Appendix C
Technical Appendix for Hazard-Specific Interventions

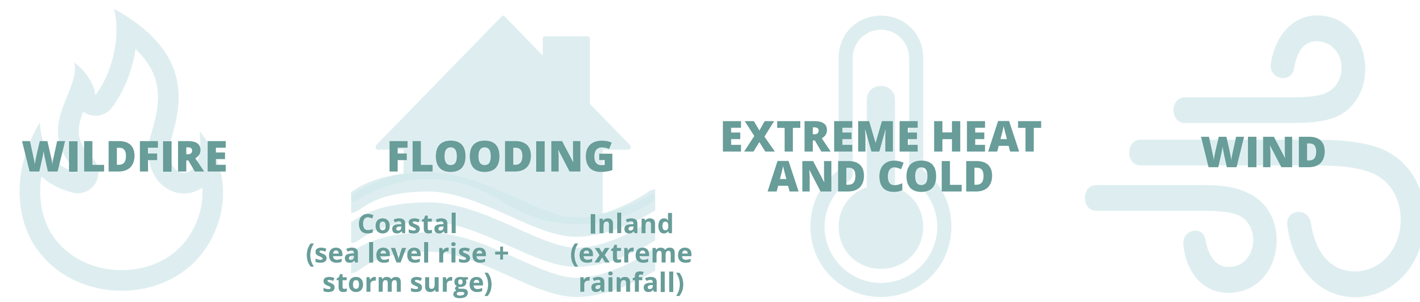
About this appendix

This section is arranged by hazard and focuses on the more technical aspects of the building code. The narratives are organized with housing in mind and according to individual hazards. That said, while the authors recognize many hazards may occur at the same time, that level of complexity is not addressed here.

Building types

- Housing — both single- and multifamily dwellings
- Existing housing stock and new construction

Hazard considerations



Key model codes referenced
International Building Code
International Residential Code
International Fire Code
International Mechanical Code (HVAC — heating, ventilation, air conditioning)
International Plumbing Code (water and wastewater)
International Wildfire Urban Interface Code
International Existing Building Code
International Energy Conservation Code
Uniform Mechanical Code
Uniform Plumbing Code
National Electric Code

Key standards referenced
ACEC 7 (wind)
ACEC 24 (flooding)
ASHRAE 90.1 (heating and cooling considerations)
NFPA (fire safety)

Exhibit 28 Modifications to code requirements for commercial buildings (IBC)

Subject	Code Section	2012	2015	2018	2021
Flood					
Mechanical equipment in manufactured homes	Appendix G	No requirement	Required to be above design flood elevation	No change	No change
Use of alternate flood data	Appendix G	No requirement	No requirement	No requirement	Only if data has been submitted to FEMA and received approval
Floodplain administrator	Appendix G	No definition	No definition	No definition	Defines designated floodplain administrator
Water courses	Appendix G	No requirement	No requirement	Documentation maintenance requirements for officials increased	Change to floodplain administrator responsible for maintaining records
Wind / Hurricane / Tornado					
Storm shelters	423	No change	Adds buildings/ occupancies where required	Adds occupant load provisions	Updates occupancy and occupant load provisions
Building wind resistance	1600	No change	Updated wind speed maps	Additional wind speed maps provided	Updated and simplified wind speed maps
Wind load calculations	1600	No change	Updated calculation methods	No change	Updated calculation methods
Storm shelters	1604	Adds section indicating seismic loads are used regardless of wind loads in some cases	No change	Added detail on shelter design loads	No change
Roofing materials attachment	1500	No change	More stringent requirements	Addresses metal roof shingles	No change
Roofing accessory attachment	1500	Attachment requirements for metal edges	No change	No change	Attachment requirements for gutter systems
Aggregate and ballast	1500	Aggregate/ballast not allowed in some conditions	No change	No change	Aggregate allowed in all conditions with parapets as indicated
Wildland Urban Interface					
Roof covering	1500	Reference to IWUIC with regard to Class of roofing	No change	No change	No change

There are no references to wildfire building code provisions in the IRC and only a minimal reference (see above) in the IBC.

Adoption of additional wildfire resilience considerations happens at the state, county, municipal, or individual levels.

Subject	Code Section	2012	2015	2018	2021
Extreme Temperatures					
Climate zones	301	No change	Tropical zones added	Revised climate zone naming	Adds significant detail for international climate zone determination
Insulation marking	303	No requirement	No requirement	No requirement	Detailed marking requirements or certification required
Building enclosure	402	No change	Significant changes to requirements for walls and openings	Increased insulation for heated slabs, clarifies insulation requirements for various components	Clarifies prescriptive versus performance requirements
Performance testing	402	No requirement	No requirement	No requirement	Building envelope testing requirement added
Equipment sizing	403	No change	No change	More detailed equipment sizing requirements added	No change
Controls	403	Minor changes to mechanical system controls added	Changes to mechanical system controls added	Significant changes to mechanical system controls added	No change
Economizers	403	Requirements for economizers added	Requirements clarified	No change	No change

Exhibit 29 Modifications to code requirements for residential buildings (IRC)

Subject	Code Section	2012	2015	2018	2021
Flood					
Concrete slabs	322	No requirement	No requirement	New requirements for slabs subject to scouring/erosion	No change
Stairs and ramps	322	No requirement	No requirement	New requirements and options to resist or avoid flood loads	No change
Tanks	322	No requirement	New requirements for tank anchoring	No change	No change
Structure	322	No requirement	New requirement in Coastal Zone A for first floor horizontal structure to be 1 foot above the base flood or design flood elevation	No change	No change
Openings	322	No change	Additional details with regard to openings serving areas below design flood elevation	No change	No change

Subject	Code Section	2012	2015	2018	2021
Wind / Hurricane / Tornado					
Windows and sliding doors	609	No change	Allows comparative analysis for different sizes than those tested	No change	No change
Exterior openings with glazing	609	No change	No change	Testing requirements for impact protection	No change
Garage doors	609	No change	No change	No change	Testing requirements for wind pressure
Soffits	704	No change	No change	No change	Requirements for soffit uplift and nailing
Photovoltaic shingles	905	No change	Additional requirements for high wind and wind resistance	No change	No change
Photovoltaic systems	907	No change	New requirements for roof-mounted systems	No change	Consolidated with 609
Photovoltaic panel systems	909	No change	New requirements for roof-mounted systems	No change	Consolidated into 607
Energy Efficiency					
Ducts	1103	No requirement	No requirement	Requirements for ducts buried in ceiling insulation added	No change
Heat recovery	1103	No requirement	No requirement	No requirement	Heat recovery ventilation required in some zones
Reports	1106	No requirement	Compliance reports required for permits and C of O	No change	Added detail to compliance reports requirements
Required energy efficiency options	1108	No change	No change	No change	Additional energy efficiency package options
Solar	Appendix T	No requirement	No requirement	Requirement for solar ready zone added	No change
Extreme Temperatures					
Heat recovery	1103	No requirement	No requirement	No requirement	Heat recovery ventilation required in some zones
Required energy efficiency options	1108	No change	No change	No change	Additional energy efficiency package options

Exhibit 30 **Modifications to code requirements for commercial buildings (IECC)**

Subject	Code Section	2012	2015	2018	2021
Climate zones	301	No change	Tropical zones added	Revised climate zone naming	Adds significant detail for international climate zone determination
Insulation marking	303	No requirement	No requirement	No requirement	Detailed marking requirements or certification required
Skylights and garage doors	303	No requirements	Separated garage door requirements	Refined tables with increased items	No change
Building enclosure	402	No change	Significant changes to requirements for walls and openings.	Increased insulation for heated slabs, clarifies insulation requirements for various components	Clarifies prescriptive versus performance requirements
Combustion air	402	No requirement	Added provisions related to appliance combustion air	Clarified requirements	No change
Performance testing	402	No requirement	No requirement	No requirement	Building envelope testing requirement added
Equipment sizing	403	No change	No change	More detailed equipment sizing requirements added	No change
Equipment fault detection	403	No requirement	No requirement	No requirement	Fault detection requirements added
Controls	403	Minor changes to mechanical system controls added	Changes to mechanical system controls added	Significant changes to mechanical system controls added	No change
Economizers	403	Requirements for economizers added	Requirements clarified	No change	No change
Kitchen exhaust air	403	No requirement	Added requirements for kitchen exhaust	No change	No change
Coolers and freezers	403	No requirement	Requirements for freezers and coolers added	No change	More detailed requirements added
Lighting	405	No change	Significant change to lighting power and lighting control requirements	Added changes to lighting controls and reductions in lighting power allowances	Added changes to lighting controls and reductions in numerous lighting power allowances
Parking garage lighting	405	No requirement	No requirement	No requirement	Added parking garage lighting controls requirements
Exterior lighting	405	No change	No change	Reduction in exterior lighting power allowances and exceptions added	Changes to lighting power calculations

Doug Beckers flickr.com/photos/dougbeckers/3477174493/

Wildfire

Wildfire risk has been increasing steadily over the past few decades. Since 1991, 19 billion-dollar disasters have been directly tied to wildfires.[55] More land is burned by wildfires in the west and southeastern U.S. than in other parts of the country and the states with the highest number of property impacts are shown below in Exhibit 31.[56] The increase in fire risk has been tied to changes in climate, including a shift in the onset of peak wildfire season.[57]

Wildfire impacts also include indirect and cumulative effects. For example, smoke generated by wildfire impacts areas hundreds to thousands of miles away from the site of combustion. Decimated forests cause the underlying land to be more vulnerable to erosion and water quality concerns. Former burn scars can become areas of slope failure. Ash can pollute nearby water sources. These very significant concerns all have implications for buildings and the health and welfare of their occupants. However, building codes focus more narrowly on the direct physical impacts of fires, so our discussions will follow suit.

55 NOAA National Centers for Environmental Information (NCEI), 2022. **U.S. Billion-Dollar Weather and Climate Disasters**.

56 EPA. **Climate Change Indicators: Wildfires**.

57 Ibid.

Exhibit 31 Wildfire Risk Analysis

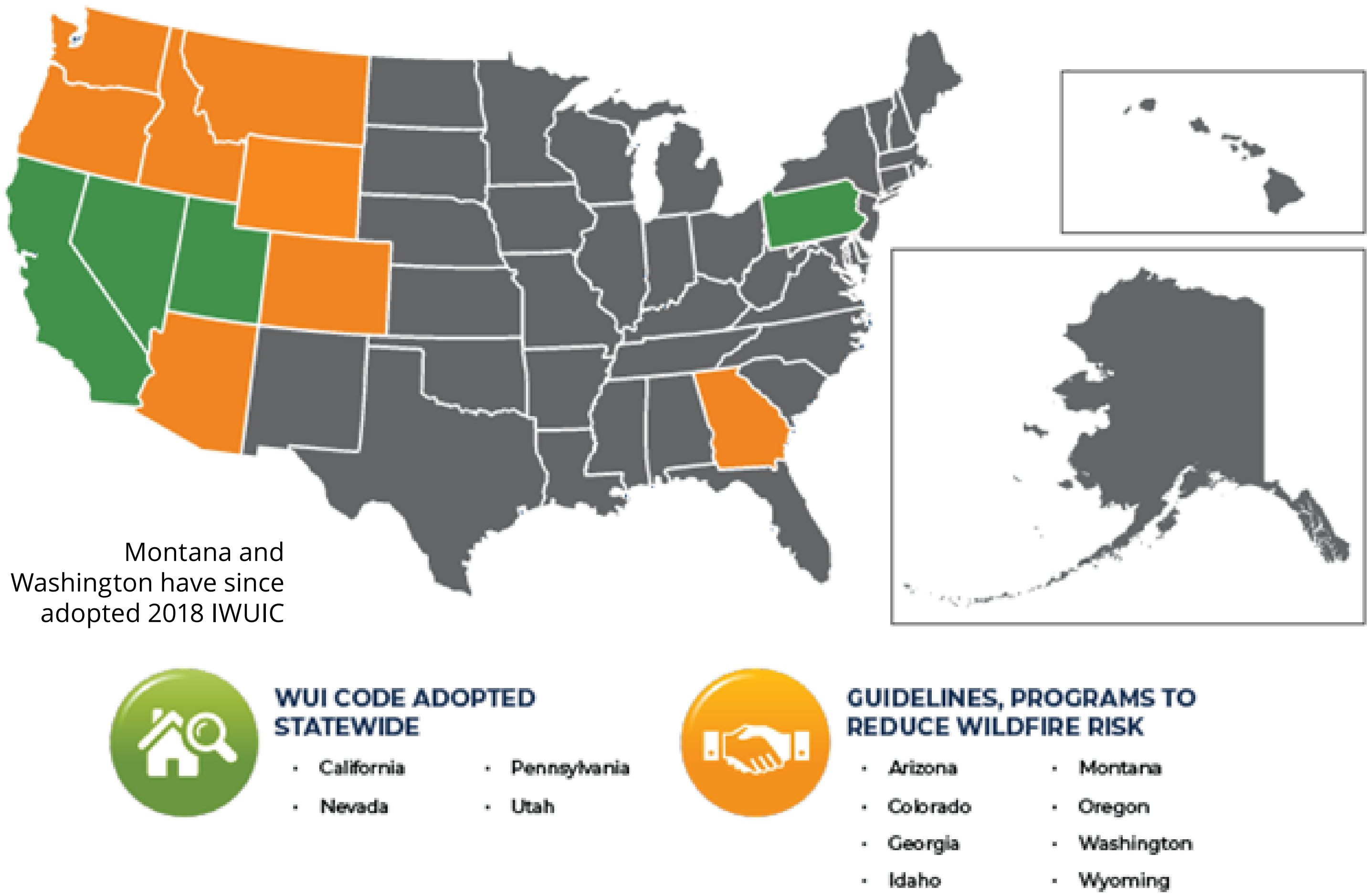
State	Number of properties at risk
California	2,040,600
Texas	717,850
Colorado	373,900
Arizona	242,200
Idaho	175,000
Washington	155,500
Oklahoma	153,400
Oregon	147,500
Montana	137,800
Utah	136,000
New Mexico	131,600
Nevada	67,100
Wyoming	36,800

Source: Verisk. **Wildfire Risk Analysis**.

Current State of Practice for Building Codes and Wildfire

Challenge: Very few states have adopted codes related to wildfire risk. Only 12 states have guidance related to wildfire risk, and of those only four have adopted the WUI code. Traditional IBC and IRC guidance do not adequately address the health and safety implications of wildfire, especially in the face of increasing intensity and spread of that danger.

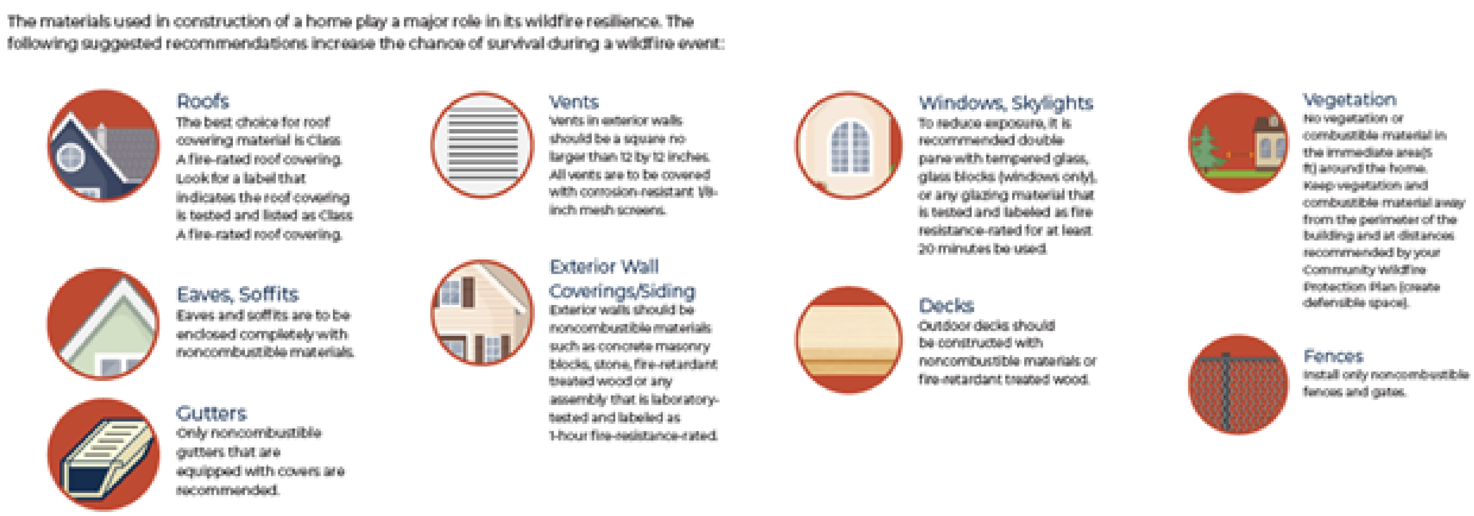
Exhibit 32 Wildfire codes and programs by state



Source: Wildfire Codes & Standards — State-by-State Reference Guide

Solution: It can be challenging to know where to start with respect to wildfire. Luckily, there is a significant body of readily available information that can be tapped. **The work on building design criteria and retrofits is perhaps best known but there are emerging sources of information on land-based interventions such as defensible space and community-based planning** (explained more below). In addition to what is offered in the model code, several individual municipalities have drafted their own standards and ordinances to support wildfire-resistant development that could be leveraged here, as well as more recent work on the cost-benefits of building for wildfire resilience (see Headwater Economics–IBHS study below).

Exhibit 33 Wildfire-resistant building construction



Source: Wildfire Codes & Standards — State-by-State Reference Guide

Challenge: Existing codes may focus more on the building and less on land-based considerations. Resilience to wildfires involves more than just building enhancements; it is also very dependent on the surrounding environment. This includes considering potential fuel sources (e.g., vegetation, other outbuildings) within the building's immediate perimeter, as well as the overall resilience of neighboring structures. Traditionally, codes have largely focused on the building itself. However, with wildfire (and other types of hazards), a community-based approach may be more effective in addressing the risk.

Solution: There has been significant attention paid to **defensible space requirements** in recent years, especially with the increase in intensity and geographic spread of wildfires. Defensible space requirements focus on minimizing the potential fuel sources within the immediate perimeter of a building. It is about creating a buffer around the building to make it less prone to wildfire impacts. California has been a leader in standardizing how these requirements are incorporated into both site development and code requirements, and provides a good starting place for those interested in learning more.

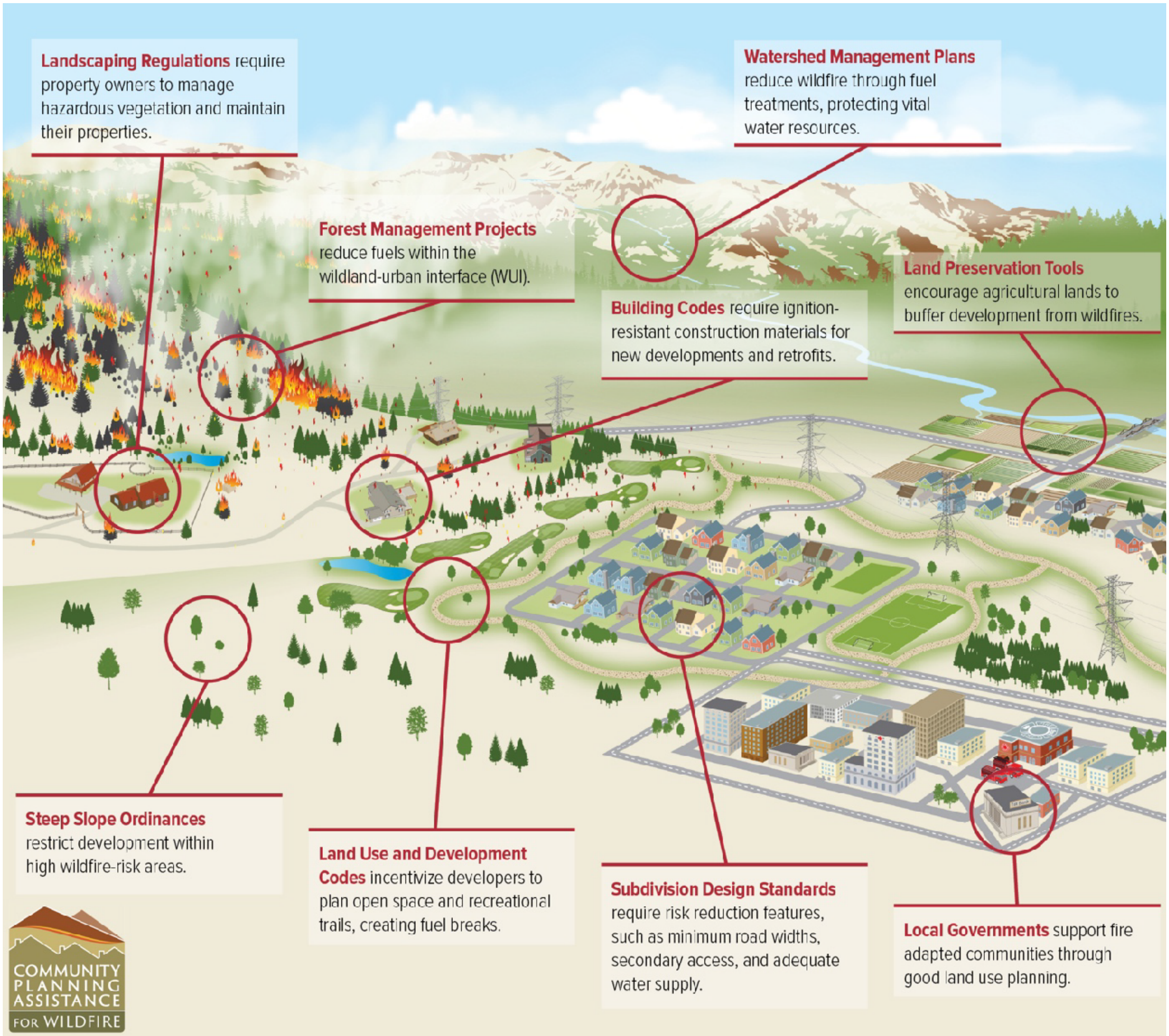
Cal Fire Defensible Space

Zones 1 and 2 currently make up to 100 feet of defensible space required by California law. Assembly Bill 3074, passed into law in 2020, requires a third zone for defensible space. This law requires the Board of Forestry and Fire Protection to develop the regulation for a new ember-resistant zone (Zone 0) within 0-5 feet of the home by January 1, 2023. The intensity of wildfire fuel management varies within the 100-foot perimeter of the home, with more intense fuels' reduction occurring closer to your home. Start at the home and work your way out to 100 feet or to your property line, whichever is closer.

The development of defensible zones has been found to be a useful intervention to slow the spread of wildfire. However, it is important to note that wildfires are not necessarily limited to wildlands and homes tucked into the mountains. The Marshal Fire in Colorado is an example where the fire impacted a traditional suburban neighborhood and was not necessarily the result of inadequate defensible space.

For **community-based wildfire planning** approaches, it may be beneficial to work with the local planning board to create zoning ordinances and overlays (similar to those proposed for flooding) to address the land use and modification opportunities that fall more within the planning realm than the code realm.

Exhibit 34 Land use planning tools to reduce wildfire risk



Source: Community Planning Assistance for Wildfire: Final Recommendations for Gunnison County, CO 2019

Depending on state and local governance structures around building codes (see **Appendix A** for a state-by-state summary), there may be the opportunity to develop **local building codes and/or ordinances that adopt more resilient building standards** with respect to wildfire risk. Chelan, Washington, is an example of a municipality that used this program to build out wildfire protection planning criteria, including a town-based WUI code that includes special building construction regulations, WUI interface requirements and fire protections requirements

Exhibit 35 Ignition-resistant construction from Chelan, Washington, Municipal-level WUI Code

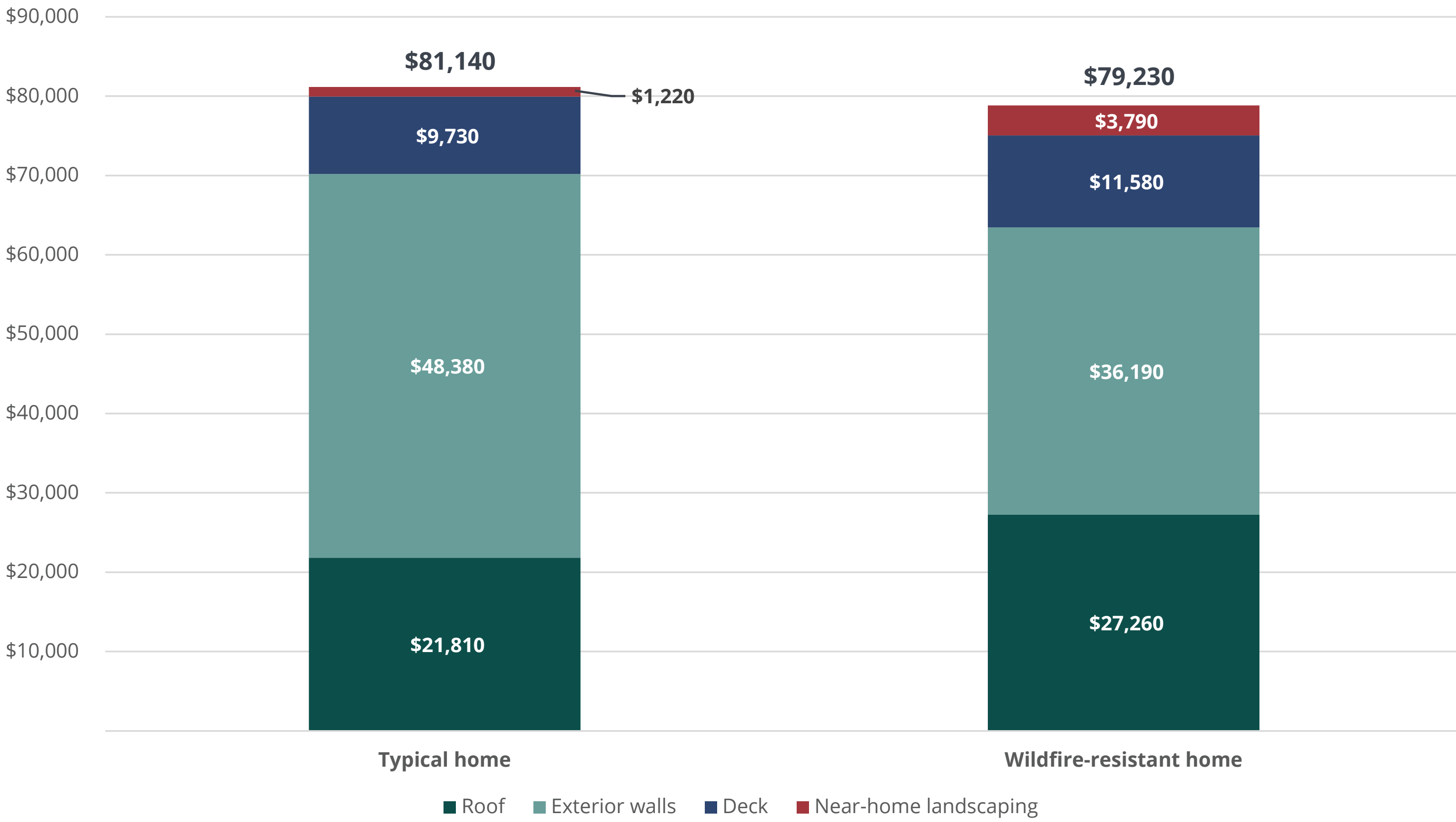
	Fire Hazard Severity					
	Moderate Hazard		**High Hazard**		**Extreme Hazard**	
	Water Supply		**Water Supply**		**Water Supply**	
Defensible Space	Conforming	Nonconforming	Conforming	Nonconforming	Conforming	Nonconforming
Nonconforming	IR 2	IR 1	IR 1	IR 1 N.C.	IR 1 N.C.	Not permitted
Conforming	IR 3	IR 2	IR 2	IR 1	IR 1	IR 1 N.C.
1.5 x Conforming	Not required	IR 3	IR 3	IR 2	IR 2	IR 1

Source: City of Chelan. **Chelan Municipal Code**.

Challenge: There is a general perception that building to a more resilient standard will involve more costly solutions. This is a particularly difficult assertion to test since the data are hard to collect (there is no centralized or standardized reporting platform for this information), there are few resources that have been invested in underwriting these types of studies, and those studies that have been conducted may not be well-socialized across the larger industry and/or within the public realm. With a readily available source of peer-reviewed work, volunteer-led planning boards do not have the capacity to challenge this perception. Likewise, without at readily-available set of design and construction codes (or guidance), developers and contractors are not likely to take the risk of doing things differently.

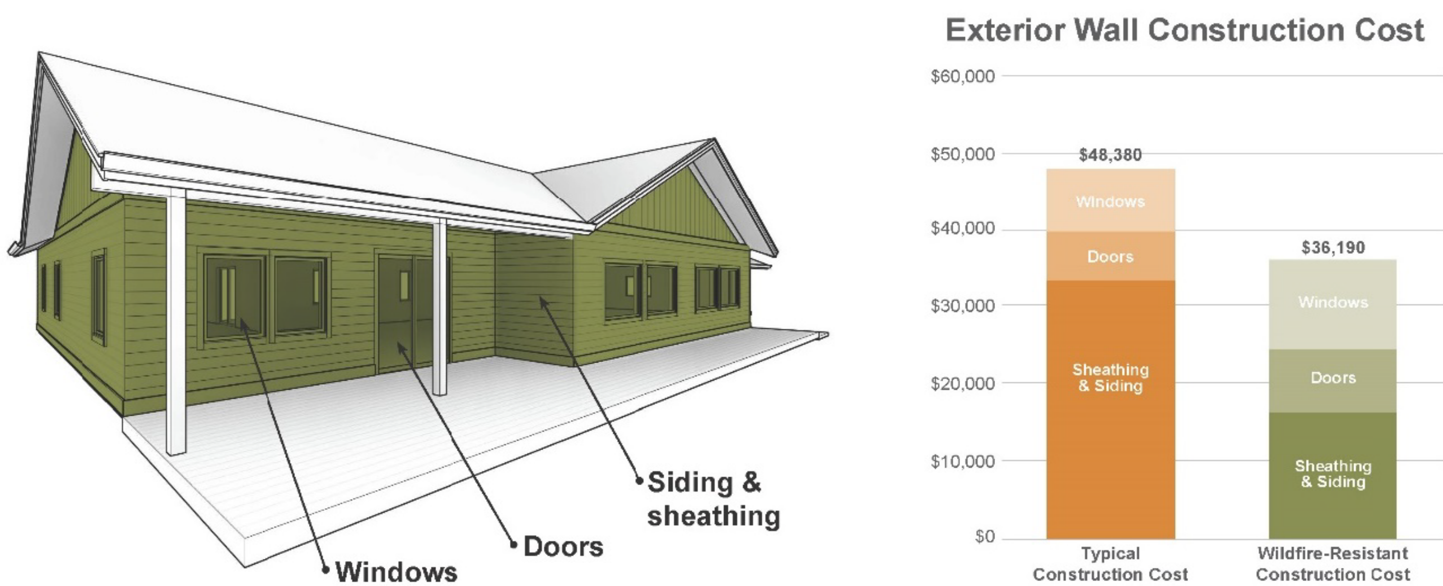
Solution: There needs to be a concerted effort to test the validity of this perception and to provide **cost–benefit analysis of more resilient building codes**. A recent **research effort** between Headwater Economics and IBHS revealed that with wildfire construction, it can actually be *less* expensive to build to resilient standards than traditional builds. The results of that work are summarized in a readily accessible format and with adequate detail to support decision-makers as they consider whether or not to adopt more stringent standards than what may be available in the base model codes. This represents the type of work needed more widely throughout the industry, across the various hazards.

Exhibit 36 New construction costs by component in typical home and wildfire-resistant home



Source: Headwaters Economics. **Building a Wildfire-Resistant Home: Codes and Costs**.

Exhibit 37 Exterior walls subcomponents and new construction cost



Source: Headwaters Economics. **Building a Wildfire-Resistant Home: Codes and Costs**.

Detailed code considerations

In states or municipalities that have adopted the International Fire Code (IFC 2021) and the International Building Code (IBC 2021) but not the International Wildland Urban Interface Code (IWUIC 2021), the jurisdictions may have inadequate protection from wildland fire impacts. In the few jurisdictions that have adopted the International Wildland Urban Interface Code (IWUIC 2021) the options available to the authorities are much greater.

ITEMS ADDRESSED BY THE IFC AND IBC:

- Combustibility of materials used for roof covering (IBC)
- Vegetative fuels adjacent to the structure (IFC)

ITEMS ADDRESSED BY THE IWUIC:

- Classification of wildland/urban interface areas within jurisdiction boundaries
- Requirement for a Fire Protection Plan
- Firefighting water supply
- Emergency services access to the site
- Structure construction materials and arrangement based on fire hazard severity
- Automatic sprinkler requirements based on fire hazard severity
- Control of nearby combustible materials and vegetation
- Maintenance schedule for continued mitigation
- Allowable roofing materials for roofing replacement

Appendices (if adopted) contain detailed requirements related to several of the items listed above.

MITIGATION MEASURES IN IBC, IFC, AND IWUIC INCLUDE THE FOLLOWING ITEMS:

1. Driveways are required where the distance from a fire apparatus access road is greater than 150 feet to an exterior wall of the building. The driveway is required to have a minimum unobstructed height of 13 feet, be a minimum of 12 feet wide and have a turnaround if it is greater than 150 feet long. Turnouts are required if it is longer than 200 feet and less than 20 feet in width. The turnaround shall have a minimum outside turning radii of 45 feet and a minimum inside turning radii of 30 feet.
2. To qualify as an apparatus access road, it must be a minimum of 20 feet wide, have 13 feet 6 inches of clear height, be designed to accommodate the loads, slopes and turning radii for the apparatus used by the jurisdiction in which it is located.
3. An approved water source capable of supplying the required fire flow for fire protection shall be provided within 1,000 feet of all buildings, or portions of buildings. Accessory buildings less than 600 square feet are exempted. The volume requirement is based on building size, construction type, separation, and the presence of automatic sprinkler protection throughout. For example, fully sprinklered, one- and two-family dwellings under 3,600 square feet in total area are required to provide 15,000 gallons of stored water available at 500 gpm. There are numerous means to provide the storage subject to the approval of the authorities (reservoirs, pressure tanks, elevated tanks, man-made ponds, etc.).
4. Ignition resistant construction is required based on the fire hazard severity, the defensible space, and the water supply to the site. There are three levels of fire hazard severity and defensible space and water

supply are either conforming or nonconforming. Different levels of ignition resistant construction include items such as specific classes of roofing material, fire-treated and non-combustible material requirements, and fire rated construction among others.

5 Replacement roofing is required to meet current requirements when 25% or more of the roof covering is replaced in a 12-month period. This requirement only applies to the area of roofing being replaced.

6 An automatic sprinkler system is required in all occupancies in new buildings required to meet the Class 1 ignition-resistant construction provisions.

7 A defensible space from 30 to 100 feet from buildings shall be provided based on the hazard rating of the wildland-urban interface area. Trees are allowed within the defensible space as long as they are 10 feet from buildings, other trees, overhead electrical facilities, chimneys, and unmodified fuels and maintained at that distance. Non-fire-resistant vegetation in the defensible space shall be significantly reduced or replaced with vegetation of a more fire-resistant variety.

8 Chimneys serving fireplaces, barbecues, incinerators, or decorative heating appliances shall be provided with spark arrestors of 12 gage wire with openings not exceeding ½ inch.

9 In states or municipalities that have adopted NFPA 1 (2021 and several previous editions) the jurisdiction can identify areas to be classified as a wildland/urban interface. In these areas the jurisdiction can require a wildland fire hazard assessment. The assessment would include the relative risk, the extent of wildland fire hazard, and applicable mitigation measures.

ITEMS ADDRESSED BY THE ASSESSMENT WOULD INCLUDE:

- Location of structure geographically
- Weather conditions at various times of the year
- Other exposing/exposed structures
- Combustibility of materials used in structure
- Vegetative fuels adjacent to the structure
- Vehicles or fixed or mobile equipment that may present an ignition source
- Other sources of fuel, fire spread or ignition that may impact the structure

The assessment can then be used to determine which mitigation measures are required. These may include:

- Ignition source reduction
- Modification of structure construction elements (Requires compliance with NFPA 1140[58])
- Removal or control of fuel sources (Requires compliance with NFPA 1140[59])
- Maintenance schedule for continued mitigation
- Emergency services access to the site
- Firefighting water supply

58 NFPA 1140 - Standard for Wildland Fire Protection

59 NFPA 1140 - Standard for Wildland Fire Protection

MITIGATION MEASURES IN NFPA 1 AND NFPA 1140 INCLUDE THE FOLLOWING ITEMS:

1. Ignition sources, such as smoking materials, may only be used within the structure or in areas designated by the authorities. Outdoor fireplaces, permanent barbecues, and grills shall not be built, installed, or maintained in hazardous fire areas without prior approval of the authorities. Openings in these devices shall have spark arrestors, screens, or doors. Fireplace and wood stove chimneys and flues shall be provided with spark arrestors with openings not exceeding ½ inch. Fuel powered model plans, rockets or balloons may not be used in hazardous areas. Lighted and smoldering materials associated with bee keeping are not allowed unless permitted by authorities.
2. Emergency services are required to have apparatus access to building sites via a fire road or similar path to within 50 feet of a building entrance. The distance for sprinklered one- and two-family dwellings and townhouses may be increased to 150 feet. This requirement may be modified by the authorities for existing one- and two-family dwellings and new one- and two-family dwelling protected by an automatic sprinkler system. The requirement for private garages, carports, agricultural buildings, and detached buildings having and area of 400 square feet or less may also be modified.
3. The access road shall be extended to within 150 feet of all portions of the exterior building wall or 450 feet if the building is provided with automatic sprinklers throughout.
4. An approved water supply capable of supplying the required fire flow for fire protection shall be provided to all buildings, or portions of buildings constructed or moved. The fire flow requirement is based on building size, construction type, separation, and the presence of automatic sprinkler protection throughout. For example, fully sprinklered, one- and two-family dwellings under 5,000 square feet in total area are required to provide 15,000 gallons of stored water for fire flow at 500 gpm. There are numerous means to provide the fire flow subject to the approval of the authorities (reservoirs, pressure tanks, elevated tanks, fire department tanker shuttles, etc.).
5. Combustibles within 30 feet of the primary structure or the distance determined in the fire hazard assessment shall be removed.
6. Exterior walls shall be sided with non-combustible material, ignition resistant material or fire retardant treated material, or have a one-hour fire rating. The underside of overhanging buildings and structural elements shall be constructed of non-combustible material, ignition resistant material, heavy timber, or fire retardant treated material or have a one-hour fire rating. Overhanging projections shall be constructed of non-combustible material, ignition resistant material, heavy timber, or fire retardant treated material.
7. Roof coverings rated as Class A shall be used. The roof coverings shall be tested with all of the assembly components of the as-built condition.
8. Exterior glazing shall be tempered glass, multilayered glazed panels, glass block or have a fire resistance rating of not less than 20 minutes with non-combustible screening (if provided). Doors shall be 1-3/4-inch solid code wood, of non-combustible materials, or have a fire rating of not less than 20 minutes.
9. Roof gutters and downspouts shall be of noncombustible material and covered with a noncombustible means to prevent debris accumulation.
10. Accessory structures shall be located a minimum of 30 feet from the primary structure. An alternative is to meet all the requirements for the primary structure.

Oliver Rich flickr.com/photos/casualcapture/8135798807

Flooding — Coastal and Inland

Flooding has significant impacts to buildings, their occupant,s and the community as a whole. Flooding can occur in coastal areas as a result of storm surge and wave run-up, as well as the slower more gradual impacts of sea level rise. Coastal flooding also introduces salinity into systems which can lead to extensive corrosion of concrete and metal materials. Inland flooding is often the result of intense and/or long-duration precipitation events which ultimately overwhelm either the natural systems (e.g., overbanking of streams and rivers) and/or human-made systems (e.g., storm drains, stormwater systems, holding ponds, levee systems).

As with other extreme weather-events, there has been a steady increase in the number of billion-dollar disasters associated with both types of flooding events. There have been recorded increases in extreme precipitation events and worsening of hurricane storm surge flooding as a result of sea level rise.[60] The majority of the existing housing stock was not designed to account for these changes which is reflected in the increasing costs associated with these types of events (same reference as above). Adjusting building codes to address these hazards in new construction is one way to incorporate greater resilience into housing, and it also provides a

60 Smith, A.B., 2022. **2021 U.S. billion-dollar weather and climate disasters in historical context**.

guide to improved standards that could be referenced in upgrading existing building stock — either proactively or building back following an event.

Current State of Practice for Building Codes and Flooding

Challenge: The code often references outdated, historical data to inform design. Currently, the code references historical climate data to inform the extent and depth of flooding, as well as the calculations used by engineers to size pipes and catchment areas for that flooding. It can also focus more on averages and less so on extreme events. Current models often underestimate the intensity of rain events, especially with respect to climate change.

Solution: Using future climate projection data in designs will accommodate how precipitation and flooding patterns may shift over the expected life cycle of the asset. This can be calculated both for riverine flows and surface flows. If there is not ready access to engineering data or mapping, online, open-source mapping can provide a useful first order proxy.

Where to find climate projection data:

- **Precipitation shifts**
- **Mapped extents of inland and coastal flooding**
- **Mapped extents of coastal flooding**

Challenge: Fire safety codes can prohibit the installation of fuels on top of the roof. This can be an issue if back-up generators and fuel tanks are located in areas of projected flooding.

Solution: Above-ground tanks can be elevated on foundations designed to resist the forces associated with flooding. **Installing tanks within vaults** with access openings above the design flood elevation is another option. In coastal high hazard areas and coastal A zones, the only option is to locate the tank above the design flood elevation on a foundation designed to resist flood loads, wave action and potentially impact from floating debris.

For **below-ground tanks, flood related loads are required to consider the potential eroded ground elevation.** Below-ground tanks are not allowed to be located under elevated structures or attached to structures at elevations below the design flood elevation.

When determining the forces on tanks for the design of foundations and the tanks, the potential flood related forces acting on tanks needs to be increased by 50% for both below ground and above ground tanks.

Challenge: Nature-based solutions are less common than more traditional, engineering solutions. Owners, developers, and contractors can be hesitant to try something “new” or use technologies with fewer case studies, lifecycle analyses, and standardized performance metrics. Alternate means of compliance could also require approval from the authorities or a variance from an appeal board.

Solution: While nature-based solutions have received less industry attention than traditional interventions, there has been a significant effort to reverse that trend over the past two decades. Today, a robust archive of peer-reviewed industry standards exists that can be leveraged with deep practitioner expertise to further explore these solutions. A good place to start is **Building Community Resilience with Nature-Based Solutions**.[61]

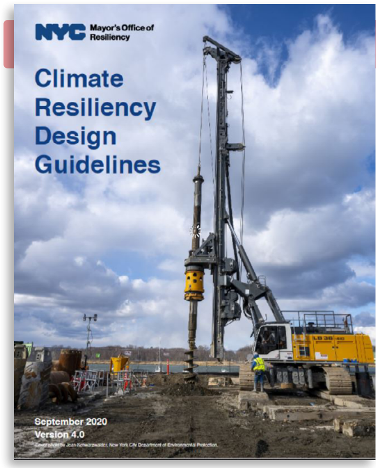
Challenge: A strict reading of ADA and egress codes could restrict the use of perimeter flood barriers. This could be a challenge as permanent flood barriers or elevation of a structure could prove too costly for the owner.

Solution: Accessibility codes do not apply to one- and two-family dwellings. For other buildings, accommodations can be provided to make travel over the barriers accessible or delay installation of gates in the barrier until egress is completed. Some alternatives may require approval by the authorities.

Challenge: Building codes focus on the particular asset when a community-based approach may be more effective and economical in addressing flood risk. The root cause of flooding often extends beyond the asset itself and may be best addressed at the watershed level or the infrastructure system (e.g., storm drain system, extensive use of non-permeable surfaces such as paved roadways, ditches, parking lots, dam and levee systems, etc.).

Solution: It may be beneficial to work in parallel with the local planning board **to create zoning ordinances and overlays** to address the land use and modification opportunities that fall more within the planning realm than the code realm. Likewise, if the root cause of the flooding is linked to **inadequacies in the design of the drainage and flood control systems**, then the efforts to address that will be **governed by industry-specific codes and regulations**, including the general welfare of the community and end users.

61 FEMA, 2021. **Building Community Resilience with Nature-Based Solutions: A Guide for Local Communities**.

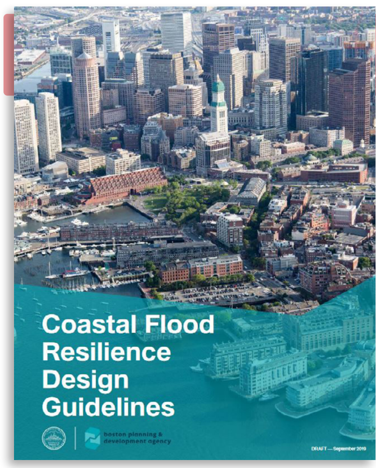


NYC'S RESILIENCE PROGRAM

New York City has taken a joint approach to tackling climate change, leveraging both the existing codes structure as well as planning and land-use related interventions.

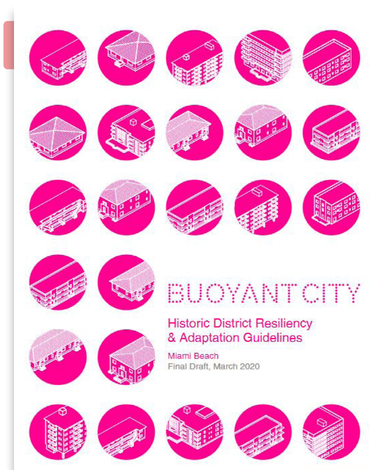
These **Climate Resilience Design Guidelines** dictate how climate change will be incorporated into city-funded capital projects. It requires that resiliency report cards be issued for all city projects and that those projects be designed to meet the design criteria outlined in the standards.

The companion piece, **Zoning for Coastal Flood Resiliency,** examines the role that land use and planning can achieve in meeting resilience objectives and proposes complementary solutions to those proposed at the building level.



BOSTON'S COASTAL FLOOD RESILIENCE DESIGN GUIDELINES AND FLOOD RESILIENCE OVERLAY DISTRICT

Boston has adopted a similar approach to NYC in adopting both **building-specific guidance** for new construction and building in areas of the city which will be impacted by sea level rise and coastal storms, and combining those efforts with the recently adopted **Coastal Flood Resilience Overlay District** that uses climate projections to inform zoning decisions related to proposed use and dimensional aspects of buildings.



MIAMI BEACH — BUOYANT CITY

Buoyant City provides a comprehensive look, combining both land use and building code criteria, to address resilience across a variety of lenses, including within building typologies, at the level of landscapes and streetscapes, accounting for historic preservation needs and providing guidance by type and strategy.

Detailed code considerations

In states or municipalities that have adopted the International Residential Code (IRC 2021) the jurisdictions have significant input into elements associated with flooding.

ITEMS ADDRESSED BY THE IRC:

- Limits authority's ability to grant modifications to requirements
- Require use of flood hazard maps or to work with official to determine design flood elevations
- Documentation of flood related areas and heights on site plans and building plans (lowest floor or lowest floor structure where wave action is possible)
- Addresses both new buildings and substantially renovated buildings (damaged or improved)
- Reference to ASCE 24, Flood Resistant Design and Construction for buildings in floodways
- Allows conformance to ASCE 24 as an alternative to meeting IRC requirements
- Requirements for mechanical, electrical and plumbing systems related to location or protection.
- Detailed requirements for design of buildings in high-hazard areas, Coastal A zones and flood hazard areas
- Manufactured home's heights, foundations, and anchorage
- Use limitations for spaces that are below or at base flood elevation
- Floodway analysis to demonstrate the work will not increase design flood elevations > 1 foot
- Flood hazard documentation as to how the buildings are designed to resist flooding
- Requirements for flood-damage-resistant-materials for interior finishes and construction materials
- Existing building provisions (Appendix AJ, if adopted) refer to the provisions in the base code.

In states or municipalities that have adopted the International Building Code (IBC 2021) the jurisdictions have significant input into elements associated with flooding.

ITEMS ADDRESSED BY THE IBC:

- Limits authority's ability to grant modifications to requirements
- Documentation of flood related areas and heights on site plans and building plans (lowest floor or lowest floor structure)
- Flood structural loads for structures in flood hazard areas, coastal high hazard areas, and coastal A zones (IBC)
- Addresses both new buildings and substantially renovated buildings (damaged or improved)
- Reference to ASCE 24, Flood Resistant Design and Construction
- Reference to ASCE 7, Minimum Design Loads for Buildings and Other Structures
- Require use of flood hazard maps or conduct study to establish design flood elevations
- Conduct floodway analysis to demonstrate the work will not increase design flood elevations > 1 foot
- Provide flood hazard documentation as to how the buildings are designed to resist flooding
- Requirements for flood-damage-resistant-materials for interior finishes and construction materials

- Protection requirements for fire pumps
- Limitations on grading and fill
- Locations for emergency power equipment
- References to ASME A17.1, Safety Code for Elevators and Escalators, for vertical transportation equipment

Appendix G (if adopted) contains management and administrative requirements in order to meet the National Flood Insurance Program.

Appendix J (if adopted) contains requirements associated with grading of sites.

The International Existing Building Code (IEBC) requires conformance to the base code requirements when the work qualifies as substantial improvement. The definition of substantial improvement is: For the purpose of determining compliance with the flood provisions of this code, any repair, alteration, addition or improvement of a building or structure, the cost of which equals or exceeds 50 percent of the market value of the structure, before the improvement or repair is started. If the structure has sustained substantial damage, any repairs are considered substantial improvement regardless of the actual repair work performed.

Design and construction requirements

ASCE 24 Indicates new construction and substantial improvements need to meet the following requirements in flood hazard areas. Dry floodproofing is not allowed in residential structures, residential portions of mixed-use structures or in Coastal High Hazard Areas and Coastal A Zones.

1. The lowest occupied floor is required to be elevated to or above the design flood elevation. Parking areas or storage spaces are not considered occupied floors; however, these spaces need to meet specific requirements with regard to wet floodproofing.
2. Foundations, piers, posts, columns, and piles need to be designed to resist hydrodynamic pressures, hydrostatic pressures, buoyancy, debris impact, and other loads such as soil and wind. Required foundation element's depth and arrangement is a function of the geotechnical conditions on the site.
3. If used, fill must be designed to be stable during all phases of flooding. This includes rapid rise, rapid drawdown, prolonged inundation, erosion and scouring.
4. The structure needs to be anchored and connected to the foundation elements to resist the effects of vertical loads, including uplift, and the aforementioned lateral loads.
5. Enclosed areas that are used for parking, building access, or storage shall be provided with engineered or prescriptive openings to allow flood waters to automatically enter and exit the structure. Openings are required in foundations and in breakaway walls.
6. Structures may not be built in areas subject to high velocity flows, ice jams and debris, flash flooding, mudslides, erosion, or at an alluvial fan apex, unless protective works are provided. Very specific requirements apply to Coastal High Hazard Areas and Coastal A Zones. These requirements address the following items.
   - a Siting above the mean high tide
   - b Elevation of the lowest structural floor member above the design flood elevation

  c. Specific deep foundation types where erodible soils are present
  d. Breakaway walls must fail without causing damage to the structure.

7. Special requirements for materials used in construction based on flood design class.
8. Interior and exterior finish and trim materials shall be flood damage resistant.
9. Electric panelboards, disconnect switches and circuit breakers shall be located above the required flood elevation based on building class. Electric conduits and cables below the design flood elevation are required to be waterproofed or conform to the provisions in the electric code for wet locations. A minimum number of 120-volt circuits may be located below the elevation provided they are designed for wet locations and on ground-fault circuit-interrupters breakers.
10. Plumbing systems components that are below the design flood elevation are required to have backwater valves or backflow prevention devices. Underground piping is required to be buried to a depth sufficient to prevent loss due to flooding and erosion. Above ground piping shall be anchored and protected to withstand the effects of buoyancy, hydrodynamic forces, and debris impact.
11. Mechanical system fuel supply lines require a float operated; automatic shutoff valve arranged to operate when floodwaters exceed the design flood elevation (DFE). Ductwork either needs to be located above the DFE or designed to resist flood related loads and be waterproofed to prevent water from entering the ductwork. Air intake and exhaust openings are required to be above the design flood elevation. Tanks associated with the equipment are required to be designed to resist flood induced loads such as buoyancy and debris impact or located above the design flood elevation. All tank openings are required to be either above the design flood elevation or designed to prevent the release of contents or the infiltration of flood waters into the tank.
12. Elevators are allowed, but the machine rooms need to be located above the design flood elevation. The equipment below the DFE need to be protected against flood damage. Controls need to be provided to prevent the elevator from descending below the DFE during a flood. The elevator shaft walls do not need to have flood openings nor are they required to be breakaway.

Wind — Extreme Events

Winds associated with severe thunderstorms account for 50 percent of all damage in severe weather-related events in the US, and are more common than tornadoes.[62] Damaging winds have speeds that exceed 50 mph and may present as downdrafts, macrobursts or microbursts, derechos, and gust fronts.[63] The term "straight-line winds" is used to differentiate these types of winds from those that are rotational and could spawn tornadoes.

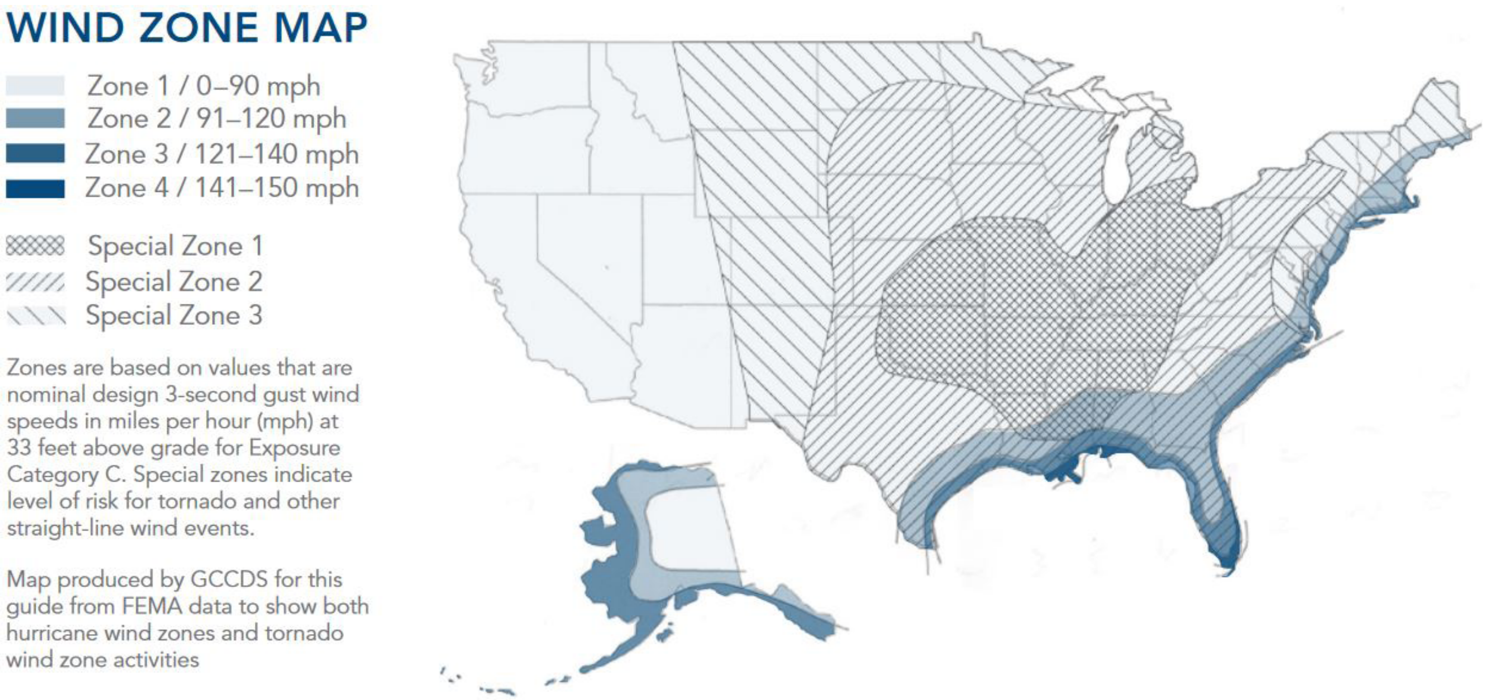
Buildings have been constructed to take wind loads into account. Roofs are especially prone to damage during these events, and wind-borne debris is a concern for all aspects of the house. In areas of tornadoes, storm shelters are common places of refuge, although they may not be specifically required by code.

62 NOAA National Severe Storms Laboratory. **Severe Weather 101: Damaging Wind Basics**.

63 NOAA National Severe Storms Laboratory. **Severe Weather 101: Damaging Wind Basics — Types**

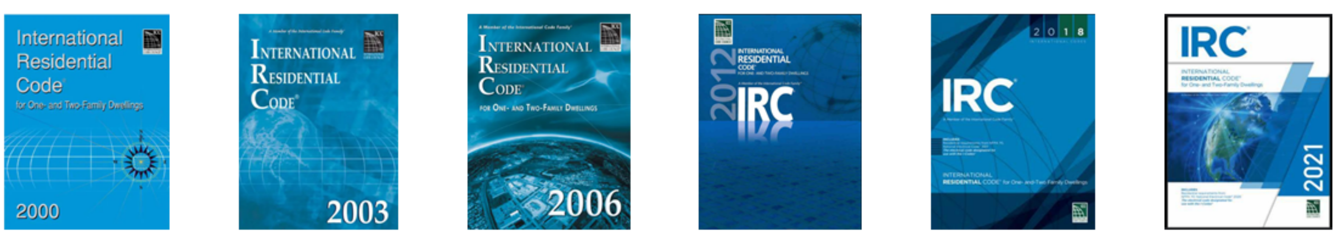
Exhibit 38 Wind zone map

Nearly 30 million US households are located in high wind zones where there is an expected three second gust of 100 mph or greater



Source: FLASH. **Resilient Design Guide**.

Exhibit 39 Evolution of IRC wind requirements (coastal wind)



2000

National wind standard including limits for wind design and protecting openings

IBC and IRC reference 7-98 wind maps

2003

Required wind testing for asphalt shingles

2006

Impact protection for windows and glass doors in wind-borne debris regions

Required wind pressure rating of garage doors

Geographic region of required wind design expanded in Gulf and Atlantic coastal areas

IBC requires opening protection in Wind-Borne Debris Region

2012

Enhanced roof underlayment requirements to minimize water intrusion if roof covering lost or damaged

IBC and IRC reference ASCE 7-10 updated wind maps

2018

Update in wind standard to significantly improve the connection of plywood/OSB roof decks to roof framing

I-Codes reference ASCE 7-16 with updated wind maps and updated roof design loads

2021

Significant improvements in roof overhand soffit construction to limit damage and water intrusion

In some areas, roofs required to have a sealed roof deck to minimize water intrusion

Source: IBHS (unpublished data) and FEMA (2020)

Current State of Practice for Building Codes and Wind

Exhibit 40 Evolution of IRC requirements (inland wind)

2000
Conventional construction methods can only be used in certain non-high wind areas

2006
Required wind pressure rating of garage doors

2009
Significant improvements to wall bracing methods

When installed, storm shelter has been designed and tested in accordance with ICC 500

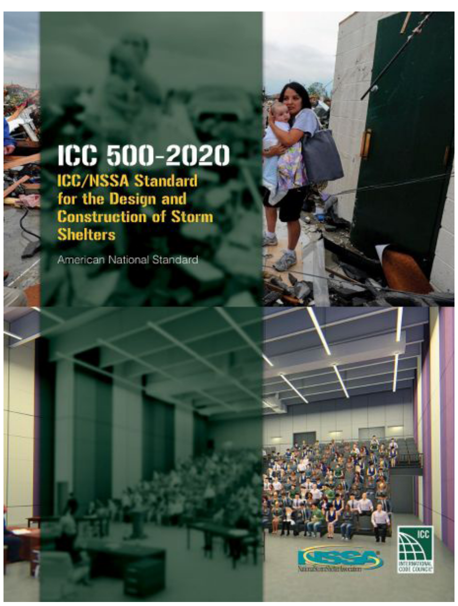
2012
Improved requirements for connecting roofs to walls

2021
Improvements to minimal fastening requirements for wood frame construction including the roof deck

Source: IBHS (unpublished data) and FEMA (2020)

Challenges: How do I determine expected wind speeds in my area? It can be difficult to know what sources to use and which ones have relevance for building code considerations.

Solution: The American Society of Civil Engineers (ASCE) is the professional organization that issues the standards for wind code design that are incorporate by reference into building codes used in the United States. The organization offers **an online tool** that lets individuals search for wind code requirements based on address.



Challenges: What resources exist for tornado resilient building codes? Storm shelters are a viable solution for people living in tornado-prone areas. However, the inability to predict a tornado's geographic impact and intensity can make it difficult to construct a business case based on traditional metrics. There is ongoing controversy about how cost-benefit rations are calculated for tornado-based building code interventions and from whose perspective.[64]

Solution: Existing standards for storm shelters can be referenced for individuals and communities that are interested in working beyond required code standards for both new construction and existing buildings (**ICC/NSSA 500 Standard for the Design and Construction of Storm Shelters**). Some states, like Alabama, have mandated the 2014 ICC/NSSA-500 Standard for

64 As an example, see **How the Building Industry Blocked Better Tornado Safeguards**, *New York Times*.

certain building types and uses, and could be a good model for other states and communities looking to do the same.

Challenge: What industry standards exist for wind resilience? I live in a wind-prone area and would like to invest in resilience but am unsure what standards exist for wind-resilience, are they for new construction only, if there are opportunities for retrofits and whether I can afford it.

Solution: For those entities looking to build beyond minimal code requirements, there are voluntary-based programs which can be used to inform design and construction criteria. One example is the Fortified Home program led by the IBHS and developed in partnership with leading industry experts. **Fortified Wind is a nationally recognized standard** that requires that the roofs be structurally tied to the building in ways that minimize their likelihood of being lifted off and damaged during significant wind events.

The construction method was developed to address some of the key vulnerabilities in homes that made them less able to withstand wind damage from hurricanes, tornadoes and other severe storm events. The standard includes "beyond code" interventions that will greatly reduce enhance a structure's overall resilience to these events, with a focus on minimizing overall damage in order to reduce (or avoid) post-event repairs, relocations or interruptions to daily living. An easy-to-use **website** (https://fortifiedhome.org/) allows interested parties to learn more about the program, find qualified contractors in their area and an easily navigable roadmap about installing Fortified products following an event.

The North Carolina Insurance Underwriting Association (NCUIA) actually provides grants to eligible policy-holders to install Fortified Roofs through their **Strengthen Your Roof** program (https://strengthenyourroof.com/). NCUIA sets aside $15 million a year to underwrite the program and has recently started to offer similar incentives to inland residents.

Smart Home America has taken Fortified (enhanced resilience) guidance and turned it into readily-usable standards in Alabama and Louisiana. The organization also offers grants of up to $10,000 to all Alabama residents whose primary residence is in Alabama. They also provide information as to how individuals can qualify for additional tax and insurance incentives across not only Alabama, but including Connecticut, Florida, Georgia, Louisiana, Maryland, Mississippi, New Jersey, New York, North Carolina, Oklahoma, Rhode Island, South Carolina, and Texas.[65]

Detailed code considerations

In states or municipalities that have adopted the International Residential Code (IRC 2021) the jurisdictions have moderate input into elements associated with wind.

ITEMS ADDRESSED BY THE IRC:

- Where windborne debris protection is required
- Requirements for storm shelter information on documents submitted for permit

65 Smart Home America. **List of Mitigation Insurance Discounts and Tax Savings**.

- Protection of openings by requiring assemblies to pass missile tests in windborne debris regions
- Requirements for alternate protection using wood panels
- Roofing materials designed to resist high wind forces
- Roofing attachment requirements for high wind areas
- Design of structure to resist high wind forces (wall construction, anchorage details, etc.
- Reference to ICC 500, ICC/NSSA, 2020, Standard for the Design and Construction of Storm Shelters
- References to several standards and the IBC for high wind area design options

Windborne debris protection is required in areas where the site in a hurricane prone region and is within 1 mile of the coastal mean high-water line and the ultimate design wind speed is 130 mph or greater or in areas where an Exposure D condition[66] exists upwind at the water line and the ultimate design wind speed is 140 mph or greater: or Hawaii. Where windborne debris protection is required, glazed openings are required to meet the large missile test of ASTM E1886 and ASTM E1996 (as modified by IRC). As an alternative, wood panels 7/16 inch thick and less than an 8-foot span are permitted. Specific attachment requirements apply.

Special requirements apply to the design of buildings where the ultimate design wind speed exceeds 140 mph and the building is located in a special wind region as determined by the jurisdiction. The requirements apply to items such as attachment of the structure to the foundation, attachment of the roof to the walls, connections of the roof system members etc.

The designer has the option of designing to one of several codes/standards as follows.

1. AWC Wood Frame Construction Manual (WFCM)
2. ICC Standard for Residential Construction in High-Wind Regions (ICC 600)
3. ASCE Minimum Design Loads for Buildings and Other Structures (ASCE 7)
4. AISI Standard for Cold-Formed Steel Framing—Prescriptive Method for One- and Two-Family Dwellings (AISI S230)
5. International Building Code

In states or municipalities that have adopted the International Building Code (IBC 2021) the jurisdictions have significant input into elements associated with wind.

ITEMS ADDRESSED BY THE IBC:

- Where windborne debris protection is required

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66 Exposure D. Exposure D shall apply where the ground surface roughness, as defined by Surface Roughness D, prevails in the upwind direction for a distance of not less than 5,000 feet (1524 m) or 20 times the height of the building, whichever is greater. Exposure D shall apply where the ground surface roughness immediately upwind of the site is B or C, and the site is within a distance of 600 feet (183 m) or 20 times the building height, whichever is greater, from an Exposure D condition as defined in the previous sentence.

Surface Roughness B. Urban and suburban areas, wooded areas or other terrain with numerous closely spaced obstructions having the size of single-family dwellings or larger.

Surface Roughness C. Open terrain with scattered obstructions having heights generally less than 30 feet. This category includes flat open country, and grasslands.

Surface Roughness D. Flat, unobstructed areas, and water surfaces. This category includes smooth mud flats, salt flats and unbroken ice.

- Protection of openings by requiring assemblies to pass missile tests in windborne debris regions
- Requirements for alternate protection using wood panels
- Requirements for glazing in exterior handrails or guards
- Roofing materials designed to resist high wind forces
- Roofing attachment requirements for high wind areas
- Design of structure to resist high wind forces (wall construction, anchorage details, etc.)
- Requirements for storm shelters in emergency operation facilities and educations occupancies.
- Storm shelter construction and location
- Reference to ICC 500, ICC/NSSA, 2020, Standard for the Design and Construction of Storm Shelters
- Reference to ICC 600, 2020, Standard For Residential Construction In High-wind Regions

The Existing Building Code references ICC 500 for new storm shelters or storm shelters built in existing buildings.

Wind-related requirements

1. In windborne debris areas, as determined by wind speeds in figures within IBC, protection is required in areas where the site in a hurricane prone region and is within 1 mile of the coastal mean high-water line and the ultimate design wind speed is 130 mph or greater or in areas where an Exposure D condition exists upwind at the water line and the ultimate design wind speed is 140 mph or greater: or Hawaii. Where windborne debris protection is required, glazed openings within 30 feet of grade are required to meet the large missile test of ASTM E1996 and glazed openings located more than 30 feet above grade are required to meet the small missile test of ASTM E1996. As an alternative, wood panels 7/16 inch thick and less than an 8-foot span are permitted for R-3 and R-4 occupancies where the mean roof height is 33 feet or less. Specific attachment requirements apply. Protection is not required for openings located more than 60 feet above ground and over 30 feet above aggregate surfaced roofs located within 1,500 feet of the building.
2. Once the wind speed and exposure category are determined in accordance with the provisions in the IBC or ASCE 7, the design of the building with regard to connections, wall construction, and attachment to foundations shall be in accordance with the provisions of ASCE 7. There are several exception to this requirement for residential structures.
3. Laminated glass is required where glazing is installed in handrails or guards in windborne debris regions. Special requirements apply where the top rail is supported by the glazing.
4. Roofing materials are required to meet the manufacturer’s installation and rating requirements for the wind speed applicable to the building.

John Benson flickr.com/photos/j_benson/40665457015

Extreme temperatures

Buildings are designed assuming a relatively consistent climate throughout their lifecycle, the relative rarity of extreme events, and the upper bounds that those extreme events will reach. While there have been yearly variations in weather, the overall average of those events (especially with respect to seasonal temperatures) has remained within a predictable range. In other words, until recently, there has been no apparent shift in average seasonal temperatures. However, that predictability has started to wane in the last decade, and what was once a non-trending variable is now showing significant shifts in some geographies.

Two recent examples include the heat dome in the Northwest in 2021 and the extreme cold snap that hit Texas that same year. Most of the buildings in either the Pacific Northwest or Texas were not designed to accommodate those types of fluctuations. Some of the challenges that occurred were the result of a lack of resilience within the buildings with respect to those extremes. People living in Oregon had never had to consider the intensity and duration of those heatwaves, although people in Texas surely have and designed their building stock to accommodate those. Likewise, the building stock in Texas was not designed to withstand such an intense and long-period of cold temperatures, while buildings in the Northeast have been built to withstand those very types of events. The impacts from those events were exacerbated by the lack of adaptive capacity (ability to withstand long-duration heat anomalies) within the building stock.

Exhibit 41 Evolution of code (HVAC — energy focus)

1975
ASHRAE Standard 90-1975: developed in response to the 1970s energy crisis

1999
ASHRAE 90.1

2000
IECC
Inaugural year

2001–2016
ASHRAE 90.1
3-year cycle

2003–2018
IECC
3-year cycle

2019
ASHRAE 90.1

2021
IECC

Sources: ASHRAE (2021); ICC (2021); DOE (2021)

Current state of practice for building codes and extreme temperatures

The International Energy Conservation Code and ASHRAE 90.1 Standard are both referenced when determining the appropriate climate considerations for sizing of HVAC (heating, ventilation and air conditioning) and related mechanical equipment. The design of these systems is based on an assumed external climate, balanced with the performance of indoor heating, cooling and ventilation needs. In general, the IECC includes requirements for both one- and two-family dwellings and commercial buildings (including multifamily buildings) that incorporates ASHRAE Standard 90.1 which speaks to multi-story commercial and multifamily buildings.

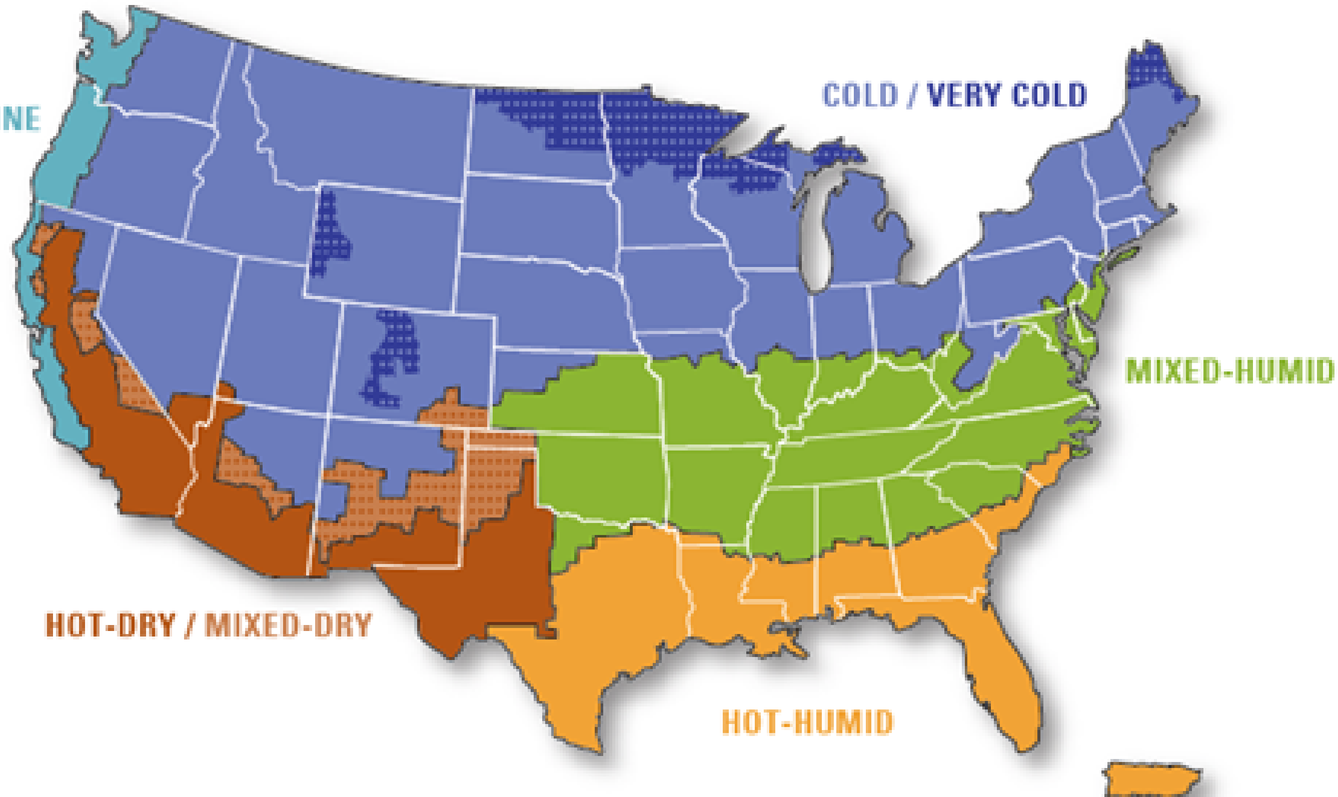
HEATING, VENTILATION, AIR CONDITIONING (HVAC) CODES —ASHRAE STANDARD 90.1 AND IECC

Air conditioners, heat pumps and HVAC units are all examples of equipment that are used to change indoor temperature and humidity levels. ASHRAE standards (referenced by the IECC) are used to specify the performance expectations of a unit and to size it based on occupant needs. The performance expectations are informed using a climate zone map that was developed by the Department of Energy. While this map is useful in relaying *historic* weather patterns, it does not account for climate change.

No requirements exist in the codes related to extreme heat or cold. However, there is the ability to change the inputs used to determine the boundaries of those systems and what is possible. There is the option to increase and decrease the high and low temperatures the systems are required to be designed to. Once that is done, the calculations are the same whether it is for current or future temperatures.

Exhibit 42 Climate region guide

Seven of the eight U.S. climate zones recognized by Building America occur in the continental United States. The sub-arctic U.S. climate zone, not shown on the map, appears only in Alaska.



Source: U.S. DOE (2015). **Guide to Determining Climate Regions by County**.

Challenge: The code often references outdated, historic data to inform design. Currently, the code references historic climate data to inform the specific sizing inputs (for example, average winter and summer temperatures, wet bulb and humidity averages). It also focuses heavily on averages, and does not adequately account for temperature extremes.

Solution: Using future climate projection data in designs will identify how those temperatures may shift over the expected life cycle of the asset. For example, most mechanical equipment has an average life expectancy of 30 years. The units should be designed to account for higher annual temperatures and flexibility to remain fully operational during more extreme and longer-duration heat waves.

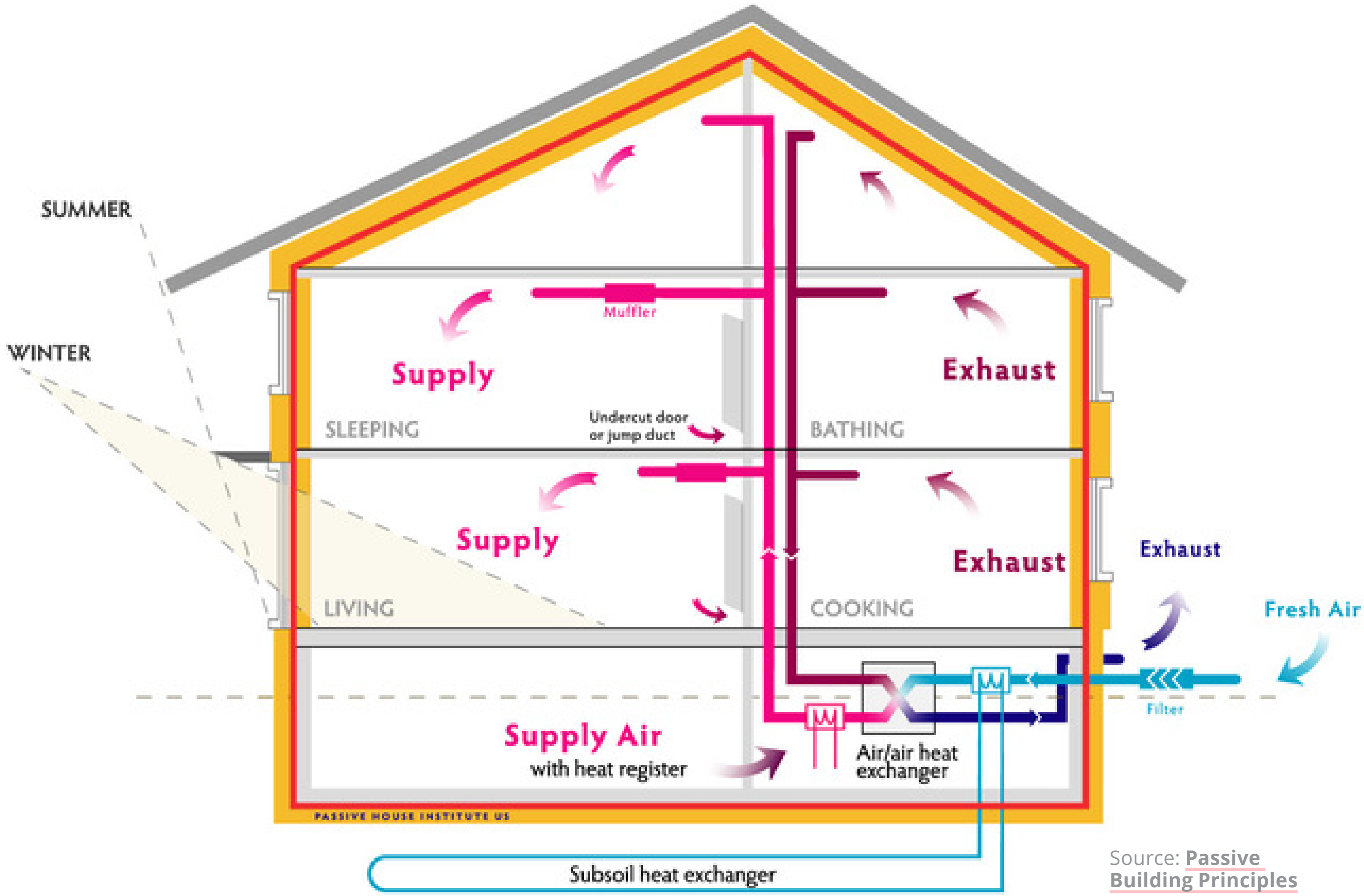
Where to find climate projection data:

- **Climate Toolbox:** Shift in average annual temperatures, number of days above and below 32 degrees F, and number of days greater than 90 and 100 degrees F
- **The Climate Explorer:** Similar data plus heating and cooling degree days

Challenge: How can buildings be designed to be more resilient to heat and cold while remaining energy efficient?

Solution: Well-insulated and ventilated buildings can enhance the overall resilience of a dwelling by allowing the occupant greater control over how heat is retained or dispersed during extreme events, while also reducing the overall energy requirements need to balance those extremes (e.g., onsite combustion of heating fuels or heavy use of air conditioning systems for cooling). The Passive House design strategy captures this intent and has been receiving more attention across the building sector because of that.

Exhibit 43 Passive house principles



Source: Passive Building Principles

Challenge: What can be done to solve for cooling and heating needs for existing buildings?

Solution: Several existing strategies can be leveraged, many of which may not require amending current building codes. Below are representative examples:

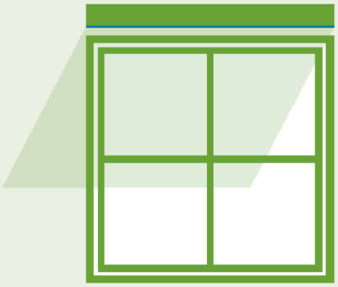
Exhibit 44 Passive measures

SMART SURFACE STRATEGY	WHERE TO USE	BENEFITS SUMMARY
Cool roofs	• Globally applicable, with most benefits accruing in warmer climates • Highest efficiency gains in single story structures with high roof to wall area ratio	• Net energy savings • Improved indoor comfort • Air temperature reductions (at scale*) • Cancels warming effect of atmospheric GHGs • Does not interfere with occupants' use of the roof (e.g., sleeping space) • Compatible with rooftop solar PV installations.
Cool walls	• Globally applicable with additional evaluation when applied to buildings that are close together and unshaded • More benefit on buildings with low roof to wall area and wall to window area ratios	• Net energy savings • Improved indoor comfort • Air temperature reductions (at scale*)
Cool pavements	• Location-specific, with a focus on low-traffic and pedestrian areas • Highest thermal comfort benefit when applied to urban paved surfaces	• Net energy savings • Air temperature reductions (at scale*) • Improved pavement life • Reduced outdoor lighting needs/improved nighttime visibility • Cancels warming effect of atmospheric GHGs
Green roofs	• Primarily applicable in areas with sufficient precipitation to support vegetation, on structures with sufficient support to bear the weight, and in areas where stormwater mitigation is a priority	• Net energy savings • Improved indoor comfort • Air temperature reductions (at scale*) • Extended roof life • Better stormwater management • Improved biodiversity and habitats • Potential for urban agriculture • Tends to increase property values • Compatible with solar PV installation
Green walls	• Similar to green roofs	• Net energy savings • Improved indoor comfort • Air temperature reductions (at scale*) • Aesthetic value
Permeable pavement	• Lower traffic areas such as parking lots, alleys, or curb lanes	• Better stormwater management • Cooler surface tempertures • Local cooling (if moisture is present) • Reduced traffic noise • Reduced ponding/surface water on roadways
Tree canopy and parks	• Globally applicable where adequate water is available and appropriate local species that are suited to future climate conditions	• Energy savings (when properly positioned) • Improved indoor comfort (if shading buildings) • Air temperature reductions (at scale*) • Improved air quality • Improved thermal comfort for pedestrians • Improved biodiversity and habitats • Aesthetic and recreational value

Source: ESMAP. 2020. **Primer for Cool Cities: Reducing Excessive Urban Heat**. Energy Sector Management Assistance Program (ESMAP) Knowledge Series 031/20. Washington, DC: World Bank.

Representative shading strategies to reduce impact of extreme heat events on interior spaces:

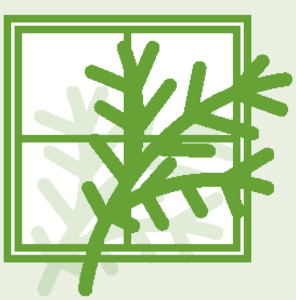
Exhibit 45 Window shading exterior treatments



Overhangs.
Overhangs are best for south-facing windows. The sun is high overhead during hot summer months, and a relatively short overhang can provide effective shade.

Awnings.
Like overhangs, awnings block sunlight effectively. Awnings often extend further than overhangs work best on east- and west-facing windows.

Exterior roller screens, shades and shutters.
Roller screens, shades or shutters are more common in Europe. They block sunlight before it strikes the window, and some products provide high wind protection too. In the U.S., exterior roller shutters are used primarily in coastal locations prone to hurricanes. Most shade screens allow some visibility, even when fully deployed.

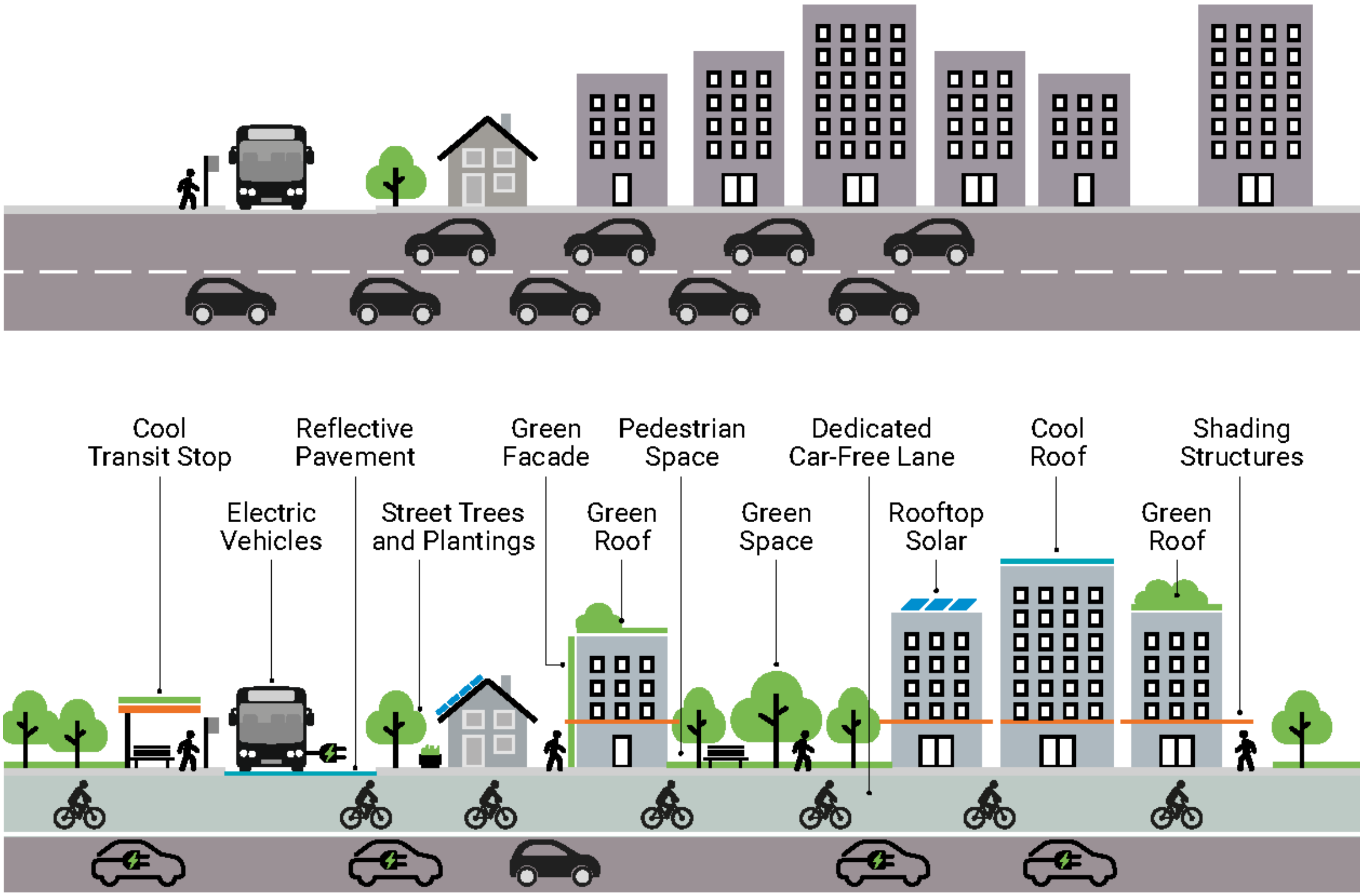


Vegetation.
Deciduous vegetation blocks sunlight in the summer. In the winter, when it sheds its leaves, it allows sunlight to penetrate. Greenery also provides important psychological and health benefits for residents.

Source: Enterprise Community Partners. **Strategies for Multifamily Building Resilience**.

City-scale strategies for addressing heat island impacts that combine building codes, land use ordinances, and other design, planning, and regulatory interventions:

Exhibit 46 Conventional (top) versus heat-resilient (bottom) urban areas



Source: RMI; **Beating the Heat: A Sustainable Cooling Handbook for Cities**
Note: in the figure, the conventional urban area has a high proportion of impervious surfaces and single-occupancy vehicles. By comparison, the heat-resilient urban area has a higher proportion of green space, cool surfaces, alternative modes of transport, and electric vehicles.