Resilient Retrofits

Climate Upgrades for Existing Buildings

Urban Land Institute

About the Urban Land Institute

The Urban Land Institute is a global, member-driven organization comprising more than 45,000 real estate and urban development professionals dedicated to advancing the Institute's mission of shaping the future of the built environment for transformative impact in communities worldwide.

ULI's interdisciplinary membership represents all aspects of the industry, including developers, property owners, investors, architects, urban planners, public officials, real estate brokers, appraisers, attorneys, engineers, financiers, and academics. Established in 1936, the Institute has a presence in the Americas, Europe, and Asia Pacific regions, with members in 80 countries.

More information is available at uli.org. Follow ULI on Twitter, Facebook, LinkedIn, and Instagram.

About the ULI Urban Resilience Program

ULI's Urban Resilience program is focused on how buildings, cities, and communities can be more resilient to the impacts of climate change and other environmental vulnerabilities. The program works with ULI members to provide technical assistance, advance knowledge through research, and catalyze the adoption of transformative practices for real estate and land use policy.

About the Resilient Land Use Cohort

This report is part of a larger series of resilience technical assistance and learning opportunities called the Resilient Land Use Cohort (RLUC). The RLUC is a network of ULI district councils, member experts, and community partners in seven cities working together to identify strategies to be more resilient in the face of climate change and other vulnerabilities, including floods, extreme storms, droughts, wildfires, and extreme heat, as well as the related social, environmental, and economic impacts.

The RLUC provides on-the-ground technical assistance through ULI's flagship technical assistance models—Advisory Services panels and technical assistance panels. These panels leverage ULI member expertise to advise on complex real estate and land use challenges related to climate resilience and to address planning, zoning, land use, development strategy, housing, and infrastructure. ULI's Urban Resilience program convenes the cohort regularly to learn from national best practices and to discuss peer cities' next steps for advancing resilience through land use policies and development strategies. Funding for this engagement and the cohort is provided by the ULI Foundation with support from JPMorgan Chase.

Cover: The CaixaForum Madrid, a redeveloped electric power station.

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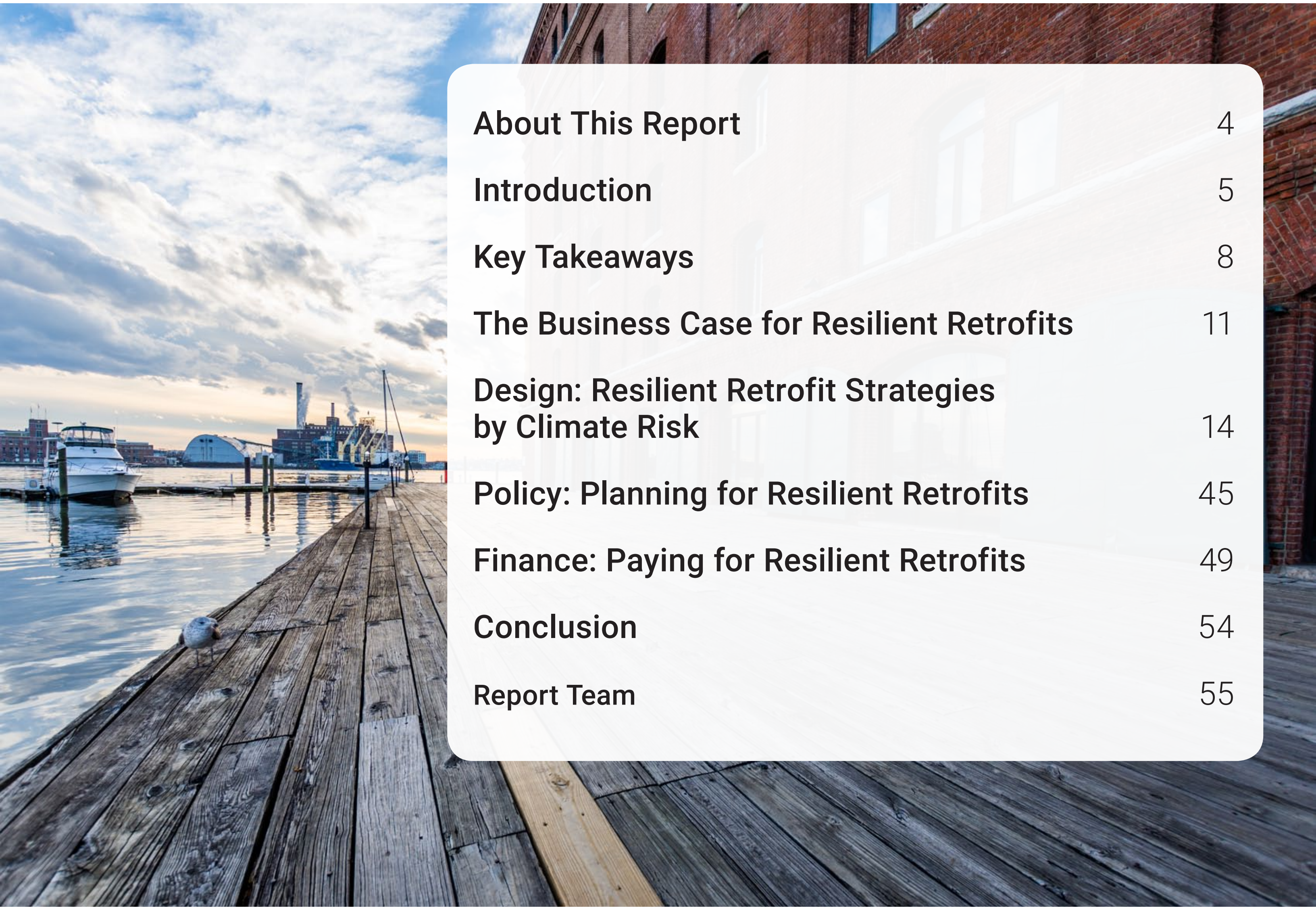


About This Report

Resilient Retrofits: Climate Upgrades for Existing Buildings introduces real estate actors, designers, policymakers, and finance professionals to the opportunities and challenges of preparing existing buildings for accelerating physical climate risks, including extreme temperatures, floods, storms and high winds, seismic risks, water stress/drought, and wildfires. The report includes the following:

- The business case for resilient retrofits
- A summary of several design strategies for each physical climate risk
- A selection of public-sector policies influencing the retrofit context
- An array of financing solutions applicable to retrofits

An untold number of buildings are at risk from a changing climate, but resilient retrofit techniques exist for nearly any building type and physical risk. As design knowledge, supportive policy, and financing tools come into greater alignment, resilient retrofits can become mainstream practice, enhancing building value and service life while delivering co-benefits for health and sustainability along the way.

The report's key takeaways follow and are explored in further detail in the Introduction. Social equity informs each key takeaway and should be prioritized throughout retrofit planning and implementation.

Key Takeaways

Design	Resilient retrofit strategies exist for every major hazard, and owners should plan comprehensively for multiple hazards.
	Resilient retrofits should address both adaptation and mitigation.
	Resilient retrofit planning should be comprehensive, but implementation can be incremental.
Policy/Planning	Resilient retrofit regulations/processes for buildings are still an emerging strategy for portfolios and citywide policy.
	Resilient retrofits present significant policy challenges.
	Community engagement is key to successful implementation.
Finance	Resilient retrofits are a potentially transformative economic opportunity.
	Resilient retrofits have a strong potential business case, which can be enhanced further by policy and market changes.

Introduction

As climate risks like floods and wildfires intensify, existing buildings must be strengthened. There is no way around it: today's buildings will still represent two-thirds of the global building stock by 2040.

Retrofitting buildings to prepare them for climate risks is a daunting challenge: resilient retrofits are a larger and more difficult task than simply designing new buildings to withstand natural hazard events. Scaling up retrofits into mainstream practice faces significant barriers in cost, design complexity, policy, social equity, and market inertia.

However, the need for resilient retrofits is also a generational opportunity: the chance, and the responsibility, to remake the world's vulnerable buildings into a more fitting image for the hazards they will face.

This publication introduces the basics of design, policy, and finance when retrofitting buildings for extreme temperatures, floods, storms and high winds, seismic risks, water stress/drought, and wildfires, and why and how owners, designers, and policymakers can act to protect the health of occupants and the value of buildings.

In addition to desktop research, interviews, and a focus group, this resource draws on lessons learned from the Resilient Land Use Cohort, a technical assistance and peer learning network managed by ULI's Urban Resilience program, which developed recommendations on retrofitting for resilience in U.S. cities, such as New York, Nashville, and Houston.

What Are Resilient Retrofits?

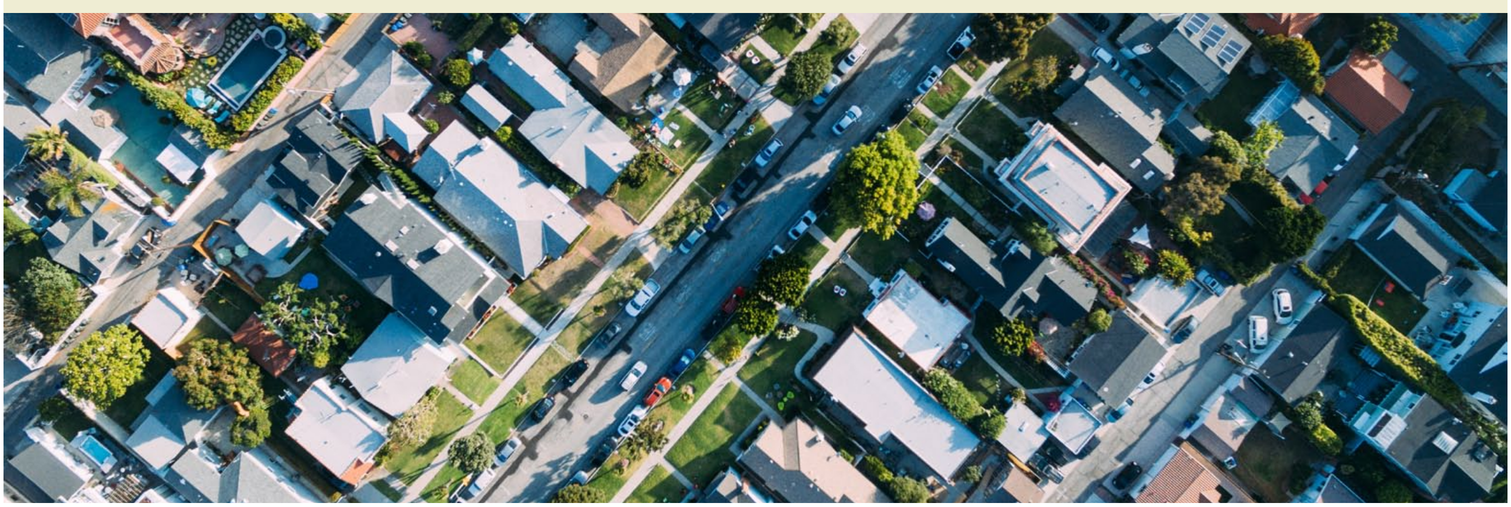
Resilient retrofit solutions come in an array of scales, costs, and levels of protection—from simpler techniques like reflective roofs or fire-resistant siding to comprehensive upgrades that replace building envelopes, elevate first floors, or replace mechanical equipment. For the purposes of this report, a resilient retrofit will include any modification that reduces a building's vulnerability to physical climate risks. The report will focus primarily on modifications that are performed while buildings are fully operational—major renovations completed during building repositioning or adaptive reuse can sometimes be closer in nature to new construction because of the lack of occupants and opportunities for significant design changes.

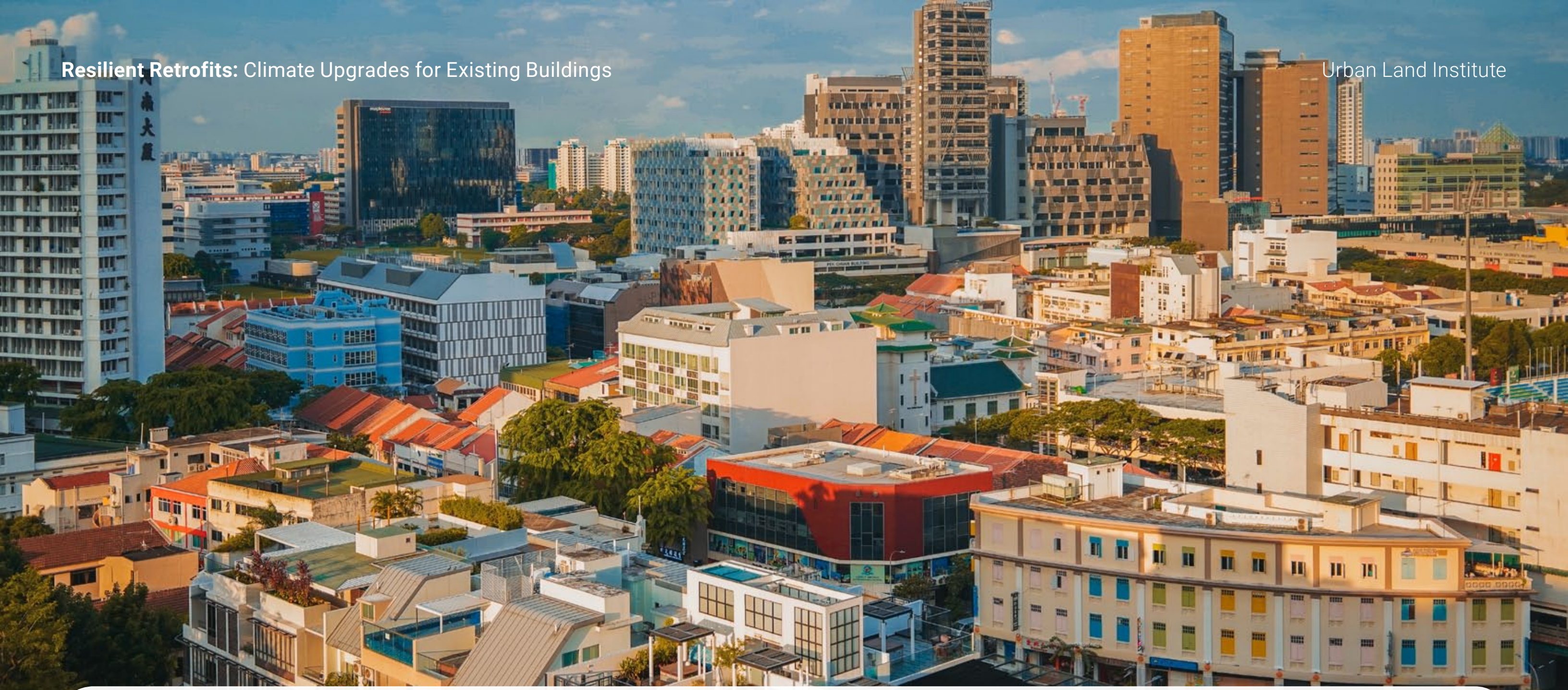
Buildings can be retrofitted for many different purposes—for example, a new occupancy type, aesthetics, or higher performance. For many with the goal of higher performance, the word "retrofits" refers primarily to energy efficiency or building decarbonization improvements, such as LED lighting or upgrading heating, ventilation, and air-conditioning (HVAC) systems. These adjustments are critical to decreasing a building's carbon emissions (which may eventually reduce the severity of climate risks that all buildings face). In addition, they have essential resilience co-benefits like improving runtime on backup power or helping with chronic weather risks like extreme heat and drought. However, on their own, energy retrofits do not guarantee that a building can withstand physical shocks like hurricane winds or earthquakes. Thus, the strategies and performance outcomes of resilient retrofits are overlapping but not always identical to those of energy retrofits.

Types of Resilient Retrofits

The U.S. Department of Energy's Better Buildings Solution Center breaks down resilient retrofits into three categories:

1. **Structure hardening** (mitigates property damage, injury, and system outages in the event of disaster):
   - Seismic retrofits
   - Wind-resistant roofs and windows
   - Flood mitigation
2. **Resource conservation** (reduces the energy and water demands of a building, increasing the amount of time it can operate on backup power and reducing the impact of disruptions):
   - Efficient lighting and heating, ventilation, and air conditioning
   - Water efficiency measures
   - Building envelope improvement, like enhanced insulation
3. **Energy supply** (helps ensure that critical building systems can continue operating during a grid or fuel supply interruption):
   - Renewable energy
   - Combined heat and power
   - Battery storage
   - Backup generation
   - Microgrids
   - Electric vehicle charging





Why Retrofit for Resilience?

In the United States alone, recent research indicates that 12.4 million residential properties and 900,000 commercial properties are at risk of flooding. Globally, the World Resources Institute estimates that 72 million people and $174 billion of urban property are already at risk from coastal and river flooding. Add in the costs of damage and threats to life safety from other risks, such as earthquakes, high winds, or wildfires, and the need to retrofit buildings to reduce exposure becomes even clearer.

Current building codes do not accomplish this goal. Many safety standards in building codes are designed to protect occupants in the event of a natural hazard, as they should be, but they do not ensure that the building can quickly resume operation and avoid sustained disruption, or even that the building itself does not suffer major damage—the goal of resilient design. Retrofitting to this above-code goal can be expensive for some hazards; for example, often only long-term holders and institutional or government assets can justify the cost of above-code seismic retrofits, but this approach is key to minimizing direct and indirect losses.

Neighborhood-scale infrastructure, such as living shorelines, parks, and tree canopies, are essential to reduce vulnerability. However, building-level solutions are critical complements to these larger projects, providing additional protection or addressing hazards best managed at the asset scale. Resilient buildings also play important roles as social infrastructure: community buildings like schools or libraries often become de facto resilience hubs, providing shelter, information, and coordination during climate events. The severity and rapidity of accelerating climate risk require an all-of-the-above, multiscale approach by public and private actors.

In addition, retrofits protect and enhance building value, and deliver a variety of financial, social, and environmental returns. The National Institute of Building Sciences (NIBS) found that resilient retrofits carry a four-to-one benefit/cost ratio to society, and even higher ratios can often be achieved in high-risk areas. Investing now ensures that properties and residents are prepared for the long term (see "The Business Case for Resilient Retrofits").

Finally, building owners already allocate significant resources to the maintenance and improvement of their properties. In the residential sector alone, every year over 1 million U.S. homes replace their siding and 6 million homes replace roofs and windows—all of which are opportunities to retrofit for wildfires, high winds, and extreme heat, for example. Ongoing renovations in the form of annual maintenance are already occurring, and they can be tapped to yield much higher resilience dividends.

Key Takeaways

Pursuing resilient retrofits creates a complex, interacting set of design, policy, financing, and social equity considerations. The following sections contain several key takeaways for stakeholders across sectors to consider when embarking on the resilient retrofit process.

As an overarching takeaway, social equity should be prioritized in the resilient retrofit process. Frequently, though not exclusively, properties serving low-income and Black, indigenous, and people of color (BIPOC) communities bear higher exposure to climate hazards. These communities also face barriers in accessing capital to adapt because of historical disinvestment and structural racism. Small-scale property owners also encounter a lack of time and staff to manage the complex retrofit process. Finally, resilient retrofits may increase building value, posing a potential risk to affordability. Design, policy, and finance solutions that address these concerns should be prioritized as resilient retrofits scale up.

Design

Resilient retrofit strategies exist for every major hazard, and owners should plan comprehensively for multiple hazards. Assets are often vulnerable to more than one type of risk. Planning for all hazards an asset will face over its life cycle is more cost-effective than planning individually, as it highlights opportunities to find co-benefits (e.g., choosing both flood- and fire-resistant materials) and resolve tensions (e.g., whether to locate mechanical equipment in the basement or on the roof for buildings subject to earthquakes and floods).

Resilient retrofits should address both adaptation and mitigation. Pairing retrofits for physical risks with energy retrofits is more efficient in both cost and time, reduces the consequences of power outages, and creates cost-saving opportunities that bolster the business case for retrofitting.

Resilient retrofit planning should be comprehensive, but implementation can be incremental. A comprehensive plan for the long term does not mean owners need to tackle everything at once. Phasing implementation into short-, medium-, and long-term strategies that align with annual maintenance needs helps make retrofits more manageable from a practical and financial standpoint and allows owners to prioritize a building's or a portfolio's most pressing needs.

Policy/Planning

Resilient retrofit regulations/processes for buildings are still an emerging strategy for portfolios and citywide policy. Resilient retrofit programs in earthquake- and hurricane-prone regions of the United States have been operating successfully for decades, and retrofit design knowledge continues to improve as new technology and climate risk data appear. Many individual owners and policymakers have begun implementation, and many examples of retrofits exist. However, comprehensive, multihazard portfolio or citywide policy strategies on retrofits have yet to become mainstream practice in commercial real estate and the public sector. This situation may change as building performance standards (BPSs) become more common.

> "Where the market is right now is, a lot of companies are performing resilience risk assessments, but are not at the stage of actually implementing retrofits."

—Daniele Horton, founder and chief executive officer, Verdani Partners

Resilient retrofits present significant policy challenges. Developing building retrofit policies/programs at any scale of government faces the challenge of reflecting the diversity of a city's or region's building types, design contexts, climate risks, and socioeconomic and cultural challenges and preferences. Existing regulation—whether local, state (e.g., zoning and building requirements or historic preservation rules), or national (e.g., floodplain requirements)—can also hinder or support retrofits and will influence policy development.

Community engagement is key to successful implementation. Like any large-scale building project, the needs, interests, and contributions of multiple stakeholders must be coordinated on goals and methods. In addition to owners, local stakeholders might include tenants, property or asset managers, maintenance staff, contractors, and lenders. And as efforts scale up across a neighborhood, city, or portfolio, stakeholders may expand to include community groups and city officials on the public side and environmental, social, and governance (ESG) teams, risk management teams, and investment committees within real estate companies.

Elevating buildings along coastlines is a retrofit strategy that can reduce flood risk and damage from storm surge.

> "Investment in a community outreach team is invaluable. On a lot of projects, this is seen as the cherry on top, a nice thing to have, but it's more than that. On projects this disruptive, it's literally what allows the project to continue without having stakeholders stop the project."

—Joy Sinderbrand, vice president, recovery and resilience, New York City Housing Authority

Finance

Resilient retrofits are a potentially transformative economic opportunity. The scale of need for retrofitting untold numbers of buildings globally for climate risk, and the related jobs creation and workforce development opportunities in multiple

Adding green facades to structures helps reduce heat gain, keeping interior temperatures comfortable.

sectors, create significant investment and growth prospects. In addition, the degree to which climate risk becomes priced into real estate, and whether owners take steps to mitigate risk through retrofits, could have widespread impacts on property values. If these changes are managed with equity in mind, the financial benefits of this transition can help build wealth in socioeconomically marginalized communities.

Resilient retrofits have a strong potential business case, which can be enhanced further by policy and market changes. Resilient retrofit costs vary according to a number of factors. However, in addition to the benefit/cost ratios mentioned previously, research and project profiles show that retrofits carry financial and other benefits to multiple stakeholders throughout the real estate value chain. Resilient buildings are also best positioned to avoid a "brown discount" when selling that may affect the deal if the building is not sufficiently hardened for market expectations.

Benefits can include enhanced value, marketability, and access to capital; reduced insurance premiums; avoided losses from damage or disruption; lower costs of compliance with regulation; and social/community returns, in addition to direct financial savings when measures combine building hardening with energy efficiency.

Payback can face limitations when climate risk is not priced into building value, market assessments, or insurance costs. However, this circumstance is slowly changing (see ULI's series on climate risk and real estate investment with investment manager Heitman for more). As climate risks worsen and climate risk disclosure evolves, ensuring that buildings can withstand extreme weather events will likely become a prerequisite for protecting returns and access to investment, as well as building occupants. Enhanced resilience incentives and financing tools can also help create better payback.

The Business Case for Resilient Retrofits

Valuing the payback from resilient retrofits can require more wide-ranging and long-term thinking than traditional building upgrades. Two significant barriers exist to justifying the upfront costs of many resilience upgrades: (a) potential or perceived lack of direct short-term payback and (b) uncertainty about whether and how much climate risks will actually affect the asset during the hold period, both of which particularly affect short-term holders.

Retrofits can become expensive, though incentives, grants, and retrofits with direct savings can curb costs. However, as climate risks intensify, failing to invest in resilience upgrades will likely cost far more. Moreover, not every building in a portfolio will need retrofitting (see "Assessing Risk and Vulnerability"). In addition, sources of payback for resilient retrofits are diverse, and as interest in resilience grows, market forces may be aligning to support an even wider array. Many of these returns have been documented in ULI's library of resilient project briefs, *Developing Urban Resilience*.

"The fundamental thing we've got to acknowledge in this process is the financial pressure. Right now, the financial pressure of a real estate developer is typically a 24- to 36-month development cycle. . . . If you're really going to solve the problem of the built environment, retrofits, and resilience, you've got to do it at the scale of most developers, which is sub-36 months."

—Clay Haynes, founder, Public Square

Adding mineral wool insulation to an exterior wall for energy efficiency and heat management.

Flooding poses unique threats to historic buildings.

Enhanced value, marketability, and access to capital. Resilient buildings stand out, creating a competitive advantage that can be seen through faster leasing and sale, ability to attract tenants and customers, higher resale values, and better financing. Indeed, enhanced access to capital is a critical value-add, as investors increasingly expect owners to disclose and address climate risk, for example, through reporting systems like GRESB or the Task Force on Climate-Related Financial Disclosures. Leading real estate firms like LBA Realty are starting to assess the resilience of an asset during due diligence before acquisition and incorporating costs of upgrades in the capital expenditure plan, helping incentivize resilience investments even among short-term holders.

Cases of severe climate risk may simplify the equation; buildings whose ongoing functionality is threatened by chronic and intense climate risks, such as sea-level rise, may simply require retrofits no matter the cost if the building must remain in use—for example, with historic, culturally essential, or government properties.

> Resilience measures at a resort in South Florida lowered annual insurance premiums by an estimated $500,000, offering a significant reduction in annual operating expenses.

Reduced insurance premiums and preserving access to insurance. As losses from climate events mount, insurance providers are offering discounts to customers that take proactive action to harden their properties. For example, the U.S. National Flood Insurance Program (NFIP) has long discounted premiums to owners for various flood mitigation measures; some insurers in wildfire-prone regions, like California, offer discounts of nearly 20 percent for homes that retrofit roofs and other features. Many U.S. states require insurers to offer steep discounts, in some cases of up to 50 percent, to residential and commercial owners who upgrade their property's hurricane wind resistance. As climate risks intensify and premiums and insurability fluctuate, retrofitting to preserve access to affordable insurance will become more important, especially for low-income property owners and long-hold owners.

Avoided losses from damage and disruption. Climate impacts cause property damages, raise maintenance expenses, and disrupt continuity for commercial and residential buildings. However, proactive retrofit investments can often cost far less than the damages that would have been incurred to a nonretrofitted building. Although costs vary significantly by retrofit measure and building type, FM Global found that "for every $1 a company spends to protect structures from hurricane, wind, and flood damage, estimated loss exposures decrease by an average $105 due to reduction in risk of property loss and business disruption." And NIBS estimates that

- Wildfire retrofits could avoid $8 in losses for every dollar invested, as can hurricane/wind retrofits;
- Retrofit strategies that mitigate riverine flooding, like elevating buildings, HVAC systems, or wet floodproofing, can each avoid $2 in losses for every dollar invested; and
- Retrofitting soft-story conditions for increased seismic resilience can avoid $12 for every dollar invested.

An analysis by FM Global found that "for every $1 a company spends to protect structures from hurricane, wind, and flood damage, estimated loss exposures decrease by an average $105 due to reduction in risk of property loss and business disruption."

"The amount invested to mitigate resilience risks will be a lot lower than the potential financial damages that the properties could face."

—Daniele Horton, founder and chief executive officer, Verdani Partners

Lower costs of compliance with regulation. Requirements around resilience are accelerating, whether from increased support for adopting the recommendations of the Task Force on Climate-Related Financial Disclosures or through local legislation. For example, some localities such as Boston have implemented resilience requirements for buildings in high-risk areas, while cities like Oakland are passing new seismic retrofit ordinances in earthquake-prone regions in the western United States. Because a retrofit program should begin with risk and vulnerability assessments (see "Assessing Risk and Vulnerability"), owners and companies that take this step early to understand their risk profile will be able to integrate needed upgrades into their planned capital expenditures and be better positioned for compliance.

Returns for multiple stakeholders. A broad view of return on investment, like that recommended in NIBS's *Roadmap to Resilience Incentivization*, also includes the returns that accrue to tenants, who want safe and reliable places to live and work that create less stress and disruption and who may pay a premium for them; lenders, investors, and insurers, who want to ensure that their capital is protected; and governments and the wider public, who bear increased costs of climate impacts.

For returns to the public sector in particular, recent ULI reports on retrofitting aging public housing towers in Toronto and New York City found that "quantifying the financial benefits of reduced emergency services (fire, ambulance, and temporary housing), health care (hospital visits and mental health resources), and other social program expenses associated with ensuring safety and quality of life" would significantly boost return on investment.

Design: Resilient Retrofit Strategies by Climate Risk

A wide variety of design approaches exists to prepare existing buildings for climate risk, and more are constantly being innovated. This section introduces a selection of strategies that building owners and the architecture, engineering, and construction professions can explore to adapt to **extreme temperatures, floods, seismic risks, storms and high winds, water stress/drought, and wildfire.** Many of these techniques have co-benefits and tradeoffs to consider as the design process unfolds, and some solutions apply across hazards (such as backup power) and are therefore included in each section. Though hurricanes and other storms involve both flooding and wind impacts, these risks are discussed separately as they require different design approaches.

Social equity should be a key design consideration across hazards. Developing culturally sensitive strategies in partnership with the stakeholders most affected by physical climate risks will help ensure that their needs and concerns are included throughout the process.

The American Institute of Architects has collected an array of resilience design resources to help guide adaptation to each of the climate risks presented in this primer, and more. See specific guidance on designing for physical climate risks here.

Assessing Risk and Vulnerability

The first step toward retrofitting for climate risk is to identify which physical hazards a portfolio or area will be exposed to. Many organizations begin with a multihazard risk assessment or vulnerability assessment (the latter tends to include socioeconomic information about the populations most threatened by hazards). Resources such as the American Institute of Architects' course on conducting vulnerability assessments can provide more detail for designers.

Assessing Risk in New and Existing Buildings: A Perspective from New World Development

New World Development (NWD), based in Hong Kong, China, is integrating climate-related risks into its Enterprise Risk Management and enhancing properties' climate resilience and adaptability by conducting ongoing assessment and monitoring. NWD has worked recently to establish climate resilience design guidelines that integrate various climate mitigation and adaptation measures into new developments and major refurbishment and construction activities, covering the full property life cycle from acquisition and redevelopment to design and construction, facility management, and the engagement of building users. The guidelines, currently being finalized, will cover climate risks that are pertinent to major business locations, such as flooding, water stress, extreme temperatures, and extreme wind, and suggest resilience improvement measures.

NWD has assessed the impact of climate-related risks (flooding, water stress, extreme temperatures, and extreme wind) on 14 major properties in the Greater Bay Area of China under two scenarios from the Intergovernmental Panel on Climate Change: (a) a medium-risk scenario where global average temperature increases by no less than 2.5 degrees Celsius (known as Representative Concentration Pathway [RCP] 6.0) and (b) an extreme scenario where temperature increases by over 4.0 degrees Celsius (RCP 8.5). Recognizing that flood risks are becoming more pressing, NWD began to conduct a detailed flood risk assessment, including a review of existing public drainage records, two-dimensional hydraulic modeling, coastal overtopping modeling, and flood extent map generation at two buildings in Hong Kong. Based on the findings in the assessment, NWD identified locations with potential flood risk and installed floodgates accordingly, such as in basement car parks and plant rooms and at building entrances, and also established regular inspection and maintenance protocols.

Jackson Cheung
Manager, Sustainability
New World Development

Free resources such as the National Risk Index of the Federal Emergency Management Agency (FEMA)—which provides a nationwide assessment of vulnerability to 18 major hazards at the census tract level along with social vulnerability and community resilience—can be a helpful starting place for understanding local risk. Ultimately, asset-level or even building component–level data are often most useful, and can be acquired from climate risk analytics providers.

Real estate ESG leaders, such as New World Development and LBA Realty, have started to incorporate climate risk assessments and strategy into due diligence and even enterprise-level risk management, to inform overall business and investment strategy.

These assessments should identify which buildings should be prioritized—for example, on the basis of level of exposure to risk, building condition and useful life, social vulnerability, or a benefit/cost analysis of retrofit investments. As risk assessments might not include recommended retrofit strategies, it may be necessary to pursue further study and consider **how to retrofit for multiple risks**—finding synergies or addressing conflicting needs is essential. Strategies with co-benefits or tradeoffs that affect preparation for multiple risks will be noted in the sections that follow.

"We're thinking about renovation of developments holistically, not piece by piece. NYCHA has enough lessons learned to say, 'we're doing top to bottom renovation, what can be incorporated?' It's not just repair, or bringing up to code, but mitigating risk and placemaking to improve the lives of residents."

—Joy Sinderbrand, vice president, recovery and resilience, New York City Housing Authority

Many risk assessment methodologies exist that can provide a starting point. For instance, design, planning, and engineering firm Arup is developing a framework known as the Roadmap to Resilience, which lays out a multistep process any sector can use for responding to all hazards faced:

1. Understand and quantify risks to building stock (including likelihood and severity of damage, repair costs, downtime, and casualties, as well as impacts on the wider community, for example, jobs hosted within building, population, and business displacement, erosion of the tax base);
2. Develop mitigation strategies (including physical intervention and operational measures) and associated costs, and conduct cost/benefit analysis; and
3. Prioritize and implement retrofit investments accordingly and develop policy frameworks for guiding future decision-making.

If risk cannot be feasibly mitigated, it may be worth considering a buyout strategy, as covered in ULI's report *On Safer Ground: Floodplain Buyouts and Community Resilience*.

"One update we're working on [to Cambridge's net-zero action plan] is to integrate resilience with energy efficiency and electrification. On one hand, it's easier to silo the two things, but in reality it's not how owners look at it. You can't ask them to do electrification, efficiency, and renewables, and then come back later and say you should do floodproofing; it needs to be considered together.

—John Bolduc, environmental planner, city of Cambridge, Massachusetts

When Should Owners Retrofit?

Opportunities for retrofits include during the acquisition process; in line with scheduled capital expenditures or financing cycles; at the end of equipment service life; during repositioning; predisposition; and after experiencing a climate event when other work may be occurring.

Daniele Horton, founder and chief executive officer of Verdani Partners, notes that it is now best practice to include resilience risk assessments and mitigation strategies during all stages of the building life cycle, including due diligence for new acquisitions, standing assets, and new development projects. In addition, Horton recommends a three- to six-year implementation strategy for portfolios:

- Year 1: Establish program, goals, targets and strategies, and responsible parties, and implement a resilience policy
- Year 2: Perform desktop portfolio risk assessments, understand portfolio risks, and identify high-risk properties
- Year 3: Perform additional on-site risk assessments for high-risk properties
- Years 4+: Implement risk mitigation strategies and ensure optimal operation practices
- Year 6: Develop public/private partnerships and collaborate on regional solutions

However, architect Satpal Kaur emphasizes:

> "For most buildings, there will never be a good time [to retrofit]. Knowing you have to do it one day, start planning now to think better about a systems approach that brings less disruption."

In a pinch, sandbags can be used as a low-tech "temporary retrofit" option and stepping stone to enhanced floodproofing.

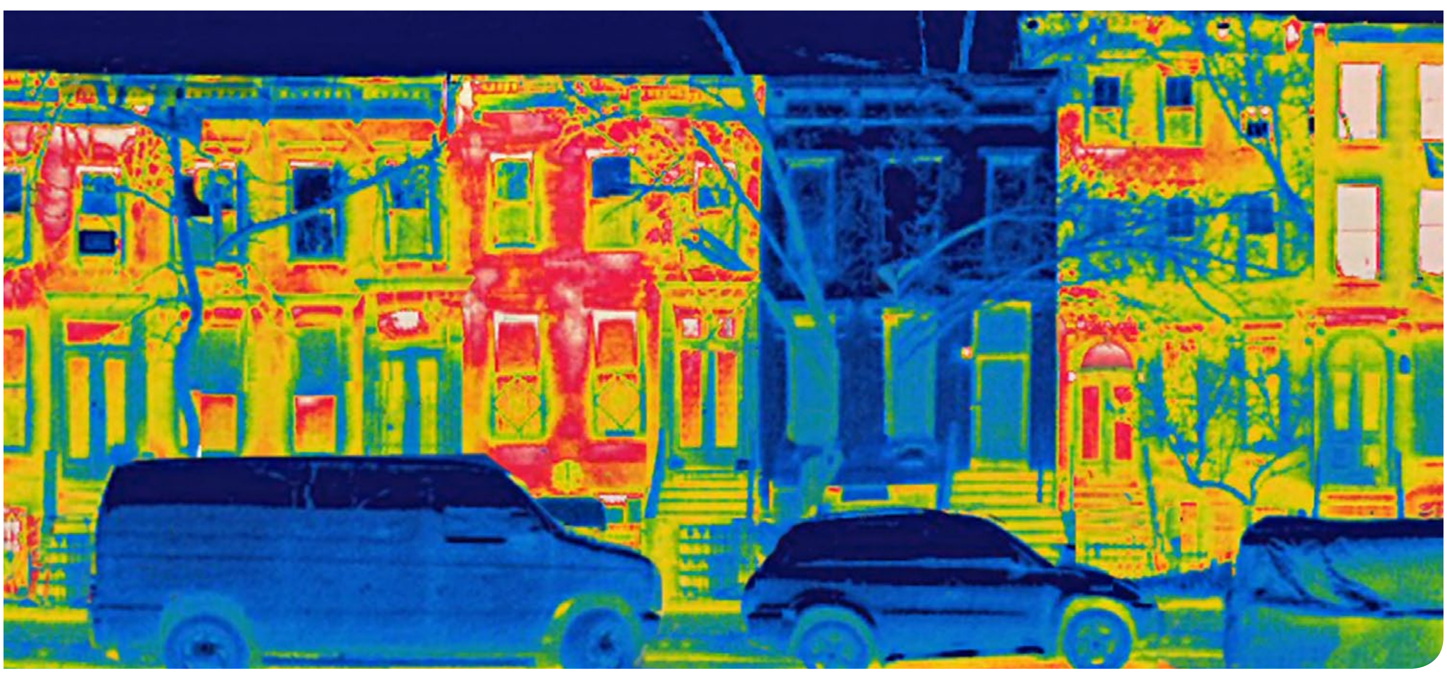
Extreme Temperatures

Extreme temperatures, whether rising average temperatures or more severe heat waves and cold snaps, have the potential to wreak widespread impacts. Consider the thousands of excess deaths during Europe's 2021 summer heat wave and the U.S. Pacific Northwest's heat dome, or the disruption in Texas and other parts of the southern United States from extreme cold in February of that year, which killed hundreds of people and caused nearly $200 billion in damages.

Resilient retrofit strategies for extreme temperatures focus on enhancing the building envelope's ability to maintain thermally comfortable temperatures indoors; providing efficient cooling or heating; and increasing passive survivability, a building's capacity to remain habitable during power outages. For example, the Ken Soble Tower retrofit project in Ontario, Canada, added insulated cladding such that the building could remain warm for two days in winter and cool for four days in summer during a power outage, compared with the typical two hours in winter and a half day in summer, respectively.

Unsurprisingly, retrofits for extreme temperatures have a higher degree of overlap with energy efficiency retrofit strategies than other climate risks discussed in this primer. A selection of retrofit strategies is listed in table 1; the following design guidelines have more information:

- *Turning the Heat: Resiliency in New York City's Heat-Vulnerable Neighborhoods*, Urban Design Forum
- *Architect's Guide to Building Performance*, American Institute of Architects
- *Scorched: Extreme Heat and Real Estate*, ULI



Passive House retrofits (building in blue) can drastically increase protection from extreme temperatures, keeping buildings comfortable in hot and cold weather.

Table 1. Extreme Temperature Retrofit Strategies	
Cool roofs/cool facades	Light-colored or reflective surfaces reflect heat from the sun, reducing indoor temperatures and required cooling energy. A variety of reflective coatings and materials exist in an array of colors that can be used to increase reflectivity.
Green roofs/green facades	Roofs or walls covered in vegetation reduce heat absorbed from the sun and provide localized evaporative cooling, reducing temperatures indoors and immediately adjacent to the building (especially true for green facades) while increasing biodiversity. Green roofs can also provide an on-site green space amenity if safely accessible to occupants or the public. **Co-benefits and tradeoffs: In addition to their heat and energy benefits, green roofs can also help retain stormwater, reducing local flood risk.**
High-performance building envelopes	Passive envelope strategies—such as enhanced or continuous wall and roof insulation, double- or triple-pane windows, careful air sealing, and smart glass—can all help maintain comfortable indoor temperatures in hot and cold weather, without using any energy. Consider a Passive House or similar design approach (as appropriate for the local climate). **Co-benefits and tradeoffs: High-performance envelopes are a key component of net-zero buildings, as they create deep reductions in the energy needed to heat and cool a building.** **Remember to consider embodied carbon when choosing building materials, especially insulation. Natural materials like sheep's wool or hay bale products have much lower embodied carbon emissions than spray foam insulation, for example.**
Operable windows	Buildings lacking windows that open to the outdoors can quickly overheat during a power outage.
Exterior shade features	Overhangs, awnings, and exterior shutters, blinds, or louvers can all keep heat from entering the building, reducing indoor temperatures. Exterior features are more effective at blocking heat gain than interior curtains or blinds. These features can be designed to allow solar heat gain in winter to help reduce heating energy in temperate climates. **Co-benefits and tradeoffs: Moderating heat gain also reduces energy needed for heating and cooling.**
Efficient HVAC systems (e.g., heat pumps)	Modern HVAC systems, especially heat pumps, provide efficient heating and cooling while reducing energy costs. These systems will likely be necessary to complement passive design strategies as extreme temperatures worsen. Consider adding indoor ceiling fans in mild climates to help with airflow. **Co-benefits and tradeoffs: All-electric HVAC systems like heat pumps have no on-site carbon emissions. Any rooftop or external equipment should be secured to ensure that it does not become a hazard during high winds. Regular maintenance will help avoid debris buildup that could ignite during wildfires.**

Table 1. Extreme Temperature Retrofit Strategies continued

Smart building systems (internet of things and network-linked sensors)	Smart building systems enable accurate management of indoor thermal comfort and environmental quality, for example, by automatically adjusting HVAC systems based on temperature or humidity sensors, or automatically opening or closing windows based on outdoor temperatures or air quality. **Co-benefits and tradeoffs: Buildings equipped with these systems can significantly reduce energy use and operating costs in numerous systems, such as by turning lighting or HVAC off in unoccupied rooms or identifying malfunctioning components.**
Energy efficiency retrofits	In addition to envelope and HVAC improvements, consider pursuing other energy efficiency upgrades, such as installing efficient lighting and appliances. Efficient buildings reduce the impact on the energy grid, helping ensure that it can stay operational during times of high demand (like heat waves).
Backup on-site power (e.g., solar plus battery storage)	Backup power ensures that the building remains comfortable in the event of a larger power outage. On-site renewable energy, like solar panels and battery storage, ensures that this power source is low carbon and protective of local air quality—unlike common alternatives, such as diesel generators.

Considerations and Challenges

Design for the whole building. Successful extreme temperature retrofits will consider all systems of a building. Each system has significant impacts on other systems' ability to help maintain comfortable temperatures. Tweaking one system may affect the timing and details of other retrofits; for example, creating a more efficient envelope allows the use of smaller HVAC systems, and envelope strategies should be considered first. In addition, complications can arise when adjustments are not made with the whole building in mind; for example, when multiowner condominiums or multitenant office buildings allow individual units to retrofit without considering larger impacts.

Impacts of building typology. Buildings with simpler shapes and features, such as "big box" industrial buildings, are easier to retrofit; portfolios with many similar building types will find it easier to scale up retrofits. In addition, building use can complicate the retrofit process; hospitals and schools, for example, which have higher ventilation needs, can be harder to account for.

Quick Wins on Managing Heat from LBA Realty

"We were having cooling issues, especially on the upper floors with southwesterly solar exposure. In an effort to balance the temperature, LBA installed window tinting on all windows, which consists of single-paned glass with little heat rejection characteristics. Based on our engineer's longstanding experience at the building, he felt strongly that tinting would result in considerable energy reductions, reduced wear and tear on base building HVAC equipment, and an approximately 15 percent reduction in tenant comfort complaints. After project completion, our HVAC hot calls were significantly reduced, allowing the building engineers to focus on other pertinent issues. The film is performing above expectations and our energy savings have been significantly improved."

—Michelle German, director, ESG and sustainability, LBA Realty

Availability of technology. New retrofit approaches, such as the construction of prefabricated and panelized facade systems, are not currently available in all markets or require other advanced technologies like laser scanning (to model the building's exterior) that many smaller building owners may not have access to. Beginning with larger buildings and developing standardized retrofit models that can be implemented more broadly may help reduce costs and increase accessibility. Similarly, some alternative technologies, such as external insulation finishing systems, are not recommended for wildfire-prone areas.

Benefits beyond the building. Efficient buildings emit less waste heat into their surroundings from mechanical systems like air conditioners, and vegetative strategies like green facades also provide some localized cooling effects. Considering how these retrofits can support more comfortable communities is key to maximizing broader paybacks.

Historic preservation and other policy barriers. Changes to building facades may be limited in areas with historic preservation requirements, restricting design flexibility. Similarly, zoning restrictions, such as lot-line exceedance limits may require zoning variances to allow the installation of new, insulated facades. Adjustments can be made by adding insulation to exterior walls from the building's interior or working with zoning officials and neighboring owners to approve variances, though these steps may involve greater disruption to tenants and slow down the approvals process.

Project Profiles

DBS Newton Green, DBS Bank, Singapore

Located in a tropical climate, Singapore is highly vulnerable to extreme heat; however, the city-state is also at the forefront of green buildings. DBS Bank, a leading financial services group based in Singapore, is meeting the climate challenge head on with the redevelopment of a 30-year-old office building located in Newton, which will become the city-state's first net-zero bank building. Named DBS Newton Green and set to be completed in the first quarter of 2022, the building has several heat resilience design features:

- A slatted facade structure and extended roof overhang that will shade the building from solar heat gain while facilitating natural ventilation
- A biophilic exterior that will cover half the building with native plants, providing additional shade and evaporative cooling; plants will be watered with air-conditioner condensate and selected for their ability to provide habitat for endangered native species

(Kaia Architects Pte Ltd.)

- Ceiling fans in lobbies and corridors to provide low-energy cooling features, and energy recovery ventilators that precool outdoor fresh air with previously cooled air, controlled by carbon dioxide sensors that can initiate fresh air flush-outs when needed, improving indoor air quality
- Ten percent of floor area converted from air-conditioned to naturally ventilated spaces, reducing energy costs of cooling

These elements accompany the building's energy efficiency features, such as a 250,000-kilowatt rooftop solar array, heat pump water heaters and solar refrigerators, and occupancy-based lighting and air-conditioning systems, all of which combined enable the building to reach net zero by reducing energy consumption by over 580,000 kilowatt-hours annually, boosting energy resilience at the same time.

DBS Bank's S$5 million (US$3.7 million) investment in the project is supported by a grant from Singapore's Building and Construction Authority under the government's Green Buildings Innovation Cluster Programme, demonstrating the value of public/private partnerships to achieve both resilient and sustainable buildings. Retrofitting will not end with DBS Newton Green. Erwin Chong, group head of corporate real estate strategy and administration at DBS, notes, "We believe that the future of the office needs to be sustainable, and our aim is to eventually scale these innovative technologies across the rest of our offices, branches and lobbies."

Energiesprong, the Netherlands, and RiseBoro Community Partners, New York City

Retrofitting building envelopes can protect occupants from outdoor temperature extremes, whether hot or cold, and it also has dramatic impacts on building energy use and carbon emissions. However, deep envelope retrofits are often time- and cost-intensive and can be intimidating to undertake. The Energiesprong retrofit model, developed in the Netherlands, provides a quickly scalable alternative that could shorten the process to a matter of weeks, even for larger buildings. This approach laser-scans

Prefabricated, insulated panels regulate heat and speed up the retrofit process. *(Energiesprong International and Fabrice Singevin)* building envelopes and then fits prefabricated, highly insulated wall and roof panels over the old facade, also integrating heat pump technology for heating, cooling, and hot water.

These retrofits can drop energy use by nearly 80 percent, helping buildings reach net zero or Passive House standards, and small buildings can be completed in a single day. The insulated panels—sometimes up to eight inches thick—also drastically increase the building's resistance to temperature change and passive survivability in a power outage, especially if on-site renewables like solar are added. Over 5,700 homes have been retrofitted in the Netherlands, and the program is starting to spread in Europe and the United States—the latter in part due to pilots, such as REALIZE by the Rocky Mountain Institute, and implementation by housing nonprofits, such as RiseBoro Community Partnership.

RiseBoro, which provides low-income housing and social services, built the first Passive Building–certified, affordable multifamily building in the nation in 2013. RiseBoro has since committed to retrofitting its entire 150-building portfolio with techniques based on the Energiesprong approach and Passive House principles, including (a) recladding with insulated, airtight assemblies (prefabricated panels used in Europe are not yet commercially available in the United States); (b) using high-performance windows and doors; (c) electrifying building systems with heat pumps and induction stoves; (d) adding energy recovery ventilators and fresh air ducts; and (e) relocating mechanical equipment and distribution lines on the building's exterior. Upgrades at a specific development, Casa Pasiva, are estimated to save the organization $180,000 annually, while costs per unit average out to roughly $125,000 and also cover interior renovations, such as new flooring, bathrooms, and kitchens.

"A lot of what Passive House is, is just quality-controlled construction—air control, moisture, controlling for mold, pests, smells, all those things that affect people's lives in housing that don't get looked at when building a multifamily building—now you have to look at it. A lot of outcomes [like better indoor air quality] are from quality control, but they have a big impact on tenants."

—Ryan Cassidy, director of sustainability and construction, RiseBoro Community Partnership

Most of this work can occur on the building's exterior, causing much less disruption to tenants—one of the biggest concerns retrofits can raise. These retrofits not only can increase resilience to extreme temperatures, but also can greatly improve indoor air quality.

One of the larger barriers to implementation is policy prohibiting exceeding lot lines—adding several inches of insulation may go over allowances in zoning, and sometimes require legal permission from neighboring properties, which can significantly slow the process. In addition, continuing to scale will require ongoing coordination with tenants, management, and construction teams.

Floods

From all the risks discussed in this primer, retrofitting for flood risk represents perhaps the greatest potential for reorganizing the built environment. Chronic intrusion of water may sometimes trigger steps as significant as elevating or repurposing the first floors of many buildings in severely flood-prone areas. Building owners, users, and designers will need to think comprehensively about their specific flood risks and how best to preserve their building's functionality and accessibility, especially in coastal areas, as water inevitably intrudes farther into developed areas.

This section addresses flooding from coastal sources (storm surge, sea-level rise, and tidal flooding), riverine flooding, or heavy rain. Retrofit design approaches generally fall into one of two categories: (a) keeping the water out (dry floodproofing) or (b) letting the water in safely while minimizing damage (wet floodproofing).

A selection of retrofit strategies is listed in table 2; the following design guidelines have more information:

Coastal Flood Resilience Design Guidelines, Boston

Retrofitting Buildings for Flood Risk, New York City

Ready to Respond: Strategies for Multifamily Building Resilience, Enterprise Green Communities

Reducing Flood Risk to Residential Buildings That Cannot Be Elevated, FEMA

> "Nature is going to take its course regardless, but we need to make the building respond to it, too. We can design accordingly, and . . . choose a system that allows the building to dry out over time. Even if we try to completely floodproof, water will find its way in regardless. Finding a way it can go in, breathe, and then dry, that's best."
>
> —Satpal Kaur, founder and design and building science principal, SATPAL

Elevating buildings above the floodplain is feasible for some smaller, detached structures (left); others may need flood barriers (right).

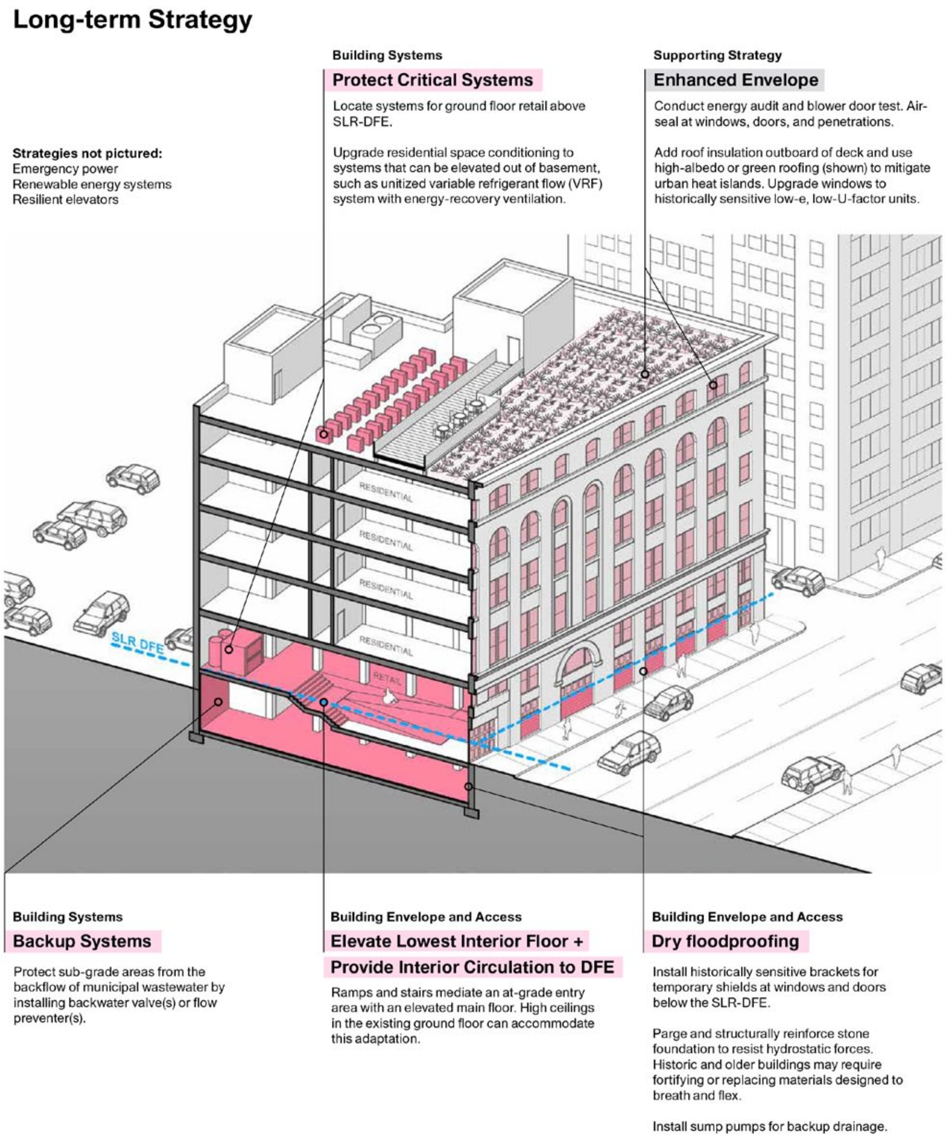
Table 2. Retrofit Strategies for Floods

Dry floodproofing (prevent water from entering the building)	Install watertight/floodproof barriers for doors, windows, or other openings, seal any cracks or gaps in walls and entrances with sealants or waterproof membranes, add a sump pump with backup power to drain any water that enters the area, and add a backflow valve to prevent sewer and drain backups. This method places significant pressure on the building structure (hydrostatic pressure) and is unsuitable for residential buildings unless they have concrete or masonry walls and a slab-on-grade foundation; commercial buildings are more suitable for this strategy. Dry floodproofing is most suitable when flood depths are below 3 feet, floodwater is slow moving, and flooding lasts less than three days. As dry floodproofing is not guaranteed to fully prevent water entry, it will usually not result in flood insurance premium reductions under the U.S. National Flood Insurance Program (NFIP).
Wet floodproofing (allow water to enter the building safely)	In areas below flood levels that are not used as living space, install flood vents in the foundation and enclosure walls to allow water in and out automatically, preventing structural damage from hydrostatic pressure. Install water-resistant materials like concrete or tile finishes in areas intended to receive floodwater, and backflow valves to prevent sewer and drain backups. Relocate/elevate utility equipment (see below) and any high-value contents stored in areas below flood levels. Wet floodproofing may help qualify buildings for reduced insurance premiums under the NFIP.
Elevation of entire building	Completely raise the building above current and future flood levels on piles or columns, allowing water to pass underneath. This strategy is likely suitable primarily for smaller, detached buildings; it is difficult or impossible in dense urban areas. Elevation may help qualify buildings for reduced insurance premiums under the NFIP. **Co-benefits and tradeoffs: Remember to provide underfloor insulation on the lowest level to prevent heat loss.**
Elevation/relocation or hardening of utility systems	Relocate utilities (e.g., HVAC and mechanical, electrical, and plumbing systems) to roof, upper floor, raised platform in basement, or floodproofed/elevated annex building (if space and systems allow). If not feasible to relocate/elevate systems, add dry floodproof solutions, such as flood doors or barriers, around them. **Co-benefits and tradeoffs: Making changes to HVAC systems may be a good opportunity to invest in a more efficient option, such as heat pumps.**
Repurpose or relocation of ground-floor or first-floor uses above flood levels, or fill in of basements	Floors located below current or future flood levels should not be habitable and should be converted to a safer use, such as parking, building access, storage, or if allowed by zoning, commercial use. Consider filling in basements to the nearest adjacent grade and installing passive flood vents to minimize basement flooding. If allowed by zoning, rooftop or lateral building additions can compensate for space lost from lower floors.

Table 2. Retrofit Strategies for Floods continued

Flood-resistant elevators	Elevator pits often extend below the lowest floor and are highly vulnerable to flooding and access issues. Install elevators with motors and controllers above flood levels. Reinforce the elevator shaft portions below flood levels. Install a sump pump for any water seepage into the elevator pit. Set controls to prevent elevator cab from lowering into floodwater and install flood alarms in the elevator pit. Dry floodproof any components that cannot be elevated.
Elevation of first floor and addition of external or internal access features	If internal ceiling heights allow, the first floors of buildings can be raised above flood elevations. To preserve accessibility, interior or exterior stairs or ramps should be added. To create attractive entrances, consider adding landscaping or other enhancements to exterior access features, or use flood protection features as an on-site open-space amenity or gathering area.
Water-resistant materials	In building areas below flood levels, replace water-sensitive materials, such as drywall, with water-resistant materials, such as concrete or tile, to reduce cleanup and risks of mold. **Co-benefits and tradeoffs: Note that use of concrete may increase a building's embodied carbon.**
Green roof, blue roof, or other rainwater catchment system	A green roof (roof covering using living plants), blue roof (roof designed to detain and slowly release rainwater), or other system to catch and hold rainwater can reduce stormwater runoff, decreasing flood levels. See ULI's *Harvesting the Value of Water* report for more on these strategies. **Co-benefits and tradeoffs: Green roofs and blue roofs can reduce solar heat entering the building, helping keep buildings cool and lowering energy usage and carbon emissions from HVAC systems. Green roofs benefit areas affected by drought by providing an opportunity to use rainwater for nonpotable uses.**
Backup on-site power (e.g., solar plus battery storage)	Backup power ensures that the building remains comfortable in the event of a larger power outage. On-site renewable energy, like solar panels and battery storage, ensures that this power source is low carbon and protective of local air quality—unlike common alternatives, such as diesel generators.

Water-resistant finishes like polished concrete floors are attractive and require little maintenance after a flood.



Boston's Coastal Flood Resilience Design Guidelines provide a detailed, illustrated set of strategies and considerations for retrofitting multiple building types, from one- and two-story homes to industrial buildings and the mixed-use building pictured here. The guidelines primarily address flood risk but call out areas of overlap with other climate risks and sustainability practices. *(Boston Planning and Development Agency)*

Adapting Historic Buildings to Flooding

Historic buildings face unique challenges to becoming flood-resistant. The National Parks Service has a guide to rehabilitating these structures with flooding in mind. Learn more.

Considerations and Challenges

Urban design. With options ranging from installing large flood protection systems to raising entire buildings, flood retrofits can create major aesthetic impacts on the urban realm, as buildings' exteriors, accessibility, and relation to the street level may change. Designs that affect building exteriors should find ways to soften the visual impact with landscaping, barriers that double as usable space, or other approaches.

Historic preservation. Similar to the challenges posed by extreme temperature retrofits, building modifications in areas with historic preservation regulations may require additional review or face design constraints that limit floodproofing options.

Cost of insurance. Lowering costs may be a primary concern for building owners. Selecting an approach that reduces insurance premiums is an important design consideration, as in the United States, not all measures will reduce premiums paid under the NFIP.

Triggering other legal requirements. Changing grades or building access may affect buildings' compliance with the Americans with Disabilities Act and require additional modification, which can add cost.

Active versus passive solutions. When considering flood protection systems, choosing "passive" options that do not require time and labor to deploy can help ensure that buildings are not caught by surprise floods and activation costs remain low.

Project Profiles

Asset to Portfolio to Neighborhood Scale

Asset: 701 Brickell, Miami—Nuveen Real Estate

Miami, one of the most at-risk coastal cities in the world, has a long history of preparing for hurricanes. Nuveen Real Estate, owner of 701 Brickell, has embedded climate resilience in its long-term ESG strategy and invested in a number of floodproofing steps at this coastal skyscraper from bottom to top.

Retrofit strategies include installing custom flood barriers, elevating transformers within basement electrical rooms, replacing the building's original generator, caulking windows and replacing sealant on building facades and balconies, and repairing and strengthening facade panels.

Though flood barriers are essential for protecting lower floors from floods, window and facade treatments are key in regions with wind-driven rain. If water seeps into building materials through unsealed windows, resulting mold issues can be difficult and expensive to remediate.

Nuveen's total investment for this asset is about $1.6 million, with the return on investment tied to future-proofing the building and meeting market demands. Most directly, the improvements reduce repair and maintenance costs associated with minor flood events that insurance deductibles would not necessarily cover. In addition, key stakeholders such as insurers, lenders, tenants, and future buyers expect increased transparency on climate-related risks and value owner investments in building resilience. Overall, these improvements elevate a building to a new market standard that requires similar resilience measures to mitigate exposure to regional climate risks.

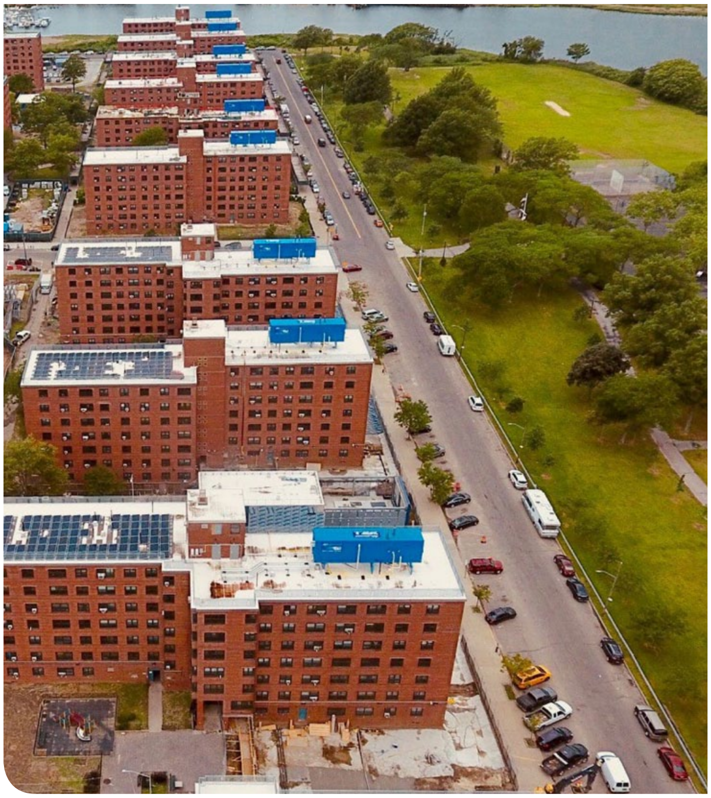
701 Brickell, Miami. *(Daniel Christensen, CC 3.0)*

Portfolio: New York City Housing Authority (NYCHA)

Since being severely damaged by Hurricane Sandy in 2012 and receiving a record $3 billion in federal recovery funds, NYCHA has been working to retrofit 35 Sandy-damaged public housing developments and integrate resilience to all climate hazards into capital work across its portfolio of over 300 campuses, which serve over 400,000 residents.

NYCHA's *Climate Change at NYCHA* details the benefits and challenges seen from various retrofit steps taken to protect buildings and residents from coastal flooding, including

- Installing new, efficient boilers
- Installing backup generators at 200 buildings



Relocated mechanical equipment (blue) accompanies new solar panels. *(Flood Resilience at NYCHA)*

- Protecting critical equipment by sealing mechanical rooms with flood doors/barriers, relocating generators onto the roof, or building new, raised annex buildings
- Floodproofing, including installing deployable, active flood barriers for windows and doors at 22 developments, passive barriers at 11 developments, and wet floodproofing at 6 developments

NYCHA's experience working at scale in occupied buildings carries important lessons on the tradeoffs inherent in various retrofit approaches (e.g., deployable barriers are cheaper than passive barriers but require trained staff to activate) and the importance of working with tenants. Joy Sinderbrand, NYCHA's vice president of recovery and resilience, notes the importance of resident buy-in to disruptive projects—which sometimes requires staff to go door-to-door—since resident cooperation is critical. For example, a crane lifting generators onto roofs is possible only when tenants are willing to vacate upper floors temporarily.

Neighborhood: HafenCity, Hamburg

Hamburg, a port city in northern Germany, has long been adapting to flooding due to its location along the Elbe River, which experiences storm surges coming inland from the North Sea. HafenCity, a redeveloped and partially artificial island in the river, is a showcase for neighborhood-scale resilience strategies, including retrofits.

The island's primary adaptation strategy was to elevate most of the land roughly eight meters (26 feet) above high-tide lines (a millennia-old Dutch technique known as a *terp*) and to construct resilient new buildings atop the higher ground. However, the island is also home to UNESCO-protected red-brick warehouses from the 1880s, which cannot be elevated.

To ensure that these structures are protected, lower floors received floodproof windows and other hardening measures. Perhaps most impressive, however, given the likelihood of submersion, elevated pedestrian bridges were added that run the length of multiple blocks of buildings, and exits were built in on the second levels of buildings to ensure that occupants could exit safely in the event of a major flood.

This method knits together building- and neighborhood-level retrofits to ensure greater access and mobility than building strategies alone can provide.

Access to historic buildings during flood events is maintained via connected, raised walkways.

(Midtown Equities)

Quick Wins to Protect Buildings: Deployable Flood Walls

Deployable flood walls, like the Aqua Fence, are a popular strategy for many real estate owners because they do not require extensive building modifications. Though they are not technically retrofits, this strategy can be more quickly installed than structural floodproofing and does not leave a permanent visual impact on the building, making them a helpful short-term operational solution as more intensive and enduring approaches are considered.

Companies such as New World Development, Commonwealth Properties, and Parkway have successfully implemented this technique. Commonwealth, in particular, notes that, among the benefits, its Aqua Fence system requires eight hours, several full-time equivalents, and a Bobcat to deploy: these temporary barriers present some challenges about access for heavy machinery, staffing, and the advance warning required before a flood.

Seismic Risk/Earthquakes

The links between worsening climate change and earthquakes are less well understood than the other risks in this primer; however, the process of assessing threats to buildings and safety and developing retrofit strategies is similar across hazards. In addition, some evidence shows that alternating cycles of drought and heavy precipitation, large-scale withdrawal of groundwater for industrial operations, and activities associated with hydraulic fracturing—all of which have climate implications—may affect local seismic activity.

Seismically active regions—especially in the western United States—have some of the longest-running public-sector building retrofit programs to speak of and can therefore provide a wealth of lessons for effective design, policy, and funding strategies.

Retrofit strategies focus on (a) strengthening resistance to shaking among structural components or the entire building, (b) reducing the amount of shaking the building experiences, and (c) ensuring a continuous load path for transferring energy safely through the structure. A selection of retrofit strategies is listed in table 3; the following design guidelines have more information:

- *Resilience-Based Design Initiative (REDi) Rating System for Earthquakes*, Arup
- *Techniques for the Seismic Rehabilitation of Existing Buildings*, FEMA
- *Reducing the Risks of Nonstructural Earthquake Damage—A Practical Guide*, FEMA

Table 3. Retrofit Strategies for Seismic Risk/Earthquakes

Soft-story/weak-story building retrofits	Buildings whose first floors lack adequate structural strength or stiffness—such as mixed-use residential buildings with first-floor storefronts or parking—are vulnerable to collapse during an earthquake because of wider openings and fewer partition walls. San Francisco, Berkeley, and Los Angeles, which are home to thousands of this building type, have mandated retrofits for these structures. Additional bracing—whether through moment frames, shear walls, or fasteners—that reinforces the structure can provide enhanced stiffness and stability. See FEMA's and Simpson Strong-Tie's design resources on this specific retrofit type for more detail.
Unreinforced masonry (URM) building retrofits	URM buildings (a historic, preseismic building code construction method in which walls [load-bearing or not] consist of brick, cinder block, or other masonry material that lacks reinforcement, such as through rebar) are highly vulnerable to collapse or "peeling off" of exterior masonry walls during earthquakes. Retrofit approaches: • Reinforcing URM columns or walls with fasteners or materials that increase shear strength, such as shotcrete, fiber-reinforced polymer, or textile-reinforced mortars • Anchoring URM walls to the roof or floors with fasteners • Bracing parapets and chimneys (chimneys may require replacement or removal) • Reinforcing large openings with special moment frames • Fastening URM veneer wythes to backing wythes for exterior walls • Adding new foundation elements to URM walls, such as concrete slabs and footing with enhanced reinforcements See Simpson Strong-Tie's resources on URM buildings for more detail.

Table 3. Retrofit Strategies for Seismic Risk/Earthquakes continued

Unreinforced masonry (URM) building retrofits (continued)	**Co-benefits and tradeoffs: URM buildings are also vulnerable to high winds, and these retrofits may address both risks.** **In addition, envelope retrofits for URM walls that include both reinforcing material and insulation, such as textile-reinforced mortar, can also boost resistance to extreme heat and wildfire depending on the material.** **Higher use of traditional concrete and steel, however, may add to a building's embodied carbon if low-carbon options are not specified.**
Nonductile concrete building retrofits	Nonductile concrete buildings—older structures built without sufficient reinforcement to withstand lateral shaking during earthquakes—are vulnerable to crumbling or collapse. Structural evaluation is required to determine whether a building fits this category. Retrofit approaches may include • Reinforcing concrete columns to provide additional stiffness • Adding bracing, concrete shear walls, or base isolation (see below), new steel moment frames • Strengthening specific structural components
Brace-and-bolt retrofits	Brace-and-bolt retrofits are a simpler technique for smaller wood-frame residential buildings on raised foundations, which are vulnerable to sliding off the foundation during earthquakes or the collapse of "cripple walls"—short walls between the frame and foundation. This low-tech, low-cost retrofit braces these walls with wood or bolts the frame to the foundation. Some programs, like California's Earthquake Brace + Bolt (EBB) program, also require water heaters to be strapped and braced to prevent gas or water line leaks and damage. See California's EBB program for more detail or Simpson Strong-Tie's guide to conducting this retrofit.
Base isolation	Base isolation reduces the amount of shaking that a building experiences by severing the building's connection to its foundation and adding steel or reinforced concrete beams above isolating pads, which then separate the building from shaking ground during earthquakes and allow the base to vibrate while the building remains steady. This technique allows the avoidance of upgrading nonstructural components.
Supplemental dampers	Dampers can act as shock absorbers for excess motion energy or counteract force by acting as a counterweight, as in a pendulum. Counterweights are known as tuned mass dampers and often take the form of heavy balls on springs set into upper floors or as slosh tanks with high volumes of liquid, sometimes on roofs, both of which move back and forth counter to building vibrations during earthquakes. These systems do not work as well in a building that is already stiff, as dampers act as a brace and connect floors that need to move based on dampers. Moment frame buildings with steel or concrete columns have greater flexibility and are well-suited for dampers.
Nonstructural retrofits	According to FEMA, "Nonstructural failures have accounted for the majority of earthquake damage in several recent U.S. earthquakes." These elements include architectural components, such as interior partitions or veneers, ceilings, or chimneys; mechanical, electrical, and plumbing equipment, such as water heaters, ductwork, or piping; and even furniture, such as bookshelves or storage. These elements require securing or retrofitting to avoid causing significant damage.

Considerations and Challenges

Complexity. Seismic upgrades range from simple, affordable techniques to better secure structures to their foundations, such as the brace-and-bolt retrofit described previously, to highly complex and invasive targeted or comprehensive retrofits for which costs can approach as much as 80 percent of the building's replacement value, in which case it may be more cost-effective to replace the structure entirely. As Arup notes in a seismic vulnerability and retrofit analysis completed for the University of British Columbia, targeted retrofits that reduce vulnerability to select structural components cost less and are potentially less invasive than whole-building retrofits. However, they may not achieve the same benefits and in some cases can introduce new problems as the hierarchy of possible failure points shifts from the previously weakest points in the structure, which are strengthened by retrofits, to other vulnerable locations that are not mitigated.

"If you are in a seismically active region, it would be hard to achieve resilience without incorporating seismic energy elements like base isolators or dampers. While I've seen the 'brute force' approach with many walls put in to make [the building] stiffer . . . this can actually increase acceleration on floors and damage nonstructural components such as piping, elevators, and facades. If those components are damaged, the building can't be utilized. Solving structural-only issues on a retrofit might introduce some issues that will keep you from achieving resilience goals."

—Ibbi Almufti, associate principal and risk and resilience practice leader, Arup

Exterior braces can help reinforce buildings against seismic risks.

Considering nonstructural components. Traditional seismic approaches to increase building stiffness can exacerbate stress on nonstructural components, which may then require additional bracing that raises cost. Addressing nonstructural vulnerabilities is a current gap in structural engineering for seismic risk.

Combining seismic and other retrofits. Because of the need to address major structural issues, seismic retrofits can be a timely opportunity to address other risks—for example, by installing flood vents or insulated facades—to help drive greater value. There may also be additional co-benefits beyond savings; for example, electrification retrofits that transition the building from gas to all-electric HVAC and cooking systems ensure that gas lines cannot cause explosions or fires after earthquakes if not automatically shut off. In addition, new techniques for seismic retrofits that rely on wood, such as cross-laminated timber, can provide greater structural strength while contributing less to a building's embodied carbon. For more detail, see ULI's *Electrify: The Movement to All-Electric Real Estate* and *Embodied Carbon in Building Materials for Real Estate* reports.

Moment frames (red column) can be added to reinforce soft stories.

Soft-Story Buildings

The U.S. Resiliency Council's story map on soft-story buildings presents the risks and opportunities for retrofitting in Southern California. Learn more.

Project Profile

Orizuru Tower, Hiroshima

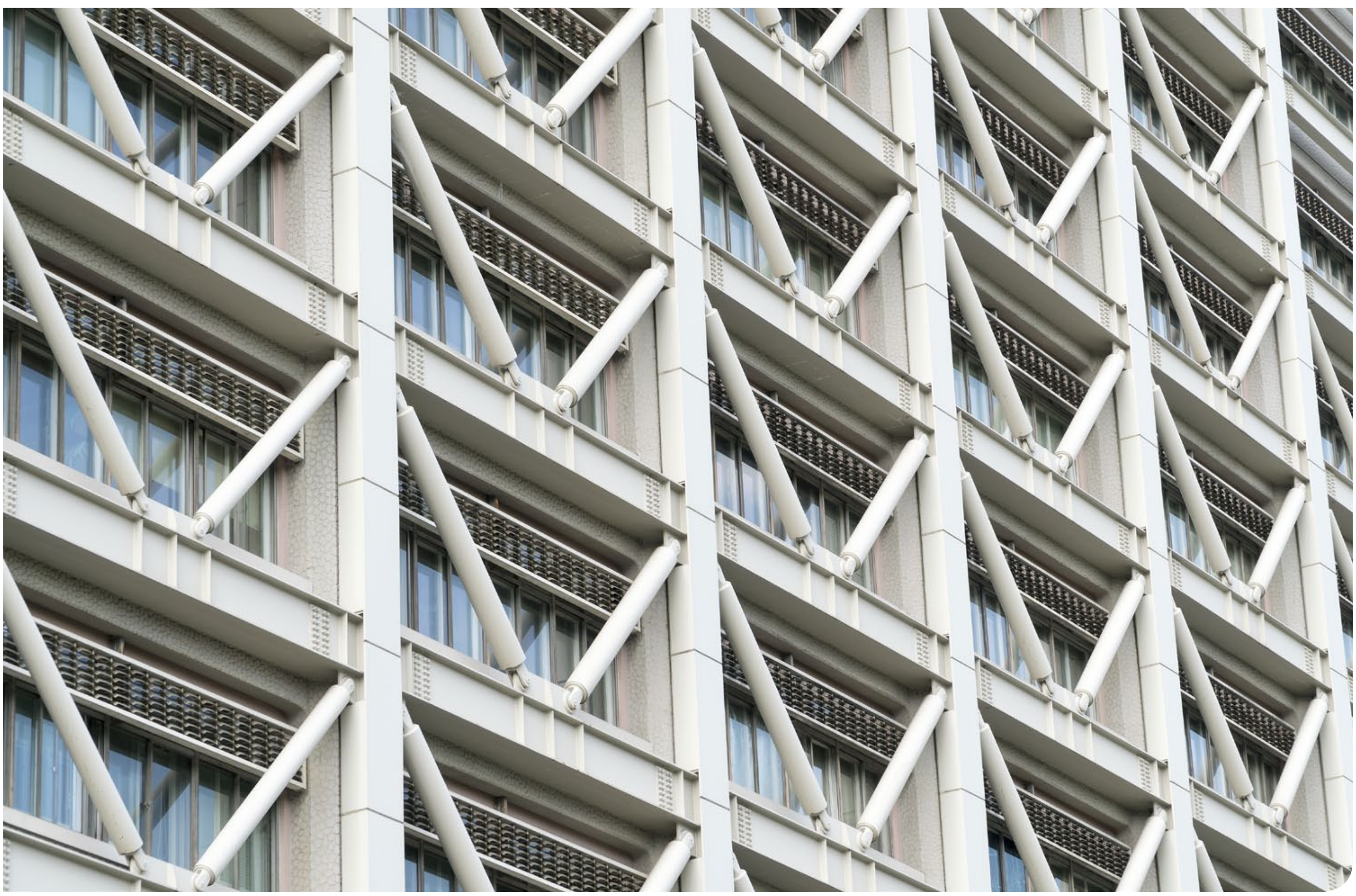
Orizuru Tower, a mixed-use office tower in Hiroshima, Japan, built in 1978 and retrofitted for reopening in 2016, overlooks the city's Peace Memorial Park and Atomic Bomb Dome. The 14-story tower combines offices with a first and top floor that are open to visitors, with perhaps the most signature feature being an open-air observation deck that looks over the park and dome and a wall of paper cranes that have become an important peace symbol, and a main tourist draw for the city.

With an original steel-embedded reinforced-concrete structure that did not meet seismic capacity under newer building codes, engineering and design firm Arup worked with local office Sambuishi Architects

to retrofit the building for earthquake risk. The existing building framing was connected to a new reinforcing-steel framing with high-tension steel bars, while new spirally sloped staircases and extended balcony on the east and west sides of the building, respectively, act as reinforcing elements as well. A new pile foundation was added to one portion of the building to transfer loads directly into the ground. Finally, to lighten the structure, its heavy concrete walls were replaced with lightweight facade elements. Seismic performance is now 1.5 times the capacity required.

In addition, the project combined seismic retrofits with energy efficiency and adaptations for extreme heat through passive design. In response to a study of prevailing winds and modeling fluid dynamics, new facade openings were sited to maximize natural ventilation, providing a cross-breeze for office spaces that provides cooling and connects occupants to the outdoors, rather than relying on energy-intensive air conditioning.

Orizuru Tower's success as a new historic and cultural icon that attracts significant tourism demonstrates both the value of retrofitting older structures with the potential to become unique assets, and the opportunities for linking retrofit approaches across different risks for greater co-benefits.



Storms and High Winds

High winds, whether from hurricanes, thunderstorms, tornadoes, or other storms, can cause damage by directly affecting structures and by exposing structures to water intrusion. Addressing wind vulnerability therefore goes hand in hand with flood retrofits to ensure that structures can withstand strong storms.

Wind retrofit strategies emphasize strengthening impact resistance from windborne debris and improving structural stability against wind loads coming from multiple directions—whether uplift on the roof or laterally on walls. Weak points in a building's envelope, even from seemingly minor openings like garage doors, can cause significant damage if left unaddressed. A selection of retrofit strategies is listed in table 4; the following design guidelines have more information:

- *FORTIFIED Construction Standards*, Insurance Institute for Building & Home Safety (IBHS)
- *Wind Retrofit Guide for Residential Buildings* and *Successfully Retrofitting Buildings for Wind Resistance*, FEMA
- *Resilience-Based Design Initiative (REDi) Rating System for the Next Generation of Buildings: Extreme Windstorms*, Arup

Storm shutters (above) and strong roof material (top of page) provide impact resistance against windborne debris.

Table 4. Retrofit Strategies for Storms and High Winds

Impact-rated windows and doors, including skylights; wind-rated garage door	Replacing windows and doors, especially roll-up or garage doors, with models rated for impact ensures that they can resist damage from windborne debris. Installing wind-rated garage doors can also provide additional protection to withstand wind pressure. Though an operational solution, all external and internal doors should be closed before a storm arrives—closing internal doors can singlehandedly reduce wind loads on roofs by up to 30 percent, according to the IBHS. **Co-benefits and tradeoffs: Higher-performance windows help reduce energy use and costs, and depending on their make, may include tempered glass that reduces vulnerability to wildfire.**
Storm shutters	Storm shutters for windows provide additional protection or an alternative to impact-rated windows. A variety of designs exists. Plywood should only be used as a last resort before a storm if no other options are available and should be at least ¾-inch thick. **Co-benefits and tradeoffs: Storm shutters can also be used as an external shade device to reduce solar heat gain, improving resilience to extreme heat while lowering energy costs.**
Sealed windows and exterior walls/roofs	Ensuring that windows are tightly sealed helps prevent intrusion from wind-driven rain, which can cause extensive damage. Sealing any other cracks or gaps in the building will also be helpful. **Co-benefits and tradeoffs: A more tightly sealed building envelope will also improve resilience to extreme temperatures and reduce energy costs.**
Roof-to-wall, wall-to-wall, and wall-to-foundation connections	Connecting all structural elements with hurricane ties, clips, straps, and additional connectors/fasteners creates a continuous load path that transfers force safely into the building's foundation. **Co-benefits and tradeoffs: This technique is also essential in seismic zones.**
Strengthened/sealed roof deck	Strengthen connections between the roof deck and trusses/rafters with additional fasteners. **Co-benefits and tradeoffs: The roof deck can also be sealed with flashing tape over joints, covering the roof with a water-resistant membrane or wind-resistant underlay to resist water intrusion.**
Wind-rated roof material	Ensure that roofing materials are rated for wind and impact resistance, whether asphalt shingle, metal, or an alternative. **Co-benefits and tradeoffs: Impact-resistant roofs also protect against hail, and Class A roof materials will also help protect against wildfire damage. Although an important strategy for extreme heat and stormwater management, green roofs may not be suitable for wind-prone regions without special design approaches, as in the green roof developed for the University of Miami.**
Secure rooftop equipment	Building mechanical systems, such as HVAC or solar panel equipment, should be securely attached to the roof with straps or other fasteners.
Backup on-site power (e.g., solar plus battery storage)	Backup power ensures that the building remains comfortable in the event of a larger power outage. On-site renewable energy, such as solar panels and battery storage, ensures that this power source is low carbon and protective of local air quality—unlike common alternatives, such as diesel generators.

Considerations and Challenges

Residential versus commercial strategies. Some structural wind retrofits, such as improved roof-to-wall connections, are more applicable to smaller residential structures. Commercial buildings may benefit more from focusing on addressing water intrusion from wind-driven rain through roofs and windows and the impact resistance of windows and curtain walls, especially when glazing composes a high percentage of the building envelope.

Addressing low-hanging fruit. Often, simple, low-cost retrofits that improve connections between roofs, walls, and foundations, discussed earlier, with small fastening equipment can have a major impact by creating a continuous load path—a means of transferring wind forces safely through the building. Fortunately, this technique is also highly applicable to earthquake-prone regions and will increase resilience to both risks.

Designing to various levels of protection. Owners and designers should consider how comprehensive a "package" of retrofit solutions to implement. One way of categorizing escalating protections for buildings is demonstrated by the FORTIFIED construction standard, an above-code approach developed by the IBHS that addresses vulnerabilities to high winds, hail, hurricanes, and tornadoes for both commercial and residential structures. FORTIFIED has certification levels (Roof, Silver, and Gold) that accumulate protection: first, addressing roof vulnerabilities; then, adding in impact-rated doors, windows, walls, and protected mechanical, electrical, and plumbing equipment; and finally, ensuring that the building has a verified continuous load path.

Clips help secure roofs to walls, increasing resistance to winds and earthquakes.

Project Profile

Resilient South Florida Resort

Redevelopment—somewhat distinct from retrofits completed during tenant or owner occupation given the greater flexibility in design—is an ideal time to enhance resilience to physical risk. Recognizing the high risk posed by hurricane winds and storm surge, a resort in South Florida in the midst of redevelopment several years ago embarked on a comprehensive set of resilience upgrades to ensure that the resort could remain operational in the event of a major storm. Upgrades included

- Installation of hurricane-rated windows and doors throughout the property, with large missile impact–resistant glass on levels up to 30 feet and small-missile glass above 30 feet
- Fortification of the property cooling towers with a steel enclosure to protect from wind and storm-surge debris
- Procurement of five emergency generators with a 2,000-kilowatt capacity that are strategically placed after an event to provide electrical service
- Installation of a 20,000-gallon underground diesel fuel tank to run the emergency generators for up to 10 days
- Relocation of the property's electrical infrastructure to an elevation of 20 feet, well above storm-surge height, to protect critical electrical components—switchgears, transformers, and electrical panels

The owner estimates that its resilience investments boosted the insurable value of the property by 50 percent, lowered annual insurance premiums by about $500,000, and save about $110,000 per year as the impact-resistant windows are energy-efficient low-E rated.

Water Stress/Drought

Drought is a long-term "stress" event, rather than a single "shock" event like a storm or heat wave, caused by prolonged decreases in precipitation. Water shortages affect building operations and quality of life by increasing the utility costs of water or, in dire cases, making water unavailable for drinking, plumbing, or mechanical processes. Drought conditions are worsened by climate change's increasing temperatures, which encourage evaporation from soil; accordingly, drought can also exacerbate wildfire risks and flood risks from infrequent, sudden rain (hard, dry soil is less absorbent and can cause flash flooding).

The western United States has been experiencing what is known as a mega-drought for several years, and the World Health Organization estimates that water scarcity already affects 40 percent of the global population, and up to 700 million people are at risk of displacement by drought by 2030. Some areas severely affected by drought are even briefly banning new development until water supplies are more consistent—retrofitting in these cases ensures that markets can continue to grow. (See ULI's report *Water Wise: Strategies for Drought Resilient Development* for more on the impacts of and management strategies for drought in real estate.)

The primary building retrofit approaches for drought focus on replacing fixtures with water-efficient options, which are cost-effective in any region. On-site water reuse systems like graywater and rainwater harvesting may have a role as well, with co-benefits for managing flood risks; however, these systems are more difficult and expensive to install in existing buildings, though costs may be decreasing as technology options increase. Selected water stress retrofit strategies are presented in table 5; the following resources have more information:

- *Water Reuse Practice Guide*, William J. Worthen Foundation
- *Resilience Strategies for Drought*, Center for Climate and Energy Solutions

Table 5. Retrofit Strategies for Water Stress	
High-efficiency fixtures	Fixtures for toilets, showers, faucets, and urinals can be replaced with options that use less water, such as those labeled with the EPA's WaterSense program (similar to the Energy Star label). Some water utility providers may offer rebates for installing these systems. **Co-benefits and tradeoffs: Water-saving fixtures also reduce energy use, cutting multiple utility costs.**
On-site water reuse systems	Consider installing systems to reuse water from a variety of sources, whether rainwater (for which even a collection barrel or cistern attached to downspouts is effective) or a more complex system that taps into plumbing systems. New technologies that aim to process and reuse water from various sources, whether graywater (such as used sink water or process water from dishwashers and washing machines, air-conditioner condensate, etc.) or blackwater (water with biological waste) are being developed, and with careful planning, can be retrofitted into existing buildings. **Co-benefits and tradeoffs: These systems can sometimes be integrated as part of a green roof. In addition, water reuse systems can reduce stormwater runoff, decreasing flood risks, and may in some cases be able to provide water if a natural hazard event disrupts utility water supplies.**

Considerations and Challenges

Public health and regulation. Use of on-site water systems is highly regulated because of public health concerns, and regulation differs from state to state in the United States as no federal regulatory system exists. Regulatory and code compliance is a key consideration for developing on-site water systems; new policy frameworks are being developed in some cities, such as Los Angeles, New York, and Boston. San Francisco already requires some large new buildings to include on-site water reuse systems, helping build market demand for new technologies and service providers. However, projects in other locations may need to work with local government to undergo custom permitting for these systems.

Existing infrastructure. Extensive water reuse systems must be connected to existing plumbing infrastructure, which means they can reduce strain on municipal sewer and wastewater treatment systems; however, they also add complexity for project design and engineering. However, companies like Epic Cleantec are developing on-site water recycling technologies for commercial and multifamily buildings that claim to reduce water demand by up to 95 percent and energy consumption by up to 40 percent by simultaneously treating water and recovering heat to produce energy while simplifying the construction, permitting, and maintenance process.

Project Profile

1455 Market Street, San Francisco, Hudson Pacific Properties

Water comes from unexpected places, and with some ingenuity, can be put to good use to reduce strain on public drinking water. At 1455 Market Street, a 1978 building formerly home to a Bank of America data center and now host to additional tenants like Uber and Square, owner Hudson Pacific Properties began noticing issues with groundwater intrusion. Normally, groundwater intrusion can cause damage on its own and contribute to compound flooding (when combined with heavy rain or sea-level rise, for instance). However, engineers developed a system to capture and treat the water and direct it into the building's cooling system for use as process water, rather than discharging it into city storm or sewer systems. This method has been able to capture 2 million gallons per year, offsetting almost 15 percent of the potable water previously used for the building's cooling system.

Wildfire

As wildfires grow in frequency and severity with the likelihood of affecting new places, preparing for their impact will be essential in many regions previously unused to their destructiveness. The strongest wildfire-resilience approach combines building retrofit strategies with site- and neighborhood-scale landscape management. For an overview of the broader approaches to wildfire resilience, see ULI's report *Firebreak: Wildfire Resilience Strategies for Real Estate*.

Retrofit strategies focus on hardening the building's envelope to render it less susceptible to ignition. Many involve reducing the combustibility of materials and the entry of embers, which can travel miles ahead of a wildfire. In addition, regular maintenance protocols are essential, as accumulated debris (like leaf litter) or materials stored around the building are common sources of ignition.

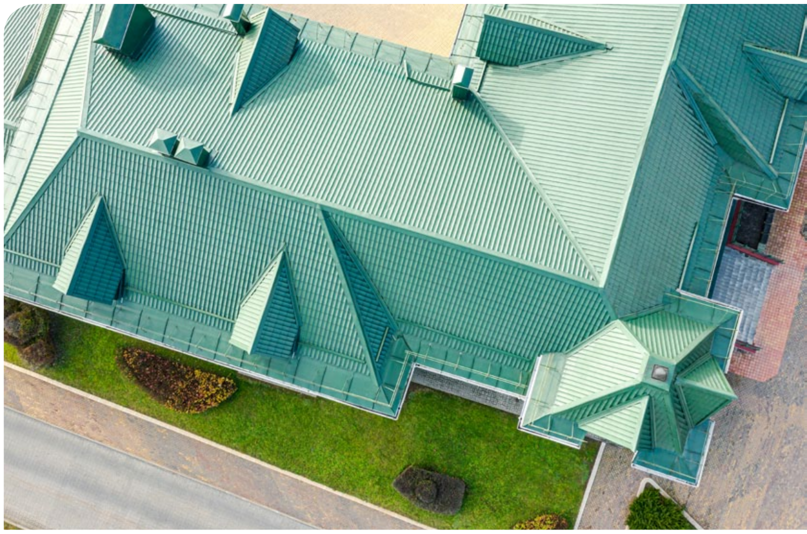
Selected wildfire retrofit strategies are presented in table 6; the following resources have more information:

Regional Wildfire Retrofit Guides, Insurance Institute for Business & Home Safety

Wildfire Home Retrofit Guide, University of Nevada, Reno

"For wildfires, we need to think of the building as [a system] of multiple components, those being the roof, the walls, the windows, the vents. . . . When we think about retrofitting the structure against the hazard, we need to think about clusters. A good example would be the siding of the wall, the windows, and the eave."

—Daniel Gorham, research engineer, Insurance Institute for Building & Home Safety



Fiber cement siding can be made to resemble wood and provide fire resistance (left); metal or tile will also protect roofs from ignition (right).

Table 6. Retrofit Strategies for Wildfire

Wildfire-resistant roof **(Class A under the ASTM E108/UL 790 standard)**	Roofs are rated from Class A to Class C, with Class A providing the greatest protection. Many commercial roofing materials are already rated Class A, like stone-ballasted single-ply membranes, or asphalt shingles, clay, slate, concrete tile, or metal. Roof replacement projects should target Class A materials, as roofs are one of the most vulnerable aspects of the building envelope. **Co-benefits and tradeoffs: Class A roofs may also help protect against impacts from wind-driven debris and hail.**
Tempered insulating glass windows and deployable, noncombustible shutters	Single-pane annealed glass windows are vulnerable to shattering in the extreme heat of a wildfire, exposing the building interior. Replace them with multipane tempered glass, which is three to four times more resistant to heat exposure. Consider adding shutters as an additional layer of protection in densely developed areas. **Co-benefits and tradeoffs: Installing double-paned windows also improves energy efficiency, lowering utility costs and increasing resilience to extreme temperatures.**
Noncombustible cladding and exterior doors	Combustible cladding/siding such as wood and vinyl are common in multiple building types and are highly vulnerable to catching fire. They can be replaced with concrete, fiber cement, stucco, brick/masonry, metal, or wood treated with fire retardants. FEMA also recommends replacing exterior insulation finish systems. **Co-benefits and tradeoffs: Some cladding systems, such as fiber cement and concrete, are higher in embodied carbon.**
Exterior wall insulation (nontoxic) and airtightness	Enhancing exterior wall insulation may reduce heat transfer to the interior of the building during wildfires. Adding insulation is easily combined with replacement of siding or cladding. In addition, natural materials for insulation, such as hay bale, wool, or hempcrete, are all fire-resistant or fireproof, and will not release toxic byproducts when burned. Tightly air-sealed buildings are less vulnerable to the intrusion of smoke from wildfires, a key health risk that spreads far beyond the wildfire area. **Co-benefits and tradeoffs: Enhancing building insulation and air sealing can drastically reduce heating and cooling energy and costs and also increase resilience to extreme temperatures.** **Natural insulation materials also reduce embodied carbon, and in some cases, even sequester carbon (such as hay bale insulation).**
Ember-resistant vents	Metal screens on building vents, of one-eighth inch or finer, are critical to restricting the entry of embers. Screens are a highly important, low-cost retrofit that will make a significant difference in a structure's wildfire resilience. Consider vents for cooking, HVAC systems, etc.
Gutter covers	Install noncombustible gutter covers that are parallel to the slope of the roof, where possible, so ignitable debris does not build up.
Noncombustible walkways, balconies, decks, stairs, fencing	Building exterior access features or attached structures, such as fencing, should be replaced with metal or lightweight concrete if available, or plastic composite or hardwood if not.

Table 6. Retrofit Strategies for Wildfire continued	
Enclosed/soffited eaves	Eaves should be enclosed with noncombustible soffits, as they are vulnerable to ember entry. In addition, heat can build up below and cause combustible material to ignite.
Flashing at roof-wall intersections and base of wall	Roof-wall intersections (e.g., where dormers are located) create corners in which embers can ignite accumulated debris, as can the base of walls where they meet the ground. Noncombustible flashing installed at these points can reduce combustibility.
Enhanced air filtration	To reduce the health risks from smoke infiltration and poor air quality, consider installing high-performance air filters, such as MERV 13 or higher, in ventilation systems. Note that higher-performing air filters may raise operational energy usage. **Co-benefits and tradeoffs: Enhanced air filtration and better air quality have broad-reaching health benefits, including mitigating rising air pollution from extreme heat and risks of viral transmission from COVID-19.**
Backup on-site power (e.g., solar plus battery storage)	Backup power ensures that the building remains comfortable in the event of a larger power outage. On-site renewable energy, such as solar panels and battery storage, ensures that this power source is low carbon and protective of local air quality—unlike common alternatives, such as diesel generators.

Considerations and Challenges

Aesthetics. Some property owners do not prefer the look of some noncombustible materials, such as fiber-cement siding. However, options exist that closely mimic the look and feel of traditional wood cladding but offer much higher protection.

Prioritization and incremental costs. Many smaller property owners may face financial challenges in implementing numerous retrofit strategies. Addressing the most vulnerable parts of the building can help prioritize strategies. For example, if cost is prohibitive for replacing the entire siding, owners can swap in matching noncombustible options or flashing for the first several feet above grade to minimize expenses. Similarly, choosing resilient options or additions during normally scheduled renovations is key—for example, if already planning a roof replacement, it would be prudent to address gutters, vents, and any roof-wall flashing simultaneously, for a smaller incremental cost increase. Similarly, rather than replacing an entire wood deck or other extension, the area closest to the building can be replaced with metal grates or another noncombustible option.

Tradeoffs with energy efficiency and carbon emissions. Many wildfire resilience strategies enhance building energy efficiency and reduce emissions, like higher-performance windows and building envelopes. However, some material choices—such as greater use of cement and concrete—may contribute to much higher embodied emissions. Careful material selection can ensure that multiple goals are met. In addition, solar panels can create opportunities for debris accumulation that must be cleared regularly.

Building surroundings and density. In denser urban areas where structures are closer together, or less dense areas where the landscape is heavily vegetated, buildings are at greater risk and greater levels of protection may be required. For example, tempered-glass windows and noncombustible siding become more important in dense areas.

Dual-pane, tempered-glass windows are essential for fire resistance.

Unique building vulnerabilities. As with all retrofits, each building must be approached individually. With wildfire risks, for example, buildings with complex roof shapes with many corners are more vulnerable to debris accumulation and ember ignition, as are commercial buildings with flatter roofs and more rooftop equipment, such as solar panels or HVAC systems. Addressing the specifics of the building type is essential to reducing its vulnerability.

Project Profile

Single-Family Home, California

Steve Quarles—a University of California Cooperative Extension adviser emeritus, former chief scientist for wildfire and durability at the IBHS, and resident of a wildfire-prone region in California—has put his knowledge on buildings and wildfire resilience to use for his own single-family residence. Occupying a 1965 home in a lower-density area, Quarles has been slowly upgrading over time to increase the structure's resistance to ignition, beginning with replacing windows with dual-pane, tempered-glass windows with metal-clad frames, noting that the cost for tempered glass has come down since its installation in the mid-2000s.

Later, after a decision to add solar panels and realizing they would outlast the existing roof—indeed, Quarles notes, "roofs tend to wear out quicker than any other part of a building," and are key sources of vulnerability—the existing Class A asphalt composite-shingle roof was upgraded to a more durable standing seam steel roof (also Class A). Installation of the metal roof also included installation of an additional fire-resistant underlay. Higher-quality gutter covers were also installed, as were fire- and ember-resistant vents on certain sections of the roof; the main roof section already had an unvented design.

A siding replacement was unnecessary because of the building's distance from other buildings, though an intermediate option would be to replace the siding on the one wall close to a neighboring home. Besides greater peace of mind, these retrofits also had aesthetic benefits, as well as energy savings when the dual-pane windows were installed. Though a single-family home differs in scale from a large commercial or multifamily building, many of these same steps would apply across property types.

Policy: Planning for Resilient Retrofits

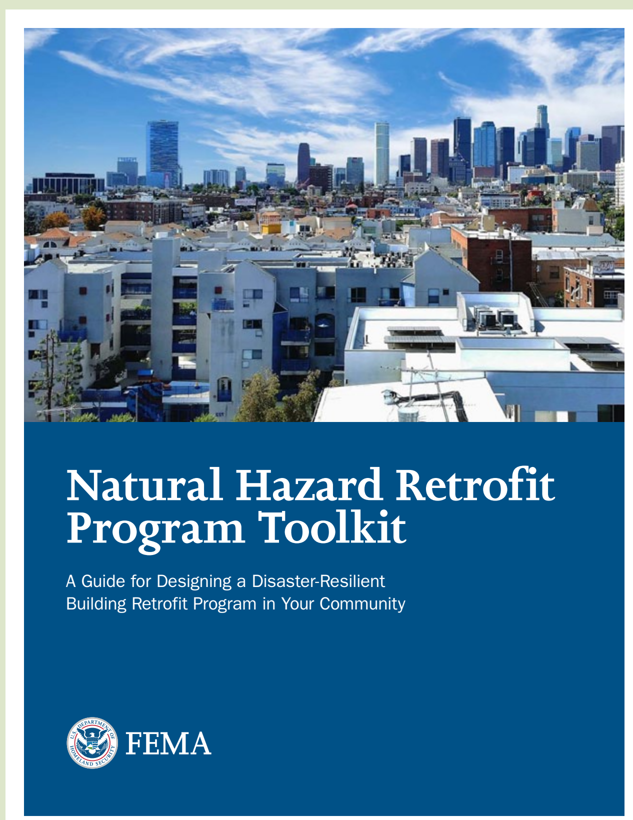
Although retrofit policies for specific risks exist in certain regions of the United States, most jurisdictions have yet to develop public policies and plans that cover all buildings at risk from all hazards.

Without a systematized approach that combines incentives and mandates, resilient retrofits remain limited in scope. Uncertainty regarding both the specifics of climate risks across geographies and investment horizons and what the private sector may eventually be required to do when retrofitting buildings creates reluctance to begin the process proactively. To meaningfully scale up implementation, a comprehensive policy and planning approach is necessary to provide structure and lay out guidelines, standards, and technical assistance that real estate owners can draw on.

Despite these obstacles, early iterations of retrofit policies can provide guidance. This section discusses several barriers that must be addressed to increase the effectiveness of retrofit policies and provides several examples of resilient retrofit policies already in place.

FEMA's Natural Hazard Retrofit Program Toolkit

Designing a new retrofit policy or program is a daunting challenge for many governments, given the scale and complexity of the issue. FEMA's *Natural Hazard Retrofit Program Toolkit* provides initial guidance and lessons learned based on case studies and interviews with retrofit programs around the United States. The toolkit lays out a six-step process for identifying risks and vulnerabilities, assessing built environment contexts, determining funding sources, and designing, preparing for, and implementing the program.



Policy Barriers: Equity, Data, and Existing Requirements

Social equity is a core challenge for resilient retrofit policy. For example, in the United States, low-income and BIPOC communities are frequently most exposed to compound risks, such as flooding, extreme heat, and poor housing quality. These communities also experience restricted financial and political resources because of structural inequalities and racism, such as historic and current disinvestment and exclusion from decision-making, as covered in ULI's 2021 *Environmental Justice and Real Estate* report.

Retrofit-related equity issues—such as the threat of accelerated displacement from rising property values, the inability to comply with costly regulations, or the lack of access to funding, expertise, and time to conduct retrofit projects—must all be incorporated into policy development. Unless potential impacts on historically marginalized communities are addressed and authentic community engagement informs regulation, policymakers risk failure in passing new legislation. This type of blockage occurred with a recent seismic retrofit requirement ordinance in Portland, Oregon, that was halted because of community pushback that feared rising rents and impacts on culturally significant buildings, such as churches in African American neighborhoods.

Data availability and logistics of policy/program management are also essential barriers. Retrofit policies require city governments to obtain detailed information on the characteristics and vulnerabilities of local building stock to all current and projected climate hazards, which smaller communities may not possess or be able to collect. Ensuring that city staff is available to manage communication, outreach, and technical assistance and to connect owners to financing is also a significant hurdle.

Existing policy can also add roadblocks to retrofitting. For example, zoning requirements like height restrictions, lot-line or setback requirements, placement of mechanicals, or floor/area calculations can prevent owners from elevating or building roof additions to offset the loss of usable first floors because of flood risk, adding thicker insulation and facade materials to resist extreme temperatures, or locating mechanical equipment on roofs or side yards out of flood zones. Amending zoning codes can be politically difficult and time-consuming. In addition, as mentioned earlier, historic preservation regulation can also create significant barriers for retrofits that affect building exteriors in historic districts or structures.

Existing Policy Precedents

Retrofitting for climate hazards is not a new process, and many localities within the United States have had programs and policies to support or require retrofits for decades, especially in earthquake-prone regions. Following is a selection of longstanding and newer retrofit policies.

Note that although the hazard provisions of the International Existing Building Code (IEBC) provide guidance for how to incorporate hazard mitigation into building alterations, they only apply to buildings undergoing repairs, alterations, changes of occupancy, and additions or relocations in states or municipalities where the IEBC has been adopted. This section instead focuses on policies that encourage or require real estate owners to conduct retrofits for the specific purpose of increasing resilience.

Seismic Retrofit Ordinances in the Western United States

Cities in California (Los Angeles, San Francisco, Oakland), Oregon, and Washington have passed or considered passing mandatory seismic retrofit ordinances because of the region's high vulnerability to earthquakes. These ordinances usually require that certain building types conduct retrofits to address specific seismic flaws, such as "soft story," nonductile concrete, or unreinforced-masonry buildings. Some ordinances date to the 1980s, like Palo Alto's, though many are more recent. Los Angeles, for example, requires owners of buildings with soft stories to complete retrofits within seven years, and owners of suspected nonductile concrete buildings have three years to determine whether their structure requires retrofits, and if so, 25 years to complete them. Incentive and technical assistance programs, like California's Earthquake Brace + Bolt program, are often precursors or accompaniments to the ordinances and provide financial assistance or connect owners to licensed contractors to complete required retrofits.

Innovative Zoning for Flooding Retrofits

Some communities on the front lines of sea-level rise and coastal storms have passed new zoning rules in response to the need for widespread retrofits in deeply at-risk areas. After extensive damage from Hurricane Sandy in 2012, New York City building owners encountered significant barriers among zoning rules to retrofitting, such as the height limits and floor/area requirements mentioned earlier. In response, the city passed temporary and then permanent zoning changes known as the Zoning for Coastal Flood Resiliency amendment, which provides enhanced flexibility on allowable height increases, placement of mechanicals, allowed streetscape improvements, and other design features, and expands the areas covered by flexible rules from the 100-year/1 percent annual chance to the 500-year/0.2 percent annual chance floodplain.

Similarly, in 2021, Boston also adopted a Coastal Flood Resilience Overlay District, which requires buildings that already require development review to also undergo a resilience review if located in a specified floodplain; relaxes requirements on height, floor area, and access features similar to New York's ordinance; and requires buildings to follow the city's Coastal Flood Resilience Design Guidelines, which specify appropriate retrofit strategies for flooding and call out co-benefits for other risks.

Flexible zoning rules can allow buildings to exceed height limits if they need to be elevated.

Floodplain Management Ordinances

In the United States, construction in FEMA's federally defined floodplains is regulated by local floodplain management ordinances, which thousands of communities possess. These ordinances usually apply to both new construction and "substantial improvement" projects for existing buildings, which may trigger retrofits to ensure that buildings are protected from flooding in some way, whether they are completely elevated, have their lowest occupiable floor above flood levels, or are wet or dry floodproofed. For example, Santa Barbara County, California's ordinance requires all substantial improvement projects in the floodplain to

- Be constructed with materials and utility equipment resistant to flood damage, using methods and practices that minimize flood damage;
- Elevate the lowest floor, including the basement, two feet above the base flood elevation, and two feet above the highest adjacent grade for certain high-risk zones;
- Floodproof nonresidential construction two feet above the base flood elevation so that the structure is watertight, with structural components capable of resisting hydrostatic and hydrodynamic loads and effects of buoyancy; and
- Design fully enclosed, nonbasement areas below the lowest floor used solely for vehicle parking, building access, or storage and that are subject to flooding to automatically equalize hydrostatic flood forces on exterior walls by allowing the entry and exit of floodwater.

In addition, buildings that are repetitively damaged or substantially damaged by floods may be eligible for enhanced financial assistance from the federal government under the NFIP's Increased Cost of Compliance program.

Green Reroofing Requirements

Several European cities, such as Hamburg, Germany, and Basel, Switzerland, have institutionalized requirements for green roofs during roof replacements to increase resilience to extreme temperatures and bolster stormwater management. Basel passed greening requirements in its building code for flat-roof replacement projects in 2002 and expanded those requirements in 2010 by mandating that all flat roofs that are part of a retrofit project be green. Incentive programs that provided direct subsidy on a square-meter basis ran for several years in the mid-1990s and 2000s to stimulate uptake and facilitate owner buy-in, a common strategy to enhance community support for new regulation.

Denver also requires buildings over 25,000 square feet to install a green roof when the building requires a roof replacement, echoing that regularly scheduled maintenance is a great time to add resilience solutions.

Building Performance Standards

Cities in the United States are beginning to pass more stringent requirements for existing buildings to retrofit to meet energy efficiency or carbon emission standards, often known as BPS ordinances, such as that recently passed in St. Louis. Although these standards frequently do not directly address retrofitting for physical climate risks, efficient buildings provide indirect benefits for resilience (as noted previously). In addition, mandates for energy retrofitting create opportunities to add in the financing and construction of resilient retrofits simultaneously and cost-effectively.

Finance: Paying for Resilient Retrofits

Developing financing for resilient retrofits may be the most difficult aspect of the process. Cost is a significant barrier, creating an access issue for low-income building owners; incentives and financing options that can lower the barrier to entry are critical to equitable implementation. Phased implementation of retrofit strategies can help spread out costs over time, but upfront costs can remain daunting.

Incentives for hardening buildings against physical risk are less common than energy efficiency incentives; projects that combine the two have a higher likelihood of securing financing. The National Institute of Building Sciences' *Roadmap to Resilience Incentivization* lays out how the real estate value chain and public-sector actors can develop more compelling incentive structures, considering mortgages, insurance policies, tax incentives, grants, and other mechanisms.

However, resilience incentives do exist, and they are not the only method of financing retrofits. This section discusses several funding options available to owners.

"Investments in [risk] mitigation have not reflected the value they return. This is because the interests of all those in the supply chain—developers, owners, tenants, insurers, lenders, communities—are poorly aligned. Building owners pay extra to make a building resilient, while other stakeholders (taxing authorities, lenders, etc.) enjoy free co-benefits. Incentives transfer co-benefits back to people who pay the initial cost of resilience. That allocates costs and benefits more fairly, aligns stakeholder interests, promotes resilience, and makes infrastructure less expensive to own in the long run."

—National Institute of Building Sciences, *Roadmap to Resilience Incentivization*

Combining building hardening with energy efficiency or renewables strengthens the business case for retrofits.

Capital Expense Budgets

Although perhaps an obvious solution, for owners with sufficient capital, as climate resilience in general becomes a more common aspect of risk management, resilient retrofits may accordingly become viewed as standard—paid for by capital expense budgets based on the expectation that retrofits create returns or avoid losses from damage or discounts at the time of sale.

However, questions of **property type, location,** and **investment criteria** may also complicate which properties can be feasibly retrofitted within a larger portfolio. For example, commercial properties can pass through the cost of retrofits as an operational expense to tenants, whereas multifamily properties may not; some locations' rent costs can support recovery of retrofit investments, whereas others' rent costs cannot; and value-add properties can often be retrofitted for resilience, whereas fully stabilized core properties may not.

"I want to get to the point where [retrofitting] is contemplated for underwriting **because** assets were flagged for climate risks."

—Michelle German, director, ESG and sustainability, LBA Realty

Loans and Financing

For many real estate owners without large capital budgets, securing financing will be critical to bringing retrofits within reach. Several potential financing options for retrofits are discussed below, including both existing and emerging tools.

Property Assessed Clean Energy + Resilience (PACE+R) Financing

PACE+R financing—known by various names (C-PACE for commercial, R-PACE for residential, and +R after resilience elements were added)—has grown in popularity as a financing strategy for retrofit projects, especially those related to energy efficiency. PACE+R financing, active and operating in 26 states, provides upfront capital with low interest rates and terms of often 20 years or more. The loan remains attached to specific properties as a tax assessment that transfers to new owners in case of sale, and typically 100 percent of hard and soft costs are covered.

Projects covered by PACE+R programs—like that of King County, Washington—usually include both energy projects, such as HVAC or lighting replacements and electric vehicle charging, and investments toward resilience, such as seismic hardening or wind and flood risk reduction. C-PACE is not available in all states, or globally, and not all states will fund physical risk resilience projects. In addition, PACE+R also requires primary mortgage or other lenders to consent to the assessment's becoming senior to private financing, a significant barrier for many real estate firms, though this factor may be changing as lenders become more familiar with the program.

"There is one school of thought that says C-PACE loans are just that, they are loans, and you should analyze the transaction in light of how it fits into the overall capital structure. The other way to look at it is to treat the cost of the upgrades and their financing costs [C-PACE loan payments] as an operating expense. If it can be classified as an operating expense per the terms of the lease, how does that play into net cash flow? If structured properly, could the cost of these improvements and payments be considered an operating or capital expense that could be passed through to tenants, particularly in triple-net leases? As an investor, you need to understand these approaches and how to look at it in light of operating performance, cash flow, and capital structure."

—Kevin Augustyn, senior vice president, DBRS Morningstar

Adapting Commercial Mortgages and Loan Vehicles

When renewing building financing, retrofits that increase building value by reducing operating costs and boosting net operating income—often those with an energy efficiency benefit, such as high-performance envelope retrofits for extreme heat—should be considered in the underwriting process. For example, RiseBoro Community Partnership in New York City incorporates the deep savings it achieves when retrofitting in its loans for refinancing buildings by underwriting to those savings, securing higher loan values.

Though harder to quantify, the value of other resilient retrofits that lack direct energy efficiency components can still be captured in underwriting through avenues mentioned in the "Business Case" section of this report, such as enhanced marketability, rental income, or occupancy.

Working with lenders to communicate this opportunity will help it become more common.

A recent report by McKinsey notes that banks are increasingly acting on the needs and prospects for incorporating climate risks into capital allocations and loan approvals and mobilizing new funding for climate-related projects.

Other financing vehicles are also changing to reflect resilient retrofits. Green mortgages can support these goals, and are already on offer from large providers like Fannie Mae (e.g., the HomeStyle Energy mortgage) and Freddie Mac (e.g., the GreenCHOICE mortgage). Targeting single-family homes, these mortgage options allow borrowers to finance the costs of improvements when purchasing or refinancing, up to 15 percent of the home's value postupgrade. Eligible improvements include energy and heat resilient measures, such as solar panels, air sealing, insulation, high-efficiency windows, and HVAC upgrades; water conservation measures, such as low-flow fixtures; and even wildfire, earthquake, and flood resilient measures, such as foundation retrofits or storm surge barriers. The Rocky Mountain Institute has recommended streamlining and scaling the process of offering these products to reach more homeowners, especially low- to moderate-income homeowners, as national uptake has so far been lower than needed.

Green banks, like the DC Green Bank, are already at work financing projects that combine energy efficiency and climate resilience, such as the redevelopment of Faircliff Plaza East, an affordable and all-electric housing project by developer Jonathan Rose that will be targeting Passive House certification and incorporates a green roof to improve stormwater management. These institutions are critical for mobilizing private capital toward building-level adaptation.

Larger companies can issue green bonds to support resilient retrofits if the funds are dedicated broadly enough to cover multiple sustainability- and resilience-related activities. Green bonds have been used primarily to fund retrofits that reduce energy use and carbon emissions, and less often for strengthening buildings or infrastructure against physical climate risks. As the Global Center on Adaptation notes, bonds that include physical risk reduction activities are more often issued by local governments and government-backed entities to support development of public infrastructure than by private companies for individual asset hardening. However, investor demand for green bonds has grown rapidly and outstrips supply, and interest in "thematic" bonds focused on social or environmental impact has grown greatly since the COVID-19 pandemic.

Real estate companies are increasingly turning to green bonds to finance climate-related activities. As a prime example, in early 2021, New World Development priced a sustainability-linked bond of 10 years and $200 million, allocated to long-term sustainability initiatives, including addressing physical climate risks.

Traditional sources of funding can also be modified to reach underbanked populations. In the Philippines, for example, microfinance institutions that already serve millions of households partnered with nonprofit Build Change to develop a small loan pilot program for low-income households that financed seismic and typhoon retrofits.

State and Local Grants and Incentives

In the United States, a number of local and state programs have sprung up to help owners incentivize implementation, including financial and nonfinancial components. Conducting further research into local incentives can help dismantle some of the financial barriers to implementation.

Some function at the state level: California's Earthquake Brace + Bolt program mentioned previously; the Safe Home program in South Carolina and the Strengthen Alabama Homes program, which provide grants of $5,000 and $10,000, respectively, to owners for strengthening their properties against wind and hurricane damage in partnership with the IBHS's FORTIFIED program; and the Florida Hurricane Loss Mitigation Program, which funds retrofits for storm and flood damage for residential and commercial properties. Though these amounts are smaller, they may be sufficient to pay for low-cost, highly effective retrofit techniques for the vast number of smaller buildings vulnerable to climate risks.

Other local programs use larger funding streams to deliver larger grants, like Berkeley's seismic retrofit grant program, which uses a federal Hazard Mitigation Grant from FEMA and can provide upward of $100,000 to building owners. Still others use local funding streams like the Charlotte-Mecklenburg retroFIT floodproofing grant in North Carolina, which covers up to 95 percent of eligible mitigation project costs for commercial and residential owners with buildings in the floodplain, using stormwater utility fees.

Utilities also offer grants for specific resilience features, such as a grant program from utility company PG&E that provides $100,000 to create a resilience hub within new or existing buildings. In addition, although they focus primarily on energy efficiency, many local utility-run weatherization programs fund upgrades to homes or businesses that also boost resilience to extreme temperatures, such as the Mass Save program in Massachusetts.

Beyond grants, municipalities can offer property tax abatements for resilient retrofits. New York City—which requires most major roof renovations to install green roofs, solar panels, or both—offers up to $15 per square foot for green roof retrofits, which are also eligible for the city's C-PACE program. Abatements are higher in neighborhoods with greater social vulnerability to extreme heat and stormwater overflow. Washington, D.C., offers a similar $15-per-square-foot green roof rebate, and Houston has also developed a tax abatement program for green stormwater infrastructure, including green roofs.

Finally, some locations—like Chicago—offer nonfinancial incentives, such as expedited building permits, for renovation projects that include green roofs, rainwater harvesting systems, or energy resilience components like solar panels.

Federal Grant and Loan Programs

In the United States, federal funding is one of the largest potential sources of retrofit funding, but its application process carries a reputation for being complex and time-consuming. When eligible, property owners are usually required to apply through their local government to access this funding. However, several programs are worth mentioning.

The Hazard Mitigation Grant Program (HGMP), which is applicable across multiple hazards, and the Flood Mitigation Assistance Grant are both major grant programs run by FEMA that have subsidized large, expensive retrofit projects postdisaster. These grants often prioritize larger community infrastructure or facilities, like airports, hospitals, or historic structures, but not exclusively; some municipalities use their funding streams to support individual projects, such as Berkeley, California's seismic retrofits or Charlotte-Mecklenburg's buyout program. FEMA's Building Resilient Infrastructure and Communities grant, which is meant to apply to communities predisaster, covers similar projects as the HGMP.

Similarly, the U.S. Department of Housing and Urban Development's well-known Community Development Block Grant Disaster Recovery and Mitigation programs—which state and local governments apply for and then disburse to affected residents and businesses—can also be used for resilient retrofits in areas recently affected by climate hazards.

Finally, emerging revolving loans programs—such as those created by the recent Safeguarding Tomorrow through Ongoing Risk Mitigation (STORM) Act, which provides low-interest funds to states and local governments to set up loans for resilience and risk reduction across multiple climate hazards—may come into play as a funding strategy for retrofits; for example, addressing structures repeatedly or severely damaged by flooding is a main goal of the STORM Act.

Other national governments have also created financing programs to support resilient retrofits. In Singapore, for example, the National Parks Board has run the Skyrise Greenery Incentive Scheme since 2009, which provides grants that cover up to 50 percent of the cost of installing green roofs or vertical greenery on existing buildings. This program has funded over 100 buildings since its inception.

Conclusion

Resilient retrofits are a complex process for small and large property owners alike, and the real estate sector and local governments are still in the initial stages of grappling with the scale of need and organization required to encourage private-sector action.

Nonetheless, existing retrofit programs and project profiles provide lessons learned to get started. Retrofit design techniques are well understood, market interest in resilient buildings is growing, and new financing vehicles are expanding to meet demand—especially if owners can successfully link investments in energy efficiency with building hardening. The main questions are how to align these factors sufficiently to achieve rapid uptake in response to accelerating climate risk, and how to do so equitably across social and economic lines to ensure that the process leaves no stakeholder behind.

In the coming years, the real estate sector can expect resilient retrofits to become mainstream practice: there is simply no other way to ensure that the investments held in existing buildings are protected long term. There is no need to wait; the sooner owners, designers, policymakers, and finance professionals act to safeguard occupants and enhance value, the greater the opportunity.

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