Reducing Interruptions to Mid- and High-Rise Buildings During Floods

FEMA

HURRICANE SANDY RECOVERY ADVISORY *RA4, March 2013*

Purpose and Intended Audience

During Hurricane Sandy, damage to critical building systems in mid- and high-rise buildings crippled building operations and affected thousands of occupants. Critical building systems (including, but not limited to, components such as the mechanical, electrical, plumbing, gas installations, communications, and fire suppression) are essential to the functionality of a building. Hurricane Sandy and other recent disasters demonstrate that buildings do not have to be severely damaged or collapse to be rendered inoperable. Lessons learned from the type of damage incurred can be used when repairing systems in existing buildings and designing them for new buildings to make mid- and high-rise buildings more resistant to disruption in future flood events.

The focus of this advisory is on design enhancement and techniques to reduce flood risk for mid- to high-rise buildings. Reduced flood risk decreases building service interruptions and lowers risks to tenants. This advisory incorporates observations from FEMA's Hurricane Sandy Mitigation Assessment Team (MAT) and describes best practices from successful local flood-resistant structures. The use of best practices is presented as a holistic approach to reduce flood risks in all structures. Mitigation measures include elevating critical building systems, floodproofing, and planning for power disruption. The recommendations in this advisory explain how to limit the interruption of building services caused by floods, but are not intended to enable buildings to remain occupied during an event or encourage sheltering in place. The audience for this Recovery Advisory includes building owners, operators, and managers; architects; engineers; building officials; and contractors.

Key Issues:

1. Critical building systems are often placed on the lowest floors or subgrade (basement) levels in mid- and high-rise buildings due to building code requirements, policy mandates, costs, placement before consideration of flood hazards, or simply because the upper floors are more desirable for other uses.
2. Building systems located on lower floors are more vulnerable to flood damage. When critical building systems are damaged, building service is typically interrupted. Tenant risks significantly increase as a result of dark hallways, lack of elevator service, limited fire communication and suppression equipment, and lack of power to other systems.
3. To prevent flood damage and avoid interruption in building service, critical systems within the facility should be elevated above the base flood elevation (BFE) or protected from flood damage.

Terminology

Flood Insurance Rate Map (FIRM): A map produced by FEMA to show flood hazard areas and risk premium zones. The SFHA and BFE are both shown on FIRMs.

Special Flood Hazard Area (SFHA): Land areas subject to a 1 percent or greater chance of flooding in any given year. These areas are indicated on FIRMs as Zone AE, A1-A30, A99, AR, AO, AH, V, VO, VE, or V1-30. Mapped zones outside of the SFHA are Zone X (shaded or unshaded) or Zone B/Zone C on older FIRMs.

Base Flood Elevation (BFE): Elevation of flooding, including wave height, having a 1 percent chance of being equaled or exceeded in any given year (also known as "base flood" and "100-year flood"). The BFE is the basis of insurance and floodplain management requirements and is shown on FIRMs.

Design Flood Elevation (DFE): Regulatory flood elevation adopted by a local community. If a community regulates to minimum NFIP requirements, the DFE is identical to the BFE. Typically, the DFE is the BFE plus any freeboard adopted by the community.

This Recovery Advisory Addresses:

- Protecting critical building systems by elevating and floodproofing
- Emergency power considerations
- Limiting building operation interruption

Protecting Critical Building Systems

The location of building systems is a critical factor in the continuing performance of mid- to high-rise buildings during a flood event. Even when flooding does not cause structural damage to a building, the inundation of lower floors can impair critical building systems, causing the building to be closed for weeks or months. The preferred method for protecting critical building systems is elevating them or relocating them to a floor with an elevation higher than the BFE or design flood elevation (DFE).

Elevating Critical Building Systems

Approaches for elevating utilities, controls, and equipment in existing and new facilities include:

- Installing platforms on the floor to elevate the equipment in place
- Relocating systems from below-grade or the first floor to a higher floor (or even the rooftop)
- Relocating systems to a higher elevation in a different building

When elevating equipment, both the appropriate elevation height and the codes and design restrictions that may affect their placement should be considered, as described in this section.

Determining how high to elevate equipment: Communities enforce floodplain management regulations and building codes that include requirements for buildings in mapped Special Flood Hazard Areas (SFHAs). The basic requirement in an SFHA is to protect buildings and systems to at least the BFE as determined from FEMA Flood Insurance Studies and Flood Insurance Rate Maps (FIRMs). National Flood Insurance Program (NFIP) regulations require buildings to be constructed with electrical, heating, ventilation, plumbing, and air conditioning equipment and other service facilities that are designed and/or located so as to prevent water from entering or accumulating within the components during conditions of flooding.

Following large storm events, such as Hurricane Sandy, FEMA may perform an assessment to determine whether the BFE, shown on the Effective FIRMs, adequately reflects the current flood hazard. The resulting Advisory Base Flood Elevations (ABFEs) are provided to communities as a tool to support recovery and future resiliency. Communities must use ABFEs when designing recovery or mitigation activities funded using FEMA grants (e.g., Public Assistance or Hazard Mitigation Grants).

A common misconception is that buildings located outside of the SFHA have little risk of flooding. During Hurricane Sandy, many of the buildings damaged were outside of the SFHA, and in some cases outside the area expected to be inundated during a 0.2-percent-annual-chance flood event (500-year flood event). Over 20 percent of NFIP claims received by FEMA—approximately one-third of requested disaster assistance for flooding—is for damage to buildings located outside of the SFHA.[1] Refer to Hurricane Sandy Recovery Advisory No. 2, *Reducing Flood Effects in Critical Facilities*, for more information on assessing flood risks for locations outside of SFHAs.

When evaluating flood risk, it is important to remember that floodplain modeling was based on data available at the time. The models do not account for future conditions throughout the expected useful life of a building. Elevating existing systems can be difficult, so planning should include consideration of flood hazards that may change significantly over the life of the building due to urban development, flood protection projects, geologic processes

ABFEs and BFEs

FEMA recommends that communities apply the adopted ABFEs to new construction, buildings undergoing Substantial Improvements, and Substantially Damaged structures to ensure that construction is built stronger, safer, and less vulnerable to future flooding events.

Construction and repair of buildings in communities that have adopted ABFEs must use the revised elevation in place of the BFE shown on the Effective FIRM.

Post-Hurricane Sandy ABFE maps are available for parts of New York and New Jersey at http://www.region2coastal.com/sandy/abfe. FIRMs for all other participating communities are available at https://msc.fema.gov.

1 http://www.floodsmart.gov/floodsmart/pages/flood_facts.jsp

such as subsidence and erosion, climate change, or other future conditions. Elevating critical building systems above the 0.2-percent-annual-chance flood elevation is a best practice to make buildings less vulnerable during extraordinary future flood events. Refer to Hurricane Sandy Recovery Advisory No. 5, *Designing for Flood Levels Above the Base Flood Elevation After Hurricane Sandy*, for more information on SFHAs, BFEs, ABFEs, FIRMs, and Flood Insurance Studies.

Code requirements and design considerations: The building codes adopted by the States of New York and New Jersey are based on the International Building Code (IBC). The IBC references the standard ASCE 24, Flood Resistant Design and Construction, which is published by the American Society of Civil Engineers (ASCE). In new construction or existing buildings that are undergoing Substantial Improvements, critical building systems must be elevated to the height specified by ASCE 24-05 for that structure's category (Table 1). As a best practice to protect building systems from inundation, FEMA recommends using the ASCE 24-05 elevations shown in Table 1 whenever possible when retrofitting them in existing buildings.

It is important to consider the dead load on the building structure when elevating equipment to a higher floor (see Figure 1). The additional load may require structural reinforcement of the space where the equipment is being relocated. In some cases, special consideration should be given to the isolation of or resistance to vibration loads induced by mechanical equipment. It is also important to ensure the equipment will comply with code requirements when exposed to a different hazard. For instance, a generator moved to the rooftop to protect against flooding will need to be protected from seismic and wind loads.

Terminology

Substantial Damage: Defined by the NFIP as "damage of any origin sustained by a structure whereby the cost of restoring the structure to its before-damaged condition would equal or exceed 50 percent of the market value of the structure before the damage occurred."

Substantial Improvement: Defined by the NFIP as "any reconstruction, rehabilitation, addition, or other improvement of a structure, the cost of which equals or exceeds 50 percent of the market value of the structure before the 'start of construction' of the improvement. This term includes structures that have incurred 'Substantial Damage,' regardless of the actual repair work performed."

Refer to FEMA P-758, *Substantial Improvement/ Substantial Damage Desk Reference* (2010) for more information. Homeowners should consult a local building official to determine whether their local codes and regulations have more restrictive definitions.

Table 1. Minimum Elevations for Utilities and Associated Equipment

Structure Category *	Flood Hazard Areas (Zone A)	Coastal High Hazard Areas (Zone V) and Coastal A Zones: Orientation of LHSM Parallel** to Wave Approach	Coastal High Hazard Areas (Zone V) and Coastal A Zones: Orientation of LHSM Perpendicular** to Wave Approach
II. All buildings and other structures except those listed in Categories, I, III, and IV	BFE + 1 foot or DFE, whichever is greater	BFE + 1 foot or DFE, whichever is greater	BFE + 2 feet or DFE, whichever is greater
III. Buildings and other structures that represent a substantial hazard to human life in the event of failure (school with capacity greater than 250, power generation stations, etc.)	BFE + 1 foot or DFE, whichever is greater	BFE + 2 feet or DFE, whichever is greater	BFE + 3 feet or DFE, whichever is greater
IV. Buildings and other structures designated as essential facilities (hospital, fire and police stations, etc.)	BFE + 2 feet or DFE, whichever is greater***	BFE + 2 feet or DFE, whichever is greater***	BFE + 3 feet or DFE, whichever is greater***

BFE = Base flood elevation: The required minimum elevation for the lowest floor under the National Flood Insurance Program (NFIP) as delineated on FEMA Flood Insurance Rate Map (FIRM). If a building is located in a community that has adopted Advisory Base Flood Elevations (ABFEs), those elevations must be used instead of the BFEs shown on the FIRM.

DFE = Design flood elevation: BFE or higher depending on ASCE Structure Category and on State and local floodplain management requirements (i.e., some jurisdictions may require freeboard).

LHSM = Lowest Horizontal Structural Member

* Refer to ASCE 7 or ASCE 24 for complete definitions

** Parallel means ≤ +20 degrees from the direction of wave approach; perpendicular means > +20 degrees from the direction of wave approach

*** In the upcoming edition of ASCE 24, it is anticipated that buildings in Category IV will be required to be elevated to the BFE + specified freeboard, or DFE, or 500-year elevation, whichever is greater.

Floodproofing

If elevating is not practical, critical equipment can be protected by floodproofing. Floodproofing is any combination of structural and non-structural additions, changes, or adjustments to a building that reduces flood damage. Floodproofing measures can reduce the length of time a building is unoccupied following a flood; however, they are ***not*** intended to help maintain building occupancy ***during*** a flood event. FEMA is currently developing a publication on floodproofing non-residential structures (FEMA P-936), which is scheduled for release later in 2013.

> **Terminology**
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> **Residual Risk:** Remaining exposure to damage after other known risks have been countered, factored in, or eliminated. For example, a building elevated to the ABFE/BFE is still vulnerable to damage when the 1-percent-annual-chance flood is exceeded.

Figure 1: Temporary structural support system for electrical and mechanical room equipment being elevated from subgrade to a higher floor in a high-rise building in lower Manhattan. The temporary columns will eventually be replaced with a permanent support system.

Dry floodproofing: Dry floodproofing entails making a building or an area within a building substantially impermeable, meaning that no more than 4 inches of water depth will accumulate during a 24-hour period (FEMA 1993). Dry floodproofing measures typically include strengthening the foundation, floors, and walls to resist hydrostatic loads and the application of waterproof coatings, impermeable membranes, backflow prevention valves, and flood shields over windows and doors. Some water may accumulate in the protected area, however, so an internal drainage collection system is required. The drainage system typically includes a sump pit, sump pump, emergency power to the pumps, and a discharge point above the DFE.

Dry floodproofing does not eliminate all potential for flood damage to a building, as flood levels can exceed the design of the floodproofing measures (Figure 2). Additionally, when incorporating a floodproofing measure, it is critical to evaluate the flood loads on the building structure to ensure the protective measure is not creating a structural hazard. For instance, if a door or shield is installed, all components, connections, and gaskets protecting a given dry floodproofed enclosure must be able to resist anticipated flood loads and be considered substantially impermeable as a system. Existing wood frame; spalled or cracked concrete; and unreinforced or inadequately reinforced masonry or concrete walls and floors are examples of especially vulnerable situations that should be flagged for further analysis before retrofitting an area into a dry floodproofed enclosure. Refer to Hurricane Sandy Recovery Advisory No. 2, *Reducing Flood Effects in Critical Facilities*, for details on evaluating flood loads and additional information on dry floodproofing.

Dry floodproofing involves:

- Conducting a detailed building evaluation to identify potential floodwater points of entry (such as pipe and conduit openings, doors, vents, and windows), collect flood hazard and load data, identify flood warning time, and consider residual risk.
- Designing the dry floodproofing system to prevent water from entering up to the DFE. Measures may include:
  - Installing or constructing substantially impermeable walls and floors
  - Sealing wall penetrations, such as pipe, conduit, vent, and other openings
  - Installing flood shields to close openings
  - Reinforcing the structure to resist lateral and uplift flood loads

– Installing backflow prevention valves

– Adding internal drainage systems along with a discharge point above the DFE

– Providing emergency power for critical system components (sump pumps)

- Developing an operations and maintenance plan

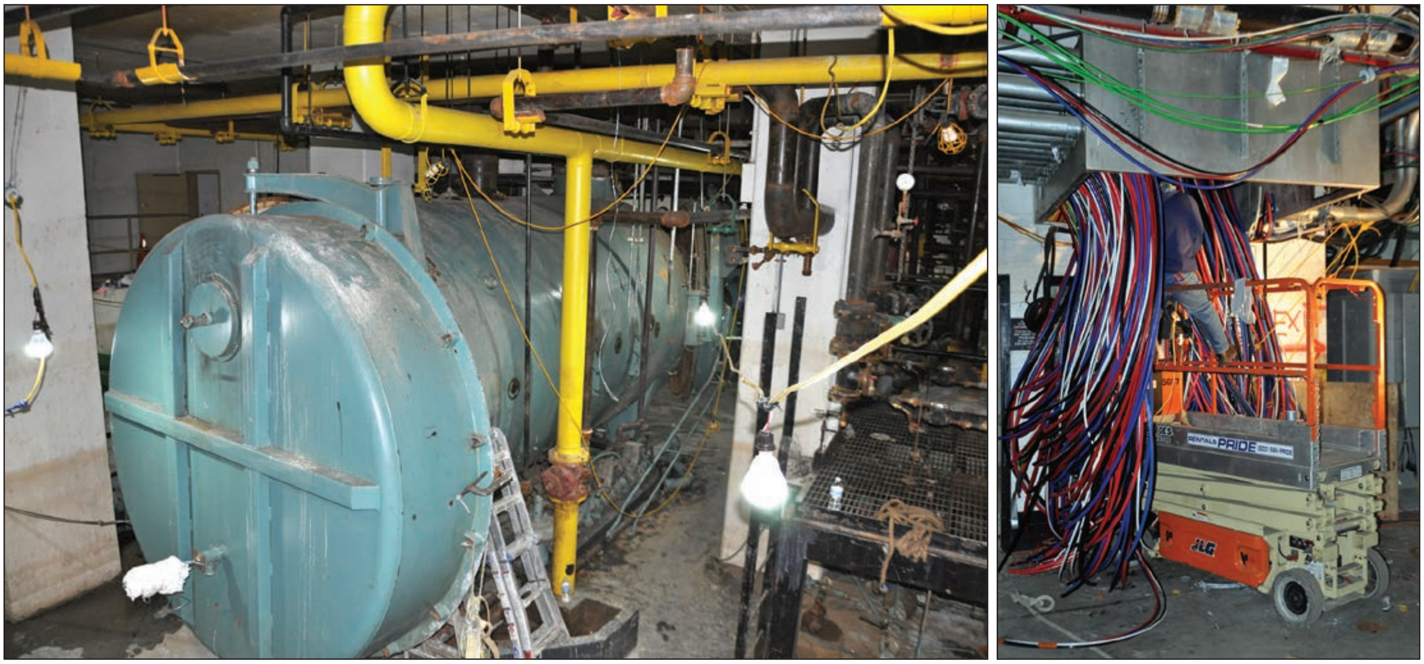

Figure 2: This mechanical room (left) in a recently built high-rise in lower Manhattan was inundated when dry floodproofing measures were overtopped by Hurricane Sandy floodwaters. This photograph shows electrical conduit (right) being replaced throughout the subgrade levels after being submerged in saltwater.

NFIP regulations prohibit dry floodproofing measures in new buildings, buildings determined to have Substantial Damage, or buildings undergoing Substantial Improvements in non-residential or multi-use buildings located within Zone V, also called the Coastal High Hazard Area (for more information, refer to 44 CFR Section 60.3(c)(3) and NFIP Technical Bulletin 3-93). ASCE 24 also prohibits dry floodproofing measures in High Risk Flood Hazard Areas, including the Coastal A Zone. To receive full credit for flood insurance rating, the NFIP requires that dry floodproofing measures protect the structure up to 1 foot above the BFE (or ABFE, if applicable) and be completely passive measures that do not require human intervention. ASCE 24-05 specifies limitations on flood velocity, human intervention, flood warning time, and other factors related to dry floodproofing (refer to Section 6.2 of ASCE 24 for a complete list of requirements). In addition, ASCE 24-05 requires minimum elevations when dry floodproofing, as shown in Table 2.

Identifying all potential **floodwater points of entry** can be complicated in mid- to high-rise buildings, especially in urban environments, where utilities may have multiple entry points and buildings may be interconnected below ground.

Table 2. ASCE 24-05 Minimum Elevations for Dry Floodproofing

Structure Category*	Minimum Elevation
II and III	BFE + 1 foot or DFE, whichever is greater
IV	BFE + 2 feet or DFE, whichever is greater**

BFE = Base flood elevation: The required minimum elevation for the lowest floor under the National Flood Insurance Program (NFIP) as delineated on FEMA Flood Insurance Rate Map (FIRM). If a building is located in a community that has adopted Advisory Base Flood Elevations (ABFEs), those elevations must be used instead of the BFEs shown on the FIRM.

DFE = Design flood elevation: BFE or higher depending on ASCE Structure Category and on State and local floodplain management requirements (i.e., some jurisdictions may require freeboard).

* Refer to ASCE 7 or ASCE 24 for complete definitions.

** In the upcoming edition of ASCE 24, it is anticipated that buildings in Category IV will be required to be elevated to the BFE + specified freeboard, or DFE, or 500-year elevation, whichever is greater.

The model building codes and NFIP regulations provide an alternative that allows equipment to be located below the DFE. This alternative requires that such equipment be designed, constructed, and installed to prevent damage from floodwater. Protection can be provided by a floodproofed enclosure, for instance, that would prevent floodwater from entering or accumulating (see Figure 3). When such floodproofing measures are implemented, it is important to consider how the protected area would be adversely affected if flooding exceeds the design level of the enclosure.

Figure 3: Dry floodproofed fuel pump room adjacent to generator fuel tank vault in lower Manhattan

Wet floodproofing: Wet floodproofing prevents or provides resistance to damage from flooding while allowing floodwater to enter the structure or area. Application of wet floodproofing measures is generally limited to enclosures below elevated structures and must use flood-damage resistant materials. For more information, refer to NFIP Technical Bulletin 7-93, *Wet Floodproofing – Requirements for Buildings Located in Special Flood Hazard Areas in Accordance with the National Flood Insurance Program* (1993).

Application of wet floodproofing is typically limited to parking, building access, and storage areas below the DFE. Wet floodproofing measures include:

- Using flood damage-resistant materials below the DFE
- Elevating utilities, controls, equipment (including elevators), and important contents above the DFE
- Configuring electrical and mechanical systems to minimize disruptions and facilitate repairs
- Installing flood openings to allow automatic entry and exit of floodwater to equalize hydrostatic pressure
- Installing pumps to gradually remove floodwater from the building after a flood event

Integrated floodproofing measures: In some cases, dry and wet floodproofing measures are combined to reduce flood risk. For example, a building in lower Manhattan had floodproof enclosures for fuel pumps and tanks throughout its basement (Figure 3) along with wet floodproofed corridors and sump pumps throughout the basement. The basement experienced limited flooding, and the building had little to no functional downtime compared to an adjacent facility that was closed for 2 weeks. Integrating wet floodproofing measures within floodproof enclosures helps reduce recovery time if the dry floodproofing is overtopped during a flood event.

Emergency Power Considerations

Most buildings with emergency power use either battery-powered systems for emergency power and/or generators for longer duration outages. ***Battery-powered systems*** are typically used for emergency egress lighting, data servers, alarm systems, and other small equipment. ***Generators***, on the other hand, typically service a number of systems, including heating, ventilation equipment, fire pumps, elevators, and domestic water booster pumps.

Proper planning when designing and locating emergency power systems is essential for maintaining function during a major disaster. To protect emergency power systems, facility managers should first identify the emergency power needs and then decide how best to prevent the emergency power from failing during a flooding event.

Emergency power planning considerations: When planning the needed emergency power supply for a building, it is important to consider the following: (1) how long the building may be without utility power; (2) what equipment is critical to functionality and needs to be connected to the emergency power supply distribution; (3) whether equipment will be damaged or lost during rapid, unexpected power loss or power restoration (surges, spikes); and (4) how quickly backup power is needed (seconds, minutes, hours, etc.).

Since it is difficult to predict the duration of a power outage before a major event, building operators and owners should consider factors such as the time needed to evacuate a building and the time needed to obtain additional temporary power. Using this information, owners and operators can establish the minimum length of time that emergency power will be required. For example, a continuity of operations plan for a high-rise data center may specify that emergency power will be required for 1 day to allow for the transfer of data to a back-up facility or 3 days to install a temporary generator on site.

It is important to consider the entire emergency power supply system as a whole or it may not function during an emergency. An effective plan should identify:

- Which building systems require emergency power
- What emergency power capacity is needed, how quickly it must be activated, and for how long
- Effective protection for the generator, such as locating it in an elevated and hardened position
- How distribution equipment, transfer switches, fuel pumps, and critical equipment supplied by the emergency power system will be protected
- A reliable and consistent fuel source for the generator (source should also be protected from flooding by being properly anchored, submersible, or elevated)

After identifying how long the building is likely to require emergency power, the next step is to identify what building equipment must be operated during the outage. Essential equipment may include life-safety equipment needed to evacuate the building; fire pumps; emergency lighting and outlets; heating and cooling elements such as boilers, pumps, chillers, and air handlers; domestic water booster pumps to provide water to upper stories; elevator controls; sump pumps; and any other equipment critical to operating the building (communications, alarm systems, food preservation, data centers/servers, medical, etc.).

Fuel source considerations: Selecting a fuel source for a generator is just as critical as estimating the power outage duration and deciding what equipment will need emergency power. The fuel source must be reliable to ensure it is available when the generator needs to operate. For example, natural gas companies often preemptively turn off the gas supply before a hazard event, making municipal gas an unreliable source during an event. Similarly, a below-grade fuel storage tank vent must be located well above the DFE to prevent fuel from contaminating floodwater and floodwater from entering the fuel tank. Additionally, fuel tanks must be protected from buoyancy and crushing forces when submerged in floodwater. Refer to Hurricane Sandy Recovery Advisory No. 2, *Reducing Flood Effects in Critical Facilities*, for additional information. If possible, a redundant fuel source should be identified. A building may need multiple storage tanks or can install an emergency connection for temporary fuel in case the primary source is compromised.

Protect the entire emergency power system: The emergency power equipment and controls must be protected to ensure they will be available when needed. The generator contains controls that monitor output and adjust fuel based on the electrical power drain. A ***transfer switch*** regulates whether power is drawn from the electrical utility or the emergency source; this switch also prevents backfeeding generator power into utility lines. A ***fuel pump*** supplies the fuel to the generator. The ***distribution panel and electrical feeders*** supply the emergency power to the critical equipment. Protecting these components by properly locating or floodproofing them is just as critical as protecting the generator and fuel source, since failure of any element will cause the entire system to fail. The fuel pump in Figure 3 is an example of a protected emergency power system component.

Limiting Building Operational Interruption

In addition to elevating critical building systems or installing floodproofing measures, the following mitigation measures may reduce the loss of building services during flood events:

- ***Establish and maintain a connection point for temporary utilities.*** Several building managers interviewed after Hurricane Sandy stated they intend to establish or maintain a connection for at least temporary heat and power in the event of a future need. The building managers plan to prepare their buildings' infrastructure for quick transfer to a temporary power source, install a platform for the equipment, and establish an access point for emergency power.
- ***Establish and maintain redundancies.*** Establishing redundancies reduces the likelihood of losing service for the entire building. For example, one high-rise building visited after Hurricane Sandy had four electrical points

of service that all converged into one below-grade electrical switch gear room. The building manager plans to modify the system by distributing the services to four elevated switch gear rooms spread throughout the building, offering redundancy in case one is compromised. It is critical for these redundancies to be maintained throughout their life so they operate as intended when needed.

- ***Protect elevator service.*** Loss of elevator service in high-rise buildings hinders vertical building access and significantly affects building service and operations. Elevator and conveyance system components should be protected sufficiently to enable restoration of elevator service to the building as quickly as possible. When feasible, elevator equipment such as electrical controls and hydraulic pumps should be located above the DFE. If such equipment must be located below the DFE in the elevator pit, it should be protected using flood damage-resistant components.

Additional lessons learned include:

- ***Steam and gas heating systems are less prone to prolonged disruption than oil furnaces.*** Most of the buildings heated by steam and gas were online within a week or two after Hurricane Sandy, while those with oil furnaces were still reliant on an emergency heat source 2 months later. In addition, damaged oil tanks contaminated buildings, which complicated restoration and repairs.
- ***Use flood damage-resistant material.*** Use of such materials in lower floors reduced repair efforts in many of the buildings flooded during Hurricane Sandy. Repairing flooded buildings offers a good opportunity to improve flood-damage resistance.
- ***Limit use of lower floors.*** Buildings where lower levels were limited to parking, building access, and storage areas (e.g., fuel vaults) experienced less flood damage than those with multi-use lower levels.
- ***Elevate temporary equipment.*** Placing temporary equipment on scaffolding or platforms adjacent to facilities reduced the number of times temporary utility equipment had to be shut down and relocated (see Figure 4).

Figure 4: Temporary chillers elevated on scaffolding during repair of a high-rise building in lower Manhattan

Resources and Useful Links

American Society of Civil Engineers (ASCE). 2005. ASCE 24-05. *Flood Resistant Design and Construction*. Available at http://www.asce.org.

FEMA (Federal Emergency Management Agency). 1993. NFIP Technical Bulletin 3-93. *Non-Residential Floodproofing – Requirements and Certification for Buildings Located in Special Flood Hazard Areas in Accordance with the National Flood Insurance Program*. Available at http://www.fema.gov/library/viewRecord.do?id=1716.

The FEMA Region II Web page provides useful information and links for disaster survivors and recovering communities, including available FEMA assistance and recovery initiatives. Please refer to http://www.region2coastal.com.

FEMA. 1993. NFIP Technical Bulletin 7-93. *Wet Floodproofing — Requirements for Buildings Located in Special Flood Hazard Areas in Accordance with the National Flood Insurance Program*. Available at http://www.fema.gov/library/viewRecord.do?id=1720.

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FEMA. 2013. Hurricane Sandy Recovery Advisory No. 2. *Reducing Flood Effects in Critical Facilities.* Available at http://www.fema.gov/library/viewRecord.do?id=6994.

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