Fact Sheet 3.3.2: Roof Systems—Low-Slope Roofs

The mitigation objective of this Fact Sheet is to improve the resilience of low-slope roof systems to allow a building to continue to be used or quickly repaired following a hurricane, with an end goal of rapidly returning the building to full functionality.

Roof systems include all the building elements above the top of the wall system (addressed in Fact Sheet 3.2, *Wall Systems and Openings*). Roof systems can be classified by roof shape and building size. As shown in Figure 3.3.2.1, low-slope roof systems include the following components: framing, connectors and fasteners, roof deck, insulation, covering, edges and overhangs, parapet walls, roof vents, roof drainage, and openings, as well as roof-mounted equipment. Low-slope roofs have a pitch of fewer than 3 feet vertical to 12 feet horizontal (3:12) for metal roofs, 2.5:12 for clay tile roofs and 2:12 for ballasted roofs).

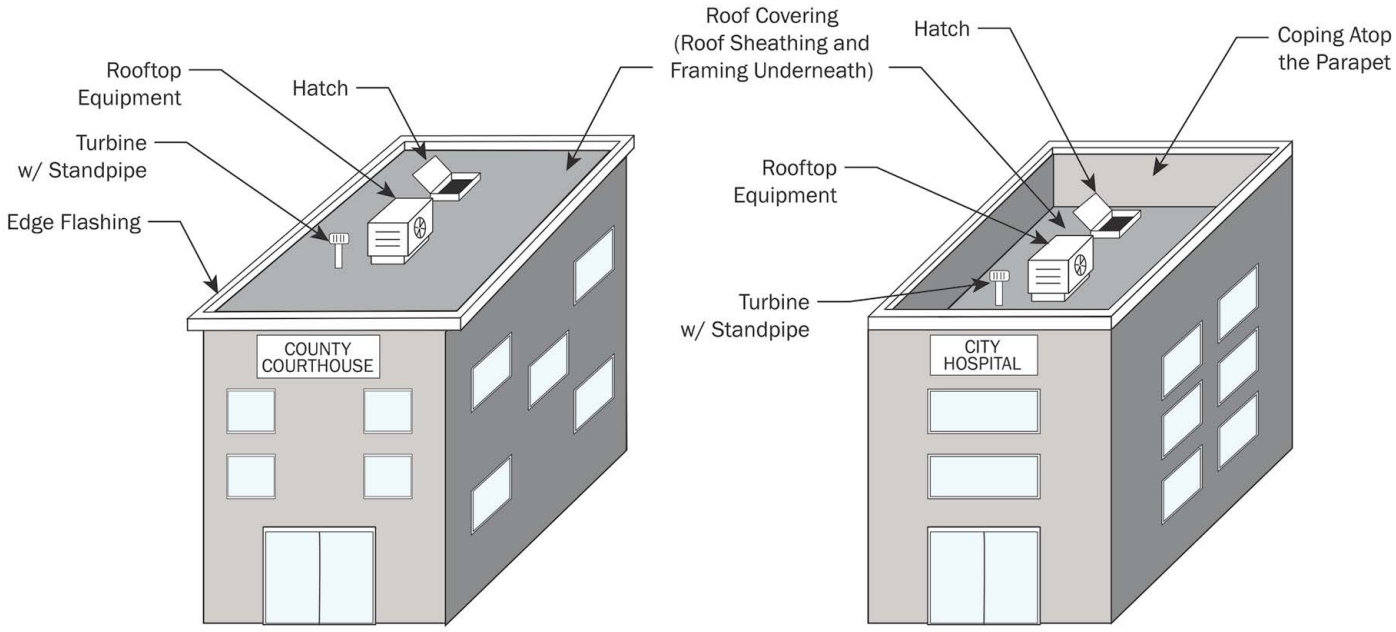


Figure 3.3.2.1. Basic components of typical low-slope roofs featuring overhangs (left) and parapet walls (right).

Definitions

Elements of low-slope roof systems include the roof deck, roof covering, and edge metals. For this Fact Sheet, mitigation options also are provided for:

Framing—Provides the main structural support for the roof. Low-slope roof framing elements may include roof joists, roof slabs and decks, and concrete or steel roof beams.

Connectors and Fasteners—Link the roof framing to the wall system and hold elements of the roof system together. Low-slope roof connectors and fasteners may include hurricane straps or ties secured with nails or screws, steel bolts or welds, and concrete or grout with steel reinforcing bars.

Decking/Sheathing—Covers the roof framing on all framing systems except concrete roof slabs and provides additional structural strength to wood or metal framing. Low-slope roof sheathing may include plywood or oriented strand board (OSB) for wood-framed roofs and metal decking or panels for steel-framed roofs.

Covering—Protects roof framing and sheathing from rain, snow and wind-driven rain. Low-slope roof coverings may include built-up roof (BUR) layers, metal, modified bitumen membrane, ethylene propylene diene terpolymer (EPDM) membrane, single-ply polyvinyl chloride (PVC) or thermoplastic olefin (TPO) membrane.

Edges and Overhangs—The roof border frequently is at more risk of damage from wind uplift forces and wind-driven rain entry than the rest of the roof. Low-slope roof elements typically include either concrete overhangs or masonry parapet walls with metal wall and cap flashing, coping or fascia covers along the edges.

Vents—Provide airflow in attic spaces needed to vent cooler air in the hotter months and vent warmer air in the cooler months to lower heating and cooling costs. Ventilation components may include turbines and standpipes.

Drainage—Removes water off the roof and away from the structure. Low-slope roof drainage components include interior drains, gutters or scuppers connected to downspouts, and secondary or emergency overflow scuppers or drains.

Skylights and Roof Hatches—Provide rooftop access and/or an overhead source of natural light. Low-slope roof opening components include steel or wood-framed hatches and glass or clear polymer skylights.

Rooftop Equipment—On low-slope roofs, rooftop equipment typically may include heating/ventilation/air conditioning (HVAC) equipment, vents and fans, elevator equipment penthouses, antennas and communications towers, solar panels and lightning protection systems.

Table 3.3.2.1 summarizes some common mitigation solutions that can improve the performance of low-slope roof systems common to public buildings. These strategies are then discussed in the sections that follow.

Table 3.3.2.1. Mitigation Solutions for Low Slope Roof Systems

Solutions and Options	*Wind*	*Wind-Driven Rain*	*Rainfall*
Mitigation Solution: Secure or Eliminate			
Option 1: Eliminate or Secure Gravel Ballast Roofs	✓	✓	✓
Option 2: Secure, Minimize or Eliminate Roof Overhangs	✓	✓	
Option 3: Secure or Replace Roof Vent Turbines	✓	✓	✓
Option 4: Secure Access Panels and Hatches	✓	✓	✓
Mitigation Solution: Add or Increase			
Option 1: Add Roof-Mounted Equipment Pedestals or Relocate Inside	✓	✓	✓
Option 2: Add a Secondary Membrane	✓	✓	✓
Mitigation Solution: Strengthen or Improve			
Option 1: Strengthen Roof Framing and Connections	✓	✓	
Option 2: Upgrade Wood Sheathing/Decking	✓	✓	✓
Option 3: Improve Metal Roof Decking	✓	✓	✓
Option 4: Strengthen Edge Flashings, Copings and Fascia Covers	✓	✓	
Option 5: Improve Gutters	✓	✓	✓
Option 6: Strengthen Roof Access Hatches and Skylights	✓	✓	✓
Option 7: Strengthen Roof-Mounted Equipment and Component Connections	✓	✓	
Mitigation Solution: Upgrade			
Option 1: Upgrade Roof Covering with Tested Systems	✓	✓	✓

In addition to physical mitigation measures, it is important to create and follow a regular roof maintenance schedule. The roof should be inspected at least twice per year, ideally in the spring and fall, to evaluate the condition and identify potential repair needs. Inspections also should be done after high wind events to assess if storm-related damage occurred. Needed repairs should be completed quickly after the inspection to ensure additional damage does not occur.

Mitigation Solution: Secure or Eliminate

This solution involves reinforcing low-slope roof elements vulnerable to wind or wind-driven rain damage or removing those elements from the roof system. Mitigation options focus on roof coverings, overhangs and vent components vulnerable to damage or failure from positive or negative wind pressures resulting in wind-driven rain entry.

Option 1: Eliminate or Secure Gravel Ballast Roofs

Gravel ballast sometimes is placed on low-slope roof coverings to protect the covering from sun damage and provide a small amount of resistance to uplift. However, gravel ballast often is loose and frequently becomes a source of wind-borne debris (missiles) that can break windows and other openings on the building and surrounding structures. Consider the following mitigation options:

- Remove loose gravel ballast roof coverings in high-wind regions. Note that the 2009 and later editions of the International Building Code prohibit gravel ballast roof surfacing in hurricane-prone regions. An engineer can recommend other roofing types.
- Consider securing the gravel ballast on roofs for less-severe wind conditions by applying a strong adhesive over the gravel ballast system to keep the gravel from becoming airborne.

CONSIDERATIONS:

Option 2: Secure, Minimize or Eliminate Roof Overhangs

Roof overhangs on low-slope roofs create a major source of uplift failure for the roof system, allowing wind-driven rain to enter, which can damage the building's interior. Consider the following mitigation options to address vulnerable overhangs in buildings:

- Secure moderately sized (12-inch to 16-inch) overhangs with stronger materials, connectors and fasteners to resist uplift forces and protect against wind-driven rain entry. Ensure a registered professional with knowledge of local wind forces reviews the design to confirm the stronger components comply with local codes and regulations.
- Large overhanging roofs covering porches and other open areas connected to the main building should be designed as either a single-roof structure or as a separate-roof structure not attached to the main building.
- For new construction or existing buildings with large roof overhangs that are damaged and need to be replaced, consider redesigning the roof system to minimize or eliminate overhangs.
- A licensed design professional with knowledge of local wind load requirements should design new or reconfigured roofs in accordance with required codes, standards and specifications. The design professional should implement the latest consensus-based codes, standards and specifications and consider code-plus measures in the design, as appropriate.

CONSIDERATIONS:

Option 3: Secure or Replace Roof Vent Turbines

For large public buildings, turbines that use wind power to pull humid air out of attic spaces can be mounted on top of short or long standpipes and installed on low-slope roofs. Turbines often are poorly fastened and can become bent or dislodged by high winds during hurricanes, creating entry points for wind-driven rain. Consider the following mitigation recommendations:

- Attach roof vent turbines to the roof sheathing or framing with straps and connect the roof vent turbine head to the standpipe with sheet metal screws instead of relying on a simple friction fit with dimple punches.
- Consider temporarily removing turbine heads before hurricanes and plugging the tops of the standpipes to prevent rain infiltration. Even high-wind-rated turbines will rotate at above-design speeds and can be easily damaged by wind-borne debris. To anchor the plug to the standpipe, use a wooden plug that covers the entire hole and has blocks that rest against the walls of the standpipe where screws can be installed.
- Consider installing roof vent turbines that have been tested and evaluated to meet local code regulations and wind force requirements.

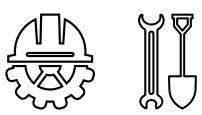
CONSIDERATIONS:

Option 4: Secure Access Panels and Hatches

Strong winds can blow off access panels on rooftop-mounted HVAC equipment. The panels then become wind-borne debris that can puncture and tear roof membranes, allowing rain to enter the building. If the equipment is not specifically manufactured for the panel to resist the local wind forces, consider the following:

- Attach hasps and locking devices like carabiners.
- Modifications to HVAC equipment, such as attaching locking devices to access panels, must be customized. Detailed design may be required.
- The manufacturer should approve modifications to equipment.

CONSIDERATIONS:



Mitigation Solution: Add or Increase

This solution involves adding an element or increasing the size or quantity of an existing roof system component to protect it from damage in future wind, wind-driven rain, and rainfall events. Using this solution can help improve the performance of roof sheathing, drainage, and roof-mounted equipment components.

Option 1: Add Roof-Mounted Equipment Pedestals or Relocate Inside

On low-slope membrane roofs, poorly anchored roof-mounted equipment can be knocked out of place by high winds or wind-borne debris impact. This often leads to tearing and peeling of the roof membrane as the equipment skips across the roof. Consider the following techniques to deal with this issue:

- Add a concrete curb or pedestal on which to mount rooftop equipment to provide a solid connection point without having to break through the surrounding roof membrane. This improvement should be made together with strengthening equipment connections, as described in Mitigation Solution: Strengthen or Improve—Option 7 (see below) and as shown in Figure 3.3.2.2. Pedestal size and weight are design considerations to be addressed by the engineer.

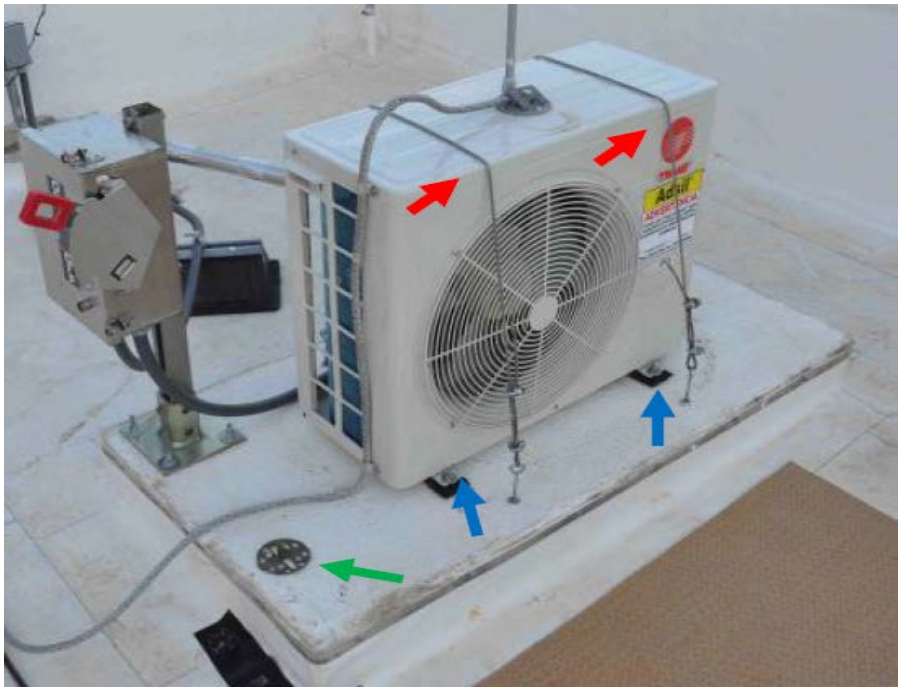
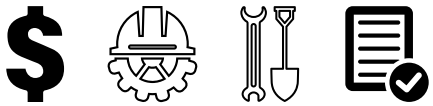


Figure 3.3.2.2. Condenser bolted down to concrete curb (blue arrows) with tie-down cables (red arrows), but the lightning protection system is no longer secured by its connector (green arrow).

- Make sure rooftop equipment supports are either tested to comply with local code regulations or designed by a professional familiar with the wind requirements of the region.
- Lightning protection systems are critical to keeping equipment safe during lightning storms. Ensure such systems are properly secured to equipment.
- In situations where roof-mounted equipment is difficult to anchor or the equipment itself is unlikely to withstand high winds, wind-borne debris impact and wind-driven rain, consider moving the equipment inside the building or move it into a rooftop penthouse to protect it from damage.
  - This approach may require moving existing systems and contents.
  - This approach also may need to meet additional clearance and ventilation requirements to hold the relocated equipment.
  - Penthouses need to be designed and constructed as per ASCE 7 to resist local wind design speeds specified in the most recent building code edition.

CONSIDERATIONS:

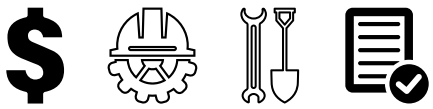


Option 2: Add a Secondary Membrane

Installing a secondary membrane over a concrete deck can provide extra protection against damage from debris impacts and wind-driven rain. When evaluating this option, keep these considerations in mind:

- Seal the secondary membrane at the edges, openings and penetrations to prevent water from entering.
- Use a layer thickness that meets requirements for local wind design speeds specified in the most recent building code edition.
- Install insulation over the secondary membrane. The insulation helps absorb energy from debris impacts.
- Install the primary membrane over the insulation. Consider a modified bitumen membrane, which is more resistant to puncture than other membrane systems used for roof coverings.

CONSIDERATIONS:



Mitigation Solution: Strengthen or Improve

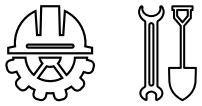
This solution involves upgrades to one or more of the existing roof system elements to help improve resistance to wind, wind-driven rain and rainfall events. Multiple mitigation options use this solution to protect low-slope roof system components and maintain a continuous load path throughout the roof system.

Option 1: Strengthen Roof Framing and Connections

Use the following techniques to make sure the roof framing and connections between the roof and wall framing are strong enough to withstand both horizontal and uplift wind forces. As part of these solutions, note that NFIP Technical Bulletin 8, *Corrosion Protection for Metal Connectors and Fasteners in Coastal Areas*, recommends all exposed roof connectors and fasteners within 3,000 feet of the coastline should be either hot-dipped galvanized steel or stainless steel to resist salt spray and corrosion.

- Strengthen all low-slope roof-framing types using materials prespecified in FEMA P-55, *Coastal Construction Manual*, and FEMA P-424, *Design Guide for Improving School Safety in Earthquakes, Floods, and High Winds*.
- Strengthen roof connections by installing anchors, straps, reinforcing bars, connectors and fasteners compatible with the roof system. As with wall framing connections discussed in Fact Sheet 3.2, *Wall Systems and Openings*, roof connectors and fasteners must be strong enough to resist hurricane wind forces. See FEMA P-543, *Design Guide for Improving Critical Facility Safety from Flooding and High Winds*, for additional information.

CONSIDERATIONS:



Option 2: Upgrade Wood Sheathing/Decking

Upgrade wood roof sheathing/decking by making the following improvements listed in Technical Fact Sheet 7.1, *Roof Sheathing Installation*, of FEMA P-499, *Home Builder's Guide to Coastal Construction*.

- Install wood sheathing/decking panels for high-wind regions, including plywood or OSB rated as "Exposure 1" or better with a minimum thickness of 15/32-inch (outside of the Florida High-Velocity Hurricane Zone [HVHZ] only).
- Sheathing/decking layouts for low-slope roofs should be installed to match APA—The Engineered Wood Association recommendations.
- Improved sheathing/decking connections should use a minimum of 8d (i.e., 2 ½ inches long), full round-head deformed-shank nails, ring shank nails, or screws; staples are insufficient and should not be used in high-wind areas.
- Increase nailing frequency for sheathing systems that do not meet current wind load requirements.

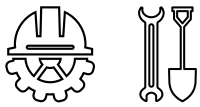
CONSIDERATIONS:

Option 3: Improve Metal Roof Decking

Improve metal roofing performance using the following for materials, installation details and connections per Technical Fact Sheet 7.6, *Metal Roof Systems in High-Wind Regions*, of FEMA P-499, *Home Builder's Guide to Coastal Construction*; FEMA P-543, *Design Guide for Improving Critical Facility Safety from Flooding and High Winds*, and local building code requirements. When evaluating this option, consider the following:

- When clip or panel fasteners are attached to mailers, note the connection of the nailer to the nailer support.
- When clip or panel fasteners are loaded-in withdrawal (tension), use screws instead of nails.
- Make sure clips are correctly spaced.
- Use the correct clip type for the wind speed and roof panel type.
- Closely space fasteners at hip and ridge flashings. Please refer to the manufacturer's tested assemblies or technical requirements from the Sheet Metal and Air Conditioning Contractors' National Association (SMACNA) for additional information.

CONSIDERATIONS:



Option 4: Strengthen Edge Flashings, Copings and Fascia Covers

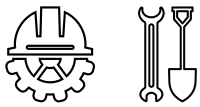
Public buildings with low-slope membrane roofs often fail at the edges of high winds from lifting and peeling metal edge flashings, copings, or fascia covers. FEMA P-543, *Design Guide for Improving Critical Facility Safety in Flooding and High Winds*, recommends the following approaches to strengthen these components:

- Reinforce metal edge flashings, copings and fascia covers with stronger materials and improved connectors. Design these elements to resist wind uplift as per ANSI/SPRI ES-1, *Test Standard for Edge Systems Used with Low Slope Roofing Systems*, referenced in the International Building Code.
- Attach edge flashings, copings and fascia covers with wood or masonry screws and washers instead of cleats, as shown in Figure 3.3.2.3. Also install anti-bridging bars on roof membrane liners.

- If cleats are used to attach the roof membrane, place a peel-stop bar over the roof membrane near the edge flashing or coping. The bar provides secondary protection against membrane lifting and peeling if the flashing or coping fail. The bar should be well anchored to the parapet or deck.

Figure 3.3.2.3. Both vertical faces of coping were attached with exposed fasteners (¼-inch diameter stainless steel fasteners spaced 12" on center) instead of concealed cleats following Typhoon Paka (1997) in Guam to prevent the flashing from tearing in future storms.

CONSIDERATIONS:



Option 5: Improve Gutters

Storm damage research has shown that—when lifted by wind—gutters cause the edge flashing, which laps the gutter to lift as well, resulting in a progressive peeling of the roof membrane. This leaves the roof exposed to potential water entry and damage. The following measures can be used to protect gutters from wind damage and make sure they provide needed storm runoff volume:

- Use gutter materials and connections designed to resist wind, water and ice loads as per ANSI/SPRI GD-1, *Structural Design Standard for Gutter Systems Used on Low-Sloped Roofs*, for both low-slope and steep-slope roofs using a safety factor of 2.0 as in Figure 3.3.2.4.

Figure 3.3.2.4. Sheet metal straps (circled) attached to an existing gutter to increase wind uplift resistance.

- Gravity-support brackets can be designed to resist uplift loads. In addition to being attached at its top, the bracket should also be attached to the wall at its low end. Bracket spacing will depend on the gravity and uplift loads, the bracket's strength, and the strength of the connections from gutter-to-bracket and bracket-to-wall.
- Use separate sheet metal straps at 45-degree angles to the wall to resist uplift loads. The strap spacing will depend on the gutter uplift and strength of the connections from gutter-to-strap and strap-to-wall.
- Regularly inspect gutters to clean vegetation and other debris that builds up and tighten loose connections. Keep trees surrounding the building trimmed back so they do not extend over the rooftops.

CONSIDERATIONS:

Option 6: Strengthen Roof Access Hatches and Skylights

Roof access hatches and skylights can be a point of entry for water and wind if they are not rated for the wind zone in the area where the building is located or if they are not properly sealed. Strengthen roof access hatches and skylights to help reduce damage to the interiors of public buildings as follows:

- Strengthen roof access hatches using thicker hatch door materials and more robust hatch frames with thicker seals, more durable hinges, and tougher locks compared to non-tested or off-the-shelf roof hatches.
- Upgrade older plastic skylights with wired glass or other impact-resistant glazing materials with thicker seals and frames compared to non-tested or standard seals and frames.
- Use skylight installation and performance standards, including ASTM E2112 and ASTM E330.

- Consider replacing hinged skylights with closed skylights to reduce the risk of wind-driven rain entry and for increased security.

CONSIDERATIONS:

Option 7: Strengthen Roof-Mounted Equipment and Component Connections

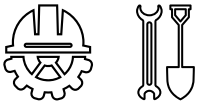
Some mechanical and electrical equipment may be located on the roof. If this equipment is not protected in a rooftop penthouse, strong winds can dislodge the components from where they are attached to the roof. Rooftop equipment connections can be strengthened using the following methods:

- Follow specific design guidance such as *Calculating Wind Loads and Anchorage Requirements for Rooftop Equipment*, published by the American Society for Heating, Refrigeration and Air Conditioning Engineers (ASHRAE).
- Where specific design guidance is unavailable, follow the practices outlined in *Recovery Advisory 2, Attachment of Rooftop Equipment in High-Wind Regions* from FEMA P-2021, *Mitigation Assessment Team (MAT): Hurricanes Irma and Maria in the U.S. Virgin Islands;* FEMA P-543, *Design Guide for Improving Critical Facility Safety from Flooding and High Winds*, or similar advisories for details on the number of screws needed to secure select rooftop equipment.
  - Table 1 of the Recovery Advisory provides recommendations on the number of fasteners to use for different types of equipment.
  - The advisory also includes best practices for hold-down connectors, anchors and straps to resist wind uplift pressures, as shown in Figure 3.3.2.5.

Figure 3.3.2.5. Rooftop periodic gas line supports using a steel angle welded to a pipe that was anchored to the roof deck for lateral and uplift resistance (left). Use of intermittent membrane flashing to secure a lightning protection system conductor (center). Cables attached prevent rooftop equipment cowling from blowing off (right).

- Make sure rooftop equipment attachments are designed to meet local code requirements and meet the requirements of ASCE 7.
- For lightning protection systems, conductor connectors should be mechanically secured to the inside face of the parapet nailer and properly sealed to be watertight. On built-up and modified bitumen roofs, attach air terminal base plates with asphalt roof cement. For single-ply membranes, attach the air terminal base plates with pourable sealer.
- Evaluate the strength of roof-mounted antennas as per the latest version of ANSI/TIA-222, *Structural Standard for Antenna Supporting Structures and Antennas and Small Wind Turbine Support Structure*s, to determine if additional guy wires, bracing or tower strengthening are required.

CONSIDERATIONS:



Mitigation Solution: Upgrade

This solution involves removing a roof system that has been destroyed or significantly damaged and replacing it with a stronger roof system that is resistant to wind and wind-driven rain.

Option 1: Upgrade Roof Covering with Tested Systems

For low-slope roofs where the roof framing or structural support system is sufficient to resist wind loads but the roof covering is not, consider removing the existing roof covering and upgrading it with a system that has been tested to meet the local wind requirements. This also presents an opportunity to fix any ponding issues that may occur with the existing roof covering. In hurricane-prone regions, it is recommended that roof coverings with gravel ballast surfacing, lightweight pavers or cementitious-coated insulation boards be replaced to avoid blow-off.

- Storm damage research has shown that sprayed polyurethane foam (SPF) and liquid-applied roof systems are very reliable performers in high winds.
- Built-up roofs and modified bitumen systems have demonstrated good wind performance provided the edge flashing or coping does not fail, which happens frequently.
  - Design flashing and coping to comply with ANSI/SPRI ES-1, Wind Design Standard for Edge Systems Used in Low Slope Roofing Systems.
  - Use exposed fasteners to attach the vertical flanges of copings and edge flashings as they have been found to be a very effective and reliable attachment method.
- Mechanically attached and air-pressure equalized single-ply membrane systems are prone to degradation after debris impact; this roofing system is not recommended for hurricane-prone regions.
- When upgrading a roof covering, remove the old roof covering down to the deck rather than just re-covering the roof. This allows the structural integrity of the roof to be evaluated and problems to be addressed.
- It may be necessary to re-skin the parapet with sheathing before installing new base flashing.

CONSIDERATIONS:

REFERENCES:

Detailed technical information on hurricane mitigation of low-slope roofs can be found in these publications. Much of the residential information also applies to non-residential buildings.

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