identified the location of green roofs.

This mapping campaign informed the adoption of new zoning requirements that acknowledge the long-term impacts of increased flooding and heat due to climate change. Developments over a certain size are subject to the city's Green Building requirements and Green Factor standards, which are performance-based standards encouraging heat mitigation through site and landscape design. Sites need to achieve a "Cool Score" by including features including green roofs, cool roofs, cool pavements, and other landscaping and shading strategies.[106]

In response to this growing demand for cool roofs, the city is also focusing on cool roof deployment. Electrify Cambridge, managed by Abode Energy Management, is Cambridge's program to support residents with clean, sustainable, all-electric home energy upgrades. Their residential and commercial consultations include education on the benefits, costs, and efforts associated with installing cool roofs.[107]

105 Cambridge Roof Mapping
106 Cambridge Cool Score
107 Electrify Cambridge

Building Envelope Design

In addition to roofs, the rest of the building envelope also acts as a critical barrier for protecting human comfort and health during extreme weather events—both heat and cold. Passive design strategies can go a long way in improving the performance of the envelope and the energy efficiency that results from alleviated pressure on mechanical systems. Passive design strategies refer to methods that harness natural dynamics to create and maintain comfort within a building. Qualities such as insulation and air tightness are useful in cold climates as well as indispensable to reduce heat gain inside buildings during periods of hot weather. Replicating thoughtful envelope strategies from structure to structure means that decisions made at the building scale can have cumulative impacts across a city.

Below is a selection of passive strategies that may be utilized within the building envelope, which can enhance performance during both summer and winter.

Air Sealing and Weatherization

The building envelope plays an important role in establishing a building's thermal resilience. High-performing envelope systems can reduce interior heat and cold by insulating against outdoor temperature swings.

Air leakage is a large culprit for indoor temperature swings. When the building envelope has gaps, cracks, or poorly sealed joints, outdoor air infiltrates the interior, impacting indoor temperatures and forcing mechanical systems to run longer and at a higher capacity to maintain indoor temperatures.[108] Weaker envelopes make mechanical equipment less efficient, increasing energy use and associated costs to condition a space. Well-sealed envelopes improve both thermal performance and indoor air quality, enabling mechanical and filtration systems to operate as designed and maintain safe indoor conditions during extreme weather events.

[108] US Department of Energy: Air Leakage

Air sealing and weatherization upgrades are impactful ways to strengthen envelope integrity, helping with thermal resilience to extreme heat. Key weatherization strategies with dual benefits for heat and cold include roof and wall insulation to reduce temperature transfer and stabilize indoor temperatures; air sealing of the exterior envelope to block infiltration; introducing high-performance fenestration (double-glazed, low-E, well-sealed windows); incorporating exterior shading devices such as overhangs or louvers; and designing cool or green roofs to reduce roof surface temperatures and cooling loads.[109] These strategies may be applied to both new and existing buildings.

Material Selection

In addition to promoting air sealing and weatherization strategies, material choices for walls can offer dual benefits in the summer and wintertime. Materials with high thermal mass have the potential to store thermal energy and shield interior spaces from external temperatures. Placing heavier, denser materials such as concrete, stone, or masonry strategically throughout the structure, including on the ground and in the interior, absorbs heat from the sun during the hottest hours and distributes it slowly as outdoor temperatures drop during the evening and night. The same property can be used to store cooling during the summer daytime hours to mitigate temperature swings.

Windows, Glazing, and Shading

Low solar heat gain coefficient (SHGC) glazing reduces radiant heat transmission and cooling loads during the summer, and when combined with multipaned construction, the assembly significantly improves the building envelope’s insulation performance. In winter, low-SHGC glazing can limit passive solar heat gain, which can be a disadvantage in cold, sunny climates where wintertime solar radiation can meaningfully offset heating demand. For this reason, best practice cold-climate design would balance SHGC with orientation: using higher-SHGC glazing on south-facing façades to capture winter sun, while applying lower-SHGC glazing on east, west, and unshaded exposures to control glare and heat loss. Multi-pane window assemblies can also reduce heat loss by increasing thermal resistance and reducing interior surface condensation risk. Low-e coatings also help retain indoor heat by reflecting longwave radiation back into the conditioned space, improving comfort near windows during cold periods.

Vegetation can provide insulation, save energy, absorb carbon dioxide, and reduce pollution. Just as green roofs insulate the rooms below, living walls covered with vegetation are also effective on sun-exposed western and southern facades, moderating the air temperature between the green wall and the wall of the structure. Vegetated walls can provide an insulating benefit both in the summer and the winter, but the benefit diminishes if plants lose their foliage in the winter. Cold climates present real challenges for vegetated walls. Harsh winters can cause exposed vegetation to die if the thermal mass of the wall assembly and the root zone are not adequately protected from freezing. Modular soil-based systems with greater depth tend to perform better in colder climates. Additionally, vegetated walls located in sheltered locations or

[109] ASHRAE, EPA, NIST: Planning Framework for Protecting Commercial Building Occupants from Smoke During Wildfire Events

on south-facing facades where solar gain helps moderate temperatures have been more successful in colder conditions.

Orientation, Shading, and Trees

In the wintertime, south-facing windows draw in solar energy as the sun travels low across the sky. In the summertime, heat buildup can be prevented by overhangs and other shading devices including trees that block sun rays from accessing interior areas. Adjustable shading elements can deflect direct sunlight at certain times of the day while still allowing light or heat to enter when desired. These elements may be integrated into a building design or added after the fact. They may constitute roof overhangs, shutters, porches, curtains, or canvas canopies—a more efficient, cheap, and easier option to apply. Shading is typically needed most on the western and eastern elevations, which receive the most direct sunlight during the summer.

Strategic tree selection and placement is another effective and dynamic shading option. Planting deciduous trees on the south side of a structure will provide shade in the summer and allow the sun to penetrate the façade in the winter. Evergreen trees located to a building’s north and northwest will shield structures from wind in colder seasons and keep a space cool during warmer months.

Implementation Models

Building, Energy, and Green Codes

Codes and standards can accelerate adoption of best practice resilience strategies, including effective passive design strategies. Passive design principles have been integrated into many building codes. The International Energy Conservation Code (IECC), for example, sets minimum performance thresholds for insulation levels, fenestration, and air leakage, all of which reflect passive design performance. Some jurisdictions have adopted increasingly ambitious codes that go beyond the IECC approach. These are achieved through state-level stretch codes as well as through the adoption of optional IECC appendices. Massachusetts, for example, incorporated Passive House as an optional compliance path for residential and commercial buildings under the state’s Stretch Code. Washington state, New York state, Denver, and others have taken similar actions to strengthen base requirements compared to model IECC performance levels.

Green codes also promote passive strategies. Green codes are broader in scope and more explicitly oriented toward sustainability compared to building or energy codes. The International Green Construction Code (IgCC), for example, incorporates both mandatory baseline requirements as well as elective options focused on passive solar heating and cooling strategies, natural ventilation, daylighting, and thermal mass.

Spotlight: Connecticut (Climate Zone 5A)

The Draft Connecticut Climate Resilient Energy Code (CT-CRE Code) was published in 2025 as a voluntary stretch building code, intended to enhance the climate resilience of multifamily affordable housing properties.[110] In addition to covering the sizing and installation of energy systems to power essential services during grid outages, the code includes provisions for passive design improvements, recognizing the inherent benefit of energy efficiency and high-performance design. It also sets criteria for where to provide active heating, cooling, and ventilation systems with emergency power and what types of specialized controls are needed. The code was developed by analyzing the feasibility, cost, and impact of proposed measures, considered during both extreme heat and extreme cold scenarios, both of which are experienced in the Connecticut climate. The intent was to realize a positive net present value over the system's life.

Weatherization Programs

Weatherization programs offer support for conducting energy audits, prioritizing measures by cost-effectiveness, and installation of insulation, air sealing, window and door upgrades, heating and cooling system replacements, and health and safety improvements. These programs are often federally funded and administered through state energy offices or local agencies. The US Department of Energy's Weatherization Assistance Program (WAP) funds local weatherization crews who conduct these energy assessments and execute measures to increase the efficiency and safety of eligible homes. The Low Income Home Energy Assistance Program (LIHEAP), administered by the US Department of Health and Human Services (HHS), also provides eligible households with energy assistance, including financial assistance for weatherization. States with relevant programs may allocate 15 percent of their total LIHEAP funds toward weatherization.[111] In addition to WAP and LIHEAP, state utility energy efficiency programs support weatherization. Traditional weatherization programs in cold-climate cities were originally designed around heating.

As summers grow increasingly dangerous, cities and states are beginning to reshape their approaches to weatherization to bolster resilience year-round. However, providing assistance for cooling is still a large gap in many weatherization programs.[112] Currently, more than half of the country provides energy assistance for cooling through LIHEAP.[113] Most states with weatherization programs have allocated 15 percent of their total LIHEAP funds towards weatherization. Out of the states that provide cooling assistance, North Carolina, Hawaii, and Texas have dedicated the largest portions of LIHEAP funds for cooling.

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[110] Connecticut Climate Resilient Energy Code
[111] LIHEAP
[112] The Need to Expand Energy Assistance to Cooling
[113] LIHEAP Benefits Summary

Spotlight: Nebraska (Climate Zones 4-6)

19 percent of Nebraska's LIHEAP funds were utilized for seasonal cooling allocations in 2022. These funds provided financial assistance to eligible households (130 percent Federal Poverty Level and 200 percent Federal Poverty Line for Weatherization assistance) to purchase window air conditioning units or portable air conditioners during the cooling program season, which is June 1–August 31. Financial assistance was also provided for central air conditioning repair and replacement, typically up to $750.

Incentives

To support the adoption of high-performance design and infrastructure strategies that may not yet be cost-effective or mandated by existing codes and regulations, local governments may establish incentive programs. These programs aim to encourage measures that enhance environmental performance, contribute to vibrant and resilient communities, and accelerate progress toward municipal sustainability and climate action goals. Incentives may include rebates or grants to offset upfront costs, as well as other financial or regulatory benefits that facilitate implementation.

Spotlight: Littleton, Colorado (Climate Zone 5A)

The City of Littleton, Colorado has incorporated a sustainability incentive section within its Unified Land Use Code that provides development incentives, such as increased density, building height, lot coverage, and other regulatory flexibilities for projects that adopt selected sustainability practices from a prescribed menu of measures. These incentives are available for developments across zoning districts. For example, projects with a high-reflectivity roof (≥60%) and at least 50% of on-site energy from solar, geothermal, or small wind can qualify for up to a 20% density bonus above the district's gross maximum, provided Code requirements for transitioning and buffering are met.[114]

[114] Littleton, Colorado City Code § 10-1-3.4

New Buildings Institute (NBI) is a nonprofit organization driving better energy performance in buildings. We work collaboratively with industry market players—governments, utilities, energy efficiency advocates and building professionals—to promote advanced design practices, innovative technologies, public policies and programs that improve energy efficiency and reduce carbon emissions. We also develop and offer guidance and tools to support the design and construction of energy efficient buildings. Learn more at newbuildings.org.