DANIELS

Resilience Planning Guide

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JOHN H. DANIELS FACULTY OF ARCHITECTURE, LANDSCAPE, AND DESIGN

Table of Contents

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Ted Kesik is a professor of building science in the John H. Daniels Faculty of Architecture, Landscape and Design at the University of Toronto with a career focus on the integration of professional practice, research and teaching. He entered the construction industry in 1974 and has since gained extensive experience in various aspects of building enclosure design, energy modeling, quality assurance, commissioning, performance verification, and building systems integration. Professor Kesik's research interests include resilience, sustainability, durability, high performance buildings, life cycle assessment and building performance simulation. His current research involves the development of design guidelines for low-carbon buildings that are resilient and sustainable within the context of climate change and globalization. Dr. Kesik continues to practice as a consulting engineer to leading architectural offices, forward thinking enterprises and progressive government agencies. He remains actively involved in technical organizations and is the author of numerous books, studies, reports and articles related to his areas of research and professional practice.

Preface

North America, along with the rest of the world, is entering an age of climate change where we are witnessing an increased frequency and severity of extreme weather events. Aging municipal and energy infrastructure has rendered many communities vulnerable to flooding and power disruptions. While these extreme events are seldom unmitigated disasters, they have the potential to disrupt our day-to-day lives, business operations, and possibly jeopardize human safety, private and public property. Fortunately, resilience of our built environment is technically and economically feasible, but first we need to become aware of our vulnerabilities. Only then can we engage the appropriate planning strategies leading to effective resilience measures.

Resilience is an important attribute that needs to be carefully considered at the planning stage of today's building projects. This planning guide is intended to provide straightforward and cost effective means of enhancing the resilience of buildings, their supporting infrastructure, and their organizations.

Overview

This planning guide is intended to assist engineers, architects, constructors and building owners become aware of how to better plan for the improved security of inhabitants, maintain the continuity of business operations/services, and to enhance the protection of building assets.
A preview of the Resilience Planning Guide is summarized in the following highlights:

What Is Resilience?

When disasters occur it is vital that buildings continue to provide shelter under extreme weather conditions, so that inhabitants can safely and comfortably survive until normal conditions are restored. It is also important that buildings can withstand exposure to extreme conditions without suffering serious and/or permanent damage.

Thinking About Resilience

Most people live in cities and until recently did not give much thought to resilience. Resilient design requires an integrative process involving all the key players and stakeholders. As yet, there is no formal education and training for resilient design and this planning guide aims to provide a framework to managing the resilience challenge.

Built Environment Resilience Strategies

Communities are situated in landscapes occupied by road, sewer, water, energy, communications and building infrastructure - all of which connect inhabitants to goods and services. A chain is only as strong as its weakest link. It is important to harmonize resilience so that communities can better survive disasters and extreme weather events.

Overview of Resilient Building Enclosure Design

Buildings are durable goods and housing typically represents the average family's largest investment. Robust enclosure design ensures that buildings are durable, energy efficient, comfortable and also provide shelter under extreme conditions. A long service life should be enjoyed with only some routine maintenance requirements, and under extreme circumstances, the building enclosure should not fall apart or sustain irreversible water damage. Under both normal and extreme conditions, the building should not experience performance problems that can compromise secure shelter and devalue real estate investments. Resilient enclosure also address measures for thermal autonomy and passive survivability.

Integrative Design for Resilience

Buildings are more than their enclosures and it is important to critically assess the resilience of the building-as-a-system. A holistic, scenario-based approach is needed to ensure all reasonably foreseeable problems have been considered and addressed.

Emergency Planning

Tsunamis, earthquakes, wildfires and weather bombs can exceed the best resilience measures and everyone needs to develop an emergency plan when disasters strike.

Insight

Resilience, like sustainability, will not go out of style. These two performance objectives are related to one another, with sustainability being a broader and longer term goal that periodically hinges on our ability to bounce back from adversity so that the sustainability agenda is not set back and further compromised.

Resilience planning combined with prudent measures represent a sound investment strategy that reduces damage and losses, ensures continuity of building operations without disruption, and therefore deserves lower insurance premiums while enjoying higher asset valuations. People will be willing to pay more for resilience because of how it helps manage the risks and consequences associated with hazards.

For reasons of health and safety, resilience will one day find its way into codes and standards, but in the meantime this planning guide is intended to help foster the leadership needed to make resilience an everyday part of responsible design that adds value, safety and security.

The natural world we see around us embodies the very idea of resilience and it has much to offer in terms of successful strategies for adaptation to adverse and changing conditions.

What is Resilience?

Resilience is a complex attribute that is comprised of numerous aspects - some physical, some technical and some social and cultural. We become aware of resilience when it is absent or insufficient and we are unable to persevere and overcome challenges such as extreme weather events.

Resilience is not a new concept and in the past it formed the basis of so many of our building traditions, whether it was to ensure we survived a long, harsh winter or a dry, hot summer. Before people became dependent on the energy grid, houses were heated with wood, cooled by porches and natural ventilation, and illuminated by windows and candlelight.

Before the era of agri-business and mass transportation networks, food was grown locally and preserved to last until the next growing season. Most households were self-sufficient in terms of life's necessities, but communities were also closely knit because social safety nets and vital public services such as healthcare had not yet been invented.

Today, resilience is understood in terms such as emergency preparedness, climate change adaptation and support systems provided by institutions and public services. Resilience does not come about naturally, rather it is something that we have to think about and devise.

In this Resilience Planning Guide, the following definition has been adopted:

re·sil·ience

1. the act of rebounding or springing back
2. the capacity to adapt to changing conditions and to maintain or regain functionality and vitality in the face of stress or disturbance.

Thinking About Resilience

There are several important reasons people are thinking about resilience, more so today than in the past.

Phenomena like climate change have caused an increase in the severity and frequency of extreme weather events. As a result, insurers report a sharp increase in claims due to damage by flooding and winds. Households and businesses have experienced major damages and disruptions that are often not fully insured.

Building codes and standards have not kept pace with resilience risks and our buildings are more vulnerable than in the past. For example, heating systems today cannot operate without an electrical power supply even if the fuel is natural gas or oil. There is no provision in building codes to ensure some form of backup electrical energy system to maintain critical operations.

Infrastructure, such as roads, bridges, sewers and energy grids, is aging and in some cases crumbling - it is becoming much more susceptible to breakdowns and failures during extreme weather events.

Resilience measures must now compete with many other social priorities like healthcare, education, the economy and the environment. Increasingly, governments have downloaded the cost of services to individuals and businesses who can no longer rely on government to provide an adequate resilience safety net.

Fortunately, measures to enhance resilience are not necessarily complicated or costly. In many cases, the costs and disruption that arise when insufficient resilience is overcome by extreme events are many time greater that the cost of prevention and avoidance.

In nature, resilience is an obvious trait that is derived from evolution and survival of the fittest. But for the built environment and its inhabitants, resilience requires conscious effort and constant vigilance.

Thinking About Resilience

Challenges and Opportunities

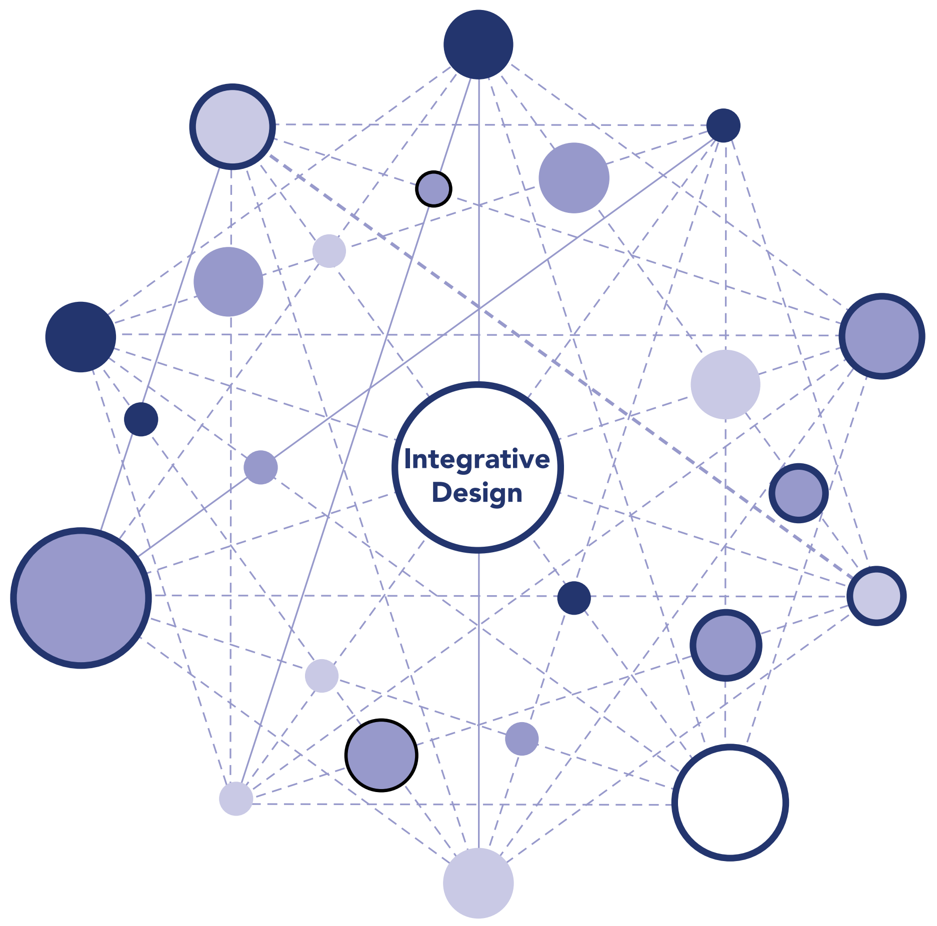
Every resilience challenge is also an opportunity to enhance security and add value. Enhancing resilience means we maintain better security against damage and loss, but we also strengthen assets and vital relationships that reinforce their own synergies.

Key Players and Stakeholders

While it is acknowledged not everyone is a key player in the resilience challenge, everyone will always be a stakeholder. However, there are some stakeholders that exert much more influence and bring more resources to the table.

Government represents all of us and it is the job of government to develop coordinated and consistent policies that encourage positive feedback loops among resilience stakeholders. Governments at all levels protect the environment and ecology, and also provide public services such as infrastructure, healthcare and education. Insurers, the financial sector, design professionals, businesses and industries are regulated by government through legislation, codes and standards that are intended to serve the best interests of households and taxpayers.

Resilience is a web of relationships that requires our system of policies, regulations, institutions, organizations, and technologies of the built environment, to be fully and effectively integrated.



Resilience and Integrative Design

Integrative design is a process that connects peoples' needs for safety, security, health and well being while properly balancing environmental, economic, and social factors.

This process works within the web of resilience to facilitate the interests of all stakeholders, Unlike the more commonly deployed "integrated design process" for buildings, integrative design goes beyond the scope of a particular policy, legislation, development proposal or technological proposition, to consider all of the factors, all of the impacts, and then provides a means by which the stakeholders can work out solutions that work for everyone.

Integrative design is a relatively new approach to dealing with the complexities and contradictions of traditionally competing interests, such as economic growth, environmental responsibility and intergenerational equity to arrive at acceptable strategies for sustainable development.

This planning guide is premised on principles of integrative design and while a number of aspects of resilience are examined individually, it is acknowledged they must all be effectively integrated to successfully meet the resilience challenge.

Thinking About Resilience

Design for Resilience Principles

1

Resilience transcends scales.

Strategies to address resilience apply to different physical and time scales - from individual buildings and communities to larger regional and ecosystem scales; from the immediate to the long-term.

2

Resilient systems provide for basic human needs.

These include potable water, sanitation, food, energy, livable conditions (temperature and humidity), lighting, safe air, occupant health, and food.

3

Diverse and redundant systems are inherently more resilient.

More diverse communities, ecosystems, economies, and social systems are better able to respond to interruptions or change. Redundant systems for such needs as electricity, water, and transportation, improve resilience.

4

Simple, passive, and flexible systems are more resilient.

Passive or manual-override systems are more resilient than complex solutions that can break down and require ongoing maintenance. Flexible solutions are able to adapt to changing conditions both in the short- and long-term.

5

Durability strengthens resilience.

Strategies that increase durability enhance resilience. Durability involves not only building practices, but also building design, infrastructure, and ecosystems.

6

Locally available, renewable, or reclaimed resources are more resilient.

Reliance on abundant local resources, such as solar energy, annually replenished groundwater, and local food provides greater resilience than dependence on nonrenewable resources or resources from far away.

7

Resilience anticipates interruptions and a dynamic future.

Adaptation to a changing climate with higher temperatures, more intense storms, sea level rise, flooding, drought, and wildfire is a growing necessity. Non-climate-related natural disasters, such as earthquakes and solar flares, also call for resilient design. Responding to change is an opportunity for a wide range of system improvements.

8

Find and promote resilience in nature.

Natural systems have evolved to achieve resilience; we can enhance resilience by relying on and applying lessons from nature. Strategies that protect the natural environment enhance resilience for all living systems

9

Social equity and community contribute to resilience.

Strong, culturally diverse communities in which people know, respect, and care for each other will fare better during times of stress or disturbance. Social aspects of resilience can be as important as physical responses.

10

Resilience is not absolute.

Recognize that incremental steps can be taken and that total resilience in the face of all situations is not possible. Implement what is feasible in the short term and work to achieve greater resilience in stages.

Excerpted from The Resilient Design Institute, http://www.resilientdesign.org

Built Environment Resilience Strategies

Resilience experts believe two trends are converging to make the need for resilience of the built environment urgent and critical. The first trend is urbanization, which is occurring at an ever increasing rate, with people concentrating in cities, many located in coastal regions or along major river systems. The second trend is that our climate is changing and becoming unpredictable, with the warmer atmosphere and higher sea levels being joined by a range of extreme weather events that are affecting coastal and inland communities alike. Severe hurricanes like Katrina and Sandy, as well as tsunamis and typhoons such as those that have devastated parts of Asia in recent years, are no longer rare and isolated events. Instead, flooding, heat waves, droughts, forest fires and ice storms becoming more frequent and severe events. Resilience in the face of climate change adaptation is now considered both prudent and imperative.

Our built environment comprises roads and bridges that interconnect buildings served by energy and municipal infrastructure, and telecommunications networks. Together these represent the physical aspects of our built environment.

The built environment also relies on a social infrastructure of essential services that range from healthcare, policing and firefighting to public transportation and municipal works. Various levels of government and their agencies deliver services including emergency response.

Resilience cannot lessen the severity of extreme weather events, and it may not always provide adequate protection to avoid damage and disruption. But when extreme weather events or disasters strike, it is important to ensure that both the physical and the social dimensions of our built environment, whether it is a large urban centre, a small town or a tiny isolated community, are sufficiently resilient to bounce back and recover their former functions, as soon as the trauma has passed.

There are several fundamental resilience strategies that may be appropriate by themselves or in some combination depending on the circumstances.

Armoring: This strategy is premised on strengthening or reinforcing an asset to be able to withstand more extreme exposure to phenomena, such as wind, rain, or earthquakes. It may also involve providing special protection such as flood proof construction for a building's electrical service, telephone and data services, emergency generators and fuel supplies, fire alarm systems and fire pumps. Alternatively, the equipment may be located on upper levels of the building far above flood water levels.

Concrete slope protection of a levee to resist erosion by tidal forces during hurricanes is an example of armoring vital infrastructure.

Built Environment Resilience Strategies

Redundancy: "Two heads are better than one," is folk wisdom that recognizes the effectiveness of redundancy. Redundancy strategies may take several forms. One form is simply providing an alternative backup for services such as electrical power by installing an emergency generator that automatically engages when there is a power outage. Another form is providing multiple levels or layers of defense, such as waterproofing a basement as well as site grading that conveys water away from the foundation. And yet another form is the mirroring of a critical facility, such as a data center, so that one can be abandoned during an extreme event and its duplicate in another location fully operationalized to avoid disruption.

Providing a second battery powered sump pump is now widely recognized as a prudent redundancy measure to prevent basement flooding when power outages and extreme rainstorms coincide, or when the main sump pump fails.

Decentralization: Exclusive reliance on centralized services means that when the centralized service goes down, our vulnerability goes up, especially if the service is vital, such as water or energy. Decentralization may be a form of redundancy, but usually it involves autonomy from a centralized service, such as when homes go off the grid and generate their own energy. Another example of decentralization is rainwater harvesting that reduces dependence on a centralized municipal water supply.

High tech woodstoves are redundant appliances that provide space heating and afford cooking during extended power outages. They are also delightful.

Training and Support Networks: Social infrastructure can also be made more resilient through training and support networks. Today, special training is available to first responders and caregivers to help them become more psychologically resilient. It is well known that individuals who work in settings where they are exposed to trauma or care for those who suffer from trauma (and the families of those who suffer from the trauma), are at risk for traumatization such as secondary stress traumatic symptoms and/or disorder (vicarious traumatization or compassion fatigue), post-traumatic stress symptoms and burnout. Support networks are vital to ensure the safety and well being of vulnerable individuals, such as very old and/or ill persons who live alone, by routinely checking up with them, particularly during and after extreme weather events or disasters. Resilient people and social organizations are key to successfully engaging the resilience challenge.

Solar powered homes with battery storage, that may or may not be connected to the grid, are much more resilient during extended power outages than conventional homes connected exclusively to the electrical grid.

Built Environment Resilience Strategies

Community Planning, Infrastructure and Services

The development of resilience strategies begins at the regional and community scales, where transportation networks are coordinated between existing and new developments so that diverse options for mobility between urban centres are made available to safely and efficiently transport people, goods and services. Critical considerations include the planning of detours and evacuation routes in the event of automobile accidents, chemical spills, fires or flooding.

Physical infrastructure in the form of roads, bridges, sewers, potable water, energy and telecommunications should be designed to withstand extreme events up to some reasonable threshold. But it is important to recognize that extreme weather events like ice storms may cause power outages and impair the safe use of roads and sidewalks, leaving people stranded, and first responders unable to get to their workplaces.

Most architects, engineers and constructors seldom get involved at the macro-planning scale in the development and implementation of strategies that are needed to maintain resilient communities. However, at the level of the typical development project, today's design professionals need to understand how to integrate solutions that are harmonized with the larger community and regional resilience strategies.

The coordination of mass evacuations to avoid impending disasters is among the many emergency measures taken to ensure the safety of communities.

Built Environment Resilience Strategies

A widely adopted working definition of community resilience is given as:

> “ Communities and individuals harnessing local resources and expertise to help themselves in an emergency, in a way that complements the response of the emergency services.”

UK Cabinet Office, March 2011.
Strategic National Framework on Community Resilience.

This definition includes the role and resilience of individuals and communities before, during and after an emergency. Local emergency responders will always have to prioritize those in greatest need during an emergency, focusing their efforts where life is in danger. There will be times when individuals and communities are affected by an emergency but are not in immediate danger and will have to look after themselves and each other for a period until any necessary external assistance can be provided. Communities will also need to work together, and with service providers, to determine how they recover from an emergency. This definition implies a framework that encourages individuals and communities to prepare themselves in the event of an emergency.

Emergency preparedness, whether at the scale of the household, a large institutional facility, or the entire community, involves coordinated planning and the provision of redundant infrastructure and services. If survival is dependent on a single asset or service, the consequences of failure are severe. But if there are numerous alternatives and lines of defence, then the likelihood of every measure failing is quite low.

Community planning must be carefully integrated at the macro scale with infrastructure and services to achieve an acceptable level of resilience. But there are also a number of more specific considerations and these are presented in the sections that follow, beginning with the idea of low impact development and building sites.

Built Environment Resilience Strategies

Low Impact Development and Building Sites

Natural landscapes are far more robust and resilient than man-made infrastructure and this has given rise to low impact development practices for communities and building sites.

Low impact development (LID) is a stormwater management strategy that seeks to mitigate the impacts of increased runoff and stormwater pollution by managing runoff as close to its source as possible. LID comprises a set of site design strategies that minimize runoff and distributed, small scale structural practices that mimic natural or predevelopment wlogy through the processes of infiltration, evapotranspiration, harvesting, filtration and detention of stormwater.

These practices can effectively remove nutrients, pathogens and metals from runoff, and they reduce the volume and intensity of stormwater flow. Low impact development practices can significantly reduce initial and ongoing life cycle costs associated with the management of stormwater, while enhancing the environmental performance of new developments. Most importantly, low impact development measures can significantly reduce incidences of flooding.

Issues such as the management of extreme snowfalls and the provision of access to persons with disabilities are among the challenges facing both existing and new developments, but better practices are emerging.

A rain garden is a bio-retention basin that contains plantings and stores excessive runoff of stormwater. Not only does it reduce loads on storm sewers, it recharges the groundwater levels with filtered water.

Bio-swales in parking lots reduce and cleanse runoff that has been contaminated by automobiles with road salts, glycols, oils and grease.

Site design to accommodate extreme snowfall events is gaining in importance due to climate change.

Site design for persons with disabilities is becoming recognized as a basic human right that affords individuals unrestricted access and escape routes.

Built Environment Resilience Strategies

Energy and Water Security

Long term disruptions of energy and water supplies can place severe stress on a community and its vulnerable citizens. People who have mobility challenges, suffer from serious illness, and/or live alone without caregivers are among the most vulnerable individuals. Low income families may not have the means to temporarily evacuate an area undergoing disaster or crisis. Some thought should be given to enhancing energy and water security so that housing developments and critical service centers are able to function until recovery is possible.

Consideration must be given to a secure supply of fuel to run combined heat and power (CHP) equipment. Natural gas distribution networks are quite robust and resilient, and alternatives include propane and fuel oil. Bio-fuels such as wood chips or pellets are increasingly deployed.

Water security is often more important than energy security because we use water not just for drinking, but to wash ourselves, clothing, dishes and inside our facilities. Sanitary plumbing also requires a supply of water, and it is critical for toilets and sinks to function when people are confined to their buildings.

Rainwater harvesting is a technique for managing stormwater while capturing and storing rainwater for both potable and non-potable uses. Advances in bio-filtration technology and ultra-violet sanitization equipment make it possible to convert rainwater into potable water. Off-the-shelf technology is now available to integrate rainwater harvesting within both new and existing developments.

Hybrid approaches to rainwater harvesting involve green roofs for cleansing the rainwater before it is conveyed to a storage tank, while also providing the numerous environmental benefits of green roof technology.

Combined heat and power (CHP) plants, also known as cogeneration plants, convert fossil fuels into electricity and heat so that larger facilities, such as seniors housing complexes, can remain operational.

Micro-cogeneration equipment is also available at the small residential scale, enabling houses to generate electricity during emergencies, and sufficient hot water to heat the homes and provide domestic hot water.

Rainwater harvesting typically deploys a storage tank to hold captured rainwater for non-potable uses, such as toilets and washing. Bio-filters and sterilizers can also provide limited quantities of safe drinking water.

Green roofs can filter rainwater, manage stormwater, enhance biodiversity, reduce the urban heat island effect and even grow food.

Built Environment Resilience Strategies

Resilient Building Systems: Structure, Enclosure, Services

Building codes and standards provide ample requirements to ensure resilient building structures that can safely withstand earthquakes, windstorms and snow loads.

Older and historical buildings can be better preserved through seismic retrofits that provide adequate resistance to earthquake forces. More importantly, seismic retrofits help ensure these occupied buildings avoid catastrophic collapse.

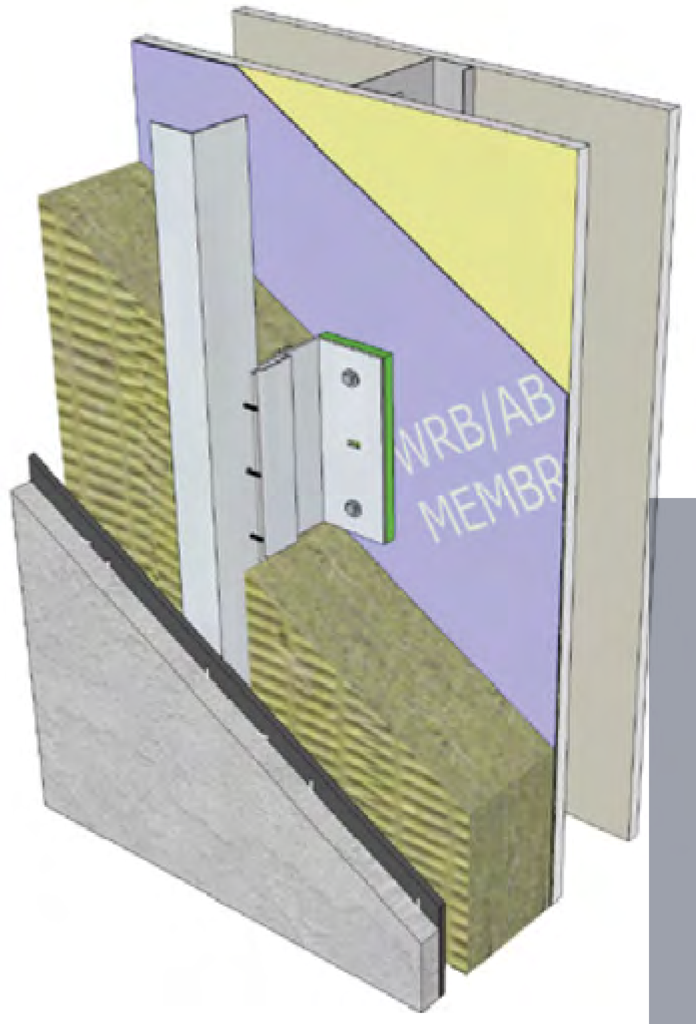
The seismic retrofitting of existing buildings is often a more critical consideration than incorporating earthquake resistance into new buildings. A great deal of research has been conducted into seismic retrofit technologies and these are now being implemented in jurisdictions that comprise older building stock prone to serious damage and collapse during earthquakes.

The risk of seismic activity is quite low in most parts of the world, however, it is now widely acknowledged that extreme weather events will increase in frequency and severity due to climate change.

Tornadoes, hurricanes, record rainfalls, ice storms, droughts, heat and cold waves are among the extreme weather events that will challenge the resilience of building enclosures.

Building enclosures comprise assemblies and components of buildings, such as the foundation walls and slabs, the above-grade walls and windows, and the roof, in order to provide a desired degree of separation between the indoor and outdoor environments.

High performance enclosures can keep the heat both in and out, and this makes it possible for inhabitants to remain in their dwellings for extended periods during power outages when heating or cooling equipment is disabled.



Superinsulated walls with thermally broken cladding attachments are examples of a trend toward high performance enclosures that are more energy efficient, comfortable and resilient than conventional approaches.

Vibration dampening technology enables buildings to withstand earthquakes, shelter inhabitants against collapse, and maintain their structural integrity.

Built Environment Resilience Strategies

Energy and Water Security

Passive survivability is defined as a building's ability to maintain critical life-support functions during extended periods of power or water service disruptions, particularly during extreme weather events. Passive survivability is largely determined by appropriate enclosure design that considers strategies such as storm resilience, cooling-load avoidance, natural ventilation, a highly efficient building envelope, passive solar heating, and natural daylighting. Additional strategies for renewable energy and rainwater harvesting/storage may also be incorporated.

Strategies for protecting large glazed areas from breakage due to airborne projectiles is a major consideration in many areas of North America. Since most high winds coincide with severe rainfall events, major water damage may result after the breakage of windows, and further damage may be suffered by the soaked facade.

An increasingly affordable means of improving the resilience of building services is through renewable energy systems. Photovoltaic panels generate electricity that can be used in the building, transferred to the electrical grid or stored on site in battery banks. Solar thermal collectors utilize the sun's energy to heat domestic hot water, and combination systems that also heat the home are now available. When the right mix of renewable energy is coupled to a high performance enclosure, the result is a highly resilient building with a reduced carbon footprint.

Resilient building enclosure strategies are further explored in the next chapter of this planning guide.

Shutters represent a proven, traditional approach to controlling daylight, providing privacy and protecting windows from damage due to airborne projectiles, such as flying debris during extreme windstorms.

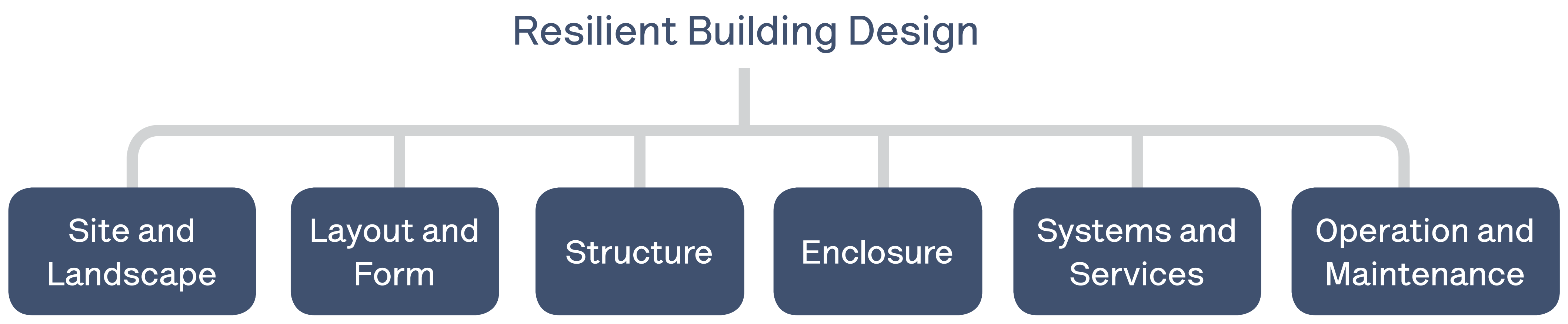
Collapse of an entire building facade in New York City occurred after it was battered by Hurricane Sandy. This challenges the popular misconception that older masonry buildings are inherently more resilient.

Movable shutter systems in modern buildings have improved over traditional shutter designs by integrating the capability to afford privacy and security while providing shading and enhanced daylighting. Insulated shutters can significantly improve building energy efficiency and passive survivability.

Technologies for generating electricity and hot water are reliable and cost effective means of enhancing resilience with investments in decentralized building services.

Resilient Building Enclosure Design

This guide will now focus on the resilience of the building enclosure recognizing that among all of the mitigation measures implemented at the site, neighbourhood, community and regional scales, those involving the environmental separation between the elements and inhabitants serve to most directly shelter people from extreme events.



Among the six key strategies for resilient buildings, enclosure design is critical to the protection of people and property. It also serves to address many other important objectives, such as energy efficiency and durability.

Witnessing the extreme weather phenomena associated with climate change, there are a number of strategies and measures that be incorporated into the design of resilient enclosures. Many of these measures serve multiple performance objectives and make for more energy efficient, durable and sustainable building enclosures.

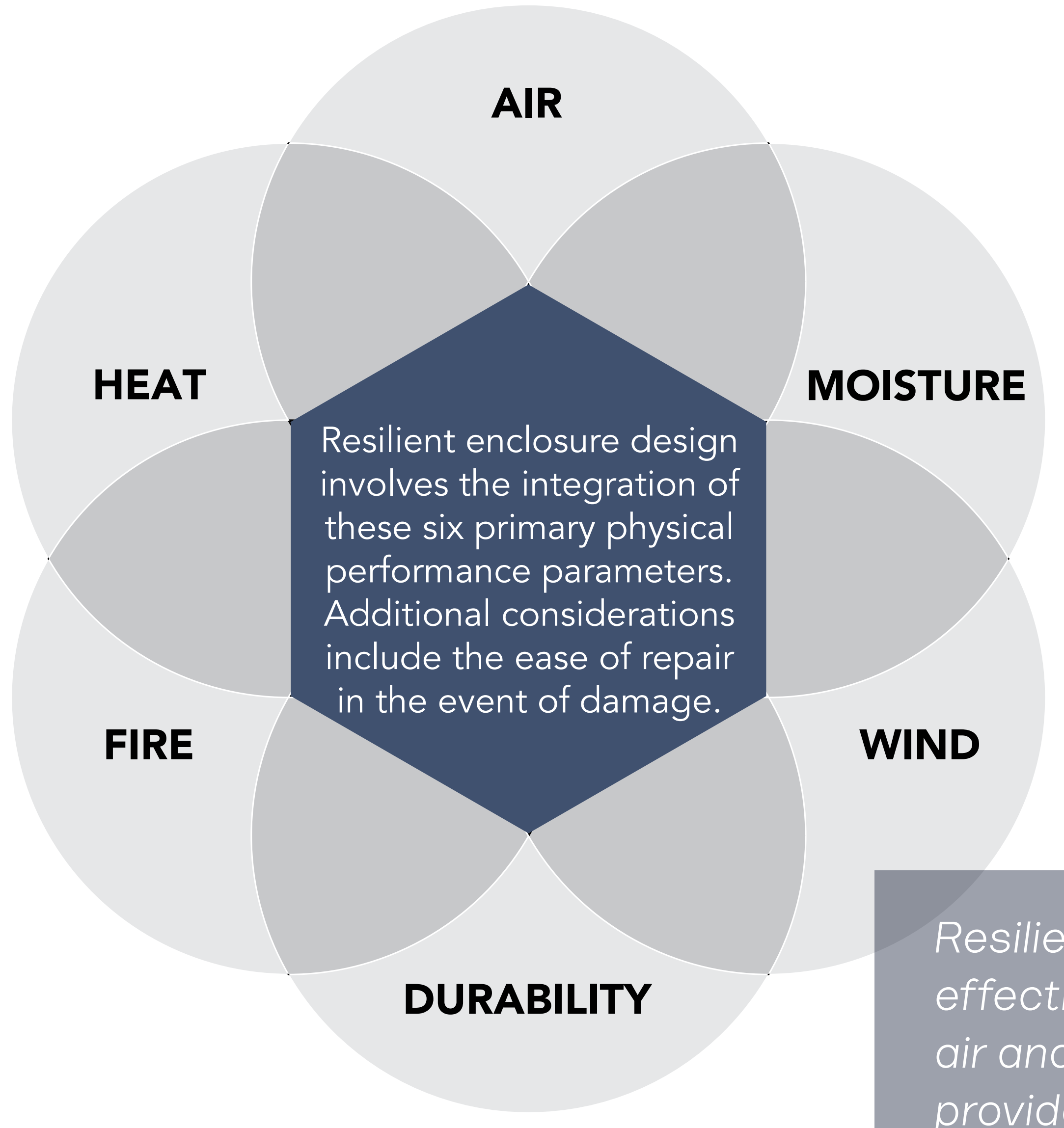
Canadian building scientist Neil Hutcheon developed a general framework to guide enclosure design across a range of performance parameters including resilience. Originally applied to exterior walls, this framework can be extended to all building enclosure components.

The major considerations in the design of enclosures are as follows:

1. Strength and rigidity
2. Control of heat flow
3. Control of air flow
4. Control of water vapour flow
5. Control of liquid water movement
6. Stability and durability of materials
7. Fire
8. Aesthetic considerations
9. Cost

Excerpted from Fundamental Considerations in the Design of Exterior Walls for Buildings, N.B. Hutcheons, Technical Report No. 13 of the Division of Building Research Council Canada, Ottawa, 1953.

Leaving aesthetic and cost considerations aside, critical requirements specifically related to enclosure design, with the understanding the structural and fire safety requirements are largely addressed through contemporary building codes and standards, involve the control of heat, air and moisture flows while ensuring the stability and durability of materials.



Resilient enclosures must effectively manage heat, air and moisture flows and provide protection against fire and wind while delivering durable service.

Resilient Building Enclosure Design

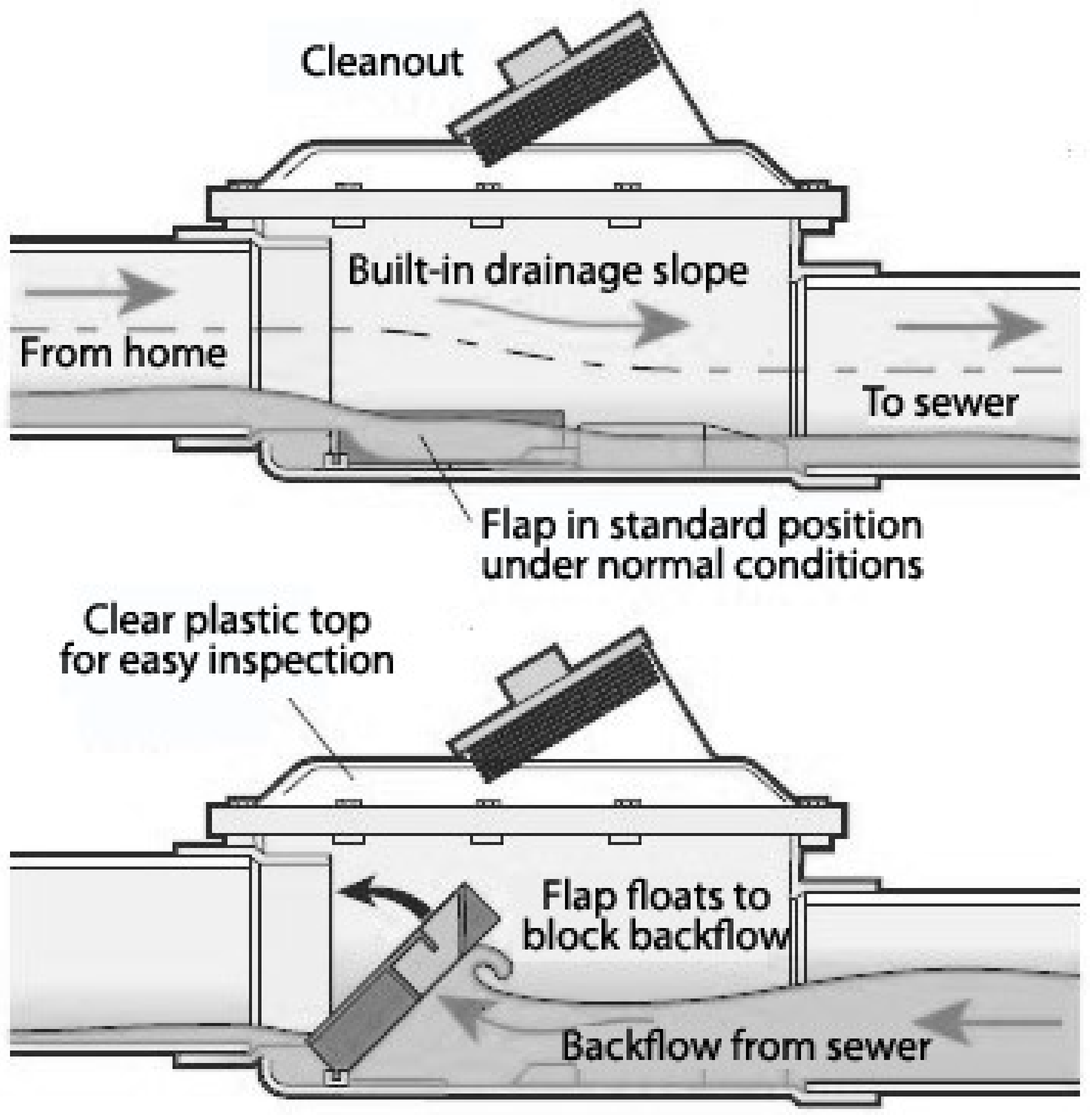
Basement Flooding and Sewer Backup Protection

Plumbing connections to sewer systems are not technically part of the building enclosure, but since they can potentially breach the integrity of the enclosure's moisture management system, it is important to assess the need for sewer backup mitigation measures.

Basement flooding due to sanitary sewer backup translates into significant health and social impacts for occupants of affected basement apartments or living areas. A flooded basement is a traumatic event that may force occupants out of their living spaces until the flooding subsides, damaged contents are removed and the basement area is sanitized, and dries out. Each sewer backup episode may mean days or weeks of displacement.

Sewer backup can happen when sanitary sewer systems receive more water than they can handle. Excess water due to infiltration and inflow can cause the sewers to "surcharge," and push water backwards through home sewer laterals and cause sewage to backup into the home through basement floor drains, toilets and sinks. Excessive surcharge in the municipal sewer can create high pressures around basement floors and the foundation, which can cause structural damage to the home.

For example, excess pressure in pipes beneath the home can result in heaving of basement floors, especially when improper backwater valves are used. When weeping tiles are connected to the municipal system through sanitary sewer laterals or storm sewer laterals, sewage can be forced back into the weeping tiles, resulting in possible structural damage to the home.



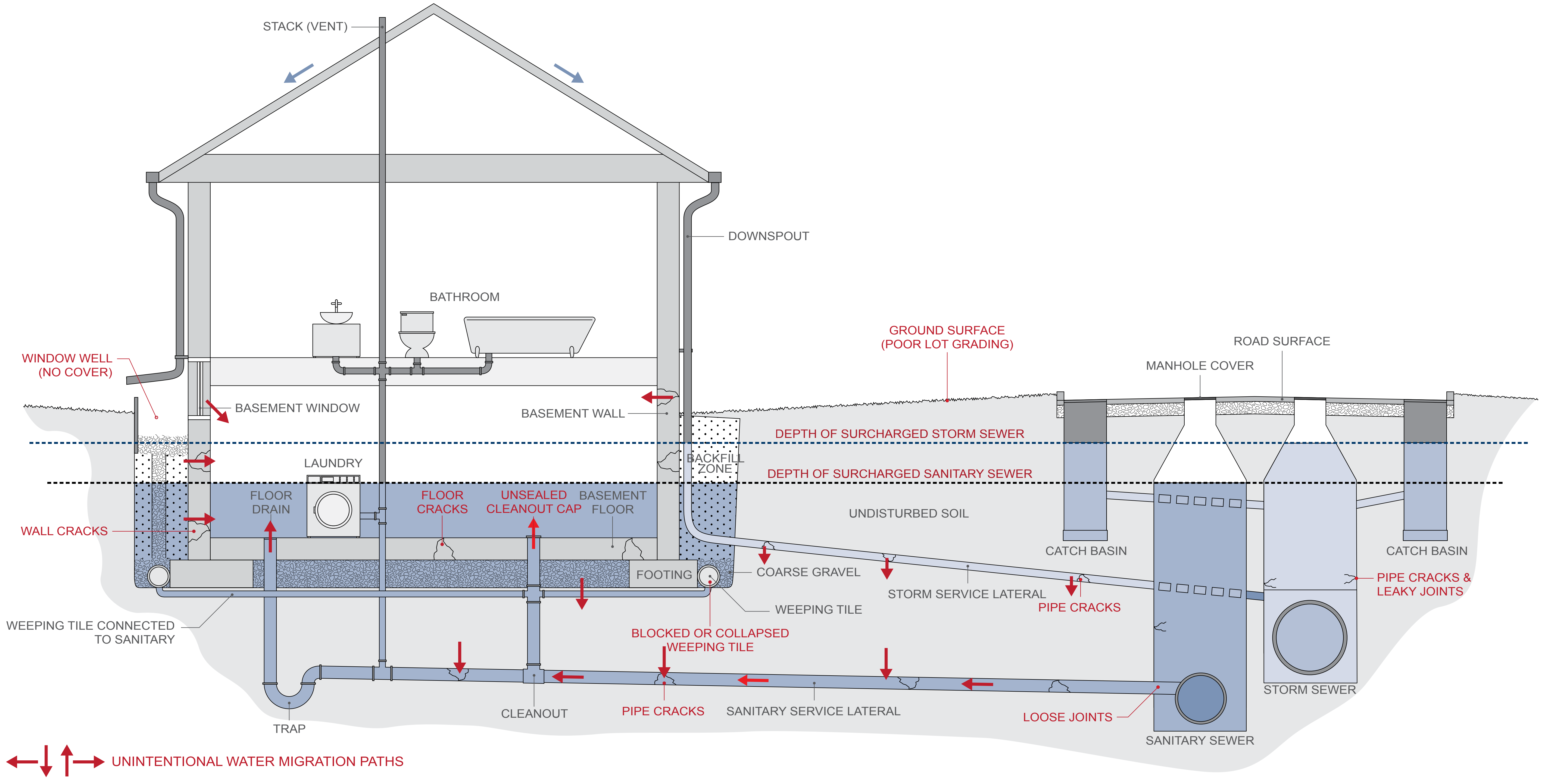
Under normal conditions the backflow flap rests in a recessed channel to allow unrestricted flow of sewage from the house drain into the sanitary sewer.

When the sanitary sewer pipes are surcharged and start to backup into the house drain, the effluent from the sewer is blocked by the backflow flap.

Image courtesy Multi-Drain Inc.

Backwater valves are an economical and reliable means of preventing sewer backups.

Resilient Building Enclosure Design



Sanitary and storm sewer backups represent weak links in the building enclosure's moisture management measures. Unintended water migration can bypass the basement enclosure through floor drains and/or enter as leaks.

Climate change has led to the increased frequency and severity of extreme rainfall events. In almost every North American city and region, this has led to sewer backups. First, intense rainfall from convective storms causes storm sewers to overload, leading to stormwater being backed up through the foundation drains to enter around the perimeter of the basement floor slab. This surcharge then enters the floor drains and flows into the sanitary sewer system. At the same time, runoff inflows into manhole covers while groundwater infiltrates through leaks and cracks in the buried piping. Together, these unintended stormwater flows cause sanitary sewer surcharges downstream that result in basement flooding.

Low impact development (LID) measures help reduce the likelihood of basement sewer backups, but many existing urban areas are difficult to retrofit. Where LID measures are implemented, they significantly reduce, but often cannot completely eliminate the risk of basement flooding, especially during extreme storms. One of the most cost effective measures to prevent basement flooding due to sewer backups are backwater valves. Many municipalities subsidize their installation in sewer backup prone areas, typically older and more dense parts of the city, where the cost of modernizing sewers is prohibitive. A growing number of municipalities require the installation of backwater valves in both the storm and sanitary connections across all new developments.

There are two important considerations associated with backwater valves. First, they must be properly installed to avoid water pressures from building up underneath the foundations. Second, there is a need for homeowner education regarding the inspection and maintenance of backwater valves.

Basement flooding can still occur even after backwater valves are installed. It is important that the lot grading directs runoff away from the building and that basement window wells are provided with properly drainage. Finally, basement windows should seal tightly to prevent water leakage in the event the site drainage and window wells are overwhelmed by extreme rain storms.

Resilient Building Enclosure Design

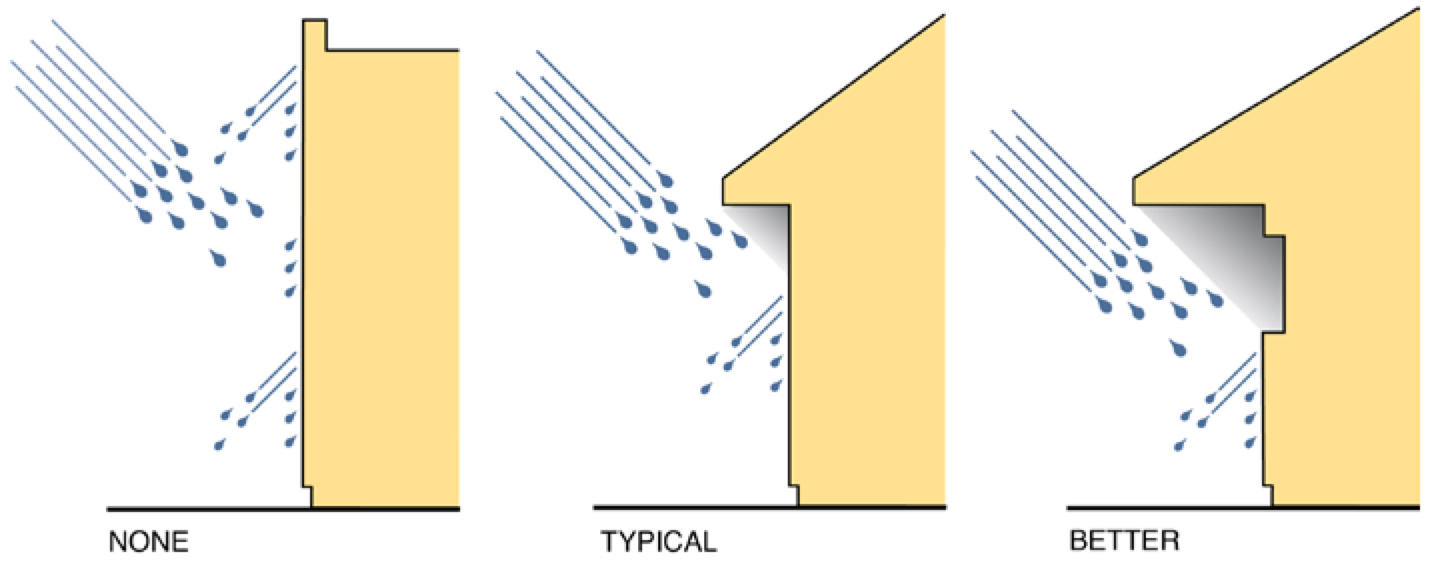
Rain Control, Air Leakage and Moisture Management

Building enclosures are the first line of defence against extreme weather events and for this reason it is important to address issues of rain control, air leakage and moisture management in enclosure design.

Rain control involves the design of the enclosure to manage rain penetration. Contemporary building science advocates an approach to rain control that is termed the 4-Ds, which stands for:

- **Deflection** - keeping as much precipitation away from the exterior wall enclosure as practically possible;
- **Drainage** - draining away any water that does strike and/or penetrate the cladding;
- **Drying** - providing sufficient ventilation to evaporate residual moisture and arranging materials for gradual drying by diffusion; and
- **Durability** - selecting materials that can withstand periodic wetting without deterioration over the service life of the enclosure.

In practical terms, drained and ventilated facades provide acceptable rain control. For most climatic regions, pressure moderated rainscreens adequately control rain for exterior walls, but in very tall buildings and for extreme exposures to wind-driven rain, a pressure equalized rainscreen is recommended. Water resistive barriers and flashings must be carefully integrated to manage rainfall penetration, especially in open joint cladding systems.



Deflection strategies in the form of overhangs and recessed windows are among the most effective means of reducing rainfall exposure. Since most facades in modern architecture offer none or little deflection, it is important to emphasize drainage, drying and durability in enclosure design.

Resilient Building Enclosure Design

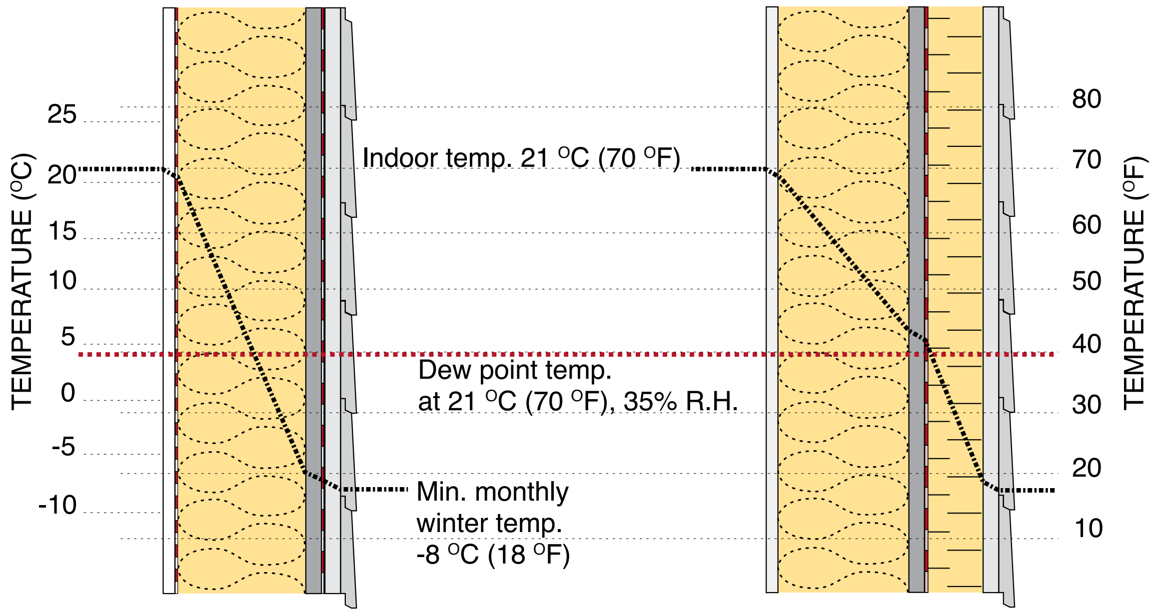
Air leakage is controlled through the provision of a continuous, structurally supported air barrier system. Attention to detailing at transitions between materials, components and assemblies is essential. It is important to delineate clearly which trade is responsible for continuity at each transition, such as the wall/roof junction. Air barriers control air leakage that can lead to moisture problems due to condensation, and it also conserves energy by reducing infiltration.

A calibrated series of fans is used to perform airtightness testing of the building enclosure. Proper enclosure commissioning deploys airtightness testing to ensure the integrity of the air barrier system.

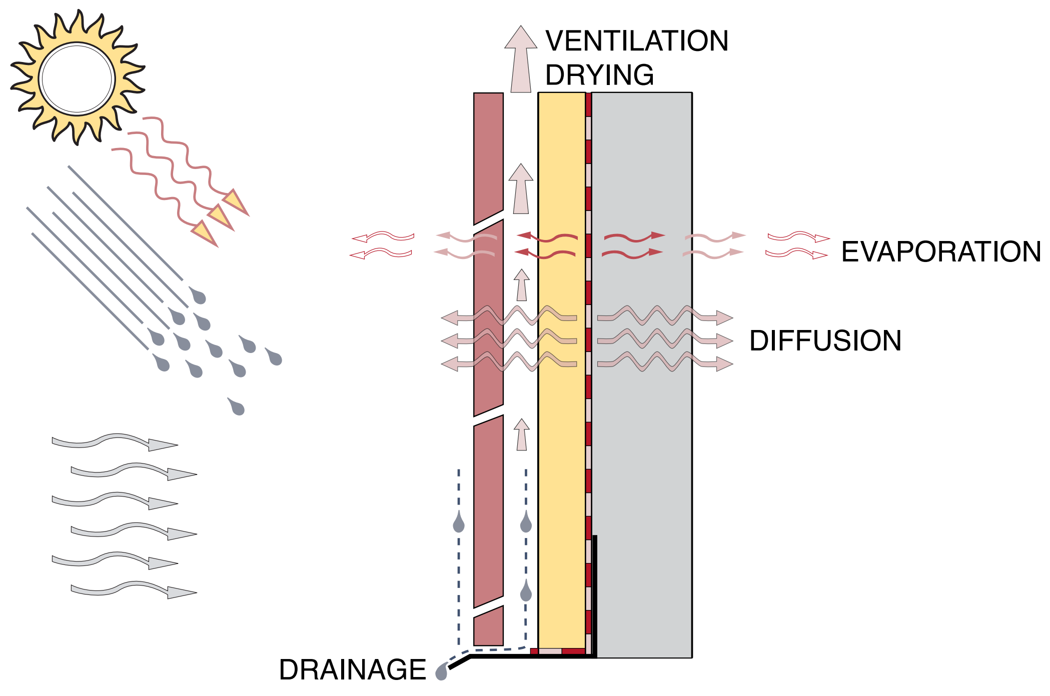
Moisture management involves the selection and arrangement of materials to minimize moisture build up in walls and roofs, and to promote drying. Prudent enclosure design begins by acknowledging that materials and workmanship are imperfect. This reality can be countered by providing multiple measures for managing moisture inside of building enclosures.

Continuous insulation outboard of the building structure addresses the demand for higher levels of thermal performance, but also helps manage moisture migration due to air leakage. It is often not practical to install all of the insulation needed to meet code requirements for energy efficiency outboard of wall and roof assemblies. One way of dealing with this challenge is to insulate the cavity in addition to providing continuous outboard insulation. However, this will require designers to account for a higher potential for condensation inside of cavities.

Except for extremely cold climate zones, the latest building research involving hygrothermal analysis and corroborated by laboratory testing, indicates that air barrier materials should be vapour permeable, to some degree, in order to promote two-way drying when both cavity and outboard insulation is provided. This will become an increasingly critical consideration as climate change unfolds. Modern buildings have a useful life of about 100 years or more. During this time, summers can be expected to become warmer and wetter and building enclosures will begin to accumulate moisture on a seasonal basis unless two-way drying is deployed.



Providing continuous insulation outboard of the structure not only improves thermal performance, but reduces the potential for condensation inside of cavities by elevating the cavity surface temperatures above the dewpoint of the indoor air.



Vapour permeable air barriers can control air leakage and manage moisture in enclosures by allowing two-way drying. Building science research indicates the required level of vapour permeability is based on climate zone. Climate change adaptation means vapour barriers at the inside face of wall assemblies should be avoided in all but the most extreme cold climate zones.

Resilient Building Enclosure Design

Thermal Control

While designing for rain control, air leakage and moisture management, it is necessary to provide adequate thermal control for occupant comfort and energy efficiency.

Thermal bridging is now recognized as degrading the overall thermal effectiveness of enclosures. In the past, building codes prescribed the minimum amount of thermal control required in buildings, but this only referred to the amount of insulation that was provided. Recent studies have quantified just how significantly thermal bridging reduces the effective thermal resistance of walls, roofs and windows. Practical solutions have been developed and are both readily available and affordable.

Thermography reveals thermal bridging in building enclosures. Recent research has indicated that shelf angles, girts and fasteners can reduce the effective thermal resistance of walls by

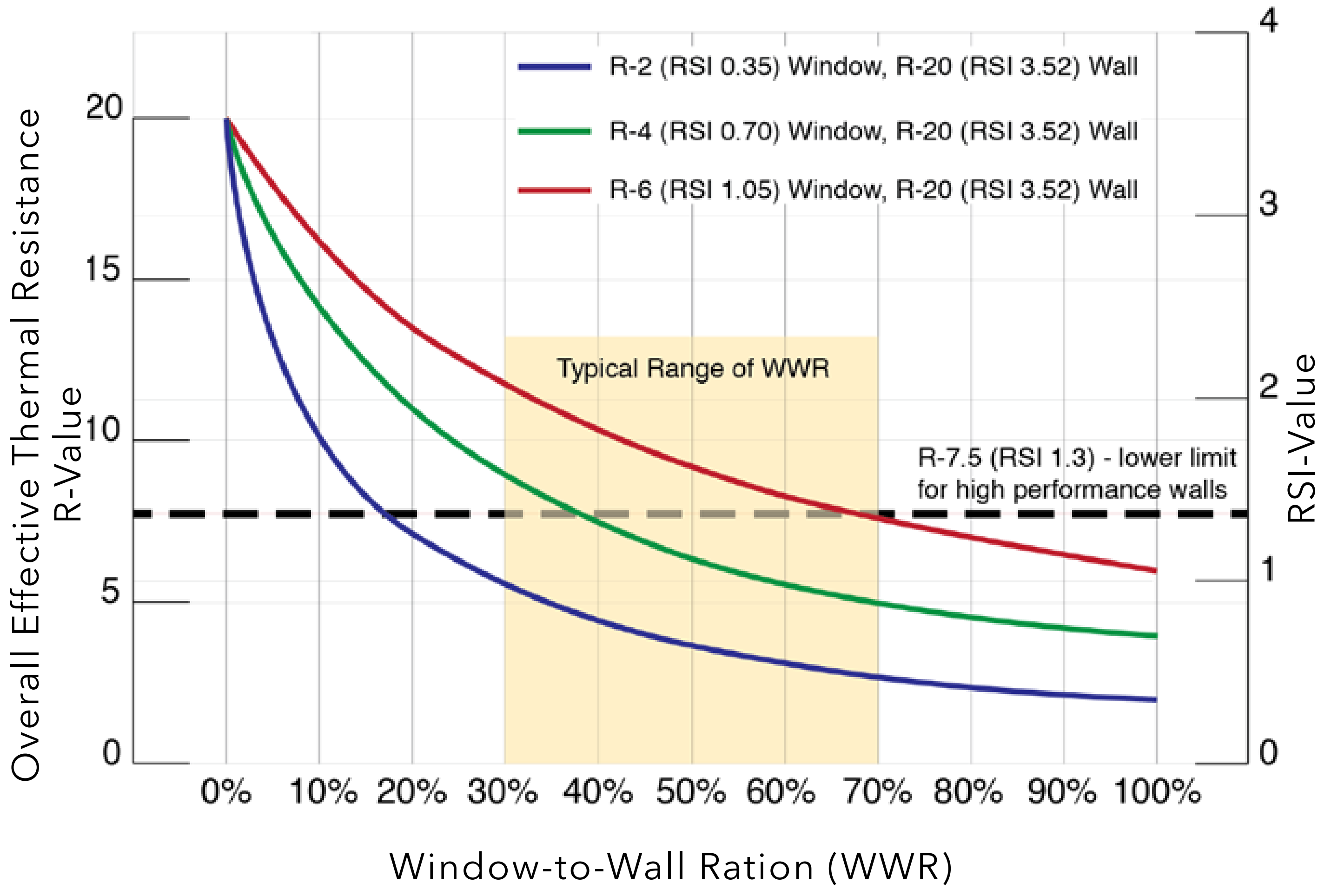
50% *or more.*

Resilient Building Enclosure Design

Thermal Persistence

Another related consideration is the thermal persistence of insulation materials across a range of temperatures and moisture contents. Not all insulation materials retain their rated thermal resistance values at very low outdoor temperatures, and most batt and blown or loose-fill insulation products can have their thermal insulating properties reduced when they become wet. Climate change forecasts predict that extreme weather events can be expected to increase in frequency and severity in the future. It is advisable to select insulation materials that can maintain their effectiveness under a broad range of environmental conditions.

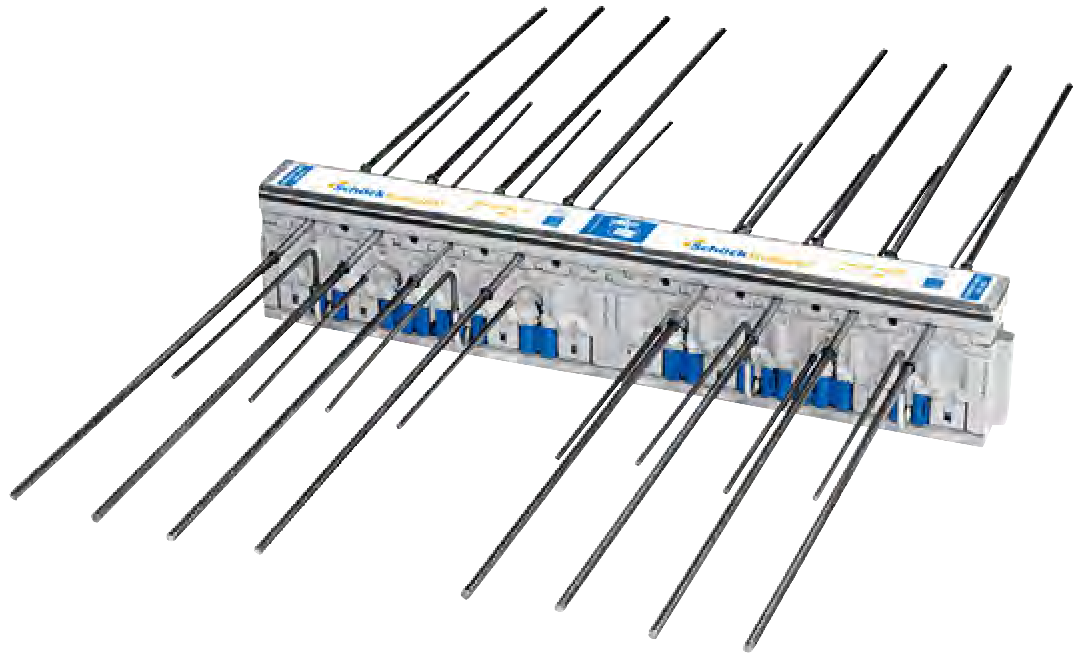
Influence of Window-to-Wall Ratio: The thermal efficiency of the enclosure is largely determined by the thermal effectiveness of exterior walls, which are strongly influenced by the window-to-wall ratio - the area of the windows as a fraction of the gross exterior wall area. Selecting high efficiency windows and limiting the window-to-wall ratio are more cost effective than adding more insulation.



For the typical range of window areas, practically no amount of insulation will compensate for low thermal efficiency windows. The amount and thermal efficiency of windows limit the overall effective thermal resistance of exterior walls. High performance windows allow for larger glazed areas without compromising thermal efficiency.

Resilient Building Enclosure Design

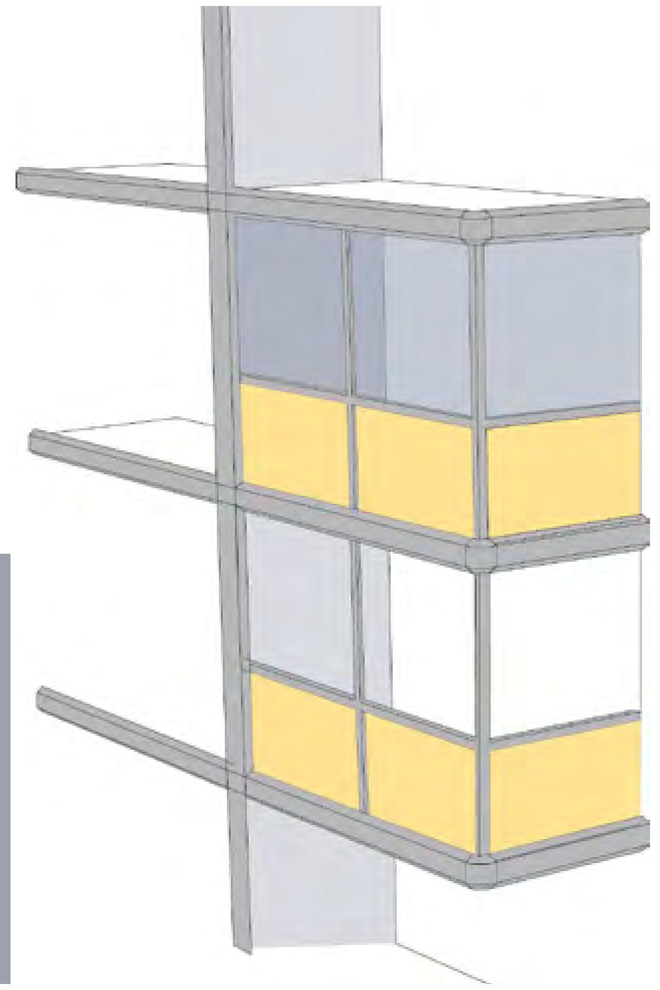
Balcony thermal breaks can enhance occupant comfort and energy efficiency for cantilevered concrete balcony slabs.



Balcony thermal break technology is proven, widely available and affordable. What's in your building project?

Contemporary balcony enclosure systems transform balconies into spaces that can be kept dry and comfortable for most of the year.

Balcony enclosures not only provide a more comfortable and habitable space, but they also enhance thermal performance as well as provide protection against airborne projectiles.



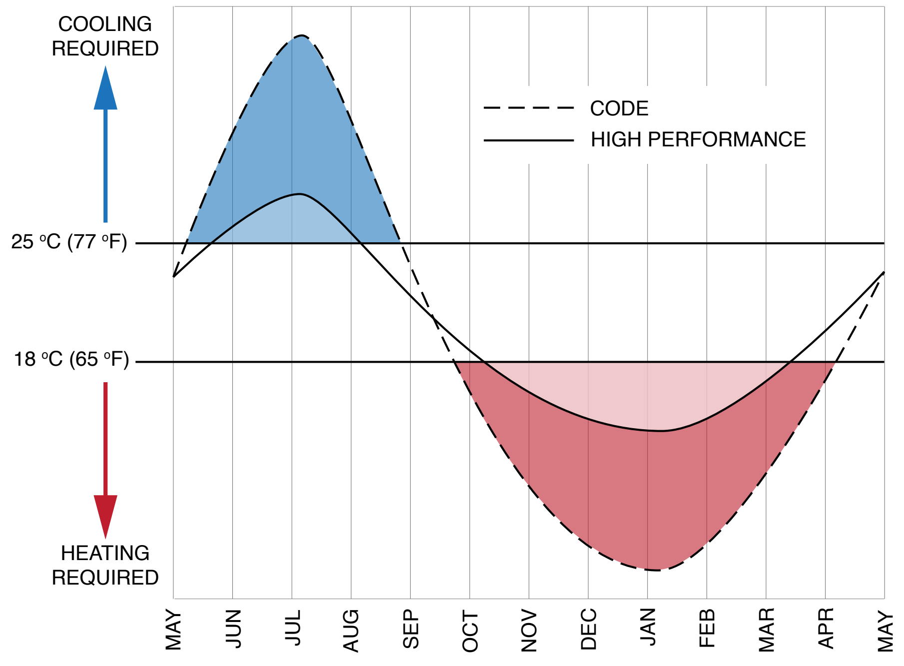
Enclosed balconies contribute to the resilience of multi-unit residential buildings by providing a buffer zone against the outdoor climate and potentially a place of refuge in the event of fire.

Contemporary balcony enclosure systems transform balconies into spaces that can be kept dry and comfortable for most of the year.

Resilient Building Enclosure Design

Thermal Autonomy (TA)

Thermal autonomy (TA) is a measure of the fraction of time a building can passively maintain comfort conditions without active system energy inputs. It is usually expressed as a fraction of the year during which time neither heating nor cooling is required.

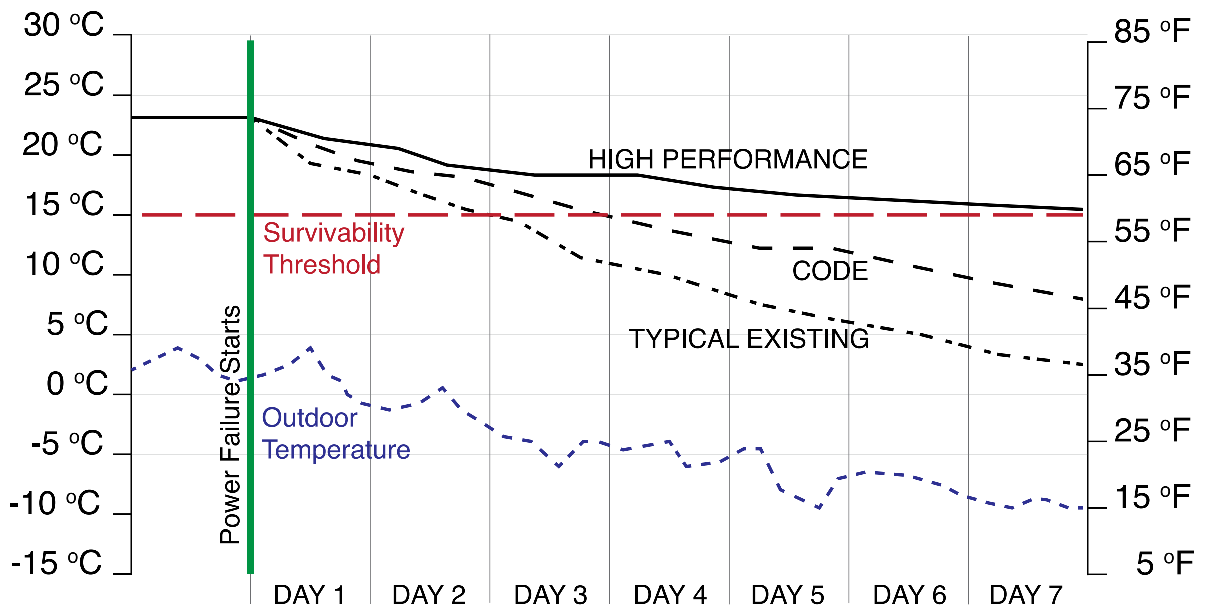


Improving the thermal efficiency of enclosures increases thermal autonomy, conserves energy and reduces the capacity of heating and cooling equipment while extending its service life. In most climate zones, it is feasible to increase thermal autonomy from about

30%
for a code minimum building to well over

70%
for a high performance building.

Recent experience has shown that typical existing buildings are vacated within less than 48 hours when an extended power failure coincides with cold winter weather. Buildings constructed to code minimum requirements perform only marginally better. High performance enclosures can provide a week or more passive survivability when disaster strikes.



Passive survivability (PS), also referred to as thermal resilience, is used as a measure of how long inhabitants may remain in their dwellings during extended power outages that coincide with extreme weather events. Passive survivability is attributable to the quality of the thermal effectiveness of the enclosure.

Resilient Building Enclosure Design

Fire Safety

In view of events such as the Fort McMurray and California fires of 2016 that coincided with periods of extreme drought, fire safety is now viewed as an increasingly important resilience strategy.

Building codes represent minimum requirements for occupancy safety in the event of fire, not what is needed to achieve resilience. Whether for new or existing buildings, it is important to assess fire risks and ensure there are appropriate counter measures in place. Simple preventive measures such as making available and sharing floor plans with first responders and firefighters can save precious time and lives.

Passive fire protection strategies include non-combustible cladding, fire separations and compartmentalization, but may be extended to building procedures and practices that limit the quantity of finishes, furnishings and contents that are combustible and may fuel a fire. Unlike active fire protection systems, only passive measures can minimize the risk of fire breaking out, and in the event of a fire, reduce the extent of fire, smoke and water damage to the building fabric. Continuous layers of non-combustible exterior insulation over water resistive air barriers detailed at transitions to achieve high levels of airtightness represent best practices for fire safety, durability and energy efficiency.

Smoke control involves both passive and active strategies. Containing and channeling smoke movement are passive measures related to the geometry and interconnectedness of building spaces. The provision of openings to flush smoke out of the building is typically an active system measure that is integrated within the fire protection equipment.

Sprinklers, alarms, emergency signage and lighting along with building automation systems (BAS) are among the active fire safety strategies that can be implemented in new buildings or upgraded in existing facilities. BAS technology can be integrated with dynamic signage and public announcement systems to safely evacuate the occupants in case of a fire or any other type of emergency.

It is important to recognize that active fire safety systems require careful monitoring, continuous maintenance and periodic testing to ensure they will properly perform their intended functions in response to fire emergencies. When active systems fail to perform, fire safety is provided entirely by passive systems, reinforcing why these should be given priority in fire safety design.

In rural areas that are vulnerable to wildfires, there are several measures that can be taken to reduce the risk of damage and loss. First, landscape a fire resistant building site and keep the area surrounding the building clear of combustible debris, avoid trees planted adjacent to the building and features like wooden fences. Second, keep gutters clear of combustible debris and select roofing that does not ignite from falling embers. Non-combustible wall cladding and fire-rated exterior thermal insulation provide added protection. Third, select windows with tempered glass and smaller glazing areas that are less prone to breakage from heat exposure, and fit windows with non-combustible interior draperies and exterior shutters. Fourth, in areas with sufficient rainfall, harvest rainwater and store it in underground tanks for use by firefighters.

When it comes to fire safety, it is better to have it and not need it, than to need it and not have it.

Wildfires such the one striking Fort McMurray, Alberta in 2016 may be unavoidable, but proper resilience measures could have minimized the damage to property and communities. [Source: Public Domain.]

Resilient Building Enclosure Design

Building Enclosure Commissioning

Building enclosure commissioning (BECx), (also referred to as building envelope commissioning) is a quality-oriented process aimed at achieving a building enclosure that meets the needs of the owners and end users according to defined performance objectives and criteria.

BECx is an important resilience strategy that goes beyond conventional procedures for HVAC systems and equipment because it ensures the quality and consistency of passive measures embodied in the building enclosure. There is an emerging trend to embed BECx in building project specifications, and there are a number of standards for BECx that can be referenced.

Regardless of the BECx framework that is adopted, it is critical to engage building enclosure commissioning at the early stages of design. Equally critical is the need to review and integrate resilience measures with BECx procedures and criteria.

Durability of the building enclosure is considered to be a long-term resilience strategy that provides reliable performance over the intended service life of a building. Building enclosure commissioning is more than peer review of building details, inspection and field testing to deliver an airtight and thermally efficient enclosure. It also involves hygrothermal analysis of building enclosure assemblies to avoid moisture problems that can lead to deterioration and mold problems. BECx is a prudent and cost effective investment to achieve better value, higher performance and enhanced resilience of the building.

In-situ testing of the building enclosure during construction can avoid the proliferation of inferior components, bad details and poor workmanship over the entire building enclosure. [Source: Z6 Commissioning LLC.]

Full scale mock-ups are a proven means of ensuring the quality and buildability of the building enclosure well in advance of the commencement of construction. [Source: David K. Ross.]

Rx for Successful BECx

The following steps are key ingredients for a successful building enclosure commissioning recipe.

1. Make building enclosure commissioning a process.
2. Retain an independent third party as BECx authority.
3. Define the owner's project requirements (OPR).
4. Align the building envelope commissioning scope with the OPR and the project's complexity.
5. Produce a written BECx plan.
6. Plan design reviews for maximum impact.
7. Establish enclosure system performance metrics during the design phase.
8. Monitor construction early and often.
9. Confirm performance after commissioning and occupancy – address defects as per provisions in the contract documents.
10. Document all modified and rejected details and specs then update / purge your knowledge base accordingly.

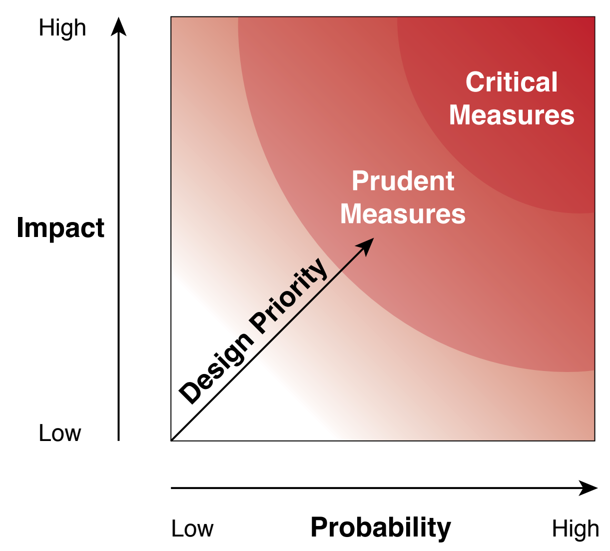
Adapted from 8 Strategies for Successful Building Enclosure Commissioning. Emily Hopps and Peter Babaian, Simpson Gumpertz and Heger. Building Design & Construction, November 17, 2014.

Integrative Design of Resilience

The building industry is gradually adopting what is termed the integrated design process where the various professionals and stakeholders involved in a project work together to develop design solutions. This is an improvement over the segregated design process that dominated

Integrative design goes beyond the integrated design process by transcending traditional hierarchies and taking an interdisciplinary approach to whole-systems design thinking. To illustrate the difference between the two approaches, integrated design focuses on the building, while integrative design considers the building in the more holistic context of its inhabitants, the surrounding community and all of its social, environmental and economic implications.

Risk = Probability x Impact



Risk is determined by considering the likelihood of an event (hazard) and its associated consequences or impacts. Design for resilience gives priority to hazards that have both a high probability and a high impact.

Assessment of Risks and Consequences

Design for resilience requires a robust integrative design process that carefully considers risks and consequences.

One technique for conducting this assessment is to employ a framework similar to the one depicted below. By identifying the hazards that may occur along with their associated probabilities and impacts, the integrative design team can establish and prioritize risks.

HAZARD	PROBABILITY Frequency/Duration	IMPACT Severity/Spatial Scale	RISK Consequences
• drought • flooding • dam failure • hurricanes • rain/ice/snow storms • hot/cold spells • earthquakes • landslides • avalanches • tsunamis • fires • explosions • power outage	• daily • seasonally • annually • 1 in "X" years • minutes • hours • days • weeks • months • years	• mild • moderate (average) • high or extreme • site localized • neighbourhood or precinct • community, town or city • region (widespread)	• inconvenience • discomfort • disruption • property damage • environmental damage • health impacts • life safety (injury, death) • disaster/catastrophe

Risk assessment framework for common hazards.

Identification of Critical Resilience Strategies

The critical resilience strategies emerge from the assessment of risks and consequences. Normally, resilience strategies consider both the typical use scenarios of a building or facility, as well as the most likely extreme events that could compromise the integrity of the building or endanger its inhabitants. These hazards are often geographically specific for weather and seismic events, but there are also many hazards that are becoming increasingly common, such as power outages, that depend more on the state of the local infrastructure than climate.

Resilience strategies that address more than a single risk are typically more cost effective than deploying separate measures to address each hazard. For example, a high performance building enclosure can be designed to provide passive survivability (a.k.a. thermal resilience) in extreme hot and cold weather spells, and also be able to withstand high winds, airborne projectiles and drenching wind-driven rain, as well as fire.

It is important to explore resilience strategies at a number of scales and from a number of perspectives. In some cases, the site in terms of its landscaping, roadways, parking, pedestrian circulation and accessibility is just as critical as the building or facilities. The next section examines a framework for resilience measures from a building-as-a-system perspective.

Integrative Design of Resilience

Building-as-a-System Resilience Measures

The building-as-a-system model helps organize resilience measures. Understanding the building-as-a-system helps identify critical factors affecting resilience.

First, it is helpful to distinguish between hard versus soft measures when planning for resilient building design.

Hard measures are also often referred to as hardening, and represent the physical aspects of a building such as its resistance to earthquakes, extreme wind forces, wind-driven rain, etc. Hard measures may be applied to the building enclosure, mechanical/electrical systems, and site and services infrastructure. There are numerous technical publications related to measures for hardening buildings to enhance their resilience.

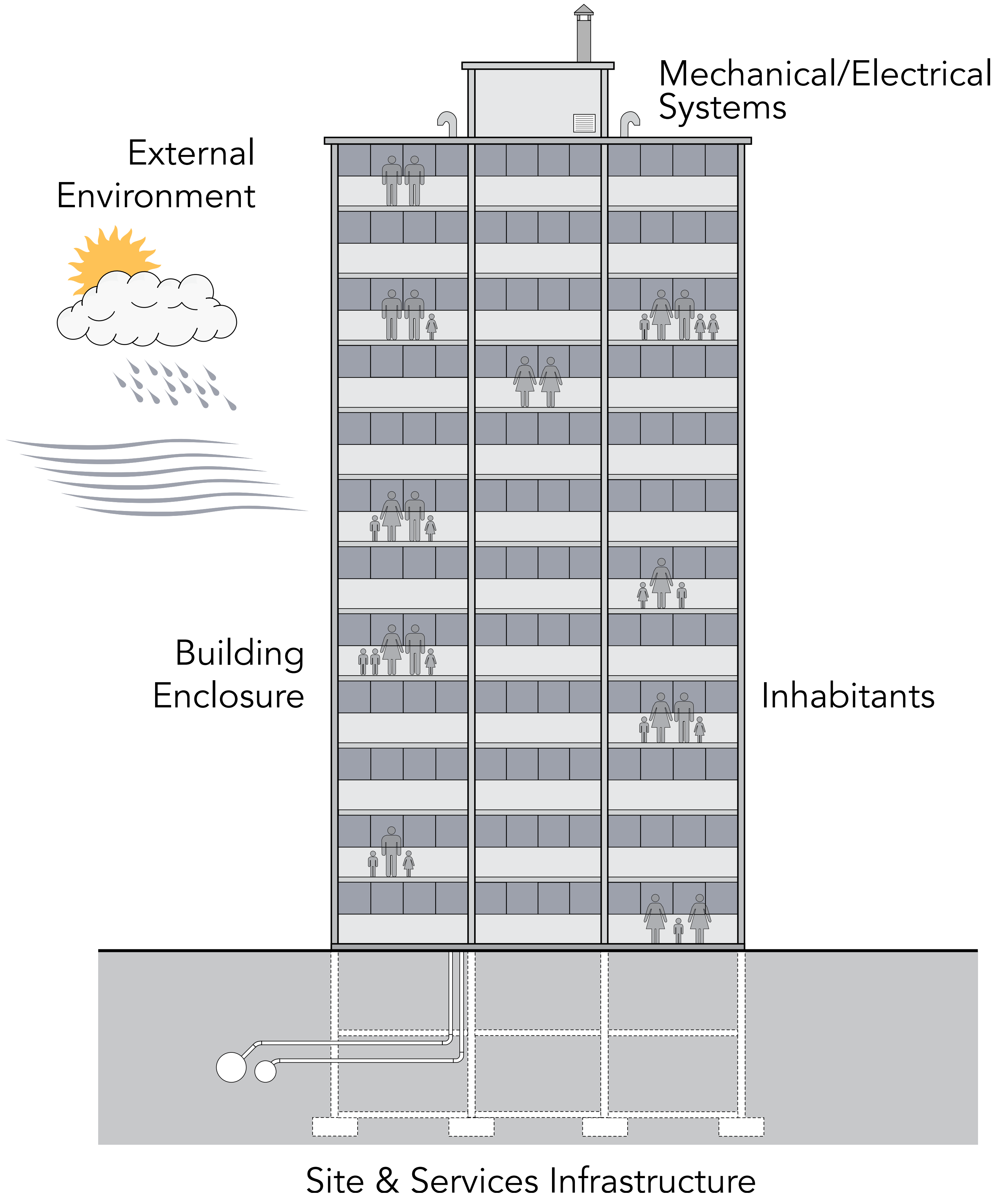
Soft measures involve practices, policies and procedures that may be invoked to cope with various types of challenging events. These measures are often community-based and do not have technology as their focus. Building inhabitants must be informed and reminded of soft measures, such as regular fire drills, so they can respond appropriately.

Looking at resilience from a planning and design perspective, it is not always possible to provide and invoke all of the resilience measures that may be identified at the planning stage for a new building, or following the appraisal of an existing facility. For this reason, among all of the soft measures, one of the most significant is creating a migratory path to enhanced resilience. It is possible during the early stages of design to plan and budget for measures that will enhance the resilience of a building such that these may later be easily accommodated. For example, window openings may be detailed to later accept exterior shutters to protect against glass breakage from wind-borne projectiles. By coupling flexible design with realistic operations and maintenance budgets, the resilience of buildings can be continually improved.

Integrative Design of Resilience

Operations and Maintenance

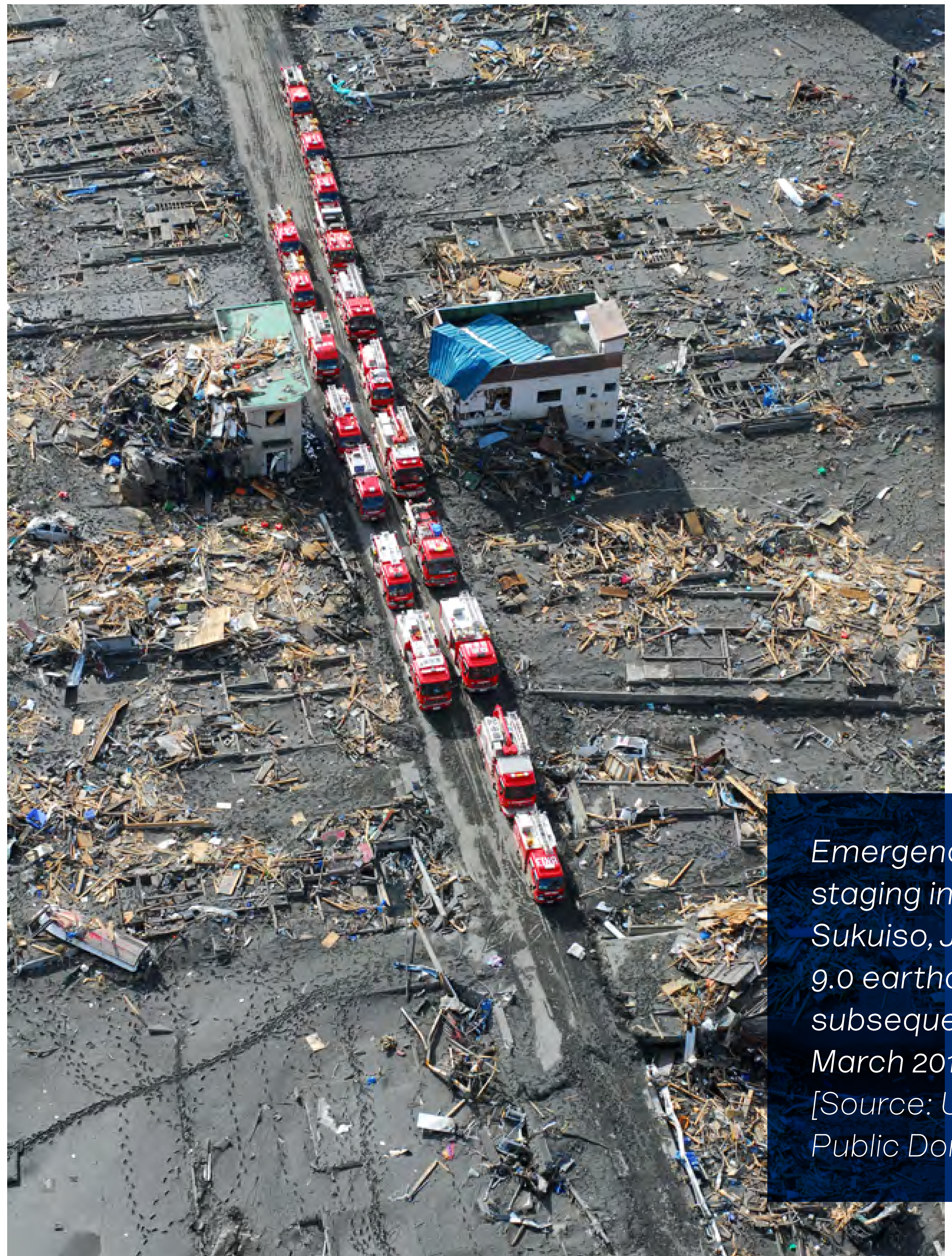
Proper operations and preventive maintenance do not only offer cost savings, but are among the most effective resilience measures for buildings. Advances in building automation systems can help achieve proper operation and maintenance, but they also require skilled operators, continuous monitoring and periodic maintenance. Total reliance on computer software, sensors and controls being entirely capable of operating and preventively maintaining a facility can become a recipe for disaster. Software bugs and glitches, sensors that go out of calibration, and controls that fail are among the many problems that will require knowledgeable personnel to manually operate systems while repairs are carried out to restore proper operations. It is the soft operation and maintenance measures that are critical to resilience and the importance of observing comprehensive maintenance schedules and monitoring procedures cannot be overstimated.



The building-as-system model is based on the behaviour and interactions between the inhabitants, the building enclosure, the mechanical/electrical systems, and the site (landscaping) and services infrastructure and how these respond to the external environment.

Emergency Planning

Emergencies may not be inevitable although often unavoidable, however, it is still possible to mitigate the extent and severity of damage and losses through proper emergency planning.



Emergency vehicles staging in the ruins of Sukuiso, Japan after 9.0 earthquake and subsequent tsunami, March 2011. [Source: U.S. Navy, Public Domain.]

What Happens When Everything Fails?

It is not possible to foresee and be fully prepared for all situations. There are times when the severity of a disaster overcomes our physical resilience measures and then we are only left with the soft resilience measures that reside in people, their communities and disaster relief organizations.

When everything fails, it is important to have a system of emergency measures and procedures that can be invoked to rescue victims, protect property and restore vital services.

Emergency Measures and Procedures

It is advisable to adopt emergency measures and procedures for the safety and security of the inhabitants, less so for the facility itself. It is not that building assets are unimportant, but their resilience attributes will either shelter the inhabitants or prove insufficient. This does not mean that facilities management staff do not require emergency protocols that correspond to various types of hazards and phenomena. But emergency measures and procedures are invoked when resilience protocols for the facility fail.

Shelter, water, food and first aid supplies are necessities under a state of emergency. An organization or institution that inhabits a building should plan to maintain a place of refuge within the building along with a supply of water and food to enable its people to withstand a specified period of time associated with reasonably expected disaster events. Alternatively, it should have an evacuation plan that can safely transport its people to emergency shelter.

Autonomous communications technology to contact emergency organizations and first responders is critical when disaster strikes. It is also necessary to keep informed those locked down by emergencies.

To minimize panic and distress, it is important to pro-actively provide building inhabitants with information about emergency measures and procedures under a variety of scenarios. Carrying out routine drills and debriefing personnel about their efficacy fosters calm and confidence under pressure of an emergency.

Redundancy is key to resilience and it is vital that emergency measures and procedures are not in the hands of so few personnel that the majority of inhabitants are helpless in their absence.

Resilience under a state of emergency is a team effort and it should be expected that proper orientation, training and practice will be required on a continuous basis to be adequately prepared.

Appendix A: Resilience Resources

The following publications are available for download from their respective organizations. They are organized in chronological order and many contain links to additional sources of information about resilience.

FireSmart: Protecting Your Community from Wildfire. (Second Edition). Partners in Protection, July 2003.

A Guide for Local Jurisdictions in Care and Shelter Planning. Alameda County Operational Area Emergency Management Organization, September 2003.

Definition, diagnosis, and origin of extreme weather and climate events. David B. Stephenson in Climate Extremes and Society, ed. H. F. Diaz and R. J. Murnane. Cambridge University Press, 2008.

The New District Energy: Building Blocks for Sustainable Community Development. Canadian District Energy Association, January 2008.

Active Design Guidelines: Promoting Physical Activity and Health in Design. City of New York, 2010.

A Framework for Establishing Critical Infrastructure Resilience Goals. Final Report and Recommendations by the Council. National Infrastructure Advisory Council, October 19, 2010.

Low Impact Development Stormwater Planning and Design Guide, Version 1.0. Toronto and Region and Credit Valley Conservation Authorities, 2010.

Building community resilience to disasters: A practical guide for the emergency management sector. GNS Science Report, September 2011.

High Performance Based Design for the Building Enclosure. A Resilience Application Project Report. BIPS 10 / November 2011 , Prepared by the National Institute of Building Sciences for the U.S. Department of Homeland Security.

Peeling back the pavement: a blueprint for reinventing rainwater management in Canada's communities. Susanne Porter-Bopp et al. Co-published by Environmental Law Centre, University of Victoria, October 2011.

72 Hours: Is Your Family Prepared? Public Safety Canada, 2012.

Protecting Your Home from Wildfire: Creating Wildfire-Defensible Zones. Colorado State Forest Service, 2012.

Strategies for Multifamily Building Resilience. Disaster Preparedness for Affordable Housing Organizations. Enterprise Green Communities, 2012.

Building Resilience in Boston: Best Practices for Climate Change Adaptation and Resilience for Existing Buildings. Prepared on behalf of Boston Society of Architects by Linnean Solutions, The Built Environment Coalition and The Resilient Design Institute, July 2013.

Resilience certification for commercial buildings: a study of stakeholder perspectives. Barbara J. Jennings, Eric D. Vugrin and Deborah K. Belasich, Environment Systems and Decisions (2013) 33: 184 – 194.

Dialogue on National Resilience. Summary Report, September 19, 2013. National Institute of Building Sciences. Washington, DC.

Preparing Health Care Facilities for Climate Change - Resource Guide. Canadian Coalition for Green Health Care, 2013.

Health Care Facility Climate Change Resiliency Checklist. Canadian Coalition for Green Health Care, 2013.

Critical Infrastructure Security and Resilience Activities Checklists. FEMA, 2013.

8 Strategies for Successful Building Enclosure Commissioning. Emily Hopps and Peter Babaian, Simpson Gumpertz and Heger. Building Design & Construction, November 17, 2014.

Resilience By Design. Mayoral Seismic Safety Task Force, City of Los Angeles, 2014.

Flood Resilience Checklist. United States Environmental Protection Agency, July 2014.

Primary Protection: Enhancing Health Care Protection for a Changing Climate. U.S. Department of Health and Human Services, December 2014.

Resilience for Free: How Solar + Storage Could Protect Multifamily Affordable Housing from Power Outages at Little or No Cost. Clean Energy Group, October 2015.

Resilient Building Design Guidelines. City of Hoboken, New Jersey, October 19, 2015.

2015 Enterprise Green Communities Criteria.

2015 Enterprise Green Communities Criteria Checklist.

Assessing the Resilience of LEED Certified Green Buildings. Cassandra L. Champagne and Can B. Aktas, Procedia Engineering 145 (2016) 380 – 387.

Resource Guide. HHS Sustainable and Climate Resilient Health Care Facility Initiative. Department of Health and Human Services, December 2015.

Best Practices Guide: Management of Inflow and Infiltration in New Urban Developments. Institute for Catastrophic Loss Reduction, February 2015.

Resilience for Free: How Solar+Storage Could Protect Multifamily Affordable Housing from Power Outages at Little or No Net Cost. Clean Energy Group, October 2015.

Opportunities to Enhance the Nation's Resilience to Climate Change. Council on Climate Preparedness and Resilience, The White House, Washington DC, October 2016.

Building Resilience: Practical Guidelines for the Sustainable Rehabilitation of Buildings in Canada. Federal Provincial Territorial Places Collaboration (FPTHPC), 2016.

Accelerating Market Transformation for High-Performance Building Enclosures: State of market, policy developments, and lessons learned from the Passive House movement. Frappé-Sénéclauze, Tom-Pierre et. al. The Pembina Institute, 2016.

Building Community Resilience to Hazards. Special Issue Editorial: Building Resilience, Guest Editor, Louise K. Comfort. Safety Science 90 (2016) 1 – 4.

Appendix B: Building Resilience Checklist

Planning

- Assessment of risks and consequences
- Identification of critical resilience strategies responding to risks and consequences
- Development of migratory path to enhanced relience (accomodation of continuous adaptation)
- Establishment of resilience performance metrics and targets (e.g., durability, passive survivability, etc.)
- Planning of site, landscaping, accessibility, low impact development, rainwater harvesting, renewable energy, district energy, emergency and/or combined heat and power, etc.
- Coordination/harmonization with community resilience and emergency measures (e.g., crisis shelter, place of refuge, cooling center, etc.)

Design

- Development of Owner's (Stakeholders) Project Requirements
- Selection of commissioning agent(s) and development of commissioning plan(s)
- Integration of resilience strategies for seismic, hurricane, flooding, extreme heat/cold spells, extended power outages, drought, wildfires, etc.
- Prioritization of resilience measures - passive versus active systems, hard versus soft measures
- Accommodation of migratory path(s) to enhanced resilience for measures that are not initially affordable/feasible
- Finalization of as-built documentation during commissioning stage of project

Commissioning

- Peer review of passive and active system strategies at the schematic design stage
- Peer review of enclosure details/ specs and HVAC system equipment/ controls/specs throughout the design development stage
- Kickoff and ongoing coordination meetings with general contractor and/or project manager and all subcontractors and trades
- Periodic site reviews and inspections
- Continuous monitoring of work
- In-situ quality assurance testing
- Confirmation construction conforms to OPR and performance metrics/ targets OR suitable remediation/ restitution as required
- Active systems start-up, balancing of HVAC systems, calibration of controls, programming of building automation system, confirmation of fire safety and security system functionality, special systems and equipment, etc.
- Handoff project documentation, operations and maintenance manual to facility manager(s) and provision of support during transition and full occupation of facility

Operations and Maintenance

- Recruitment and training of properly qualified facilities personnel
- Execution of operating, housekeeping, monitoring and maintenance procedures consistent with facility manual developed by commissioning agent(s)
- Recording of housekeeping, maintenance, repair and replacement activities
- Updating of facility documentation and procedures to reflect repairs, replacements, retrofits and renovations

Emergency Measures and Procedures

- Appointment of Resilience/ Emergency Coordinator and/or Committee for facility
- Review and rectification (if necessary) of signage, public announcement system, emergency lighting, first aid stations, fire extinguishers, etc.
- Implementation of monitoring and inspection/testing protocols for critical components, systems and equipment
- Development and delivery of emergency and safety training to building users
- Staging of fire drills and other emergency maneuvers/procedures
- Continuous monitoring and improvement of resilience and emergency measures and procedures