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The Resilient Urban Skyscraper as Refuge

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Abstract

This paper investigates the role of the Urban Skyscraper with respect to climate change resilience. Large urban centers are now experiencing the consequences of climate change, and are facing colossal social and economic impacts. As buildings that house thousands of people, urban skyscrapers possess a distinct role to play in the face of climate change events. The objective of this paper outlines how current design methodologies for urban skyscrapers can be modified to better respond to the outcomes of extreme weather events such as sea level rise, intense storms, high winds, abnormal precipitation, and extended periods of heat and cold. The paper explores how to reframe programmatic, architectural, structural and mechanical approaches to skyscraper design. In addition, the question of how an urban skyscraper can beyond protecting itself and its occupants to serve as a refuge and resource to the surrounding community is discussed.

Keywords: Adaptability; Climate; Environment; Passive Design; Refuge Areas

Introduction

Why Urban Skyscrapers?

In October 2012, Superstorm Sandy hit New York City. It was a rude awakening, causing billions of dollars of damage to buildings and infrastructure, and millions of hours of lost productive time. Sandy changed the mind-set throughout the Northeastern United States, bringing issues of resilience and adaptation to the forefront.

After Sandy, many initiatives[1–2] were taken to assess resiliency and propose improvements. Waterfronts, infrastructure, and buildings were all evaluated, expertise was sought from other flood-prone locations, such as the Netherlands, and the factors that differentiate New York – its large population, high density, economic importance and reliance on high-rise buildings for residences – were identified.

New York's skyscrapers played a key role in Sandy and its aftermath: many commercial and residential buildings were physically damaged, and the failure of residential high-rises to maintain power and water supplies displaced many occupants or made remaining in the buildings challenging and uncomfortable. It became clear that even if "business as usual" operations cannot be maintained, enabling occupants to remain in tall buildings during extreme weather events, including snow storms, hurricanes and heat waves, is an important resiliency strategy.

Resilient to what?

The most common climate resiliency challenges in urban areas are related to hurricanes, with their attendant storm surges, rainfall and wind; to power failure due to heat waves and snow storms and in some areas, earthquakes, which are also a significant risk and will necessitate different and additional resiliency strategies. This paper analysis and proposes strategies to deals with these environmental challenges.

Resiliency Needs

In a world of unlimited resources, buildings and cities would be fully functional during extreme climate events. However, existing conditions in cities and buildings, along with the high cost of redundant services and the unpredictable ways in which complex, interrelated systems fail, make this impossible. It is therefore critical to define what needs must be met before, during, and after an emergency event, and to appropriately plan to meet these needs. Because tall buildings have significant scales, they can be serviced to play a major part in providing refuge, not only for their regular occupants, but potentially for others within the community.

[1] Building Resilience Task Force, Urban Green and NYC

Abraham Maslow, an influential American psychologist, developed a hierarchy of human needs in an attempt to rationalize human motivation. This hierarchy has two groupings: deficiency needs and growth needs. The lower levels of human needs must be satisfied to enable the higher levels of activity[3] (see Figure 1).

During an emergency event, people will experience different levels of the Maslow's Human needs. During, and immediately afterwards, there are often problems with access to elements in the lowest two levels, psychological needs and safety needs.[4] As time goes on, and these needs are resolved, people will seek to address needs at higher levels. By understanding the order in which these human needs have to be met, helps to frame the approach for using urban skyscrapers as resilient refugees, because it helps to prioritize which systems need to be available at each stage of an event.

Defining Climate Resilience

Climate resilience is the capacity of a socio-ecological system to:

- (1) absorb external stresses and maintain function and
- (2) adapt and reorganize into different configurations that improve its integrity, leaving it better prepared for future climate change impacts.[5–6]

Figure 1. Maslow's hierarchy of needs (Source: FXFOWLE)

The implications of climate change for cities, particularly for rapidly growing urban centers in developing countries where the majority of inhabitants are poor or "otherwise vulnerable to climate-related disturbances"[7] are enormous. Resiliency is not evenly spread through the population. It depends crucially on the local infrastructure, information availability (i.e. social networking, etc.), and personal resources. Poverty, gender, ethnicity, and age all contribute to the resilience or vulnerability of people to climate hazards, to which both city-wide and building-based resiliency plans must take this into account.[8]

Cities depend on systems made up of physical infrastructure, information exchanges and institutional capacity. For example, electricity, a necessity of high-rise life, will depend on the performance of physical systems such as generators and grids, information systems to understand the location of power outages, and the electric company.

Resilient systems "ensure that functionality is retained and can be re-instated through system linkages" despite some failures. Other characteristics of resilient systems are shown in Figure 2.

These characteristics of resilient systems can also be applied to urban skyscrapers as a means to protect the building and its occupants, as well as support the surrounding community.[9]

Figure 1. Characteristics of Resilient Design (Source: Arup)

Urban skyscrapers as a response to an emerging need

As cities increase in population, development patterns tend to change to accommodate the additional population and density. Increased density is often achieved through high-rise residential buildings connected by mass transit systems. These high-rise residential buildings present both advantages and challenges for resiliency. The challenges related to the high concentration of people in one place, magnifies the impact of failure on the local systems. However, the opportunities derived from the high concentration of people in high rise residential communities are great. Buildings at increased scales allows for greater investment in design, technology, and systems that support the building and allows help to be provided easily by delivering goods and services to fewer locations and making information sharing between occupants easier, which than allows them to quickly become aware of, and access, emergency resources. This allows occupants to help their neighbors easily, because travel distances are negligible. Working at this scale makes it essential to work as a community because many of the issues are community-wide.

Challenges and Opportunities for Urban Skyscrapers

Climate change is impacting the design of buildings in many ways. For example, wind and rain events are becoming more extreme in many areas and summertime temperatures are continuously rising. Existing buildings with once robust designs may now be more vulnerable to extreme weather conditions. Examples of climate-related changes and risks related to buildings are indicated below:[10]

1. Building Resilience Task Force, Urban Green and NYC
2. Rebuild by Design competition, HUD
3. http://www.edpsycinteractive.org/topics/conation/maslow.html
4. http://www.deepermind.com/20maslow.html
5. Folke, C. (2006). "Resilience: The emergence of a perspective for social-ecological systems analyses." Global Environmental Change, 16, 253–267. doi:10.1016/j.gloenvcha.2006.04.002
6. Nelson, Donald R., W. Neil Adger, and Katrina Brown. 2007. "Adaptation to Environmental Change: Contributions of a Resilience Framework." Annual Review of Environment and Resources 32: 395–419. http://eprints.icrisat.ac.in/4245/1/AnnualReviewofEnvResources_32_395-419_2007.pdf
7. Moench, Marcus. Tyler, Stephen. "A Framework for Urban Climate Resilience." Climate and Development. 2012 , 4:4.
8. Moench, Marcus. Tyler, Stephen. "A Framework for Urban Climate Resilience." Climate and Development. 2012 , 4:4.
9. Moench, Marcus. Tyler, Stephen. "A Framework for Urban Climate Resilience." Climate and Development. 2012 , 4:4.
10. Alisdair McGregor, Cole Roberts and Fiona Cousins, Two Degrees: The Built Environment and Our Changing Climate (Oxfordshire: Routledge, 2013), 53.

- Increased average and extreme summer temperatures leading to thermal discomfort and increased risk of power failure;
- Sea level rise and increased flood risks from coastal surge;
- Increased rainfall and rainfall intensity causing increased flood risk;
- Changing soil moisture levels causing slope instability, subsidence and heave;
- Extreme storms increasing risk of structural failure through wind effects;
- Increased frequency and duration of heat waves.

Reduced rainfall leading to water shortages; Increased snowfall leading to increased risk of power failure

Systems must be designed for flexibility and diversity, redundancy and capacity, and to allow safe failure in order to meet fundamental human needs in extreme weather. In most cases, these new design conditions will require integrated design, taking account of all the systems within the building itself as well as its relationship to its surroundings.

Location and Site

Resilient urban skyscrapers must take into account their climate and context. Climate has traditionally been treated as a fixed condition which is based on historical data, but this is now inappropriate. Careful analysis of climate change projections is needed to develop a design that provides a robust performance in the face of future extreme weather events. Predictive tools such as Weathershift [11] can provide more representative data for future-proofing buildings.

Skyscrapers are usually built within an existing urban fabric which establishes the contextual conditions such as street levels, and their relationship to local flood elevations. The size of a skyscraper is often such that the surrounding infrastructure has to be modified, creating opportunities to improve its resiliency. In all cases, when a new building is planned, the resiliency of the supporting systems should be assessed.

Height & Density

The traditionally small site area for a high-rise means that there are limited opportunities for on-site collection of water, energy, and the on-site production of food. Reinforcing this, the large population of tall buildings means large quantities of resources are needed. Other complexities related to building height include the need for power for vertical transportation of people, water, food and other resources.

However some features of tall, densely-populated buildings can be designed to promote resiliency. These include floor-plate and unit design to maximize natural daylight, the use of sky-gardens for natural ventilation, shading, as shown in Figure 3, and use of photovoltaics on vertical surfaces with high solar exposure, as shown in Figure 4.

Space & Programming

Tall-building resiliency involves rethinking space planning and programming in regards to a range of criteria. For example, economic drivers tend to lead to large, deep-plan floor plates, which are unsuited to daylighting or natural ventilation, in both commercial and residential buildings. These drivers can also push critical mechanical and electrical equipment below ground level. A balanced approach to space planning is needed that adequately prioritizes resiliency.

A resilient tall building also needs additional programmatic elements. These include communal spaces with backup climate control and power where people can take refuge, as well as food and water storage areas. Amenity spaces in residential high rises may double as areas for refuge during a long-term power outage. Equipment rooms may also be larger than usual due to the need for system redundancy and water or energy storage.

There are examples, especially in owner-occupied buildings, of space planning that reflects attention to resiliency. For example, the New York Times Building provides a

Figure 3. Allianz Tower, FXFOWLE Architects. View of exterior shading (Source: FXFOWLE, credit: David Sundberg/Esto)

Figure 4. The Solaire, Pellie Clark Pelli, View of vertical photovoltaics (Source: FXFOWLE)

11. WeatherShift, NY City climate change report.

Figure 5. New York Times Building, Renzo Piano & FXFOWLE. View of Cafeteria (Source: FXFOWLE)

kitchen and cafeteria on a prime floor, helping to support continuous functioning of the newspaper when neighboring food services may not be available. (see Figure 5)

The financial implications of rearranging floor plans to allow for passive design and the inclusion of additional common areas can be significant. Developers and owners should evaluate the economic benefits of improved resilience, including the potential for reduced insurance premiums, improved rentability or the potential for higher common charges to cover ongoing expenses.

Food Access

Other than providing for kitchens, delivery areas, and in some instances, commercial cafeterias, access to food in tall buildings is not the responsibility of design or management teams. A few residential projects have incorporated urban agriculture but most projects addressing food production still remain unbuilt. (see Figure 6)

While food production is one part of an overall food-access strategy, a more direct approach could include storage space for food and strategies for delivery especially to the mobility-impaired occupants. Administration for this service should all be included in emergency operation plans, which are a key part of improving building resiliency.

Enclosure Design

The building skin is the first line of defense for a resilient refuge, protecting occupants from the elements. Properly designed, it can minimize heat gain and loss, provide wind protection, and promote occupant comfort. A well-designed enclosure can reduce reliance on HVAC systems and electrical lighting. In addition, the enclosure can be designed to provide ventilation during a power outage.

Current enclosure design practices do not always provide resiliency. A study by the Urban Green Council (USGBCNY)[12] simulated various high-rise building typologies in winter and summer conditions in New York City during a seven-day power outage. Pre-2000 masonry buildings were compared with post-2000 masonry buildings and all-glass buildings. As shown in figures 7 & 8, temperatures in all-glass buildings increased most dramatically during the summer condition. During the winter condition, temperatures in poorly insulated pre-2000 masonry buildings fell most dramatically.

The main drivers of internal comfort during the summer are glazing percentage and shading. In winter, insulation and infiltration drive comfor. As shown in figure 9, high-performance buildings that focus on these factors, perhaps even pursuing applicable Passive House standards, remain much more comfortable. While daylight and views are important, judicious placement of glazing can meet these goals without the energy and comfort tradeoffs of an all-glass building.

Other issues to be considered in resilient enclosure design are increased wind forces on glazing, and uplift on projecting elements such as shading devices or rooftop ballasts. Stormwater management at the lower levels may require a passive, sacrificial approach or temporary flood barriers.

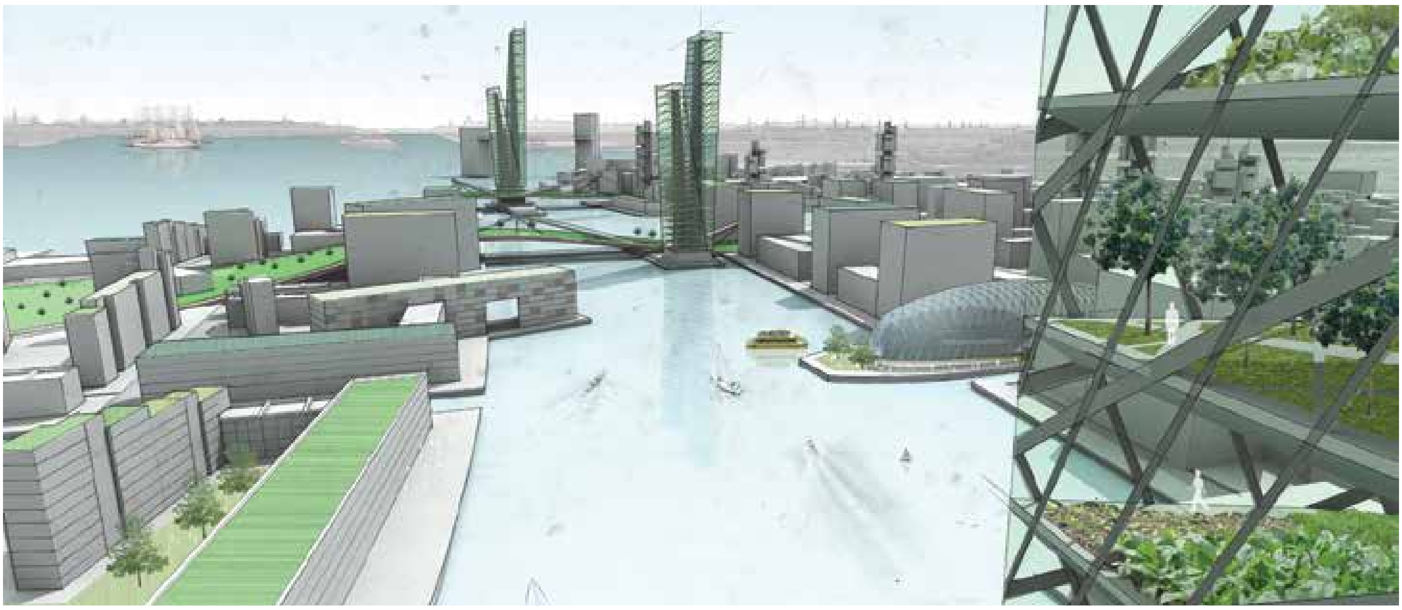

Figure 6. Nordhavnen City Regenerative Competition, FXFOWLE. View of District Food Towers (Source: FXFOWLE)

12. Urban Green Council, 2014. Baby It's Cold Inside. [pdf] New York Chapter of the U.S. Green Building Council. Available at: http://issuu.com/urbangreen/docs/baby_it_s_cold_inside [Accessed May 11, 2015].

Figure 7. Typical Building Indoor Temperatures During a Winter Blackout (Source: Urban Green Council)

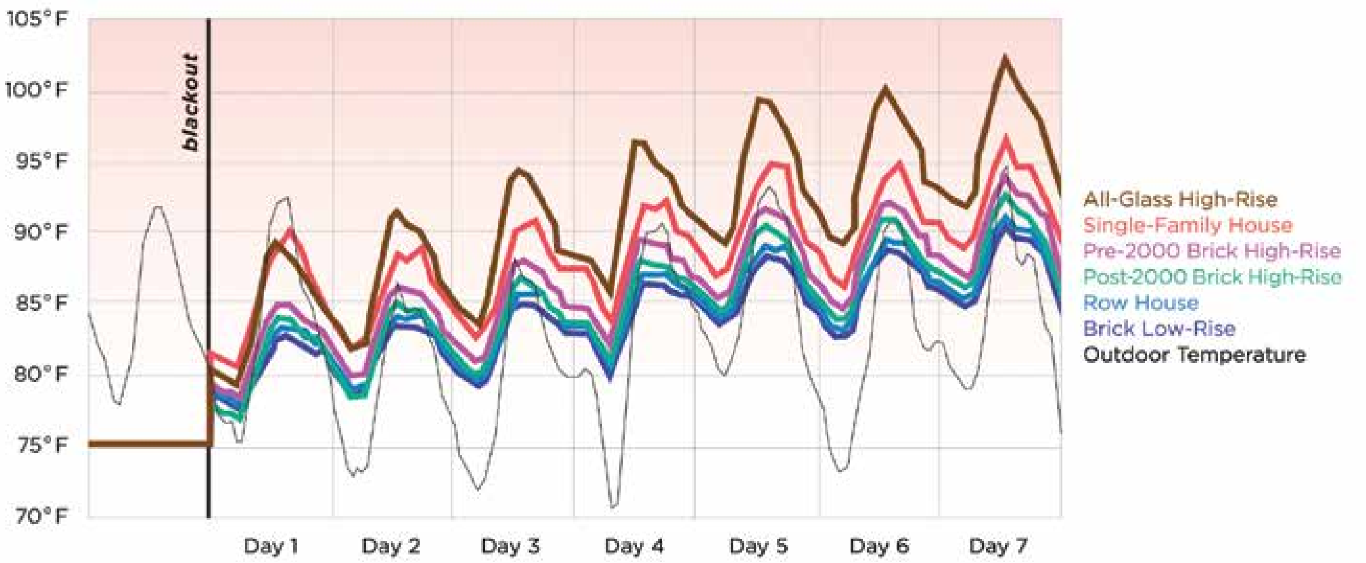

Figure 8. Typical Building Indoor Temperatures During a Summer Blackout (Source: Urban Green Council)

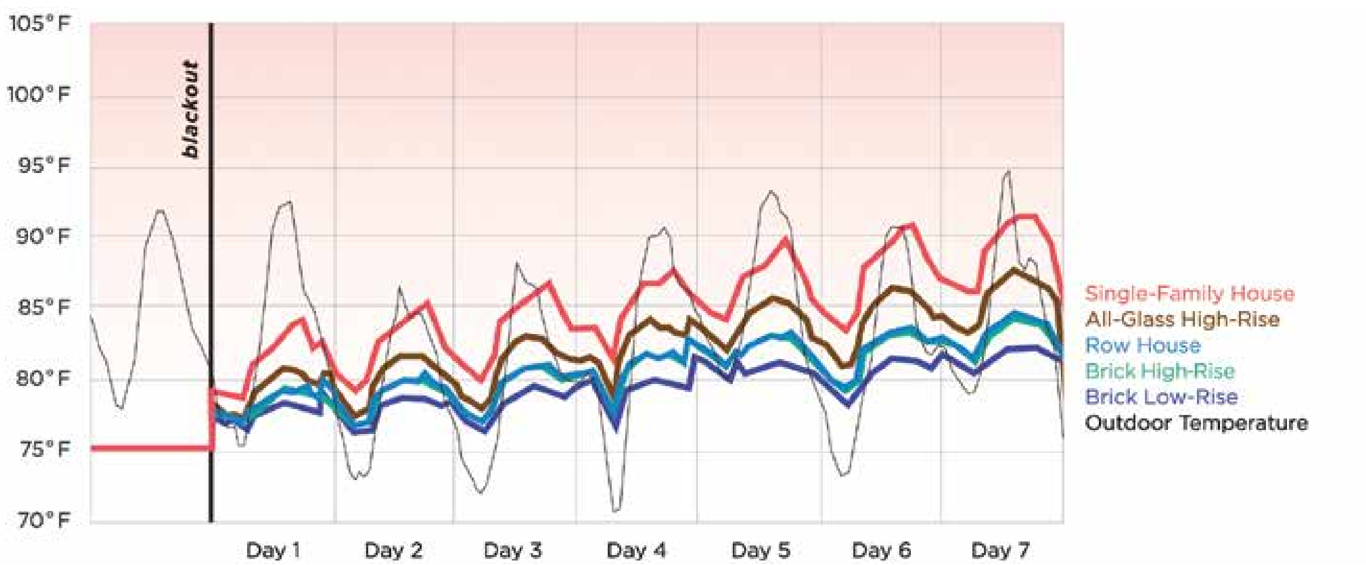

Figure 9. High Performance Building Indoor Temperatures During a Summer Blackout (Source: Urban Green Council)

Ventilation Systems

Ventilation systems are necessary in order to provide air for breathing, and removal of odors. They are also sometimes used to deliver heating and cooling.

The push for increased space efficiency on floor plates means that bathrooms and kitchens are often located towards the core of residential buildings and therefore require mechanical ventilation systems, which rely on electrical power. The loss of these systems doesn't threaten life but it can make long-term occupancy unpleasant.

Most residential buildings have operable windows to allow for occupant control of ventilation, meaning that they can be slightly ventilated under all circumstances. The size of openings may be limited by code (to prevent fall hazards) and although the resulting openings are adequate to provide basic ventilation they are often not large enough to provide enough ventilation to cool down an apartment to close to ambient conditions during hot weather.

It is possible to design high-rise buildings for good natural ventilation. The air is often cleaner at a higher level, and it can also be windier, depending on the surrounding buildings. Design elements that contribute to passive ventilation are narrow plans, the use of sky gardens and the arrangement of residential units to allow cross ventilation – with windows on more than one face of the apartment.

Figure 10. Manitoba Hydro Place, KPMB Architects. View of Operable Windows. (Source: Tom Arban)

As natural ventilation can pose challenges, most tall residential buildings in temperate or warm climates provide additional cooling through mechanical systems such as air-to-air heat exchangers, DX split-systems or other systems that rely on power to operate. Clearly, if buildings that rely on mechanical air-conditioning systems are to be made resilient, they must have resilient power supply (see Figure 10).

Water

A fundamental part of resiliency is to have an accessible drinking water supply. The maintenance of sanitation also relies on the availability of water.

The availability of water to high-rise buildings depends on both the municipal system that provides the water to the building and the distribution system within the building itself. Flood, heat, and wind events tend not to disrupt the utilitiess piping network but may disrupt remote filtration and pumping installations, especially if there is also widespread power failure. The protection and resilience of these installations is the responsibility of the utility. Once water is delivered to the site, most high-rise buildings require water booster pumps to get the water to upper levels. Maintaining power to the building's water system is a priority when planning for resiliency.

An alternative to maintaining continuous power to booster equipment that still allows for short-term power failures is to provide water storage tanks at the top of the building with capacity for a certain number of hours.

Water is also essential for sprinkler protection. Most codes require back-up pumps for sprinkler systems, and some codes require that these are run by diesel engines so that the fuel can be stored on site.

Sanitation systems are typically water-based and use gravity to remove sewage from the site. In some instances sumps and pumps are used and these must also be provided with a resilient power system if the sanitation system is to operate during power failure.

Vertical transportation systems

High-rise buildings depend on elevators for access. If a building is to be occupied for an extended period of time after an event, especially if workplace, transport systems and community facilities are compromised, it

Figure 11. View of lower Manhattan power outage after Superstorm Sandy (Source: FXFOWLE)

is essential that people can leave and return to their apartments without having to climb many flights . This is particularly the case for mobility-impaired residents, as well as for those with small children or heavy loads.

Power systems & delivery

Many of the systems in a high-rise building, including water, ventilation, cooling and vertical transportation are dependent on power to operate. Other systems such as lighting, data and appliances are also dependent on power.

As with water systems, power supply usually relies on the utility system. However, there are ways to provide buildings with their own power supply. Renewable sources can provide low-cost power in emergencies but they have variable output and are unlikely to provide the required reliability. Reliable power can be provided from local generators fired by gas or diesel fuel, such as in the case of Battery Park City. There are several considerations that will influence the design of the local generator such as quantity and duration of power required, reliability of the local gas utility, and local utility requirements for islanding – the operation of the building power independent of the utility. Emergency power generating systems can be made to pay back more quickly if they are used regularly – for example to generate heat in winter or for utility-subsidized peak-load shedding in summer. These kinds of considerations will influence payback and value for these systems (see Figure 11).

Zoning & Code

Zoning changes should consider modifications to tall building design to increase resiliency. Additional insulation reduces usable and rentable areas, as do spaces that could serve as areas of refuge or storage. In New York City, initiatives such as Zone Green or the Quality Housing Program enable the additional area taken by insulation or select amenity areas to be deducted from overall floor area ratio (FAR) requirements. Beyond not penalizing building owners for providing these areas, zoning officials should consider providing bonuses to further incentivize implementation.

Future building codes should account for building resiliency. In New York City, several building-code modifications have been made, addressing issues such as elevating building systems, increasing fuel-storage quantities, enabling temporary flood barriers on sidewalks, providing drinking water to common areas, and facilitating use of natural gas co-generation for standby power.[13] Because many of these modifications impact both codes and agency regulations, such as fire departments' and environmental protection services', proposed changes must be carefully coordinated.

Community Responsibility

Building owners are responsible for the life-safety of residents and tenants, with respect to all systems where they have control. Some high-rise buildings contain spaces where this responsibility is shared with others – the tenants or residents themselves, or property managers.

Given the impact of high-rise buildings during an emergency, questions of responsibility to the community arise. Owners could be required to allocate an area for temporary public shelter, to install publicly accessible power outlets, or even to allow community access to areas for refuge, through code. The question of how this would be regulated or managed remains.

Emergency Management

While thoughtful design is essential to resiliency, the active participation of building management and occupants is also critical. This was demonstrated by the emergency management strategy put in place by Goldman Sachs, who sandbagged their New York City headquarters prior to Superstorm Sandy, avoiding millions of dollars of damage and enabling them to return to business much sooner than other organizations.

Depending upon climate and location, emergency management plans in tall buildings could address fire-safety, hurricanes, earthquakes and terrorism risks. These plans should address consequent power outages, water shortages and food access issues, identifying areas of refuge, protocols for modifying indoor conditions to remain comfortable, locations to source potable water or food, and strategies for communication (see Figure 12).

Design Recommendations

The design community now recognizes the impact of climate change in building design. Designers and developers are modifying tall building designs through compliance with new building codes or to meet specific client requirements. The following recommendations address tall-building design through the lens of resiliency:

Design for Multiple Modes

Planning for resiliency means that multiple operational modes must be considered in the design of buildings. Buildings must be planned to be resilient to specific types of events. The operation of buildings during and after these events may not be the same as that planned for business as usual. The operation of the building may also change

13. Urban Green Council, 2013. Building Resiliency Task Force. [pdf] New York Chapter of the U.S. Green Building Council. Available at: http://urbangreencouncil.org/sites/default/files/2013_brtf_summaryreport_0.pdf [Accessed May 11, 2015].

over time based on changes in weather, sea-level rise, occupancy or patterns of use. Resilient design must identify the things that might change and how the building will perform under less than ideal conditions.

Design Resilient Systems

Resilient system design must identify any single points of failure and the possibilities for redundancy, flexibility and adaptability in the system.

High-rise buildings are heavily dependent on systems for their operation. The critical systems include power, ventilation, water supply, sanitation, and vertical transportation. Most of these systems require power, making the operation of the emergency power system critical.

It is generally not affordable to back up all the power uses in the building. Life-safety systems are typically backed up, but these are often limited to lighting, sprinkler and stair pressurization systems. The cost of additional back-up is high and must be prioritized, with vertical transportation and water supply at the top of the list. Refrigeration for food and limited lighting should also be prioritized, but can be hard to manage.

Prioritize Passive Design Approaches

Passive measures that reduce energy requirements and improve comfort is a key part of resiliency planning and should be prioritized in design. Using passive design strategies such as increased insulation, improved air tightness, natural ventilation, daylighting and shading will reduce heating and cooling loads, and the need for electric lighting as well as allowing the building to operate more effectively in emergency conditions.

These measures often have created financial savings and payback periods can be accelerated if the risks of system failure leading to cold, overheating and productivity loss are included in the calculations.

Revision the Building Program

Programming that includes space allocation for occupant and community use is important for resilient design. However, it will likely be the most financially and organizationally challenging aspect of a resilient design process. Providing areas of refuge, spaces for food storage and facilities accessible to the surrounding community may require negotiation between the building owner, community members and potentially the local municipality.

The necessary programmatic changes should be determined on a case-by-case basis, depending upon the building use and context. For example, if on site-cogeneration or energy storage provides sufficient hot water in all apartments, showers may not be needed in areas for refuge.

If building owners provide benefits to the greater community during emergencies, such as shelter, communication facilities or power, municipalities should grant incentives or bonuses to compensate them.

Conclusion

Providing resiliency to cities requires that both the city's systems and its tall buildings are designed and managed to be resilient. In order to meet basic human needs, this requires that the scenarios under which the building services are to be maintained are clearly articulated – whether they are caused by sudden events or gradual changes. These scenarios can then be used by designers, building managers and owners, and the city agencies to provide a framework for decision-making around the systems that will support the city's residents during and after a significant climate event, or as a result of gradual change in climate. It is important that the desired outcomes are clearly described and included within the design thinking.

In addition to the design of fixed infrastructure systems it is also important to consider how information will be shared after an event and to identify how the community within a building will be organized to make the best use of the available resources. While these are not strictly part of building design and may change over time, information and management plans are supported by the design work and must be kept in mind throughout the design period.

Figure 12. Sandbagged entry of Goldman Sachs Headquarters prior to Superstorm Sandy (Source: Victor J. Blue/Bloomberg)