10. Conclusions

The conclusions presented in this report are based on the MAT's observations in the areas studied; evaluations of relevant codes, standards, and regulations; and meetings with state and local officials, business and trade associations, contractors, and other interested parties. These conclusions are intended to assist the States of Alabama, Louisiana, and Mississippi; communities; businesses; and individuals in the reconstruction process; and to help reduce future damage and impacts from flood and design level wind events similar to Hurricane Katrina. The report and recommendations will also help FEMA assess the adequacy of its flood hazard mapping and floodplain management requirements, and determine whether changes are needed or additional guidance required.

Section 10.1 discusses impacts of flood hazards caused by Hurricane Katrina, including damaged lowest floor elevations, foundations and structures; and long-duration impacts. Wind hazard impacts, including those caused by the lack of an adopted building code, and performance of structural systems are presented in Section 10.2. Sections 10.3 and 10.4 discuss performance of critical and essential facilities (including shelters), and historic buildings, respectively.

10.1 Flood Hazards

Flood levels from Hurricane Katrina throughout parts of the Alabama, Louisiana, and Mississippi coasts were often much higher than the FEMA-mapped BFEs. Flood and wave effects extended well beyond the SFHAs in most communities investigated. As a result, a significant number of buildings inside and outside of the SFHA were destroyed or heavily damaged.

Two circumstances account for the fact that the high flood levels exceeded the BFEs:

1. The region's storm history, which served as the basis for the effective BFEs, was prepared in the early 1980s. Since that time, numerous storms in addition to Katrina have impacted the area. Consideration of the more recent storms can be expected to significantly increase the BFEs.
2. BFEs in the levee-protected areas of New Orleans were based on the assumption that the levees and floodwalls would protect the surrounded buildings. When developing BFEs, current NFIP standards require that a levee be certified that it has been adequately designed and constructed to provide protection against the base flood. Since the levees protecting New Orleans are USACE-certified, the BFEs for the levee-protected areas of the City (which are currently mapped with BFEs as low as -4.5 feet NGVD) only reflect flooding from precipitation that falls on and accumulates inside these areas; the BFEs do not include flooding effects from waterbodies on the non-protected side of the levee, such as Lake Pontchartrain. When levees and flood walls were overtopped or failed in Katrina's storm surge, deep water flooding was widespread behind the levees (see Figure 10-1).

Additional damage was attributed to erosion and floodborne debris, and on Dauphin Island, Alabama, erosion and scour were severe. The erosion undermined shallow foundations and piles with shallow embedment. Many areas had been weakened by prior coastal storms, which made the areas susceptible to Hurricane Katrina. The methodology used to develop the FIRMs takes into account the erosion that would likely occur during a single 100-year event. Long-term erosion and the effects of multiple storms that alter the shoreline position or dunes are not considered in the flood maps.

Along the developed shorelines of Louisiana and Mississippi, erosion and scour were occasionally a localized problem but, considering the severity of the storm surge and wave heights, were relatively mild. In those areas, the height and rapid rise of the storm surge and the relatively flat slope of the land appeared to be the factors that likely moderated the erosion.

Figure 10-1.
Levee failures resulted in widespread flooding throughout the New Orleans area.

Floodborne debris and wave damage characteristic of V Zone damage was widespread in A and X Zones in Mississippi. The unprecedented debris and resultant debris field of Hurricane Katrina included shipping containers, lumber, and bulk paper, as well as casino barges that broke from their moorings and severely impacted several buildings. Most of the floating debris field was produced as the storm surge and waves moved inland and progressively destroyed buildings, increasing the speed and severity of damage. However, the debris field eventually reached sufficient proportions in the most heavily damaged areas to function as a floating breakwater, damping the wave heights farther inland, and served to protect the landward areas from even more severe wave damage.

10.1.1 Lowest Floor Elevations

Many of the damaged buildings were pre-FIRM construction and built on slab foundations that do not satisfy current NFIP requirements. Structures next to each other in impacted neighborhoods had varied elevations and buildings that were constructed to the BFE or below (for the pre-FIRM buildings) experienced greater impacts from flood levels, damaging waves, and floodborne debris than those structures situated well above the BFE (see Figure 10-2).

10.1.2 Foundations and Structures

Structural failure was caused by severe high surge elevations, and wave and debris impacts. In areas subjected to coastal erosion and scour, shallow foundation damage was extensive and the structural failures were dramatic. Overall, since erosion and scour were not a major factor in most areas of Louisiana and Mississippi, newer stem-wall and pile foundations performed well; however, once the flood levels and wave heights exceeded the lowest floor, severe building damage resulted.

The only buildings that survived the event were those with high first floor elevations that were constructed with a well-embedded deep pile foundation structurally connected to the building frame or with deep piles that extended from the ground to the roof, or fully-engineered mid- and high-rise buildings elevated on pile, column, or shear wall foundations.

Current NFIP regulations require elevation of V Zone buildings on pilings and columns (i.e., foundations). However, the NFIP has allowed some V Zone buildings, particularly mid- and high-rise buildings, to be constructed using some solid foundation walls beneath the BFE. These walls, called shear walls, are necessary to transfer large lateral loads (e.g., wind and seismic loads) from the upper stories into the ground. Use of properly constructed, shore-perpendicular shear walls in these large V Zone buildings has not been observed by the MAT to lead to building damage or failure during coastal flood events. Some one- and two-family residential buildings require elevation above the ground in excess of one story. For these residential buildings, the technical, policy, and financial implications of using shore-perpendicular foundation walls, such as the shear walls used by mid- and high-rise buildings, should be considered. The use of any solid foundation walls beneath a V Zone building will complicate the flood insurance rating process and may lead to substantially higher flood insurance premiums than those for a building supported entirely on piles or columns (see Figure 10-3).

Figure 10-2. Elevation of the lowest floor well above the BFE as indicated by the slab in the foreground (Pass Christian, Mississippi)

Figure 10-3. Home constructed on solid, shore-perpendicular foundation walls. The walls are supported by reinforced concrete beams placed on driven piles (Dauphin Island, Alabama).

10.1.3 Long-Duration Flood Impacts in the New Orleans Area

The failure of the levee/floodwalls protecting the City of New Orleans led to deep floodwaters and long-duration flooding throughout the levee-protected areas. Directly behind the point of levee failure, some buildings experienced structural failure and were knocked off their foundations when impacted by floodwaters. The majority of the buildings observed in New Orleans, however, did not sustain significant structural damage from high velocity floodwaters. The only major exceptions observed by the New Orleans Flood Team were in the Lower Ninth Ward of eastern New Orleans and Chalmette in St. Bernard Parish. There were a couple of reasons that account for the severe structural damage observed in the Lower Ninth Ward and Chalmette:

- Some of the buildings may not have been in good condition before the storm. Thus, the winds, high floodwaters, and saturated soil conditions made them more vulnerable to structural failure.
- Some of the areas in eastern New Orleans had just been dewatered of Hurricane Katrina flooding when Hurricane Rita passed through with additional flooding from a breach of the canal repair. Strong winds and high velocity floodwaters could be the reason why the Lower Ninth Ward area was so severely damaged, while areas immediately adjacent, but in a different levee/floodwall system, were not.

The long duration of flooding had a tremendous impact on the building damage experienced in New Orleans. Since virtually all essential city services (e.g., electricity, water, sewer) were inoperable and, because the land was flooded and many roads impassable, residents were kept from their homes for up to 3 weeks. Most of the impacted buildings had extensive damage to the interior contents and building materials. The saturated conditions within the homes and buildings, combined with the warm and humid climate, led to extensive mold and mildew growth in many flooded buildings. The long-duration flooding also led to moisture entrapment within the walls and floors of flooded buildings, which could impact the structural integrity of building materials over time. Finally, the long-duration flooding also caused inundated homes and businesses to become contaminated with floodborne biological and chemical contaminants (refer to Section 10.1.3.2).

10.1.3.1 Long-Duration Flood Damage and Salvageability of Building Materials

As building owners begin to reconstruct and rebuild, building materials impacted by floodwaters will need to be either cleaned or replaced. Porous finish materials such as drywall, plaster, and insulation can be dried under some circumstances, particularly when professional drying equipment is used shortly after the flooding has occurred. However, the buildings in the New Orleans area were flooded for an extended period of time and some materials experienced permanent deterioration or contamination (refer to Section 10.1.3.2).

Exterior walls: Most exterior wall materials observed in New Orleans can be cleaned with minimal difficulty.

Wood framing: Visual observations of interior walls and floors of various residential buildings and critical and essential facilities showed little to no evidence of deterioration of the exposed portions of the wood framing due to long-duration flood exposure, except for some water staining and slight bowing of some sheathing boards in residential buildings. Based on these observations, it appears that the majority of wood framing does not need to be replaced, provided that it is properly cleaned to remove contaminants (as described in Section 10.1.3.2) and dried to remove excess moisture.

Insulating materials: After the floodwaters receded, flooded fiberglass insulation retained water, and the moisture "wicked" farther up into the paper due to capillary action. For this reason, paper-faced insulation impacted by flooding will need to be removed and replaced.

Interior wall materials: Both drywall (gypsum board) and the plaster in buildings impacted by floodwaters experienced significant "wicking" and entrapment of floodborne contaminants and are unlikely to be salvageable.

Wall coverings and coatings: Because most interior walls covered by common household paints and wallpaper were not resistant to floodwater damage, wall coverings and coatings will need to be removed and replaced as well.

Interior doors and cabinets: Interior doors and cabinetry constructed of laminated wood products subjected to long-duration exposure to floodwaters were severely damaged due to water vapor migration and are not considered salvageable.

Floors and floor coverings: Carpet and padding saturated by floodwaters should be replaced. Additionally, flooded vinyl tile and linoleum over wood sub-floors should be removed to allow the wood sub-floor to dry.

Framing connections: Most flooded connectors and fasteners can be salvaged once they are inspected and cleaned to remove floodborne contaminants.

Utility systems: Many of the flooded plumbing and electrical lines can be salvaged once they are inspected and cleaned to remove floodborne contaminants. However, other flooded utility lines and associated small equipment, such as HVAC ductwork and electrical receptacles, will need to be removed and either thoroughly cleaned or replaced.

10.1.3.2 Long-Duration Flood Impacts from Contamination

Buildings in the New Orleans area were subjected to intense flooding for an extended period of time, with waters that carried a number of biological and chemical contaminants. Based on test results of wall material and sludge samples, buildings that were subjected to long-duration flooding are likely to have levels of contaminants that may cause ill health effects to reconstruction workers who do not take appropriate safety precautions (as described in Section 11.1.3.) It is likely that other porous materials, such as drywall, fiberglass insulation, particle-board backs on cabinetry, carpet, and carpet padding may be contaminated. Similarly, appliances that were impacted by floodwaters are likely to have contamination in insulated cavities.

Contaminated building materials may be nearly impossible to clean, and the residual contamination may have adverse health consequences for building occupants. Those contaminated materials that cannot be cleaned must be removed from the buildings.

Biological Contaminants

Bacterial contamination: Environments where building materials have been wet for more than 7 days, or where the floodwater was impacted by sewage, pose the most risk for potential bacterial contamination. Bacterial contamination was found in most of the structures and typically ranged from high to extreme (high: 1,000 – 20,000 cfu/cm^2; extreme: 20,000+ cfu/cm^2). As noted in Section 8.4.2.1, *Gram Negative Bacilli* dominated the sample results. These bacteria often cause stomach problems, dehydration, internal and skin infections, and respiratory difficulties in exposed individuals. Standard flood response activities, such as pumping, mopping, and agitating the air can put the restoration workers and occupants at significant risk, while simultaneously contaminating areas of the building that were previously not affected.

The presence of the bacteria types and levels identified by the MAT means that workers involved in the tear-out and cleanup of flooded structures are at risk of disease if not properly protected. Full face respirators would shield the eyes and respiratory tract. Any wounds, even small scratches, that result from such work should be disinfected promptly and covered to prevent infection.

Fungal contamination: Substantial fungal contamination was observed in all of the inspected facilities. As noted in Section 8.4.2.2, most of the fungal types detected in the samples were dominated by *Aspergillus/Penicillium* or *Chaetomium*. Various strains of these fungal types are linked to health problems, primarily skin irritation and respiratory distress. Health effects from fungi can range from mild allergic reactions to severe illnesses in individuals whose immune systems have been compromised.

The variety of fungal types and extensive levels of visible contamination in all of the examined structures provide support for the use of extensive personal protective equipment during demolition and cleanup. The rampant fungal growth also reinforces the recommendations made in the FEMA Hurricane Katrina Recovery Advisories (Appendix E) to remove and replace porous materials impacted by floodwaters.

Chemical Contaminants

Heavy metal contamination: Thirty-six material samples and eight sludge samples were analyzed for 13 priority element pollutants designated in the Clean Water Act. The 13 elements (heavy metals) are antimony, arsenic, beryllium, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver, thallium, and zinc. A wide variety of heavy metal contamination was observed in the samples collected. In some of the samples, concentrations of arsenic, beryllium, cadmium, chromium, copper, lead, nickel, silver, and zinc exceeded 250 percent of the average values in three or more of the nine buildings sampled. However, the sample results for heavy metals were consistent with the USEPA's floodwater and sediment sample results, indicating the chemicals detected were below levels of health concern.

High concentrations of heavy metals detected in the sludge and building products saturated by the floodwaters could pose a health hazard to individuals exposed to the contaminants during demolition, cleanup, or restoration. The negative health effects of lead, zinc, and other heavy metals in adults and children are well defined in the literature from the USEPA and the CDC. The presence of heavy metal contaminants further highlights the need for restoration workers to use appropriate protective equipment.

Diesel range organics: All 35 samples analyzed for DROs had measurable quantities of DROs, with concentrations ranging from 18,000 to 3,100,000 µg/kg of hydrocarbons. Some of these samples exceeded 250 percent of the average value for the buildings sampled. However, the results were consistent with the USEPA's floodwater and sediment sample results, indicating the values were below the levels of health concern. The highest concentrations were found in wallpaper and sludge samples. From a health standpoint, DROs in building materials can impact individuals in two ways. First, skin irritation commonly occurs with frequent contact. Second, and more importantly, the organics in DROs may liberate pesticides trapped in other building materials.

Pesticide contamination: Measurable levels of organochlorine pesticides were found in 74 percent of the 35 samples analyzed for that contaminant, despite the fact that organochlorine pesticides were banned in the United States approximately 18 years ago. Chlordane was the most consistent contaminant in the samples analyzed, with levels as high as 17,000 µg/kg (2,100 µg/kg of alpha-chlordane and 2,900 µg/kg of gamma chlordane was detected in the same sample). Chlordane levels in the hundreds and thousands of µg/kg were common; some of these levels exceeded 250 percent of the average value for the buildings sampled. However, the results were consistent with the USEPA's floodwater and sediment sample results, indicating the values were below the levels of health concern.

Results indicate a relationship between the age of the house and chlordane levels. Older houses, which are more likely to be originally protected with chlordane, showed higher levels of chlordane, while newer houses generally had much lower levels.

Because the major route of entry for chlordane is absorption through the skin, there is potential for exposure to people working to demolish or renovate flooded structures without proper protection. Chlordane and similar pesticides affect the nervous system, the digestive system, and the liver in humans and animals. Chlordane is not classified as a carcinogen, although low levels of chlordane have resulted in liver cancer in mice. People exposed to high levels of chlordane experience headaches, irritability, confusion, vision problems, vomiting, diarrhea, and jaundice.

Polychlorinated biphenyls: PCBs are long-lasting chemicals often used in transformer oils and in other industrial processes. Because they are carcinogens, exposure to PCBs has been documented to cause long-term health problems. However, no PCBs were detected in any of the 35 samples collected and analyzed.

10.2 Wind Hazards

The wind speeds during Hurricane Katrina were below current design wind speeds in most areas, but the wind pressures still exceeded some of the older building code-level wind pressures. The wind conditions from the storm resulted in limited structural damage to buildings, but widespread damage to building envelopes. Poor envelope performance led to extensive damage to the interiors of residences, businesses, and critical and essential facilities. The wind-related building damage was generally a result of inadequate design, outdated codes, building age, lack of maintenance, and/or poor construction/code enforcement.

The following are discussed in this section:

- Building codes
- Performance of structural systems
- Performance of building envelope, and mechanical and electrical equipment
- Design and construction guidance
- Mitigation for existing buildings

This report's conclusions and recommendations relate only to what was observed by the MAT in the areas affected by Hurricane Katrina. In regard to hurricane wind hazards, the reader is encouraged to obtain a copy of the Hurricane Charley and Ivan MAT reports (FEMA 488 and 489) and the summary report for all four hurricanes that impacted Florida in 2004 (FEMA 490, Summary Report on Building Performance 2004 Hurricane Season, March 2005). These reports are available on line at http://www.fema.gov/rebuild/mat/mat_reprts.shtm.

Residential Construction in Florida Compared with That in Louisiana and Mississippi:

The MAT noted a stark contrast in newly constructed residences observed after Hurricane Katrina in Louisiana and Mississippi versus newly constructed residences observed after Hurricanes Charley and Ivan in Florida. In Florida, there was much more attention to nailing of shear walls and diaphragms, greater use of metal framing connectors, greater use of pressure-rated doors and windows, and, in windborne debris regions, much greater use of protected glazing. The increased attention to wind-resistant construction in Florida greatly improved the wind performance. This increased attention is attributed to Florida's response to the damage caused by Hurricane Andrew (1992). In the aftermath of Andrew, Florida adopted a statewide building code that is periodically updated. Jurisdictions in Florida also endeavor to enforce the code. These building code related measures are augmented by contractor licensing regulations and increased awareness of wind-resistant design and construction issues by designers and contractors.

10.2.1 Building Codes

Two major causes for the amount and magnitude of building damage observed in many of the areas impacted by Hurricane Katrina were the lack of an adopted building code and, where a code had been adopted, the lack of code enforcement. In some communities, a building code had been adopted, but newer editions had never been adopted, resulting in the use of an out-of-date code. For buildings constructed in accordance with the 1982 and later editions of the SBC and IBC/IRC, investigation of the damage suggested that non-compliance with building codes was a major cause of that damage.

Buildings designed and constructed to resist wind loads prescribed in the 2000 IBC, 2003 IBC, and ASCE 7 performed well structurally and showed how improvements to the building codes can produce successful results. Based on the amount of wind damage observed by the MAT for buildings constructed in accordance with the 1979 and earlier editions of the SBC, it is evident that under-prediction of the design wind loads by past building codes for critical building areas, such as roof and wall corners, led to significant building envelope and structural damage. In addition, some building elements constructed under older codes were vulnerable to damage because of the lack of specific provisions for those elements. Building envelope components such as roof coverings have much more stringent requirements in the current codes. Rooftop equipment and protection of glazing, for example, were largely ignored in older codes, but now have more stringent code requirements. Although current building codes are substantially better than those of a few years ago, some improvements are still needed (see Chapter 11).

10.2.2 Performance of Structural Systems (Residential and Commercial Construction)

Most structural failures observed by the MAT appeared to be the result of inadequate design and construction methods commonly used before 2000 IBC and 2000 IRC were adopted and enforced. Only a relatively small number of structures that were observed in the areas affected by Hurricane Katrina were constructed in accordance with current model building codes; most that were observed were constructed in accordance with older codes such as the SBC or were not constructed to any building code standards. Buildings designed and constructed to resist wind loads prescribed in the 2000 IBC, 2003 IBC, and ASCE 7 performed well and showed how improvements to the building codes can produce successful results. However, adoption of the IBC in several of the impacted communities in Alabama and Mississippi is so recent that few buildings have been constructed under those provisions.

Although a number of structural failures from wind were observed, the percentage of buildings that experienced structural failure was quite small. Structural failures predominately occurred in older buildings. In addition to wind-induced failures, some structural failures were the result of tree-fall.

Throughout the Hurricane Katrina damage zone, the limited structural damage caused by wind was most commonly observed in residential wood roof framing and occurred below current code wind pressures design levels. Inadequate nailing of roof sheathing panels, gable end wall failures, and lack of properly installed metal framing connectors were the major factors in these structural failures.

Most heavy engineered commercial buildings (e.g., casino hotels, banks, hospitals) performed well structurally, which is attributed to engineering attention paid to details and to the safety factors normally included in the performance of the engineering analysis conducted for the structures' designs. In contrast to heavily engineered structures, older pre-engineered structures, generally constructed before the mid-1980s, performed poorly. These structures are often designed to minimum standards to reduce cost. Lack of building codes and older codes often resulted in structures being constructed to minimum design requirements.

Structural damage was caused in some buildings when the building envelope was breached and significant changes of the internal pressures occurred. Failures of windows and doors on the windward face of a building have been correlated with subsequent failures of partition walls, windows, and doors on side and leeward walls, attic access panels, roof sheathing, and even whole roof structures. Numerous failures occurred at and below the design wind speed as the result of inadequate design and construction of the connections as well as contribution from internal pressurization.

Soffit failures in residential buildings often led to internal pressurization of attics and loss of inadequately attached roof decking (see Figures 10-4 and 10-5).

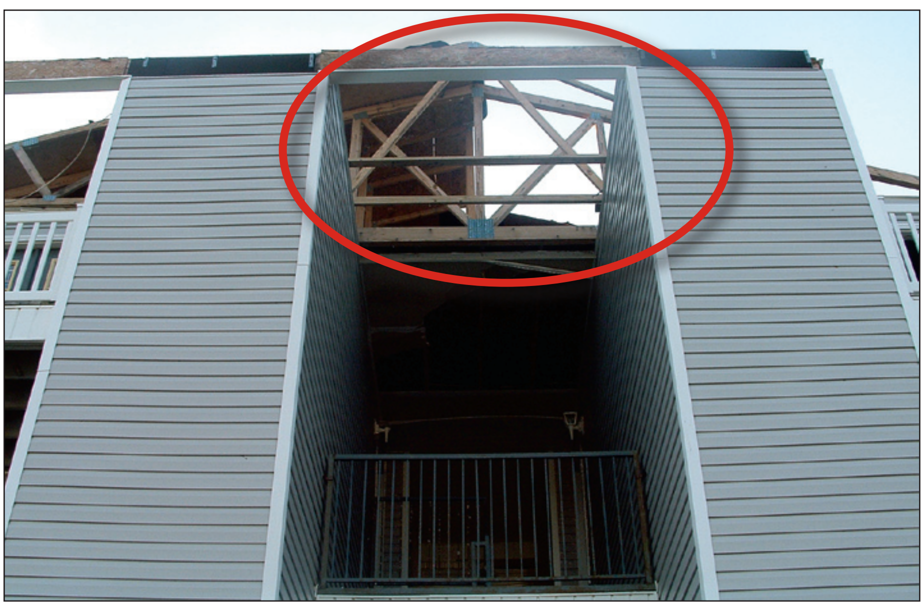

Figure 10-4.
Classic soffit failure resulting in attic pressurization and roof decking failure. The stairwell soffit (circled) was blown away during the storm (Long Beach, Mississippi).

Figure 10-5.
The failure of this apartment building was the result of inadequate connections and interior pressurization caused by broken windows and failure of the porch ceiling. Note the broken glazing (circle) and the failed porch ceilings (arrows) (Ocean Springs, Mississippi)

10.2.3 Performance of Building Envelope, and Mechanical and Electrical Equipment

Building envelope damage and damage to rooftop equipment was observed to residential, commercial, and critical and essential buildings throughout all areas visited by the MAT. Poor performance of building envelopes was a function of both inadequate wind resistance and damage from windborne debris impact. Inadequate resistance to high-wind pressures on building envelopes and rooftop equipment was responsible for much of the wind damage caused by Hurricane Katrina. Envelope and equipment damage was more widespread and significant on older buildings. The most commonly damaged elements were roof coverings, vinyl siding, soffits, EIFS, glazing, and rooftop equipment.

In addition, windborne debris caused significant envelope damage, and virtually all of the glazing damage that the MAT observed. In several instances, blown-off envelope elements became windborne debris that caused additional damage.

In part, the building envelope failure problem is due to lack of high-wind design guides for envelope assemblies and various types of rooftop equipment. Ramifications of poor performance include the following:

- **Property damage:** Property damage was extensive, requiring repair and/or replacement of the damaged envelope itself and rooftop equipment components. Even when damage to the building envelope or equipment was limited, such as blow-off of a portion of the roof covering or broken glazing, substantial rainwater damage frequently resulted because of the heavy rains accompanying the hurricane and rains occurring in the following days and weeks. Rainwater entered the buildings through the breaches in the building envelope. Rainwater and/or wind damage in the building interior resulted in the need for replacing equipment and furniture. In many cases, mold remediation was also required.
- **Loss of function:** Depending upon the magnitude of the wind and rainwater damage, repairs can take days or months. As a result, residents may not be able to return home, businesses

may not be able to reopen, and critical and essential facilities may be incapable of providing their vital services. In addition to the costs associated with repairing the damage and/or replacing the damaged property, other financial ramifications related to interrupted use of the building can include rental costs of temporary facilities or lost revenue due to business interruption. These additional costs can be quite substantial.

10.2.3.1 Roof Coverings, Wall Coverings, and Soffits

Roof coverings of many types failed during Hurricane Katrina. Some of these failures were due to the age of the coverings. Age-related failures were associated with weather-induced change in material properties and with testing limitations and design standards that were available years ago. Other failures were due to design and construction related issues or debris impact. The MAT's main observations and conclusions are as follows:

- Asphalt roof shingle performance, including newly installed shingles, was generally extremely poor. Installation deficiencies pertaining to fastener location and starter strips were commonly observed at damaged roofs. Enhanced attachment of hip, ridge, rake, and eave shingles was not observed.

- Edge flashing, coping, and gutter/downspouts failure was common. Failure of these roofing components often initiated lifting and peeling of roof membranes. Failure was in part due to inadequate design and construction attention, and, in the case of gutters, due to lack of testing and design standards.

- During Hurricane Katrina, as with many previous hurricanes, aggregate roof surfacing was commonly blown off roofs and caused glazing damage. Use of aggregate surfacing in hurricane-prone regions is problematic.

- Vinyl siding performance was generally extremely poor. Use of vinyl siding manufactured for high-wind areas was not observed.

- In general, EIFS performed poorly. For many buildings, the poor performance resulted in significant rainwater infiltration damage. Installation deficiencies were commonly observed at the investigated EIFS failures.

- Widespread loss of soffits was observed in residential construction. In numerous buildings, rain was driven into attic spaces because of soffit failures.

10.2.3.2 Windows, Doors, and Shutters

Glazing damage was observed throughout the area visited by the MAT. Use of protected glazing (either laminated glass or shutters) was not nearly as commonly observed in Louisiana or Mississippi as it was during the MAT's 2004 observations in Florida. Damage to the contents of many homes and businesses would have been prevented if glazing had been protected. Additionally, in newly constructed houses, doors and windows with wind pressure labels were only rarely observed.

10.2.3.3 Attached Equipment (Rooftop and Ground Level)

Displacement or damage to rooftop equipment was observed throughout the areas visited by the MAT. This not only resulted in the loss of function associated with the damaged units, but in many cases led to the loss of function of the occupied space due to rainwater infiltration at the displaced equipment. Rooftop and ground level equipment need additional design, installation, and code attention to adequately protect equipment from wind events. ASCE 7 provides basic information to calculate wind loads on these elements, but additional design guidance is needed.

10.2.4 The Need for High-Wind Design and Construction Guidance

Failure to adequately maintain a proper load path was observed in many instances of failed building elements. For instance, fasteners were commonly spaced too far apart, were too small, or had weak connections. There were numerous examples of failures to follow well-established basic construction practices, such as minimum edge distances for fasteners.

Hurricanes can have devastating effects on building envelopes and equipment. Unless wind resistance issues are understood by designers and contractors, envelope and equipment failures will continue to occur. Designers, contractors, and building officials need additional education and resources regarding these modes of failure. In part, the envelope and equipment problem is due to lack of high-wind design guides for various envelope assemblies and various types of rooftop equipment.

10.2.5 Wind Mitigation for Existing Buildings

Based on damage that the MAT observed, many buildings (residential, commercial, critical and essential) constructed before the mid-1990s have building envelopes with significant wind vulnerabilities, and many buildings constructed before the mid-1980s have significant structural vulnerabilities. Even many recently constructed buildings in Louisiana and Mississippi are vulnerable to wind damage.

Buildings with vulnerabilities have three likely scenarios: the buildings will be damaged in future hurricanes, they will be phased out (i.e., torn down and replaced), or they will be mitigated to avoid future damage. Mitigation is preferable to the damage and then repair scenario.

10.3 Performance of Critical and Essential Facilities (Including Shelters)

In general, buildings functioning as critical and essential facilities did not perform better than the commercial buildings. The same construction issues observed in residential and commercial buildings were observed in critical and essential facilities. Some buildings designed to critical and essential facility requirements experienced damage and partial failures during the hurricane due to lack of protection from windborne debris.

The flood- and wind-related building damage to critical and essential facilities experienced during Hurricane Katrina led to a significant, and avoidable, loss of function. Specific conclusions for critical and essential facilities based on these observations are as follows:

- Facilities that sustained damage from flooding had not been designed to withstand the level of flooding that occurred.
- Unless wind mitigation measures have been taken, older buildings used as critical and essential facilities will likely have wind damage to the roof coverings, wall coverings, window and door systems, and rooftop equipment (including communications towers and antennas). This type of damage can lead to significant loss of function at the facilities.
- Some critical and essential facilities experienced damage and partial failures during the hurricane due to lack of protection from windborne debris. Lack of protection of windows was common at hospitals, nursing homes, and schools (including schools used as shelters) and led to window failures and significant damage to building contents.
- Building components blew off of several critical and essential facilities during Katrina. Windborne debris can injure or kill first responders at EOCs, late arrivers at shelters, or those seeking medical attention at hospitals. Although people are not usually outdoors during hurricanes, buildings used as essential and critical facilities can be the exception. It is common for people to arrive at these facilities during a hurricane and additional efforts should be made to reduce the potential for windborne debris at these sites.

10.4 Historic Buildings

Historic buildings, many of which had been around for more than 100 years, were totally destroyed by Hurricane Katrina. These buildings had survived numerous previous storms, including Hurricanes Betsy and Camille, but they had not experienced the surge levels unleashed by Katrina. Many of the historic buildings sat on higher ground along Highway 90 in Mississippi and never experienced the storm surge, and wave and debris impacts produced by Hurricane Katrina. The buildings that survived the storm surge generally performed well from a wind standpoint. Most of the wind damage to historic buildings was a result of debris impacts or falling trees. In a few cases, windborne debris did cause glazing damage that led to internal pressurization, which resulted in roof failure.