

# Mitigation Assessment Team Report

# Hurricanes Irma and Maria in the U.S. Virgin Islands

Building Performance Observations, Recommendations, and Technical Guidance

FEMA P-2021 / September 2018



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# HURRICANES IRMA AND MARIA IN THE U.S. VIRGIN ISLANDS

# **Executive Summary**

In September 2017, Hurricanes Irma and Maria, two back-to-back Category 5 hurricanes, significantly impacted the U.S. Virgin Islands (USVI).

Hurricane Irma was the ninth named storm of the 2017 hurricane season. When it impacted the USVI on September 6, it devastated much of St. Thomas and St. John. Recovery operations began quickly after the storm, and were stationed in St. Croix, which was minimally impacted. Two weeks later, on September 20, Hurricane Maria passed directly by St. Croix and devastated the previously damaged USVI. Homes, schools, hospitals, infrastructure, and public services, particularly in St. Croix, were significantly impacted by this second storm. Hurricane Maria also caused further complications to the Hurricane Irma response, as emergency workers and residents dealt with multiple events and interruptions to the effort. The storms placed additional pressure on an already strained economy, which relies heavily on tourism and a thriving hospitality industry.

Over the course of the storms, extreme winds battered and impacted St. Thomas, St. John and St. Croix. Wind speeds approached, and in some locations met or exceeded, the design requirements of the 2018 *International Building Code* (IBC©) and 2018 *International Residential Code* (IRC©) which reference the 2016 version of *American Society of Civil Engineers: Minimum Design Loads and Associated Criteria for Buildings and Other Structures* (ASCE 7-16). Though the islands are subject to storm surge from hurricanes and severe storms, in the case of Hurricanes Irma and Maria, there was minor damage associated with storm surge and coastal flooding. Much of the damage from flooding was from wind-driven rain, localized ponding, and site-specific stormwater runoff.

As of July 2018, Federal agencies have provided more than \$1.7 billion to hurricane survivors, businesses, and the Territory, from FEMA grants, disaster loans by the U.S. Small Business Administration, and claims payments by the National Flood Insurance Program (NFIP). With the recovery well underway, FEMA seeks to encourage improvements to building and development approaches in the USVI and assist the local communities in ensuring robust mitigation efforts to future storms.

## **Mitigation Assessment Team**

In response to a request for technical support from the Federal Emergency Management (FEMA) Joint Field Office in St. Croix, FEMA's Federal Insurance and Mitigation Administration's (FIMA) Building Science Branch deployed a Mitigation Assessment Team (MAT) composed of national and regional experts to affected areas in St. Thomas, St. John, and St. Croix, in October and November, 2017.

The MAT was charged with evaluating damage from Hurricanes Irma and Maria, especially for buildings constructed or reconstructed after Hurricane Marilyn (1995), to identify both successful and unsuccessful mitigation techniques. This work involved: assessing the performance of residential, nonresidential, and critical facilities affected by the storms; evaluating the performance of photovoltaic (PV) facilities; investigating the effects of wind speed-up due to the islands' topography on building performance; and meeting with residents and local officials to better understand what transpired during and after the storms.

Significant damage was observed across all building types and all three of the islands, though these impacts varied greatly by the building location, previous mitigation efforts, and the effectiveness of adopting the recommended design standards. The lessons learned can be incorporated into the ongoing recovery effort and will provide a research-driven path for future improvements.

## **Conclusions and Recommendations**

Lessons learned from the MAT's observations are documented in this report and in Recovery Advisories which are available to communities to aid in their rebuilding effort and enhance building resilience. The key findings of this MAT Report, which are based on the team's observations in the field, are summarized below and fully described in Chapter 8 of the report. They are directed toward designers, contractors, building officials, and island residents and recommend disaster-resistant practices for hurricane-prone regions.

While the dual effects of Irma and Maria had substantial ramifications for the USVI, the recovery process provides countless opportunities to mitigate. This report provides specific and actionable recommendations on code issues and design provisions that build upon an already-begun investment in resilience. The findings of this report will assist local officials, residents, and design professionals as they continue the recovery process. The lessons learned and recommendations from the MAT can be incorporated into ongoing recovery efforts to improve the resilience of the built environment in the USVI and reduce future damages.

**Building Codes and Standards**: The USVI has a long history of adopting hazard-resistant building codes, with the adoption of the International Building Codes (I-Codes) starting in 2003, however; some gaps in adoption and implementation remain. Through meetings with local officials and code experts, the MAT observed that implementation of the local building code does not align with the requirements of the latest edition of the I-Codes. The MAT further observed that a lack of staffing resources and proper training hinders the implementation of the Territory's building codes and standards. Design plans—the blueprints used in building construction—were observed without technical notes or design criteria typically found on such documents for disaster-resistant buildings, which may have allowed buildings to be constructed without incorporating the latest hazard-resistant requirements found in the Territory's building code. The MAT recommends processes to coordinate policies, strengthen design procedures, and implement

systems of review and enforcement through increased staffing, additional training for code officials, and renewed enforcement of commonly observed oversights. It also recommends the creation of resources and facilitation to encourage the implementation of codes among contractors, as outlined further in the report.

**Residential Buildings**: The performance of residential buildings varied depending on their design, geographic location, and siting. Numerous buildings sustained catastrophic structural damage from wind; however, many more had primary structures that performed adequately but sustained damage to roof coverings, windows, and doors that allowed wind driven rain to infiltrate the building and contents. The widespread use of jalousie windows also allowed for water intrusion, as did roof penetrations for service-masts. The MAT specifically assessed a subset of buildings involved in the government-sponsored Home Protection Roofing Program implemented following Hurricane Marilyn. These roof systems performed well and sustained very little damage to their roof structures or coverings, though many still experienced water infiltration through jalousie windows and around door seals. Manufactured housing units performed poorly and many sustained near-total damage; these structures were neither designed nor installed in accordance with the proper specifications for high wind zones. Recommendations from the MAT include methods for managing water intrusion and improving roof performance, and developing a new wind retrofit program that builds off of these successes of the HPRP and incorporates broader mitigation for the building envelope.

**Schools, Hospitals, and Critical Facilities**: The MAT observed significant wind and water damage to schools, hospitals, and critical facilities in the USVI, many of which resulted in limitations to their emergency operations or sheltering functions during the storms. Following the storms, many schools and hospitals remained partially or completely out of service due to the damage. The MAT observed numerous instances where inadequate anchoring of rooftop equipment turned such systems into debris, resulting in gaps or punctures in the roof coverings. Mechanical penthouses, especially those housing equipment of critical facilities, where elevator and building system controls are located also exhibited failures due to wind effects and water intrusion. These failures often resulted in damages which disrupted support operations, including patient conveyance in hospitals. The MAT observed that many of the school, hospital, and critical facility roofs were poorly maintained or past their useful design life. Vulnerability assessments of roof coverings and rooftop equipment are recommended as a part of the recovery process to identify areas of weakness and needed replacement. If a new or replacement roof is required, the MAT recommends that roof coverings for critical facilities should be designed to resist high winds in accordance with the most current design standards. A regular rooftop maintenance program is recommended to help identify and address weaknesses as they develop.

**Storm Shelters**: The MAT observed that there are no public safe rooms designed to FEMA P-361 or ICC 500<sup>©</sup> designed storm shelters. Many of the buildings currently used in the USVI as refuge areas have not been evaluated by design professionals using a consistent methodology to determine their level of hazard vulnerability. The MAT recommends that ICC-rated shelters be required in select circumstances and that the USVI develop a "best available refuge area" program to evaluate existing buildings using licensed design professionals. It is recommended that the USVI promote the construction of in-residence shelters through the development of guidance for permitting and formal outreach to residents.

**Solar Panel Systems**: Several large, ground-mounted solar panel systems in the USVI sustained heavy damage that hindered the full return of electrical utility service to the islands. Some of these arrays provide a significant portion of the overall energy production in the USVI, so the damage forced a greater reliance on fuel imports and daily fuel shipments. Overall performance of these systems was highly variable

based on their designs and siting; though some suffered catastrophic and near-total damage, others were minimally affected. Currently, there are no recommended design loads specific to ground-mounted solar panel systems in U.S. or international design standards. The MAT recommends that new and appropriate design standards be developed and referenced in the I-Codes and the USVI Building Code.

**Topographic Effects on Wind Speed**: An overarching observation was that building designs regularly did not factor in the effects of wind speed-up due to the topography of the islands. The MAT recommends that DPNR should work with the Legislature to incorporate revised basic wind speed maps for the USVI that consider topographic effects as an option for determining wind pressures on buildings. To assist the local building community, the MAT recommends the USVI and FEMA provide guidance to design professionals on how to use the new maps and consider the higher wind speed criteria. The MAT also recommends that revised basic wind speed maps for the USVI should be proposed for inclusion in the next edition of ASCE 7.

# HURRICANES IRMA AND MARIA IN THE U.S. VIRGIN ISLANDS

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# HURRICANES IRMA AND MARIA IN THE U.S. VIRGIN ISLANDS

# Introduction

The Federal Emergency Management Agency (FEMA), through the Building Science Branch of FEMA's Federal Insurance and Mitigation Administration (FIMA), deployed a Mitigation Assessment Team (MAT) to the USVI to assess damage caused by Hurricanes Irma and Maria. This report presents the MAT's observations, and recommendations from the field assessments.

In September 2017, Hurricanes Irma and Maria significantly impacted the USVI only weeks apart. The effects resulting from one storm of this strength would be challenging enough; dealing with both, with their varying proximities across St. Thomas, St. Croix, and St. John, have been particularly trying for the islands and their inhabitants. In partnership with local officials, FEMA deployed supplies to the region, coordinated emergency relief services between and after the storms, and outlined frameworks to assist local communities in post-disaster rebuilding efforts.

A component of these efforts was the deployment of a MAT. This group, composed of national and regional building science and reconstruction Subject Matter Experts (SMEs), observed building performance across the islands and studied common construction practices to enhance recovery. The team identified trends in the primary causes of damage for select residential and non-residential buildings and building utility systems and assessed building failures and successes. Over the course of several trips to the Territory, the SMEs collected data, evaluated various building types across all three islands, and met with residents and local officials to better understand what transpired during the storms. The team also provided conclusions and recommendations for reducing building vulnerabilities and improving future building performance and resilience.

The results of the MAT are summarized in this report. The purpose of this report is two-fold; first, it provides guidance to communities, businesses, design professionals, local officials, residents, and other stakeholders to help encourage effective and efficient recovery in the short-term. Second, it provides a multitude of strategic recommendations to support codes and standards, design guidance, and other topics (see Chapter 8, Conclusions and Recommendations) that may benefit the long-term future resilience of not only the USVI, but other applicable areas of the U.S. Some of these recommendations address detailed practices, while others discuss the codes and standards to guide their implementation. The goal is to help outline a path forward and enable stakeholders to make changes according to local priorities. These recommendations can also be utilized by the USVI to help guide and better prepare communities, property owners, and other stakeholders for future storms and encourage their action with as much specificity as possible.

This MAT report includes a focus on several construction and development issues unique to the USVI that have not been addressed in previous MAT reports. Topics include:

- The effects of multiple storms with close but differing paths over a short period of time, particularly on building performance and water intrusion into damaged buildings
- The performance of roof improvements completed under the Home Protection Roofing Program (HPRP) following Hurricane Marilyn in 1995 as compared to roof improvements completed outside of the program
- The damage to rooftop and ground-mounted solar panels, also known as photovoltaic (PV) panels, from high winds, and the difference in performance of various array types and in different areas of the USVI
- Wind speed-up due to significant topographic effects and its impact on building performance in the USVI
- The adoption and implementation of building codes and standards unique to the flood, wind, and topography challenges of the USVI

### 1.1 Organization of the Report

This report is divided into chapters according to the building type and specialized set of issues addressed, as follows:

**Chapter 1:** Summarizes the timeline and characteristics of Hurricanes Irma and Maria, the history of select previous storms and mitigation efforts for the USVI, and overall building performance.

**Chapter 2:** Describes the USVI regulatory codes and standards and their implementation, various FEMA documents applicable to the mitigation process, safe rooms/storm shelter standards, and the details of the National Flood Insurance Program (NFIP).

**Chapter 3:** Covers the performance of single- and multi-family residential buildings, including a discussion of sites that participated in the HPRP.

**Chapter 4:** Addresses school performance, particularly with respect to wind and wind-driven rain.

**Chapter 5:** Assesses hospital building performance and the limitations to hospital building operations following the storms.

**Chapter 6:** Focuses on other critical facilities such as fire stations and airports and their unique building performance attributes.

**Chapter 7:** Discusses the performance of both rooftop and ground-mounted solar panels, with a focus on residential buildings and large solar arrays.

**Chapter 8:** Presents conclusions and recommendations for future mitigation, preparedness, and various stakeholder efforts, and discusses preliminary areas for further study.

The following appendices are included for additional information:

Appendix A: Acknowledgements

Appendix B: Bibliography

Appendix C: Acronyms

Appendix D: Recovery Advisories for Hurricanes Irma and Maria in the USVI (electronic only)

Appendix E: Basic Wind Speed Maps for the USVI

### **1.2 Overview of Recent Hurricanes**

This section provides an overview of Hurricanes Irma and Maria in the USVI as well as a history of select storm impacts to the USVI.

### 1.2.1 Hurricane Irma

Hurricane Irma originated as a tropical storm on August 30, 2017 off the west coast of Africa, approximately 420 miles west of the Cape Verde Islands. Over the course of the following week, the storm progressed westward across the Atlantic Ocean to the Caribbean just east of the Leeward Islands. By September 5, Irma had grown into a NOAA-rated Category 5 Hurricane. On September 6, Hurricane Irma passed near the USVI as a Category 5 storm, with a minimum pressure of 920 millibars (mb) (NOAA 2017a). Rainfall across the islands was estimated to be 4-10 inches from September 6-9, 2017 (NOAA 2017a).

Irma's path cut through the northern portion of the three islands; the eye of the storm tracked through the British Virgin Islands, northeast of St. Thomas and St. John. Both St. Thomas and St. John were significantly impacted by high winds. At the time of landfall in the USVI, hurricane force winds extended outward up to 50 miles from the eye, with tropical storm force winds extending up to 185 miles (NOAA 2017a). Estimated wind gusts reached approximately 150-160 miles per hour (mph) in St. Thomas and St. John. These speeds were determined from initial modeling using surface level observations and observed storm pressures (3-second gust at 33 feet for flat, open terrain [ARA 2018]). NOAA National Ocean Service (NOS) gauges measured 1.45 feet of storm surge above normal astronomical tide levels in Charlotte Amelie, St. Thomas, and 1.62 feet in Lameshur Bay, St. John (Cangialosi, Latto, & Berg 2018). Actual storm surge maximums

are unknown, as the NOS tide gauge at Charlotte Amelie did not remain functional during the storm and other gauges were not indicative of the most prone surge areas. Despite the possibility of high surge, the MAT post-storm assessment did not observe any high-water marks or notable storm surge damage. This was likely due to the steep nature of the surrounding continental shelf and the inland location of many buildings.

Impacts in St. Croix were significantly less due to its southern location and the path of the storm. Although St. Croix was not hit directly by Irma, it still experienced high winds and significant rainfall. As with the other two islands, notable effects from surge were not observed. At the time the storm passed by, a NOS gauge measured a storm surge of 2.28 feet above normal astronomical tide levels in Christiansted Harbor, St. Croix (Cangialosi, Latto, & Berg 2018). The mountainous northern side of St. Croix is sparsely populated, which, combined with the lower speeds and surge, resulted in less damage to St. Croix in general than the other islands. Figure 1-1 shows the wind swaths of Hurricane Irma as it passed by the USVI and Puerto Rico.



Figure 1-1: Wind swaths of Hurricane Irma as it passed by the USVI and Puerto Rico from August 30, 2017 to September 7, 2017. (Source: NOAA, 2018c).

### 1.2.2 Hurricane Maria

Hurricane Maria originated as a tropical storm on September 16, approximately 620 miles east of the Lesser Antilles in the Caribbean. The storm intensified quickly over the next several days and was upgraded to a Category 1 hurricane on September 17. By September 19, Maria had tracked northwest towards St. Croix and become a Category 5 storm. The storm maintained its strength as it passed by St. Croix on September 20. The estimated minimum central pressure at that time in St. Croix was 909 mb, the tenth lowest pressure ever recorded for an Atlantic Basin hurricane (NOAA 2017b). From September 20 to September 22, 2017, rainfall across the islands ranged from 8-12 inches (ARA 2018; NOAA 2017b). Figure 1-2 shows the wind swaths of Hurricane Maria as it passed by the USVI and Puerto Rico.



Figure 1-2: Wind swaths of Hurricane Maria as it passed by the USVI and Puerto Rico from September 16-21, 2017. (Source: NOAA, 2018b).

Maria's path cut south of Irma's. The eye of the storm passed approximately 20 miles southwest of St. Croix, directly affecting areas that were spared the worst impacts of Irma two weeks earlier. This quick succession of storms posed logistical challenges beyond the immediate and significant impacts of the storm. Following Hurricane Irma, relief agencies had staged their operations and gathered supplies on St. Croix. These operations were in the immediate path of Maria and had to be relocated or protected in place to ensure the reliability of ongoing and impending recovery efforts. Figure 1-3 shows the paths of the eyes of Hurricanes Irma and Maria in proximity to all three islands.



Figure 1-3: Paths of the eyes of Hurricanes Irma and Maria. Hurricane Irma passed by the USVI on September 6, 2017; Hurricane Maria passed by on September 20, 2017. (Source: NOAA, 2018a).

Winds were generally strongest along the western and southern portions of St. Croix, where the storm passed by the closest. Estimated wind gusts up to 140 mph were determined from initial modeling of surface level observations and observed storm pressures (3-second gust at 33 feet for flat, open terrain, [ARA 2018]). NOS gauges measured a storm surge of 2.85 feet above normal astronomical tide levels at Lime Tree Bay, St. Croix, though this gauge went offline for a period and may not have recorded peak height (Pasch, Penny, & Berg, 2018). Surge values likely varied substantially across the island because of the storm's location, local topography, and shoreline geometry. Despite potential surge, no notable surge damage was observed by the MAT. As with the previous storm, this was likely due to the relatively steep surrounding continental shelf.

Much as with Irma, the islands further from the storm experienced more limited impacts. Hurricane-force winds extended outward 60 miles from the eye of the storm, with tropical-storm-force winds extending up to 150 miles. This meant that St. Thomas and St. John, already in the midst of recovering from Hurricane Irma, experienced moderate wind speeds and substantial rainfall volumes. NOS gauges measured a storm surge of 1.48 feet above normal astronomical tide levels at Lameshur Bay, St. John (Pasch, Penny, & Berg 2018). Table 1-1 provides a qualitative overview of the relative impacts of Hurricanes Irma and Maria on the three islands, as well as those of previous major hurricanes Hugo and Marilyn (as further discussed in

Section 1.3.1 and Section 1.3.2). Significant rainfall events also affected the USVI in the month following the storm. Rainfall values of over an inch each were recorded on October 1, 9, 11, and 27, 2017, in St. Croix (NOAA, 2018b). These events further affected damaged buildings that had yet to be suitably repaired. The fact that such events were a further hinderance and possible source of additional damage was considered in the MAT evaluation process.

### **1.3 History of Previous Major Hurricanes**

Hurricanes Irma and Maria were the strongest hurricanes to strike the USVI since Hurricane Marilyn in 1995. According to the National Academy of Sciences (NRC 1994), other notable hurricanes that struck the USVI in the last century include the West Indian or San Felipe hurricane (1928), Hurricane San Ciprian (1932), Hurricane Santa Clara (1956), Hurricane Donna (1960), Hurricane Frederic (1979), Hurricane David (1979) and Hurricane Hugo (1989). Table 1-1 summarizes the history of damage intensities from recent major hurricanes across the three islands. Sections 1.3.1 and 1.3.2 provide a synopsis of Hurricanes Hugo and Marilyn.

Storm	St. Thomas	St. John	St. Croix
Hugo (1989)	Minor	Minor	Severe Widespread
Marilyn (1995)	Severe Widespread	Minor	Minor
Irma (2017)	Moderate Widespread	Moderate Widespread	Minor
Maria (2017)	Rain	Rain	Severe Widespread

### Table 1-1. History of Recent Damage Intensities

Note: Hurricane Irma had stronger winds than Hurricane Marilyn, but damage was not as widespread due to changes in codes and mitigation post-Marilyn, which is discussed further in this report.

### 1.3.1 Hurricane Hugo (1989)

The following Hurricane Hugo synopsis is based primarily on a report of impacts to the islands compiled by the National Research Council (NRC) of the National Academy of Sciences (NRC 1994):

**Wind Speeds:** Not a single verifiable record of surface wind speed was made in the USVI. Verifiable anemometer records were obtained in Puerto Rico, at the San Juan International Airport and the Roosevelt Roads Naval Station. Consequently, probable maximum sustained speeds and gusts for surface winds in the USVI had to be estimated from the aircraft reconnaissance winds taken, for the most part, at 10,000 feet and from the post-disaster study team's aerial and surface damage surveys.

**St. Croix:** The probable maximum wind speed was 135 mph (peak gust, Exposure C, at 33 feet above grade). The corresponding mean recurrence interval (MRI) is 300 years. The strongest winds came from the northeast and caused the heaviest damage along the north coast from the Salt River eastward to the end of the island. Damage in this area was remarkably uniform and was likely made more intense by the local terrain, which slopes steeply upward to a central east-west ridge running the length of the island. This same ridge provided some shielding for buildings located on its south (leeward) slope.

**St. Thomas:** The probable maximum wind speed was 105 mph. The corresponding MRI is 40 years. Damage on St. Thomas was not as widespread as on St. Croix; however, the terrain is substantially rougher

than that on St. Croix and much of the building damage appeared to be the result of terrain effects such as channeling and local flow acceleration due to ridges.

**Flooding:** Storm-surge levels were modest, as was expected because of the very narrow and steep shelf surrounding the Puerto Rico-Virgin Islands Platform, even with strong hurricanes. Intense precipitation fell for approximately 12 hours but did not approach record values.

**Damage:** Single-family homes suffered the greatest proportion of severe damage. There was widespread loss of roof structures on St. Croix. Many homes were built without regard to existing code requirements. Most importantly, extensive damage was observed to "do-it-yourself" types of wood construction. There were heavy losses of corrugated metal roofs, windows, and doors. Several school buildings were damaged.

Hurricane Hugo damaged approximately 85 percent of the housing stock on St. Croix (FEMA, 1996). Soon after Hugo, FEMA identified the need for adoption of an enhanced residential building code. However, an enhanced residential code was not adopted until six years later, after Hurricane Marilyn in 1995.

Federal Aviation Administration (FAA) facilities at the St. Croix airport were heavily damaged and most of the aircraft guidance equipment had to be replaced. The control tower lost all its cab windows and much of the instrumentation and communications equipment suffered water damage. Although the airport was open to light aircraft almost immediately after the passage of Hurricane Hugo, it was 6 days before a temporary air traffic control tower was operational. Military navigation and communications equipment was used in the interim. By March 1990, the terminal building and control tower were back to normal service.

At the St. Thomas airport, damage to FAA facilities was much lighter and limited air traffic control service was restored within 24 hours. The control tower lost some cab windows, likely because of wind-blown gravel from a parking lot on a nearby hill. There was additional wind and water damage to antenna structures, signal and power cables, and control tower instruments. Damage to the terminal building was superficial.

The electrical distribution lines were particularly hard hit, with damage being caused by wind or windblown debris. The telephone system was heavily damaged and limited service to businesses did not become available until December. On St. Croix, telephone service for many residences was not restored until mid-1990.

Serious water shortages were experienced on St. Croix. On the west side of Christiansted, a fuel oil tank ruptured, causing the nearby water distillation facility to shut down. The Kings Hill water storage tank, which supplied most of the island's potable water, was rendered out of service. Because of heavy demand for drinking water in preparation for Hugo, it was not possible to maintain a high-water level at the storage tank, thus making the steel tank highly vulnerable to wind damage. The near-complete disruption of water service forced residents of St. Croix to use home cisterns that had not been used for several years until the tank could be restored some time later.

**Building Code:** At the time of Hurricane Hugo, the 1972 edition of the USVI Building Code was applicable. It specified a lateral wind load of 25 pounds per square foot (psf) for buildings up to 30 feet high, 35 psf for 31-50 feet, and 45 psf for heights greater than 50 feet. The basic wind speed implied by the Code

corresponded to a 15-year MRI. This speed was exceeded during Hurricane Hugo on St. Croix and St. Thomas.

For public buildings, the 1988 edition of the *International Conference of Building Officials Uniform Building Code* (ICBO UBC 1988) was adopted in 1989 by Executive Order No. 313-1989 (FEMA 1996).

### 1.3.2 Hurricane Marilyn (1995)

The following synopsis is based on National Institute of Standards and Technology (NIST) and NOAA reports published in the aftermath of Marilyn, as well as direct observations from FEMA.

**Wind Speeds:** Unlike Hurricane Hugo, a few verifiable anemometer records were obtained in the USVI. Adjustments were made to convert the data to standard conditions (Exposure C, at 33 feet above grade). The anemometer data were combined with aircraft flight data from the NOAA Hurricane Research Division. Over open water, the maximum sustained winds were approximately 89 mph at St. Croix, and 102 mph at St. Thomas (these speeds equate to 98 and 112 mph gust, Exposure C).

Wind speed-up associated with abrupt changes in topography was discussed. The NIST report notes that the speed-up effect increases with increasing hill height and steepness of slope, and that it reaches a maximum speed at the crest and decreases with height above ground and distance from the crest (NIST 1997). Wind damage was heaviest on St. Thomas. The damage was attributed to poor building practices and inadequate code enforcement rather than to excessively high winds (NIST, 1997). There was significant, widespread damage of residences, commercial buildings, and critical facilities on St. Thomas, with nearly 75 percent of all buildings damaged. Approximately 21,000 homes were damaged or destroyed; 5,800 utility poles were damaged; the desalinization plant on St. Thomas was rendered inoperative; and repair of two sewage treatment plants was required (NOAA 1996). Damage occurred on St. Croix and St. John, but to a much lesser extent.

The most common type of damage was blow-off of the roof structure and/or roof covering. The tops of some large petroleum storage tanks near the St. Thomas airport were blown off. The air traffic control radar located on Klok Hill was blown off its tower (NOAA 1996). Other examples of Hurricane Marilyn damage are referenced in Chapters 3-5 of this MAT report.

**Flooding:** Most areas on St. Croix had a storm surge of 5-6 feet, but one location on the north coast had a surge of 11.7 feet. Rainfall of almost 12 inches was measured at Annaly, St. Croix. Storm surge on St. Thomas was 6-7 feet. Rainfall reports were as much as 10 inches, but few gauges survived the storm. It is likely that there were greater amounts in some areas (NOAA 1996).

**Building Code:** Although the 1988 UBC was adopted by Executive Order in 1989 for public buildings, most of the buildings struck by Hurricane Marilyn were constructed prior to that adoption. The 1988 UBC had very few provisions related to wind resistance of roof coverings.

In October 1995, the 1994 UBC (ICBO UBC 1994) was adopted by statute for public and non-public buildings, except for one- and two- family buildings (Act No. 6087, Bill No. 21-0138). The statute also adopted the 1995 edition of the *Council of American Building Officials (CABO) One and Two-Family Dwelling Code* (CABO 1995) for one- and two-family buildings and townhouses not more than three stories high.

### 1.3.3 Previous FEMA Mitigation in the USVI

Soon after Hurricane Marilyn struck the USVI in 1995, a team composed of FEMA headquarters technical staff and consultants from the Hazard Mitigation Technical Assistance Program (HMTAP) contractor deployed to St. Thomas. Their initial task was to evaluate the performance of residential and non-residential buildings. Initial observations revealed that inadequate roof assemblies, including structural and non-structural elements, were a primary contributor to most building failures. A sub-team was subsequently tasked with evaluating critical facilities on all three islands and making mitigation recommendations. The large-scale failure of residential roof assemblies became the focus of hazard mitigation efforts.

The following is a synopsis of the primary mitigation activities:

**Critical Facilities:** The roof assemblies on all the public schools on all three islands, the St. Croix and St. Thomas hospitals, the St. Croix Clinic, the St. Croix Emergency Operations Center, and the St. Thomas airport terminal were assessed. For each facility, the type of roof assembly and the type and cause of damage were identified. Recommendations for repair or replacement were made, including enhancements intended to avoid or minimize future wind damage.

**Prescriptive Details for Residential Construction:** FEMA and the HMTAP contractor worked with the USVI Department of Planning and Natural Resources (DPNR) to develop prescriptive details and load tables. The third edition of *Construction Information for a Stronger Home* (USVI DPNR 1996) also referred to as the *Stronger Home Guide*, was published in February 1996. See Section 2.3 for further information. See Section 3.3 for performance of homes constructed in accordance with that publication during Hurricanes Irma and Maria.

**Home Protection Roofing Program (HPRP):** A request from the Governor resulted in FEMA providing technical assistance and funding to address unrepaired roofs damaged by Hurricane Marilyn. See Section 3.2 for performance of homes repaired under the HPRP during Hurricanes Irma and Maria.

**Support to DPNR:** FEMA and the HMTAP contractor worked with DPNR to have the 1994 UBC and the 1995 *CABO One and Two-Family Dwelling Code* adopted, as discussed in Section 1.3.2. FEMA and the HMTAP contractor also provided support to DPNR, as further discussed in *Evaluation of Residential Mitigation Strategies, Hurricane Marilyn in the US Virgin Islands, DR 1067-VI* (FEMA 1996).

### **1.4 FEMA Mitigation Assessment Team**

FEMA conducts building performance studies after unique or nationally significant disasters to better understand how natural and manmade events affect the built environment. A MAT is deployed only when FEMA believes the findings and recommendations derived from field observations will provide design and construction guidance that will improve the disaster resistance of the built environment in the affected State, Territory, or region and will be of national significance to other disaster-prone regions. FEMA bases its decision to deploy a MAT on preliminary information such as:

- Magnitude of the expected hazards
- Preliminary type and severity of damage in the affected areas

- Pre-storm site conditions, such as the presence of older housing stock and aging infrastructure
- Preliminary value of study results to the rebuilding effort
- Strategic lessons that can be learned and applied, potentially on a national level, related to improving building codes, standards, and industry guidance
- Possibility that the field assessment will reveal pertinent information regarding the effectiveness
  of (1) certain FEMA grants and (2) key engineering principles and practices that FEMA promotes
  in published guidance and best practices documents

The MAT studies the adequacy of current building codes, local construction requirements, practices, and materials considering the damage observed after a disaster. In the context of Hurricanes Irma and Maria in the USVI, the MAT also compared this damage and observed practices with previous mitigation efforts, notably in this case after Hurricane Marilyn in 1995. Lessons learned from the MAT's observations are communicated through Recovery Advisories and a comprehensive MAT report available to communities to aid their rebuilding effort and enhance the disaster resistance of building improvements and new construction.

### 1.4.1 USVI Irma and Maria MAT Composition

The USVI Irma and Maria MAT involved an array of specialized experts, including input or consultation from the following groups:

- FEMA Headquarters and Regional Office engineers and experts
- International Code Council, Inc. (ICC<sup>©</sup>) representatives
- Construction and building code industry experts
- Design professionals
- Home builders
- FEMA specialists who joined the USVI Joint Field Office (JFO)

Team members included structural and civil engineers; architects; floodplain management, building code, wind design experts, critical facilities experts; and FEMA specialists with a detailed understanding of the official response, recovery, and policy processes. The individual members of the MAT are listed in the front of this document.

The USVI Irma and Maria MAT was divided into six main study areas:

- Building codes, standards, and regulations
- Residential buildings
- Schools

- Hospitals
- Critical facilities
- Solar panels

Each study area included visits to several affected locations in St. Thomas, St. John, and St. Croix to assess the performance of specific building and facility types. Additional consideration is given in the report to the effects of wind speed-up due to the unique and significant topography of the USVI. These impacts were considered by the team working throughout the six main areas of study.

### 1.4.2 Involvement of State and Local Agencies

FEMA encouraged the participation of Territory officials and locally-based experts in the assessment process. Their involvement was critical and resulted in:

- Improvement of the MAT's understanding of local construction practices
- Development of recommendations that were both economically and technically feasible for the communities and stakeholders involved
- Facilitation of communication among Federal and Territory governments, as well as the private sector
- Improvement of the Territory's coordination with the MAT's observations, conclusions, and recommendations to assist them with effecting change in their communities

The MAT met with local emergency management and government officials in many of the locations it visited. These officials gave an overview of the damage in their communities and helped to identify key sites that were not initially considered for the study. Their participation was critical to understanding local processes, as well as to obtaining practical information in a post-disaster context. The MAT also coordinated with the FEMA JFO that was set up in the Territory shortly after Hurricane Irma.

### 1.4.3 Site Selection

To establish the scope of the MAT, FEMA deployed a Pre-MAT to the islands from October 18 to October 21, 2017, four weeks after Hurricane Maria passed by the USVI. The Pre-MAT is a small, nimble, advanced team of experienced members that gather information to help develop the overall strategy and locations for the visit by the larger team in the future. When the team arrived in St. Thomas, they met with the FEMA Region II staff to review the specific damage locations of interest and plan their initial visits. The team then traveled throughout St. Thomas to review residential, hospital, school, and critical facility performance before splitting into two smaller teams to evaluate the other islands. One sub-team assessed residential and communications facility performance on St. John, while the other looked at residential and power system performance on St. Croix. After the Pre-MAT visit, the team provided a debrief to FEMA and created a list of sites deemed valuable for further assessment by investigation during the full MAT visit.

Damage observations from the Pre-MAT were supplemented by the MAT's review of aerial imagery taken immediately after the storms by the U.S. Civil Air Patrol. These images provided insight into damage levels in hard to access areas and confirmed damage trends across the islands. The FEMA Region II JFO, Territory agencies, and MAT members used this information to augment the inspection list developed during the Pre-MAT visit.

A key focus of the residential assessment was to evaluate the performance of roofs previously constructed under the HPRP. The MAT wanted to determine if these building components performed adequately, and if so, if they performed better than other examples on the island. The addresses of the homes in the program were available to FEMA and mapped by members of the MAT to determine their geographic scope. A sampling of these residences on each island was identified and included as a priority for assessment.

### 1.4.4 Building Types Selected by the MAT

The buildings selected by the MAT for damage assessment included: single family and multi-family residential buildings, schools, hospitals, fire stations, airports, and rooftop and ground-mounted solar panel systems. The buildings evaluated were in both coastal and riverine floodplains, as well as in more urbanized portions of the islands.

### 1.4.5 Field Deployment

A pre-MAT trip had a team spending 3 days in the field in October. FEMA deployed three MAT sub-teams to the USVI on November 26, 2017. Each sub-team focused on a particular geographic area or topic and was comprised of two to three engineers or specialists, including an architect on one of the teams. The three teams that evaluated sites assessed the entire breadth of building types included in the MAT on their island(s). Their work was divided as follows:

- 1. St. Thomas and St. John Sub-team: Evaluated sites on both islands, including residential buildings, schools, fire stations, and associated solar panel systems.
- 2. St. Croix Sub-team: Evaluated sites throughout the island, including residential buildings, schools, airport facilities, and associated solar panel systems.
- 3. Building Code and Processes Sub-team: Met with local officials and specialists involved with the building codes, floodplain ordinances, and other policies governing local development and construction across all three islands.

In many cases, additional or alternate sites were added as MAT sub-teams gained information on conditions or concerns in the field. When possible, building or facility owners were interviewed to gain insight into how their buildings and/or facilities withstood the storms and how recovery efforts were progressing. The three sub-teams were deployed concurrently to maximize efficiency and provide a holistic debrief of observations, preliminary conclusions, and potential recommendations to the FEMA JFO. These observations, conclusions, and recommendations were useful to help inform the immediate recovery operation and are expanded upon in this MAT report.
## 1.5 Summary of Observations

This section provides an overview of the MAT observations regarding building performance and flood and wind impacts from Hurricanes Irma and Maria in the USVI.

#### 1.5.1 Summary of Building Performance

Damage to an array of building and construction types occurred with the high winds generated by backto-back hurricanes. The reasons why some buildings experienced limited damage and others had near catastrophic failure speak to the heart of the MAT's mission. Some of these factors were purely locational, issues such as topography and proximity to the strongest winds, while others were closely tied to design (including choices of material) and/or construction workmanship. Experts from the MAT evaluated a wide variety of building categories, including residential, schools, critical facilities, and associated solar panel systems, to parse out various trends in building performance. This helped determine which targeted mitigation improvements could have the most meaningful future impacts. The following sections summarize the observed outcomes.

#### 1.5.1.1 Residential

Many homes on St. John and St. Thomas lost roof coverings, such as corrugated metal roofing panels. Some experienced more significant damage as roof sheathing and roof rafters were blown off. Much of the damage was influenced by wind speed-up associated with abrupt changes in topography. Roof failures were observed throughout the islands, often due to inadequate attachment of steel roof framing, as shown in Figure 1-4.



Figure 1-4: Inadequate attachment of steel roof framing led to metal panel roof loss failure in Anna's Retreat on St. Thomas.

Although many residences did not experience building envelop breaches, they often still had wind-driven rain infiltration at windows and doors.

Many homes constructed or repaired in accordance with the HPRP and the Construction Information for a Stronger Home, 3rd ed., displayed good performance with minimal damage to cladding components from wind forces and wind-borne debris. Liquid applied membrane roofs demonstrated excellent performance. Another common roof covering was metal panels. These exhibited good performance when properly attached and utilizing a continuous load path similar to the recommendations of HPRP and the *Construction Information for a Stronger Home*.

Manufactured home performance was observed in St. Croix. Poor performance of these buildings was notable, including failures of exterior wall coverings, roof coverings, roof decking, and unprotected openings due to wind forces and/or wind-borne debris.

#### 1.5.1.2 Schools

The observed schools were built using a range of construction techniques common from the early 1960's to post-Hurricane-Marilyn in 1995. Older construction techniques and deteriorated materials triggered wind failures of roof structures, further resulting in interior damage from water intrusion. The schools often had rooftop equipment which was not adequately secured, exacerbating the roof failures. Roof systems spanning longer distances found in gyms and auditoriums generally performed poorly (Figure 1-5). Damage was consistently observed for other ancillary school buildings such as temporary portable classrooms and older pre-engineered metal building systems. Inadequate site drainage led to additional damage from localized flooding at schools.



Figure 1-5: This auditorium experienced failure of the metal roof system. Classroom buildings experienced water intrusion from aged roof members. Groundwater intrusion was an issue in classrooms from inadequate site drainage. St. Thomas.

#### 1.5.1.3 Hospitals

Two major hospitals (Schneider Regional Medical Center on St. Thomas and Governor Juan Luis Hospital & Medical Center on St. Croix) and a healthcare center (Myrah Keating Smith Community Health Center on St. John) were visited by the team. These comprise all the major medical facilities in the USVI. Water infiltration resulting from inadequate roof systems was observed at each of the hospitals. Most hospital windows survived the hurricanes with few impact-related failures, as impact-resistant glazing or hurricane screens were utilized for protection. The health center on St. John experienced significant water intrusion, leading to the unit closing on the day the team arrived. Some of the critical operational capabilities of the hospitals were impaired during the storms, including one hospital that suffered from a failing sanitary and sewer system and loss of vertical conveyance (elevator). As an observation of positive performance, the Juan Luis Hospital and Schneider Regional Medical Center maintained power throughout the event.

#### 1.5.1.4 Critical Facilities

Many fire stations suffered extensive damage from Hurricanes Irma and Maria. Damage to some fire stations on St. Thomas and St. Croix was severe enough to prohibit ongoing operations. High winds and/ or wind-borne debris caused sectional door failure, broken windows, and roof covering damage. The breaches created in the building envelopes created opportunities for water to infiltrate into the interior of the buildings, resulting in loss of communications, flooding, and interior damage (Figure 1-6).

The St. Croix airport terminals exhibited broken skylights, poorly-secured rooftop equipment, and roof coverings that did not perform adequately. Water infiltration occurred around radio equipment at the air traffic control tower on St. Croix. Water intrusion occurred due in part to poor anchorage and sealing around the equipment. Cyril E. King Airport on St. Thomas experienced heavy water intrusion as wind-borne debris punctured the roof membrane in numerous locations and high winds blew off metal roof panels. Much of the wind-borne debris was inadequately anchored rooftop equipment.



Figure 1-6: Captain Robert O'Connor, Sr. Fire Station displaying significant roof covering damage on St. John.

#### 1.5.1.5 Solar Panels

Many ground-mounted and rooftop solar panels, also known as photovoltaic (PV) panels, were observed during the MAT assessment. Some solar panel arrays were not damaged, while others experienced catastrophic damage (Figure 1-7). A portion of the damage was caused by solar panels becoming detached, while other damage was caused by wind-borne debris (much of which was blown off solar panels).

#### 1.5.2 Flood Zones

The USVI have areas with high exposure to flooding, with approximately 1,300 flood insurance policies in force as of January 31, 2018 for an estimated population of 100,000 people. The islands are subject to storm surge from hurricanes and severe storms, but there was little damage associated with storm surge from Hurricanes Irma and Maria. Much of the damage from flooding was created by localized ponding and water runoff. The USVI MAT observed many locations in which low-lying areas experienced flooding because of ponding water that lacked sufficient drainage to transport water away from buildings after

heavy rainfall. Given the limited amount of drainage infrastructure, water runoff is often conveyed from higher elevations to lower elevations via roadways, which serve as de facto channels for water flow in heavy rainfall events. Many residents of the USVI experienced water infiltration into homes after water spilled over roadways and onto residential property. Unlike most identified flooding from riverine or coastal sources, flooding from stormwater runoff is currently not shown on Flood Insurance Rate Maps (FIRMs). Although not mapped on FIRMs, this condition can still create significant flood hazards for buildings.

The Flood Insurance Study (FIS) for the USVI warns that flood waters have inundated large areas of St. Croix in and around Christiansted in the past, causing landslides (also known as landslips) and major damage. The MAT noticed a substantial number of places on the steep slopes of the three islands where flood water activated such landslides.





## 1.5.3 Wind Speed Observations

Hurricane Irma reached the USVI on September 7, 2017 bringing wind gusts of approximately 150-160 mph on St. Thomas and St. John. The wind gust map (Figure 1-8) shows the track of Hurricane Irma and demonstrates the pervasive high wind speeds experienced throughout St. Thomas and St. John during the storm. Soon after, the outer eyewall of Hurricane Maria crossed St. Croix on September 16, 2017 and brought wind gusts of 137 mph at the Sandy Point National Wildlife Refuge on the southwest corner of St. Croix (NOAA 2017). Preliminary wind maps generated by ARA show the most severe wind speeds associated with Hurricane Maria striking the southwest corner of St. Croix, with wind speeds diminishing to the east of the island, and significantly lower wind speeds on St. Thomas and St. Croix (Figure 1-9).



Figure 1-8: Preliminary Wind Gust Map, showing the tracking of Hurricane Irma along the blue line. (Source: ARA, 2018).



Figure 1-9: Preliminary Wind Gust, showing the tracking of Hurricane Maria along the blue line. (Source: ARA, 2018)

# HURRICANES IRMA AND MARIA IN THE U.S. VIRGIN ISLANDS

# Building Codes and Standards, NFIP Regulations, and USVI Construction Guidance

A combination of local floodplain management regulations and building codes determine the requirements that govern construction in the USVI.

## 2.1 USVI Building Code

After the unprecedented damage of Hurricane Marilyn in 1995, the USVI government, with the support of FEMA, developed and implemented a new building code. Several years later, FEMA supported DPNR in the crafting of the USVI Building Code (29 U.S. Virgin Islands Code, Chapter 5), which referenced the 2003 International Code Council series of codes (I-Codes) with amendments that were specific to the Territory. These included but were not limited to requirements for cisterns, island-specific referenced standards, and other local conditions. The code attempted to improve commercial and residential building performance through hazard-resistant construction and therefore minimize or prevent wind-borne debris generated by the failure of damaged structures during storms. The legislative adoption of the 2003 I-Codes in the USVI Building Code required the use of anchoring systems, hurricane-resistant metal connectors, and shutters on some buildings. In addition to the new requirements instituted by the building code, the USVI government and FEMA provided extensive training and outreach to the design community, homeowners, contractors, and inspectors on the new requirements and mitigation strategies. (FEMA 2007). The USVI Department of Buildings, a unit within the DPNR, enforces the building and electrical codes, zoning resolutions, and other laws. Further, it is the agency responsible for enforcement of code-compliant building construction, including those within the Special Flood Hazard Area (SFHA). In 2016, the Department of Buildings performed 859 plan examinations, issued 821 construction permits, issued 84 violations, and performed 1,019 inspections throughout the Territory. New construction, repair, or alteration of individual buildings in the Territory is within the jurisdiction of the Department of Buildings, which is also responsible for ensuring the Territory meets or exceeds the minimum standards of the NFIP. Examining all development plans, including within the SFHA; issuing or denying development and building permits; conducting construction inspections; and retaining records are among the many functions the Department of Buildings

#### **2018 INTERNATIONAL BUILDING CODES**

Major differences to the 2018 I-Codes (from previous editions) are listed below. These are changes to ASCE 7-16 that have been incorporated by reference into the 2018 I-Codes:

- Roof component and cladding pressure coefficients for buildings with gable and hip roofs and mean roof heights equal to or less than 60 feet have been revised. The net effect is increased wind pressures for most of the roof configurations. In some cases, the increases are significant (more than double).
- Wind load criteria for rooftop solar panel systems have been added.

performs to ensure the USVI remains compliant with the NFIP and local ordinances. Currently, all building code and regulation enforcement is conducted by the Division of Building Permits within the Department of Buildings. The Division of Building Permits conducts additional tasks which include:

- Verifying contractor licenses and reviewing all construction plans and building designs
- Issuing permits and assessing permit application
- Conducting construction site inspections
- Monitoring/overseeing current building codes and newly proposed codes and regulations
- Educating contractors and the public about current territorial building codes (USVI DPNR, 2005)

The Department of Buildings currently adopts and enforces the 2018 I-Codes. Through the DPNR Commissioner's interpretation of the USVI Building Code, the Territory regularly adopts the latest model building codes created by the International Code Council. The USVI Building Code states the following in *Title 29 Virgin Islands Code, Chapter 5, Section 292:* 

(f) Public Buildings. The 2003 International Building Code and any subsequent amendments thereto, are hereby adopted and incorporated by reference in the Virgin Islands Building Code, and notwithstanding the provisions of any other law, shall be applicable to every public building and structure in the Virgin Islands pursuant to subsection (b) of this section. (2018 Office of the Code Revisor, 2018).

(h) One and Two-Family Dwellings and One Family Townhouses not more than three stories in height. Chapters one through forty-three, and all appendices cited therein of the International Residential Code, 2003 edition, and any subsequent amendments thereto, are hereby adopted

and incorporated by reference in the Virgin Islands Building Code, and notwithstanding the provisions of any other law, shall be applicable to every one and two family dwelling and one family townhouse not more than three stories in the Virgin Islands pursuant to subsection (b) of this section. (2018 Office of the Code Revisor, 2018).

(k) Applicability of the 2003 International Energy Conservation Code. Notwithstanding any law to the contrary, the 2003 International Energy Conservation Code and any subsequent amendments thereto are adopted and incorporated by reference as a part of the Virgin Islands Building Code, title 29 Virgin Islands Code, chapter 5, and shall be applicable to every public, commercial and residential building, or structure in the Virgin Islands.

In addition, the USVI Building Code states in *Title 29 Virgin Islands Code, Chapter 5, Section 311*:

(e) Mechanical Refrigeration. All refrigeration installations shall conform to the requirements of the International Mechanical Code, 2003 edition and any subsequent amendments thereto.

The phrases "and any subsequent amendments thereto" have been interpreted by the Commissioner of DPNR to include the amendment/update of the model codes by the International Code Council, which takes place on a three-year cycle. As a result, the Department of Buildings automatically adopts the latest published I-Codes six months after the initial published date.

The adoption of the 2018 IBC© and 2018 IRC© includes reference to ASCE 7-16, the most recent edition of ASCE 7. These codes and standards enforce ultimate wind speeds of 150-180 mph depending on the Risk Category. ASCE 7-16 provides an increase in roof pressure coefficients resulting in much higher roof cladding pressures in hurricane-prone regions than would be calculated with previous ASCE 7 editions. In addition to these higher standards, structures in the USVI may experience wind speed-up effects at hills, ridges, and escarpments which produce significantly higher wind speeds. The wind speed-up from topographic effects can produce wind pressures of twice the base design wind speed values.

## 2.2 National Flood Insurance Program

The authorizing legislation for the NFIP is the National Flood Insurance Act of 1968, as amended (42 U.S. Code 4001 et seq.). In the Act, the U.S. Congress found that "a program of flood insurance can promote the public interest by encouraging sound land use by minimizing exposure of property to flood losses." Since 1968, the Act has been modified several times.

The NFIP is based on the premise that the Federal Government will make flood insurance available to communities that adopt and enforce floodplain management requirements that meet or exceed the minimum NFIP requirements.

The regulations of the NFIP are the basis for local floodplain management ordinances adopted to satisfy the requirements for participation in the NFIP. In addition, the NFIP minimum requirements are the basis for the flood-resistant design and construction requirements in model building codes and standards. When decisions result in development within flood hazard areas, application of NFIP criteria is intended to minimize exposure to floods and flood-related damage.

The most convincing evidence of the effectiveness of the NFIP minimum requirements is found in flood insurance claim payment statistics. Buildings that predate the NFIP requirements are generally not constructed to resist flood damage, while buildings that post-date the NFIP are designed to resist flood damage.

The NFIP aggregate loss data show that buildings that meet the minimum requirements experience 80 percent less flood damage than buildings that predate the NFIP. Ample evidence suggests that buildings designed to standards that exceed the minimum requirements are even less likely to sustain damage.

NFIP performance requirements for development in SFHAs are set forth in Federal regulations at 44 CFR Parts 59 and 60. The requirements apply to all types of development proposed in SFHAs. The NFIP broadly defines the term development, and the requirements apply to new development, new buildings and structures, Substantial Improvement of existing buildings and structures, and repair of existing buildings and structures that sustain Substantial Damage (refer to the text boxes on Development and Substantial Damage/Substantial Improvement).

#### **DESCRIPTION OF FLOOD ZONES**

**V** Zones. The portion of the SFHA that extends from offshore to the inland limit of a primary frontal dune along an open coast, and any other area subject to high-velocity wave action (3 feet or higher) from storms or seismic sources. The Flood Insurance Rate Maps (FIRMs) use VE Zones to designate these Coastal High Hazard Areas.

**A Zones.** The portion of the SFHA not mapped as a V Zone. Although FIRMs depict A Zones in both riverine and coastal floodplains (as Zones A, AE, and AO), the flood hazards and flood forces acting on buildings in those different floodplains can be quite different. In coastal areas, Zone A is subject to wave heights less than 3 feet and wave run-up depths less than 3 feet.

**Coastal A Zones.** Though not shown on FIRMs, Coastal A Zones are referenced in ASCE 24-14 and ASCE 7-16. This is an area within the SFHA, landward of a V Zone, where flood forces are not as severe as in V Zones but are still capable of damaging or destroying buildings on shallow foundations. Coastal A Zones are areas where breaking wave heights are between 1.5 and 3 feet during base flood conditions.

AO Zones. Areas of shallow flooding, with depths between 1 and 3 feet in a 100-year flood.

AH Zones. Shallow flooding SFHA.

**A99 Zones.** An area inundated by 100-year flooding, for which no BFEs have been determined. This is an area to be protected from the 100-year flood by a Federal flood protection system under construction for which 100 percent of the costs are obligated and at least 50 percent of the construction is complete.

**Zones X, B and C.** These zones identify areas outside of the SFHA. Zone B and shaded Zone X identify areas subject to inundation by the flood that has a 0.2 percent probability of being equaled or exceeded in any given year. This flood is often referred to as the 500-year flood. Zone C and unshaded Zone X identify areas above the level of the 500-year flood of unknown flood risk. The NFIP has no minimum design and construction requirements for buildings in Zones X, B and C.

For a listing of NFIP flood zone designations, refer to 44 CFR 59.1.

For an explanation of zone designations, refer to the FIRM for your community.

The NFIP provisions guide development to lower-risk areas by requiring compliance with performance measures to minimize exposure of new buildings and buildings that undergo major renovation or expansion (called Substantial Improvement or repair of Substantial Damage). Taken together, administration of NFIP-consistent requirements helps achieve the long-term objective of building flood-resistant communities.

The NFIP was founded on the principle that in addition to disaster-resistant building codes, effective management of floodplain development at the local level leads to avoidance and minimization of future flood damage. DPNR anticipates a significant increase in repair/reconstruction and development within hazardous areas in the USVI over the next 12-60 months as Hurricanes Irma and Maria disaster recovery funds are allocated.

The current FIRMs for the USVI have an effective date of 2007. FEMA is scheduled to publish Advisory Base Flood Elevation (ABFE) maps and data by the fall of 2018; these include riverine analyses, storm-induced coastal erosion data, water surface elevation grids, depth grids, and critical facility flood risk summaries that can be used to support rebuilding efforts. One flood hazard aspect that should be addressed in future FIRM updates is the depiction of the Limit of Moderate Wave Action (LiMWA), which is not shown on the current 2007 maps. The LiMWA determines the landward limit of Coastal A Zones. Coastal A Zones carry minimum requirements that are higher and stronger than the minimum requirements of the NFIP.

The FIRMs produced by FEMA identify areas of varying flood hazard as flood zones. Zones A and V comprise special areas known as the SFHAs. These are zones expected to be inundated by a flood event with a 1 percent probability of being equaled or exceeded in any given year. This flood is also referred to as the base flood or 100-year flood. A description of the different regulatory flood zones is provided in the sidebar. The current FIRMs for the USVI reference revised maps and data effective April 16, 2007.

Hurricane Irma caused minor coastal flooding; however coastal erosion and riverine flooding were significant in St. Thomas and St. John. Hurricane Maria also caused minor coastal flooding and significant, coastal erosion in St. Croix. In addition, there were areas within the current effective 1-percent and 0.2-percent-annual-chance floodplains that did not receive significant storm surge but experienced wind damage. In the aftermath of these disasters, updated risk information has been and will continue to be vital in order to inform rebuilding efforts. FEMA has developed the ABFE data and other products for the USVI to increase resilience and reduce vulnerabilities within the islands. Data and products include the following:

- Riverine Advisory data, including hydrologic analyses and hydraulic analyses
- Coastal Advisory data, including storm-induced coastal erosion
- Mapping products, including 1-percent and 0.2-percent-annual-chance floodplain mapping and water surface elevation grids and depth grids
- Supporting Advisory products, including map change products and critical facility flood risk summaries

## 2.3 Construction Information for a Stronger Home

The USVI and FEMA developed *Construction Information for a Stronger Home* (the *Stronger Home Guide*) to support natural hazards-resilient home construction in the USVI. The first edition of this document was published following Hurricane Marilyn and the second in December 1995. The third edition was published in February 1996. The fourth edition (USVI DPNR, 2018) continues to advance residential construction mitigation measures and resilience techniques (Figure 2-1). This edition uses the latest advances in building code development by referencing the 2018 IRC©, 2018 IBC©, and ASCE/SEI 7-16. The previous edition was based upon the 1995 CABO One and Two-Family Dwelling Code and the 1994 UBC.





The *Stronger Home Guide* serves as general guidance for residential construction and does not satisfy all the building design requirements. Homes must meet the additional parameters stated below.

All design work covered by the *Stronger Home Guide* shall be designed by a registered design professional, such as a registered professional engineer or licensed architect in the USVI. When the *Stronger Home Guide* drawings are used for a project, they should be modified as needed in order to comply with all applicable code requirements for a given project site, then signed and sealed in accordance with USVI law, building code, and DPNR requirements. Signed and sealed drawings for permit must be submitted to DPNR, Division of Building Permits, including drawings prepared using the *Stronger Home Guide*.

The public has the option to design homes without using the *Stronger Home Guide*. If a building owner chooses not to follow the prescriptive design measures shown in the fourth edition of the *Stronger Home Guide*, a performance-based design which meets or exceeds code requirements should be completed by a registered engineer or architect licensed in the USVI, and permit drawings should be submitted to DPNR, Division of Building Permits.

The following site conditions and assumptions must be met to use the fourth edition of the Stronger Home Guide. The Stronger Home Guide is not valid if the project parameters are outside of these assumed sites and building geometric conditions:

- Mean roof height of 30 feet or less
- Gable or hip roofs with slopes ranging from 2:12 to 12:12 pitch
- Roof overhang at each side of the building cannot exceed 2 feet
- Building width of 24 feet to 40 feet
- Building length of 40 feet to 52 feet
- Maximum story heights of 11 feet 6 inches
- Building located in the following topographic conditions:
  - Exposure B with no abrupt changes in general topography as defined in ASCE 7-16
  - Exposure D with no abrupt changes in the general topography as defined in ASCE 7-16
  - Exposure B with topographic effects caused by abrupt changes in topography as defined in ASCE 7-16, constructed on the upper one-half of a hill, ridge, or escarpment, or near the crest of an escarpment
- Building is roughly rectangular with relative uniform distribution of shear resistance throughout the structure
- Building having no significant structural discontinuities

The fourth edition of the *Stronger Home Guide* has significant changes because of the incorporation of the latest building code design requirements. These revisions include but are not limited to higher ultimate design wind speed criteria, higher wind roof pressures for components and cladding because of higher pressure coefficients, wind topographic effects that include wind speed-up, considerations for seismic design as stipulated in ASCE 7-16, and current references to the latest structural wood connectors. This guide also includes an expanded general notes section and additional typical details. An updated appendix with tables and references is provided at the end of the document with designs in accordance with the latest codes (2018 IBC© and ASCE 7-16).

The appendix to the fourth edition of the *Stronger Home Guide* presents the limiting spans for structural lumber: studs, roof rafters, floor beams, floor joists, and hip and valley beams. For each lumber size, the limiting spans determined are the longest spans possible while satisfying the requirements of the 2018 IRC©. The design values for the different species of lumber are based on the design values in the 2018 American Wood Council (AWC) National Design Specification (NDS) for Wood Construction (AWC 2018a) and its Supplement (AWC 2018b).

The wind loads are determined in accordance with the envelope procedure presented in ASCE 7-16. The Basic Wind Speed is 165 mph (based on Figure 26.5-1B of ASCE 7-16 for the Virgin Islands) and is used to determine the provisions of this guidance. The wind directionality factor  $K_d$  is taken as 0.85 (as per Table 26.6-1 of ASCE 7-16). The ground elevation factor  $K_e$  is taken as 1.0. The gust-effect factor is taken as 0.85 (based on Section 26.11.1 for a rigid building).

Key significant changes in the fourth edition are as follows:

- Multiple wind exposure and topographic effects are considered:
  - Exposure B with  $K_{zt} = 1.0$
  - Exposure B with  $K_{zt} = 2.0$
  - Exposure D with  $K_{zt} = 1.0$
- Higher components and cladding loads agree with ASCE 7-16 provisions.
- Southern Yellow Pine values are the latest design values, which were recently reduced to account for the reduction in strength that has been observed in fast-growth cultivated timber.
- More sizes of lumber are analyzed than typical on the U.S. mainland, allowing for more customization specific to loads encountered on the islands.
- The rafter, roof beam, and wall stud spans are typically 10 to 15 percent shorter than previous equivalents.
- Higher ultimate wind speed criteria are used in accordance with ASCE 7-16 compared to the third edition, which used allowable stress design wind speeds.
- Enclosure classification covers both enclosed and partially open buildings.
- Rafter spacing is limited to 24 inches on center (o.c.) maximum.
- Metal roof panels have a minimum 24-gauge thickness.
- Two-story structures in exposure B with K<sub>zt</sub> = 2.0 are recommended to be reinforced masonry walls or reinforced concrete walls, and not constructed using wood walls.
- Masonry walls should use 8-inch Concrete Masonry Units (CMU) blocks, reinforced with #5 vertical bars at 24 inches o.c. in grouted CMU cells.

## 2.4 Current Efforts with the USVI Building Code

After Hurricanes Irma and Maria, FEMA supported the update of the USVI Building Code. The efforts focused on the integration of Territory-specific amendments into the USVI Building Code. As of March 1, 2018, the Territory adopted the 2018 International Code Council (ICC©) series of codes.

FEMA supported the USVI DPNR Building Department by initiating mutual aid requests for ICC© Certified building professionals through the Emergency Management Assistance Compact (EMAC) system. The request was intended to provide the initial staffing for the first six months after the disasters to assist with the influx of permits received during reconstruction. The period of support started in February 2018 and will last until September 2018. Through the utilization of EMAC, more than 10 personnel, comprised of building inspectors, plan reviewers, and permit technicians, could assist in post-disaster code enforcement efforts. This is the first time building professionals have been deployed through EMAC, with

personnel deployed from Maryland, Arizona, Minnesota, Georgia, and Massachusetts. Reimbursement for personnel was made possible through Advanced Assistance for the Hazard Mitigation Grant Program (HMGP). FEMA supported the Territory in drafting and submitting a grant application through the HMGP to fund the "Post Irma/Maria Code Enforcement Unit," which is consistent with the goal of enhancing the understanding of natural hazards and risks to the Territory. The HMGP grant was awarded and aligned with six principal goals:

- Implement mitigation programs that protect critical facilities and services enhancing the reliability of lifeline systems by minimizing natural hazard impacts
- Adopt and enforce public policies to minimize hazard impacts on structures
- Integrate new hazard and risk information into building codes and land use planning mechanisms
- Promote appropriate mitigation actions for all public and privately-owned property within the Territory
- Promote hazard-resistant construction, especially for residential structures
- Provide training to design professionals and those within the construction industry on hazardresistant construction

The grant provides support over six years to create a Building and Floodplain Enforcement Unit. This group will ensure that the building stock under repair and new construction complies with the NFIP and the 2018 I-Codes. DPNR will use the funds to increase capacity by creating a fully-staffed cadre of building code plan examiners, inspectors, and officials. In addition, a new electronic permitting system will be provided, with training for the staff, which will improve code enforcement efforts in the Territory. It is expected that the unit will examine plans and provide inspections throughout the Territory for the thousands of permit applications expected to be received in coming years.

## 2.5 Safe Rooms and Storm Shelters

Safe rooms and storm shelters are hardened structures designed to provide life-safety protection for people during high wind events such as hurricanes and tornadoes. In an island territory such as the USVI where evacuation may be difficult or impossible without adequate warning, safe rooms and storm shelters are important for life-safety protection during high wind events.

Design and construction criteria for safe rooms and storm shelters are provided in ICC 500©, Standard for the Design and Construction of Storm Shelters (ICC 500© 2014), which has been referenced by the IBC© since the 2009 edition. While this does not trigger a requirement to install hurricane storm shelters (unlike some areas of the United States in which this does trigger a requirement for tornado storm shelters), it does ensure the design and construction criteria in ICC 500© must be followed should any storm shelter be built in a community that has adopted the 2009 IBC© or later.

Although they are similar, there are differences between safe rooms and storm shelters. A safe room complies with the recommended guidance in FEMA P-361, *Safe Rooms for Tornadoes and Hurricanes:* 

Guidance for Community and Residential Safe Rooms. Storm shelters are buildings, or portions thereof, that comply with ICC 500©. All safe room criteria in FEMA P-361 meet the ICC 500© criteria, but FEMA P-361 includes recommended guidance that is more conservative than that in ICC 500©, such as elevation and siting with respect to flood hazards and using the 250-mph design wind speed for all residential tornado safe rooms regardless of their location.

Traditional buildings are designed to withstand a certain wind speed (the "design wind speed") based on historic wind speeds documented for different geographic areas. The design wind speed determines the wind pressure the structure is designed to withstand. The required design wind speed presented in ASCE 7-16 for most coastal areas ranges from 110 mph to 200 mph. The design wind speeds for new buildings in the USVI range from 165 mph to 180 mph, depending upon building use and risk category.

In contrast, design wind speeds for safe rooms and storm shelters in hurricane-prone regions in the 2018 IBC© are 190-235 mph along the Atlantic Coast and 200-250 mph for the Gulf Coast. Because wind pressures acting on buildings increase in proportion to the square of the design wind speed, structural systems of a safe room or storm shelter are designed for wind pressures from two to three times higher than those used for typical building construction (depending upon the year of design and construction). Structures designed to these higher wind pressures provide much greater resistance to wind loads that prevent damage or collapse from wind forces experienced during hurricanes.

Besides having a higher design wind speed, a safe room or storm shelter must also be resistant to wind-borne debris impacts as tested per ICC 500<sup>©</sup> depending on the design wind speed and any site-specific lay down and collapse hazards as

#### SAFE ROOMS AND STORM SHELTERS IN THE USVI

The MAT was not made aware of and did not observe any storm shelters or safe rooms that were constructed on the islands to meet the ICC 500© or FEMA P-361 criteria, respectively.

#### SAFE ROOMS AND STORM SHELTERS

FEMA defines "safe rooms" as buildings or portions thereof that comply with the criteria described in *Safe Rooms for Tornadoes and Hurricanes: Guidance for Community and Residential Safe Rooms*, 3rd Edition (FEMA P-361, 2015) for the purpose of providing near-absolute life safety protection from extreme wind events. The ICC© defines "storm shelters" as buildings or portions thereof that comply with the ICC© and *National Storm Shelter Association (NSSA) ICC©/ NSSA Standard for the Design and Construction of Storm Shelters* (ICC 500©, 2014). All safe room criteria in FEMA P-361 meet or exceed the storm shelter requirements of ICC 500©.

#### **RESIDENTIAL SAFE ROOMS**

FEMA provides prescriptive safe room plans that comply with the criteria of FEMA P-361 and ICC© 500 in *Taking Shelter from the Storm: Building a Safe Room for Your Home or Small Business* (FEMA P-320, 2014). These plans are primary intended for residential safe room use but can be used for small community safe rooms if the community safe room requirements are also met.

determined by the registered design professional. Flood and seismic hazards should also be considered when siting, designing, and constructing safe rooms and storm shelters. Consequently, the structural systems and envelope (building exterior) of a safe room or storm shelter, as well as the connections between the building elements, are very robust.

When communities and jurisdictions develop plans for hurricane community safe rooms, designers should consider other hazard-specific constraints that may be governed by local requirements that affect the movement of at-risk populations. For some communities, when there is sufficient warning time, a large proportion of the population could be expected to leave the area of anticipated immediate impact and seek shelter outside the at-risk area. For other communities, this is not the case.

ICC 500<sup>©</sup> and FEMA 361 provide the design and construction criteria for storm shelters and safe rooms, respectively. However, neither document requires the construction of purpose-built structures for life-safety protection from wind events. Currently, the IBC© has a requirement for some new buildings to include an ICC 500© storm shelter in tornado-prone regions of the country where the tornado hazard design wind speed is 250 mph (3-second gust) or greater. This information is presented in Sections 423.3 and 423.4 for specific building uses identified within Risk Category IV and selected buildings under the Category E occupancy designation. Several states and local jurisdictions also have requirements for the design and construction of storm shelters in tornadoprone regions of the country. Florida is the only hurricaneprone state that has a shelter

#### **ICC© 500 DESIGN WIND SPEEDS**

ICC© 500-14 provides design wind speeds for tornado and hurricane shelters in Figures 304.2(1) and 304.2(2), respectively. The design wind speed for a tornado shelter in the USVI is 200 mph and the design wind speed for a hurricane shelter in the USVI is 190 mph, per ICC 500©.

#### FEMA SAFE ROOM RESOURCES

For information on FEMA safe room guidance and programs, see the FEMA Safe Room Resources webpage at:

#### https://www.fema.gov/safe-rooms

The following resources provide guidance and useful information for municipalities and entities considering a safe room:

 FEMA. 2015. Safe Rooms for Tornadoes and Hurricanes: Guidance for Community and Residential Safe Rooms, 3rd Edition. FEMA P-361. Washington, DC.

https://www.fema.gov/media-library/assets/documents/3140

International Code Council and National Storm Shelter Association. 2014. ICC©/NSSA Standard for the Design and Construction of Storm Shelters. ICC© 500.

https://codes.iccsafe.org/public/document/ICC5002014

 FEMA. 2014. Taking Shelter from the Storm: Building a Safe Room for Your Home or Small Business, 4th Edition. FEMA P-320. Washington, DC.

https://www.fema.gov/media-library/assets/documents/2009

 FEMA. 2015. Safe Room Resources CD. FEMA P-388. Washington, DC.

https://www.fema.gov/media-library/assets/documents/23315

program with triggers that require some new facilities to include hurricane storm shelters (through the Enhanced Hurricane Protection Area provisions of the Florida building code).

Communities and states on the U.S. mainland that have populations exposed to hurricane risks are responsible for making determinations related to community evacuations, sheltering at-risk populations, and providing recovery shelters or refuge areas for individuals that may not be able to evacuate during a hurricane. FEMA and ICC© have worked together to develop the design criteria for these special-use buildings (or portions of buildings). The state and local government entities who are responsible for building code adoption and enforcement, emergency management and planning, and the management and maintenance of public buildings will need to work together to determine if current approaches meet the evacuating and sheltering needs of the communities they support.

## 2.6 Topography

Topography directly affects the wind flow around objects, and wind speed is known to increase in areas where hills, mountains, ridges, and escarpments exist, as shown in Figure 2-2. This wind speed-up can cause damage to buildings and other structures if they were not designed to consider these increased winds. When designing buildings, topographic effects near mountainous areas are accounted for through the topographic and directionality factor, and effective wind speeds in various design calculations. Per the I-Codes, ASCE 7, and the USVI Building Code, the basic design wind speeds near mountainous terrains shall be in accordance with local jurisdiction requirements.

The local jurisdictions have the option of determining the wind speeds in accordance with Chapter 26 of ASCE 7 or through a wind speed-up model, if one has been developed for their region. Prior to the 2017 hurricane season, only one island state or territory, Hawaii, had wind speed maps that included wind speed-up effects. The maps developed for Hawaii allow design professionals, along with the building officials evaluating design submittals for construction and repair permits, to check a map with wind speed contours that include the effects of wind speed-up. This also allows design professionals to use the ASCE 7 design processes without complicated wind speed-up calculations. Since a wind speed-up model had not been applied in the USVI, design professionals and building officials in the Territory had to rely on the challenging and complicated procedure provided in ASCE 7 to determine the local effects of wind speed-up for residential construction and renovation.

In response to Hurricanes Irma and Maria, FEMA has undertaken an effort to support the USVI in developing a set of wind speed-up maps. These maps were prepared as part of the MAT effort and are presented in Appendix E (Figure E-1 shows wind speed-up for St. Thomas, Figure E-2 shows wind speed-up for St. Croix and Figure E-3 shows wind speed-up for St. John). The wind speed-up maps can be evaluated by the USVI and DPNR to determine if they should be incorporated into the USVI Building Code. The maps could replace the basic wind speed maps and design wind speeds identified in ASCE 7 or be allowed for use as an alternative to using ASCE 7 with its own wind speed-up procedures.

The wind speed-up maps developed for St. Thomas, St. John, and St. Croix aid in the understanding of how topographic effects may increase the wind speed in areas of higher elevation, such as the mountainous areas of St. Thomas. When this speed-up occurs during a hurricane or tropical storm event, the wind speeds can increase by more than 20 percent resulting in a significant increase in the wind pressures acting on the surfaces of buildings. If these higher loads are not considered in the design and construction of a building, partial or total failure of the building may occur, as seen in Figure 2-3. This can help design professionals better account for the local conditions resulting from the USVI's unique topography.



Figure 2-2: Effects on vegetation due to wind speed due to topography.



Figure 2-3: Wind speed-up was not considered in the original roof design and likely resulted in the loss of this metal roof covering in St. Thomas.

## HURRICANES IRMA AND MARIA IN THE U.S. VIRGIN ISLANDS

# Wind Performance of Single and Multi-Family Residential Buildings

Residential building performance and roof system performance varied greatly, however, post-Marilyn roof systems built to recommended standards performed well.

Section 3.1 provides information regarding the performance of residential construction prior to and during Hurricane Marilyn (1995). The rest of the chapter provides a synopsis of MAT observations on St. Croix, St. John, and St. Thomas. Section 3.2 provides information on performance after the 2017 hurricanes. Section 3.3 provides information on the HPRP and performance of houses that were repaired under that program.

The MAT did not observe residences that were exposed to coastal or riverine flooding; however, some of the observed residences did experience water infiltration from stormwater flow.

## 3.1 Residential Wind Performance During Hurricane Marilyn

This section is based on observations of the FEMA HMTAP team that deployed to the USVI after Hurricane Marilyn. At the time of Hurricane Marilyn, a few houses had wood-framed load-bearing walls, which typically experienced significant roof and wall assembly damage. Most of the houses had concrete or CMU exterior load-bearing walls (which typically performed very well) and a roof assembly comprised of corrugated metal panels typically attached to 2x4 nailers over textured plywood panels (finish side exposed to the rooms below) over wood joist or beams. The metal panel and the 2x4 nailers were typically nailed instead of screwed, and many of the beams/joists had weak connections to the bearing walls.

The roof system typically did not incorporate underlayment. In lieu of glazed openings, most houses had metal jalousies.

There was widespread roof failure on St. Thomas during Hurricane Marilyn. Typical failure planes were metal roof panels detaching from the nailers or nailers detaching from the beams/joists. In some cases, the beams/joists detached. Figure 3-1 illustrates typical construction and represents common performance of houses on St. Thomas.



Figure 3-1: Typical residential construction and wind performance during Hurricane Marilyn (1995). The red arrow indicates a corrugated metal roof panel, the blue arrow indicates a nailer, the puple arrow indicates textured plywood, the yellow indicates a beam, and the orange arrow indicates a metal jalousie.

Figure 3-2 shows one of the few houses on St. Thomas that did not experience metal roof panel blow-off. One of the panels was punctured by wind-borne debris, which illustrates the importance of incorporating an underlayment for secondary protection against rain infiltration. The good performance of the roof panels was attributed to the following: 1) the panels were attached with screws rather than nails, 2) two rows of panel screws were installed near the eaves and 3) two rows of screws were installed on each side of the ridge flashing (Figure 3-3).



Figure 3-2: Successful metal roof covering performance, attributed to use of screws to attach the corrugated panels and enhanced attachment at eaves and the ridge.



Figure 3-3: View of the ridge flashing at the house shown in Figure 3-2. The red line indicates the flashing center line. Two rows of the screws installed on each side of the flashing, shown in red circles.

In 1995, a few houses had a roof assembly composed of a liquid-applied membrane on plywood attached to joists or beams. These assemblies offered excellent performance when the plywood and joists/beams were adequately attached and not breached by wind-borne debris. Figure 3-4 shows a house that appears to have a batten seam metal roof, however, it actually had a liquid-applied membrane on plywood. The wood battens were simply added for aesthetics. A smaller number of houses had a liquid-applied membrane on steep-slope or low-slope concrete; these also typically provided excellent performance (this type of system was also used on other building types, including schools).

At the time of Hurricane Marilyn, most homes had external gutters. In many instances, rainwater from the roof was drained into cisterns. External gutters were typically blown off on St. Thomas, which resulted in uncontrolled rain runoff from the eave and exacerbated the potential for water entry at doors and windows. Also, when gutters blew off, cistern recharging was impaired or interrupted. A few of the houses had integral gutters (Figures 3-4 and 3-5). The integral gutters were constructed with up-turned wood framing to create a dam at the eave, which was drained by outlet tubes and downspouts to the cistern. No wind-damaged integral gutters were observed.



Figure 3-4: Liquid-applied membrane on plywood, with wood battens to simulate a batten seam metal roof. The red arrow indicates the integral wood gutter.



Figure 3-5: Corrugated metal roof panels with an integral wood gutter are shown at the red arrow.

The FEMA HMTAP observations helped inform recommendations for residential repairs and reconstruction after Hurricane Marilyn. Key findings were that excellent wind performance could be achieved with integral gutters, corrugated metal panel roof assemblies, and liquid-applied membrane assemblies when adequately designed, constructed, and maintained. These findings provided the basis for the residential roof designs provided in *Construction Information for a Stronger Home* (Section 2.3) and the Home Protection Roofing Program (Section 3.3).

Implementation of the lessons learned from Hurricane Marilyn is illustrated by the St. Thomas house that is shown in Figures 3-6 and 3-7. It was reported that a metal roof on this house was damaged by Hurricane Hugo in 1989. That roof was replaced by exposed-fastener R-panels<sup>1</sup>, which were blown off during Hurricane Marilyn (Figure 3-6). Figure 3-7 shows the house in August 1996. Rather than reroofing with metal panels, a liquid-applied membrane over plywood was being installed (this is one of the roof system types in the *Stronger Home Guide*). At the time the photo was taken, special treatment at the plywood joints and screws had been applied.



Figure 3-6: View of metal roof panel damage after Hurricane Marilyn. See Figure 3-7 for a view during roof reconstruction.

<sup>1</sup> An R- panel is generic metal roof panel with a specific role. R-panels are attached with exposed fasteners.



Figure 3-7: Roof reconstruction at the house shown in Figure 3-6. The red arrows indicate special treatment at plywood joints and screws.

## 3.2 Residential Wind and Wind-Driven Rain Performance During the 2017 Hurricanes

This section addresses non-HPRP residential construction. Wind performance was highly variable, with some houses experiencing significant structural damage (Figure 3-8), while others had no apparent damage to the structure or building envelope. In large part, this variability was a function of whether the residence was designed and constructed in general compliance with the building code requirements that were implemented after Hurricane Marilyn.

The St. Thomas residence shown in Figure 3-8 was observed after the 2017 hurricanes. It was indicative of pre-Hurricane Marilyn construction. Although Hurricane Marilyn caused widespread residential damage on St. Thomas, there were weak houses that were not damaged because they were shielded by other buildings or topography. This may have been one of the pre-Marilyn houses that was undamaged, or it may have been damaged and the roof rebuilt prior to the implementation of the post-Marilyn code changes, using pre-Marilyn construction practices. The residence in Figure 3-8 is in stark contrast to the nearby house shown in Figure 3-9, which appeared to be constructed in general compliance with the *Stronger Home Guide*.



Figure 3-8: View of damage caused by the 2017 hurricanes. The roof assembly is indicative of pre-Hurricane Marilyn construction. St. Thomas.



Figure 3-9: View of a residence with a liquidapplied membrane roof and integral gutters. It was near the residence shown in Figure 3-8.

Observations on the three islands are given in the following sections: St. Croix in Section 3.2.1, St. John in Section 3.2.2, and St. Thomas in Section 3.2.3.

## 3.2.1 St. Croix

Many residences observed by the MAT were designed to the criteria of the HPRP. These buildings provided an important comparison to determine the success of the program and were examples of wider building trends across the islands. There were three main types of buildings studied on St. Croix, each with varying levels of performance to wind and wind-driven rain. The non-HPRP examples included partially prefabricated concrete structures, typical of the large Sion Farm neighborhood in the center of the island; traditional CMU buildings with wood-framed roofs; and high-performance homes, including a kit-based wood-framed home set on reinforced concrete foundations being built on the southeastern end of the island. The high-performance kit home was comprised of assemblies and components fabricated in North Carolina and brought to the home site in shipping containers. These components were then assembled on cast-in-place foundations by a licensed contractor according to specified guidelines. It was designed to resist Category 5 hurricane wind speeds and was still under construction at the time of the hurricanes and MAT. The following describes the relative observed performance of these three typologies of buildings.

#### 3.2.1.1 Roof Systems

The Sion Farm neighborhood was comprised of partially modular buildings constructed out of pre-cast concrete wall and roof panels. As Figure 3-10 shows, the buildings appeared to have been assembled and finished on-site and are made from precast concrete subcomponents. These homes did not have additional roof coverings or coatings beyond the original finished concrete surface. The roofs performed relatively well despite this lack of coating. Some of the roofs experienced interior leaks at low points, where water pooled on the roofing surface; coatings and membrane systems are available that can prevent such leaks.



Figure 3-10: Two examples of partially modular buildings constructed out of pre-cast concrete wall and roof panels. These buildings and their concrete roofs performed very well in response to wind loads. Sion Farm neighborhood, St. Croix.

Many traditional homes with corrugated metal roofs lost large sections of the roof. For some, however, entire portions—structure and covering—were missing, suggesting that the high wind speeds separated the roofs at the ring beams. Sections where the roof structure remained appeared to have the metal paneling intact. This suggested that connections between the decking and the rafters were stronger than those between the rafters and beams themselves. The high-performance kit home on southeastern St. Croix had a treated wood roof deck with a liquid-applied waterproof coating. The building did not lose any roof panels nor experience any interior leaks through the roof surface. The roof experienced no visible wind damage.

#### 3.2.1.2 Roof Structure

The Sion Farm homes had flat roofs constructed of the same pre-cast reinforced concrete panels as the walls and foundation. These roofs performed very well and experienced no visible wind damage from the storm. As mentioned above, small leaks were occasionally discovered in places where the roofline sagged from settling and inadequate rooftop drainage. Figure 3-11 shows the typical area on the roof were this type of pooling developed.



Figure 3-11: Example of ponding at low-points on pre-cast concrete roofs where leaks developed. These buildings and their concrete roofs performed very well in response to wind loads. Sion Farm, St. Croix. Some traditional CMU homes suffered extensive damage, primarily from high winds. For one home, the side that faced into the peak hurricane winds lost most of its roof structure, as shown in Figure 3-12.

This wood-framed roof had toe-nailed connections between rafters and beams with no additional connections such as strapping, plates, or bolts. This home, like many using traditional island details, had a reinforced concrete ring beam at the top of the walls intended to provide additional connectivity and continuity between components. The purpose of this ring beam was to help distribute the loads between the roof and walls.



Figure 3-12: Examples of multiple structural failures at a CMU home with wood-framed roof. Losing the roof to uplift and outward pressure resulted in impacts to CMU masonry walls (top left), concrete ring beam (bottom left), and roof structure (top and bottom right). These buildings and their concrete roofs performed very well in response to wind loads. St. Croix.

The ring beam was supporting the lower ends of wooden rafters over an open covered patio facing south. These were the longest rafters on the home. During the storms, this concrete beam over the patio rotated along its long axis from loads applied lateral to the top edge of the beam by the rafters. This suggests that pressure was being exerted outward from inside and underneath the roof structure. The long spans and large patio overhang served to increase the pressure and forces that led to the failure of the roof and ring beam.

While the large open overhang contributed to the uplift loads, the MAT observed a lack of adequate steel reinforcement in the beam and walls. The construction plans that were on-site did not have load calculations for wind or seismic shown and were prepared by a draftsman, not a licensed architect or engineer. The USVI Building Code at the time allowed for draftsmen to create building plans as well as architects and engineers.

The high-performance kit structure was undamaged. The wood-framed roof structure was robustly constructed, with an array of closely-spaced reinforced trusses; straps, plates, and a reinforced ring beam; and additional strapping to ensure continuity of the load path. Connections where the roof met the ring

beam and the ring beam met the wall followed similar protocols of strapping and reinforcement. The underside of the roof of this building is shown in Figure 3-13.



Figure 3-13: Example of a high-performance kit home built on the southeastern coast of St. Croix. Wall panel sections and trusses were assembled on-site with plates, hurricane ties, and other types of bracing. Details of the outside (top left), 1st floor overhead trusses (top right), 2nd floor (bottom left), and 2nd floor roof framing, exhibit the quality and robustness of connections. Grapetree, St. Croix.

#### 3.2.1.3 Gutters, Fascia, and Cisterns

The Sion Farm homes did not have any gutters or fascia board in their designs. Many traditional CMU homes had gutters that were damaged by the wind or blown off when the roof coverings or structures failed. The MAT observed damaged gutters in areas where the roof remained intact, indicating that gutters often independently failed and required stronger attachments. While the MAT did not observe much damage to cisterns on-site, inadequate gutters would render any cistern collection system non-functional.

#### TERMINOLOGY

Continuous Load Paths – The structural condition required to resist loads acting on a building. The continuous load path starts at the point or surface where loads are applied, moves through the building, continues through the foundation, and terminates where the loads are transferred to the soils that support the building (FEMA P-55 Glossary).

The high-performance kit home's fascia board remained intact, though no gutters or water collection system were constructed at the time of the storm. The observed strength of the overall connections in the home, from the spacing to the number of nails used, extended to the eaves and reinforced the fascia board of the building.

#### 3.2.1.4 Doors and Windows

The Sion Farm and traditional CMU homes had many window types, including glass and metal jalousie and glazed pane windows. Figure 3-14 shows examples of these types of windows.

Some windows suffered damage from windborne debris. Figure 3-14 also shows an example of this kind of damage for a glass jalousie window. Water did seep around both metal and glass jalousie windows and door gaps causing minor interior water damage, including some damage to contents. The use of concrete walls and concrete floors limited the impact of such water intrusion as these materials are flood-damage-resistant. These surfaces are relatively waterproof and only need to be cleaned off after the storms to be returned to service. Occasionally, the MAT observed shutters on non-HPRP homes. In general, these remained attached to the structure and appeared to have protected the windows adequately. The high-performance kit home had pressure-rated glazed windows that remained in place and did not sustain any damages or leaks during the storm.



Figure 3-14: Examples of windows used on St. Croix: metal jalousie, glass jalousie, and glass casement and single-hung windows. A damaged glass jalousie window and undamaged pressure-rated windows (top right) on buildings. The lower picture had metal jalousies that remained unharmed while a green tarp indicated by the red arrow is covering damage to a separate glass jalousie window. La Grange, Grapetree, and Sion Farm, St. Croix.

#### 3.2.1.5 Wall Structures

The reinforced pre-cast wall panels of the Sion Farm homes did not sustain structural damage from the storm. These homes maintained their building envelopes and were strong enough to repel windborne debris. Other traditional CMU homes did sustain some wall damage, often at the top of walls near damaged rooflines. In one case, CMU blocks were pulled off with the roof structure. Adequate horizontal and vertical steel reinforcement was not evident, and the lack of reinforcement likely contributed to wall and roof connection failures upon exposure to storm-force wind loads.

The high-performance kit home had a combination of reinforced cast-in-place concrete walls and closelystudded wood-framed wall sections. When assembled on-site, this system performed well and was not damaged.

#### 3.2.1.6 Manufactured Housing

Manufactured housing is no longer allowed to be deployed in the USVI; however, manufactured housing is often repaired even when significant damage occurs. Historically, manufactured housing has performed poorly under hurricane-force wind loads, wind-driven rain, and wind-borne debris. During these storms there was similar poor performance. The MAT visited two neighborhoods on St. Croix after Hurricanes Irma and Maria containing manufactured homes. Several of the homes sustained severe damage and were effectively destroyed beyond repair. One such home lost roofing and siding, exposing the interior of the wall finish to heavy rains (Figure 3-15). The roof, siding, and wall sheathing were all blown off the home and many of the windows were broken by debris.



Figure 3-15: Manufactured home that lost roof covering, roof decking, siding, and wall cladding. St. Croix. Another home on St. Croix suffered damage extensive enough that finished interior walls were blown into the home. The home was missing siding, sheathing, roofing, windows, and interior finish walls, and the interior was inundated with wind-driven rain (Figure 3-16). Water was driven into the space for the floor framing and the floor insulation. This area had a covering that kept the insulation in place but also made removal and replacement of the water-logged insulation impractical. For these reasons, the damage to the home was beyond repair.



Figure 3-16: Manufactured home that lost roof covering, siding, and wall cladding. St. Croix.

#### 3.2.2 St. John

A limited number of residential observations were made on St. John. Figures 3-17 through 3-21 illustrate the range of observed performance. Time limitations precluded making detailed observations on St. John.



Figure 3-17: Home with roof sheathing blown off the upper roof. The wood-framed walls and roof of the lower portion collapsed.



Figure 3-18: Home with entire roof structure missing. The assembly was blown off during the storm.



Figure 3-19: Two porch overhangs blew off and caused progressive lifting of the corrugated metal roof panels on the adjacent main roof indicated by the yellow circles. The gutter was blown off where indicated by the red arrow. Several of the doors and windows were protected by traditional wood shutters.



Figure 3-20: This corrugated metal roof sustained no apparent damage, but portions of the gutters and several solar panels blew off.



Figure 3-21: There was no apparent damage to this residence. It had corrugated metal panels and an integral gutter.

## 3.2.3 St. Thomas

#### 3.2.3.1 Main Wind Force Resisting System

The observed houses that had Main Wind Force Resisting System (MWFRS) damage (e.g., Figure 3-22) appeared to be those that were constructed prior to Hurricane Marilyn, or if constructed post-Marilyn, did not comply with the post-Marilyn building code changes.



Figure 3-22: Collapsed home with wood-frame walls and roof in St. Thomas.

Figure 3-23 shows a house design that was typical of many homes constructed prior to Hurricane Marilyn. It has structural steel roof frames and light gage purlins. During Marilyn, the roof structure blew off of several of these houses. Roof structure blow-off was also observed at several similar houses after the 2017 hurricanes.



Figure 3-23: Blow-off of a steel roof structure.

## 3.2.3.2 Roof Systems

A variety of roof system types were observed (Figures 3-24 through 3-33). The most common types were corrugated metal panels and liquid-applied membranes. Systems that appeared to be constructed in accordance with the *Stronger Home Guide* generally performed well. The common exception was roofs with external gutters. This type of gutter design was frequently blown-off in high winds during the storms.



Figure 3-24: A corrugated metal panel roof with integral gutter that appeared to comply with the *Stronger Home Guide.* 



Figure 3-25: This residence appears to have a batten seam metal panel; however it is a liquid-applied membrane over plywood with wood battens. This roof system and integral gutter appeared to comply with the *Stronger Home Guide*.



Figure 3-26: This residence appears to have a tile roof; however, it has metal panels formed to simulate tile. The panels were attached with exposed fasteners. There was no apparent damage.

Figure 3-27 shows a house that has a metal R-panel roof. All the panels and the ridge flashing stayed in place; however, there was substantial water infiltration. Wind-driven rain entered at the glass jalousies and ridge flashing and a portion of the gypsum-board ceiling collapsed due to roof leakage (Figure 3-28). It was apparent that wind-driven rain was pushed past the foam ridge closures (Figure 3-29). USVI Recovery Advisory 3, *Installation of Residential Corrugated Metal Roof Systems* (Appendix D) provides a more conservative ridge detail that would prevent water infiltration.



Figure 3-27: This residence had a metal R-panel roof. Figure 3-29 is a close-up of the ridge flashing indicated in the red oval.



Figure 3-28: View from the living room, looking up at the ridge. The 2x4 framing supported the gypsum board ceiling. The red circles indicate where light is entering due to ridge foam closure discontinuities. Winddriven rain can enter where light enters.



Figure 3-29: View of the ridge flashing indicated by red arrow. The yellow arrows indicate foam closures (one closure is dislocated). The panel and flashing screws are corroded, thus jeopardizing the service life of the roof system.

#### **COMPONENTS AND CLADDING**

The MWFRS is an assemblage of structural elements assigned to provide support and stability for the overall structure. The system generally receives wind loading from more than one surface. The Components and Cladding (C & C) are elements of the building envelope that do not qualify as part of the main wind-force resisting system.

Several gutter drainage problems were observed. Few of the observed outlet tubes had strainers, which made the downspouts susceptible to clogging from debris. Typically, the outlet tubes had a very small diameter, and often there was only one outlet tube for each gutter. The *Stronger Home Guide* recommends 3-inch diameter outlet tubes with strainers, with two outlet tubes at each gutter. Figure 3-30 shows a house that experienced interior water infiltration even though there were no apparent building envelope breaches. This house had a liquidapplied membrane roof with integral gutters.



Figure 3-30: Water entered at the ceiling/wall interface in the vicinity of the red arrow. That leakage was likely associated with inadequate sealing of the lines serving the condensers at the blue arrow.



Figure 3-31: View of the integral gutter shown by the red arrow in Figure 3-30. There was a single small diameter outlet tube in this area. It did not have a strainer. It is likely that water accumulated in the gutter and leaked through membrane breaches. The bright white area is a recent recoating.

Figure 3-32 shows a multi-family housing building that was under construction when Hurricane Irma impacted the island. It had concrete exterior walls and the windows and sliding glass doors had wind-pressure and wind-borne debris impact labels. It had a unique roof system (Figure 3-33) with a gypsum roof board that was adhered to the concrete deck with foam ribbon adhesive. A single-ply membrane was adhered to the gypsum board and was also mechanically attached to the deck. Because the membrane was adhered, it was not susceptible to fluttering. However, problems with foam ribbon adhesives can result in wind blow-off. By incorporating the redundancy of the mechanical fasteners, if the adhesive failed, the roof membrane was designed to perform as a common mechanically-attached single-ply membrane.



## Figure 3-32: View of multi-family housing building under construction.


Figure 3-33: The red arrows indicate the row of membrane fasteners. The serpentine areas are the foam ribbon adhesive between the roof deck and the gypsum roof board (they telegraph through the board).

#### 3.2.3.3 Doors and Windows

At the time of Hurricane Marilyn, metal jalousies were the most common type of window opening. The 2017 MAT observed metal jalousies, but a variety of other types of windows were observed as well, including glass jalousies, casement windows, and double-hung windows. A variety of shutters were observed, including roll-down (Figure 3-34), accordion, metal panel (Figure 3-35) and wood sheathing shutters.



Figure 3-34: This residence has roll-down storm shutters. The roof covering is an exposed-fastener R-panel roof with integral gutter. There was no apparent damage; however, it was not determined whether there was water infiltration at the doors or windows.



Figure 3-35: View of double-hung windows protected by metal panel shutters. Shutter tracks are permanently mounted to the wall indicated by the red arrow. The panels are installed prior to hurricane landfall.

Several damaged windows and shutters were observed. Few of the observed shutter assemblies had labels indicating whether they were tested. It is possible that the damaged shutters experienced loads that exceeded those specified in the test standards, or some may not have been tested assemblies. The greatest door and window problem was infiltration of wind-driven rain. Minimizing water infiltration at doors and windows during extremely high winds is challenging and requires thorough design considerations. Guidance is provided in USVI Recovery Advisory 4, *Design, Installation, and Retrofit of Doors, Windows, and Shutters* (Appendix D).

#### **STAGED CONSTRUCTION**

Staged construction is a concept that is relatively unique to the Caribbean where a residential owner builds portions of a home in stages over several years while living in the home. It is typical for the homeowner to live in one level while an upper or lower level is prepped for construction. The unoccupied level may remain prepped for construction, exposed to the elements, for several years until the homeowner is ready to begin construction. The homeowner in the image below lived on the "second level" while the ground level was prepped for future construction. Construction materials remained on site.



#### **3.3 Home Protection Roofing Program**

As noted in subsection 1.3.2, Hurricane Marilyn damaged or destroyed approximately 21,000 homes in the USVI. The majority of the damage occurred on St. Thomas and was caused by blow-off of the roof structure and/or roof covering.

While most of the affected dwellings were either insured or eligible for recovery efforts through assistance programs, a small percentage were not. As a result, a year after Hurricane Marilyn, then-Governor Roy L. Schneider appealed to FEMA for aid in repairing or replacing roofs for approximately 350 homes on the islands. Through FEMA's HMGP, funding was granted to the USVI, providing the Territory with resources for design, construction, formal construction management oversight, and quality assurance and quality control. The grant also funded a vital part of the region's post-disaster mitigation plan, the HPRP.<sup>2</sup>

One of the key components of the HPRP was to address the issue of poorly attached roofs that could be blown off during hurricanes. FEMA collaborated with local USVI officials to develop two HPRP design solutions: improving the attachment of corrugated metal roof panels and building roofs by applying a liquid-applied membrane over plywood. Both options included design solutions for improving the wind resistance of the joists or beams. The HPRP either replaced or upgraded a home's entire roof assembly, including the roof structure, regardless of the level of damage.

In the wake of Hurricanes Irma and Maria, one of the goals of the MAT was to assess a sample of St. Thomas and St. Croix HPRP homes to determine how the roofs performed. Several HPRP residences were observed by separate MAT sub-teams on St. Croix (Section 3.3.1) and St. Thomas. (Section 3.3.2). The MAT found that roofs on buildings that participated in the program generally performed well during Irma and Maria.

#### 3.3.1 St. Croix

The MAT observed 11 HPRP homes on St. Croix. None of the homes had roof damage from wind and two had leaks. At most of the homes, residents were not present at the time of the MAT observations. In these cases, it was not possible to determine whether water infiltration occurred at doors or windows.

#### 3.3.1.1 Roof Systems

The majority of HPRP roofs utilized corrugated metal panels readily available throughout the islands. These roofs were sometimes treated with a liquid-applied coating that added a further layer of waterproofing to the metal surface. Other HPRP homes utilized a liquid-applied roof membrane directly on the wood panel sheathing. This type of roof membrane system has less likelihood of wind uplift due to the integrated nature of the design. One liquid-applied HPRP roof did develop leaks along the roof edge, where it appeared that the sheathing surface was uneven, and pools had developed. A close-up of this condition can be seen in Figure 3-36.

<sup>2</sup> Further information on the HPRP can be found in: *Evaluation of Residential Mitigation Strategies, Hurricane Marilyn in the US Virgin Islands*, DR 106-VI, FEMA, September 1996.



Figure 3-36: Liquid-applied membrane roof covering on an HPRP home that developed leaks. Overall roof performance was positive for HPRP homes, but small leaks led to minor interior damage. The gutter did not comply with HPRP specifications. Sion Farm, St. Croix.

Of the 11 HPRP homes observed on St. Croix, only one was missing any portion of the roof covering. This was a notable and positive finding, considering the overall level of wind damage across the islands. Roof coverings are often the first components to fail and winds from Maria reached near design speeds. The one HPRP home with damage was located near the southwestern coast of the island. This home had a large FEMA tarp covering the roof section and was inaccessible to the MAT for evaluation. Its level of damage remains unknown, though it did not appear catastrophic, as shown in Figure 3-37.



Figure 3-37: Roof damage was evident on the HPRP home. It was the only home with moderate damage of the 11 HPRP building evaluated by the MAT. Camporico, St. Croix.

#### 3.3.1.2 Roof Structure

The HPRP homes typically had low-sloped gable or hipped wood-framed roofs built over an existing structure. Examples of each shape and construction type are shown in Figure 3-38. These roof structures performed extremely well and reported no damage. It was difficult to tell exactly how the internal sheathing and framing systems were designed because so few sustained damage; however, several specific features likely affected their performance positively. The roof extended to the edge of the

supporting wall face, where an extremely short eave remained almost flush with the building (Figure 3-39) and held up to high winds. Generally, the number and strength of connections were substantial, as the load path from roof covering to sheathing to roof structure to wall carried the wind loads adequately. The shallow slopes, lack of overhangs, and consistent strength of connections likely mitigated damage.

While the roof structures remained similar across HPRP homes, the structures beneath them varied widely. Quite a few were built over existing modular, pre-cast concrete buildings in the Sion Farm neighborhood in central St. Croix. Others were built over more traditional CMU structures and likely modified an existing wood-framed roof. Regardless of structure type, the HPRP roofs remained undamaged at the roof-to-wall connections.



Figure 3-38: The three different roof types exhibited by the HPRP homes included gable roofs (top left and right), tiered pyramid hip roofs (bottom left), and combination gable roofs (bottom right). Sion Farm and Frederiksted, St. Croix.



Figure 3-39: Detail of the roof overhang with fascia board and gutters still attached after the storm. The limited overhang and flush-mounted gutter likely helped limit water intrusion and roof sheathing peel-up. The external gutter did not comply with HPRP specifications. Sion Farm, St. Croix.

#### 3.3.1.3 Gutters, Fascia, and Cisterns

The fascia board and edge finishes were rarely damaged on HPRP homes and potentially helped brace the roof sheathing to the roof structure near edges. Proper layering of these elements also allowed for further sealing of wind-driven rain and overflow from gutters. Gutters were missing on some properties where the roofs performed well, due to lightweight clip connections. External gutters did not comply with the original HPRP specifications, as gutters were supposed to be integral. If running to a cistern, missing gutters can hinder water collection in the days following a storm. Yet, where this was observed, the gutter immediately adjacent to the downspout stayed intact and connected to the cistern system. The ability for the homes to lose gutter elements without damaging other, more valuable elements was a positive performance factor.

#### 3.3.1.4 Doors and Windows

HPRP homes had the same types of doors and windows, a combination of metal and glass jalousies, as seen in Figure 3-40, or glazed windows, as the Scion Farm and traditional CMU homes. Door and window replacements were not part of the HPRP. Only minor jalousie window damage was reported at the time of the MAT visit. Residents specifically mentioned wind-driven rain entering through jalousie openings and door gaps, causing minor interior water damage and damage to contents. As with non-HPRP homes, concrete and CMU walls and concrete floors limited the long-term impacts of such intrusion.



Figure 3-40: HPRP home with examples of both glass jalousie (left) and metal jalousie (right) windows. This type of louvered window protection was typical for most of the HPRP homes and performed with limited damage to the windows themselves. Wind-driven rain remained an issue and would frequently enter the homes through jalousie openings. Sion Farm, St. Croix.

#### 3.3.1.5 Wall Structures

The HPRP homes observed on St. Croix were constructed solely of CMU block or pre-fabricated concrete panels assembled on-site. None of these buildings sustained any significant wall damage. This speaks to the quality of the roof structures and the strength of the roof-to-wall connections. In hurricane scenarios, wall failures are most likely when the roof is damaged and no longer bracing the rest of the building. No structural failure or level of significant cracking was observed. Any debris damage that was noticed was only cosmetic and did not affect the integrity of the structures.

#### 3.3.2 St. Thomas

On St. Thomas, 20 HPRP homes were observed by the MAT. Though other homes were observed, the MAT was unable to confirm participation in the HPRP due to address inaccuracies, lack of access to the roofs, and observed significant deviation from HPRP requirements which suggested that the roofs may not have been HPRP-funded. At most of the observed homes, residents were not present at the time of the MAT. In these cases, it was impossible to determine whether water infiltration occurred at doors or windows.

Roof damage at four of the homes was limited to gutter blow-off due to a lack of integral gutter design, while damage at one roof appeared to be related to water leakage. Damage at another roof was caused by porch blow-off. Homes that fully adhered to HPRP-prescribed materials and designs performed well overall.

No MWFRS problems were observed, except for a porch blow-off, discussed in Section 3.3.2.1. No exterior wall problems were observed, except as discussed in Section 3.3.2.2.

#### 3.3.2.1 Roof Systems

This section discusses key HPRP roof system observations on St. Thomas. Figure 3-41 shows a tarped corrugated metal panel roof. One roof area had an integral gutter, while another area had an external gutter. (External gutters do not comply with HPRP specifications.) There was only a single row of screws at the eave, whereas the HPRP specified two rows.



Figure 3-41: View of a tarped corrugated metal roof.

Figure 3-42 is a view of the roof after Hurricane Irma but before tarps were put in place. There is no apparent wind damage to the roof panels or the ridge flashings. It is likely that the tarps were placed to avoid water leakage from entering at panel side laps or the ridge flashing. The HPRP specifications required triple side laps, sealant tape at side laps, and an underlayment. Without performing destructive sampling, the MAT was unable to determine if these specifications were followed. If the specifications were followed, interior water leakage would have been unlikely. However, since only a single foam closure at the ridge was specified (a non-conservative design decision), rain may have been driven past the closures. USVI Recovery Advisory 3, *Installation of Residential Corrugated Metal Roof Systems* (Appendix D) provides a more conservative ridge detail.





Figure 3-43 is a view of the integral gutter of the house. This gutter was comprised of a liquid-applied membrane over plywood per the HPRP specifications. This type of membrane requires recoating, which had not been done at this gutter. Portions of the plywood were exposed and the plywood was quite weathered, indicating that the coating had worn away prior to Hurricane Irma.



Figure 3-43: View of the integral gutter indicated by red arrow. Exposed plywood occurs within the yellow oval. Figure 3-44 shows a different house with a corrugated metal panel roof. There was only a single row of screws at the eave and hip of the roof. The panel and flashing screws were not made of stainless steel, as specified by the HPRP. There was no apparent wind damage to the roof. Although the fastener deficiencies did not result in wind problems during the 2017 hurricanes, this success does not guarantee that the roof will perform well in the future or indicate that HPRP specifications were overly conservative. Similar or stronger storms and higher wind speeds are possible that would likely stress the integrity of this design.



Figure 3-44: The yellow arrow indicated the HPRP corrugated metal panel roof and integral gutter. The red arrow indicated a tarped roof. The blue roof at the right was not tarped, but rather had blue metal roof panels.

Figure 3-45 shows a liquid-applied membrane roof with integral gutters. This design appeared to comply with the HPRP specifications and had no apparent damage. Figure 3-46 shows a corrugated metal panel roof with external gutter following Hurricane Irma. Figure 3-47 shows the difference in performance of the various roofs within the same immediate geographic area.



Figure 3-45: Liquid applied membrane roof with integral gutter.



Figure 3-46: Corrugated metal panel roof with external gutter. The red arrow indicates where the gutter blew off.



Figure 3-47: Aerial view of the neighborhood with the roofs shown in Figure 3-45 indicated by red arrow and Figure 3-46 indicated by vellow arrow occur. The entire roof structure blew off the house within the yellow circle, and part of the roof structure blew off the house within the red circle. The orange arrow indicates where a portion of the roof was tarped. The house within the blue circle had solar panels, some of which blew off during the storms. (Photo by NOAA).

Figure 3-48 shows a house with a liquid-applied membrane roof with external gutters for the lowslope portion of the roof, and metal R-panels for the steep-slope portion. The use of R-panels in lieu of corrugated metal panels was a deviation from the HPRP design specifications. There was no apparent roof system damage. The metal panel screws were also not made of stainless steel. Although this house was not close to the coast, the screws were corroded. Screw corrosion has a high potential of adversely affecting the service life of a roof system. Figure 3-49 is an aerial view of the neighborhood after Hurricane Irma. This shows the varying performance of roofs in the immediate geographic area.



Figure 3-48: Metal R-panels at the steep- slope portion of the roof and liquidapplied membrane with external gutter at the lowslope portion.



Figure 3-49: Aerial view of the neighborhood where the roof shown in Figure 3-48, as indicated by red arrow, was located. The entire roof structure blew off the house within the yellow oval. The orange arrows indicate where a portion of the roof was tarped or blown off. (Photo by NOAA).

Figure 3-50 shows a house that had a liquid-applied membrane roof with integral gutters and an open porch roof design. One end of the porch framing was supported by the house and the other end was supported by a perimeter beam on 4x4 wood columns. The columns were connected to the concrete slab with metal connectors. The connections between the columns and slab failed and the porch blew away during the storms (Figure 3-51). At some of the column connections, the anchor bolts pulled out of the

slab. At other connections, the screws between the column and connectors failed. It was apparent that the design and construction of the porch framing was not part of the HPRP work.



Figure 3-50: Liquid-applied membrane roof with external gutter. The porch on the other side of the house blew away (see Figure 3-51). (Exposure D).



Figure 3-51: An open porch over the slab area. The red arrow indicated a metal connector that was still in place. The blue arrow indicates where the connector bolts pulled out of the slab. The orange arrow indicates the door shown in Figure 3-53.

Figure 3-52 is a view of the interface between the porch and main roof. An attribute of a liquid-applied membrane over plywood is that if a plywood panel blows away, typically the membrane ruptures near the panel joint. Usually there is little progressive lifting and peeling of the membrane at the panels that remain attached.



Figure 3-52: View of the interface between the porch and main roof. The red arrows indicate the liquidapplied membrane. The yellow arrow indicates where there was localized lifting and peeling of the membrane.

#### **3.3.2.2 Doors and Windows**

Although the HPRP did not address doors or windows in its design specifications, the following are key door and window observations made at the HPRP houses. Figure 3-53 shows a broken sliding glass door on the home shown in Figure 3-51. The accordion shutter was deployed prior to Hurricane Irma. During the storm, the head track deformed, and a portion of the shutter disengaged from the track. The sliding glass door that the shutter protected was broken. Plywood was temporarily installed after the storm. The shutter did not have a label indicating whether it was a tested assembly. It is possible that the shutter experienced loads that exceeded those specified in the test standards, or it may not have been a tested assembly.

Figure 3-54 shows a house that had its entire roof structure blown off during Hurricane Marilyn. However, there was no apparent damage to the liquid-applied membrane during the 2017 hurricanes. The MAT was advised that there were no roof leaks; however, water did enter the house at the door and windows. The driveway to the house sloped down towards the entry door. A curb directed water away from the door, but it was too short to divert all of the stormwater runoff. The double-hung windows had accordion shutters. Shutters can reduce the wind-driven rain demand on windows, but to avoid water infiltration, the window assembly itself needs to be designed to resist the rain.





Figure 3-54: The liquid-applied membrane with integral gutters did not leak. However, water did enter at the door and windows.

Figure 3-53: View of a broken sliding glass door and damaged shutter.

Figure 3-55 shows a house with a liquid-applied membrane roof with integral gutters. There was no apparent roof damage but there was glazing damage. The large glass jalousie windows were protected by accordion shutters, which are permanently anchored to the wall. The three small jalousie windows were not protected. It appeared that an accordion shutter blew off at the opening shown with the mattress projecting through it.

The glazing breaches resulted in the development of high internal pressures. The roof assembly was strong enough to resist the wind uplift, but there was significant deformation of one of the side walls (Figure 3-56).





Figure 3-55: The red lines and arrows indicate broken glass jalousies.

Figure 3-56: A combination of internal positive pressure and external negative pressure (suction) resulted in deformation of the wall, shown in yellow oval.

Figure 3-57 shows a house with a liquid-applied membrane roof with integral gutters. There was no apparent roof damage; however, a set of metal jalousie windows was blown out of the wall.



Figure 3-57: The yellow arrow indicates where the meal jalousie windows blew out of the wall. The inset indicates exposed plywood indicated by red arrow. The liquid-applied membrane likely deteriorated in this area prior to the 2017 hurricanes. Some localized lifting and peeling of the membrane may have occurred during the storms.

### HURRICANES IRMA AND MARIA IN THE U.S. VIRGIN ISLANDS

# Performance of School Facilities

The USVI Department of Education managed 30 public schools on the islands of St. Thomas, St. Croix, and St. John prior to the 2017

*hurricane season.* 

Figure 4-1 shows the elementary, junior high, and high schools in the USVI. These schools do not include private and parochial schools. The public schools are typically available for grades kindergarten through 12th grade and are separated into elementary, junior high, and high schools. The St. Thomas/St. John school district has 11 elementary schools, 3 junior high schools, and 3 high schools while the St. Croix school district has 10 elementary schools, 3 junior high schools, and 3 high schools. Most of the schools were constructed between the 1950s and the 1970s, with limited upgrades in recent years. There is at least one school that was built recently as a newly constructed school to replace one that was substantially damaged by Hurricane Marilyn.

#### HURRICANE MARILYN IMPACTS ON SCHOOLS

FEMA Mitigation evaluated all the public schools in the USVI for roof assembly performance in the aftermath of Hurricane Marilyn. The following is a synopsis of the findings:

St. Thomas: Twenty-two school sites were evaluated. A few buildings collapsed and a few did not exhibit signs of damage. However, buildings typically experienced roof covering damage and many experienced roof structure damage.

St. John: Four school sites were evaluated. Minor damage was observed at one school.

St. Croix: Sixteen school sites were evaluated. Most of the buildings did not exhibit signs of damage, or they only experienced minor damage. Some buildings experienced roof covering damage and one school experienced roof structure damage.



Figure 4-1: Elementary, junior high, and high schools in the USVI.

After Hurricane Marilyn, FEMA provided roof and rooftop equipment mitigation recommendations for the USVI public schools. It appears that many of the recommendations were not implemented.

The damage to schools caused by Hurricanes Irma and Maria was extensive. Two months after the hurricanes, two thirds of the schools on St. Croix were still not open. Roof vent failures were a common problem for the schools. Damage to the building envelopes contributed to the environmental concerns as water and stagnant air remained in buildings for months. The extended period of high humidity and water inundation caused direct damage and allowed microbial damage to the schools. Many of the older buildings that had little superstructure damage have asbestos in the floor tiles and mastic adhesives, making them unsuitable for immediate occupancy before decontamination.

## 4.1 Performance Relative to Flood (Coastal, Riverine, Storm Water Sheet Flow)

#### 4.1.1 Storm Water Sheet Flows

While most of the school locations for the USVI are generally located well inland and not subject to coastal flooding, there are some notable exceptions, such as Addelita Cancryn Junior High School on St. Thomas.

Riverine or site flooding caused inundation that impacted multiple schools. Finished floor elevations of the school buildings were occasionally sited a few inches too low relative to the adjacent grade, thus making them vulnerable to low-level sheet flows. Several schools have experienced surface flooding for years due to the elevation variance. These schools could have mitigated some of the flooding with a variance of an eight inch elevation difference between the finished floor elevation and the adjacent grade.

In the case of Pearl B. Larsen Elementary school on St. Croix, the finished floor elevation was established as the same elevation as the surrounding grade, providing no protection from minor site flooding (Figure 4-2). The lack of elevation between the finished floor and the surrounding grade made the building susceptible to low-level flooding from surface flows across the adjacent terrain. The school experienced water intrusion from flows coming down a surface conveyance from the gym and across the parking lot to the rear of the building. There is no significant fall in grade along the rear of the building that is built into a slightly sloping lot. This also allows water to build up along the rear of the building.



Figure 4-2: Channelized flow (blue line) from higher grade at the gym to a parking lot at the same grade as the finished floor. This allowed water to enter at the door indicated by red arrow.

#### 4.1.2 Site Flood Flows

Schools also experienced flooding from on-site flows, specifically from the interior courtyards and cisterns. The environment of the USVI is unique in that it has sporadic rainfall with little ability to store water in natural lakes and impoundments. Thus, rainfall requires distributed storage in the form of cisterns at the buildings. Schools have cisterns for domestic water supply, as required for most buildings in the USVI, and additional water supplied by the local municipality. Cisterns are supplied with rain waters gathered from the roofs and directed to the cisterns via gutters, downspouts, and piping, and are augmented by the municipal supply.

During the hurricanes, large gutters used to capture brief, but intense rainfalls were blown off the school buildings. The gutters were often located around the perimeter of interior courtyards and could no longer carry the water away to the cisterns and the area drains located in the courtyards, and flooded. The accumulated water in the courtyards then flowed into the interior of the building through adjacent doors. Figure 4-3 shows an interior courtyard that experienced significant flooding from roof runoff, which entered the school through courtyard doors.



Figure 4-3: Larsen Courtyard flooded after gutters and downspouts failed. The red arrow indicates missing gutters. The green arrow is a gutter laying on the ground.

In some cases, the cisterns received the rainfall flows but lacked the capacity to handle the large water volume of the event. In the case of the Larsen School, the cistern did not have a bypass or an overflow to route the excess water away from the holding tank and the space above it flooded (Figure 4-4).



Figure 4-4: Flooding in music room after cistern overflow at Larsen School.

At the Ulla F. Muller Elementary school, groundwater from the hillside seeped out of the ground at the courtyard. After Hurricane Maria, a groundwater drainage system was installed (Figure 4-5).



Figure 4-5: View of the Muller courtyard as work on the new groundwater drainage system nears completion.

#### 4.2 Performance Relative to Wind and Wind-Driven Rain

#### 4.2.1 Main Wind Force Resisting System

The MWFRS of USVI schools were represented by multiple types of construction. The schools used reinforced concrete walls, CMU walls, and meal building systems (MBS) with infill walls. The MBS systems are generally a steel moment frame system with reinforced concrete or CMU infill walls. The framed roof system utilizes the roof diaphragm to distribute lateral loads to the lateral force-resisting system. The observed MBS roof systems ranged from heavy wood-framed construction to metal frames.

Two portable classrooms at Muller were not well-anchored and were susceptible to overturning. However, because they were shielded from Hurricane Irma's strong winds by the main two-story building, they remained on their CMU pier foundations (Figure 4-6).



Figure 4-6: These portable classrooms were shielded by the main building indicated by the yellow arrow. The inset shows a broken metal strap indicated by red arrow between one of the classrooms and a ground anchor.

Reinforced concrete construction performed well at Charlotte Amalie High School on St. Thomas (Figure 4-7). The walls and roof remained intact with little damage.



Figure 4-7: View of Charlotte Amalie High School with reinforced concrete construction showing little damage to the classroom buildings after the hurricanes. The damage to buildings at Eulalie Rivera Elementary School ranged from minor to complete devastation. The school campus has two types of construction (Figure 4-8). The first type was a traditional CMU wall building with a wood-framed roof. This type of construction had minor to moderate damage and could be repaired. There was also damage to the metal roof panels and vents.



Figure 4-8: Front office of Eulalie Rivera Elementary School showing traditional construction that exhibited fair to good performance.

The second type of construction was a composite panel system. These panels were made from thin aluminum sheet-metal skins bonded to corrugated cardboard. The system was used for the roof and walls and a corrugated metal roof was installed over the composite panel roof. The nails used to attach the corrugated metal roof to the composite panels did not provide adequate pull-out resistance due to the thin metal skins of the panels. While the corrugated metal roof system often remained intact, it was removed in large sections from the structure (Figure 4-9)

It appears that water migrated into the panels over many years and caused delamination of the composite panels. Once delaminated and no longer a composite material, the strength of the individual materials and the panels' ability to support loads were near zero. Figure 4-10 shows the panels draped over chairs and desks in the classrooms while Figure 4-11 shows the west wing at the southwest corner of the campus. Figure 4-12 is a comparison of the performance of old and new construction. The same kind of damage was observed in similar construction at portable classrooms after Hurricane Marilyn. Numerous causes from delamination to inadequate anchorage eliminated any ability of the building to withstand storm-force winds.



Figure 4-9: Corrugated metal roof overlay removed in large sections from the composite panel system wing of the school.



Figure 4-10: Composite wall panels made from aluminum skins and 3-inch honeycomb bonded cardboard indicated by red arrow.



Figure 4-11: View looking northwest at the newer west wing of Eulalie Rivera Elementary School. This wing was comprised of composite panel construction and suffered near-complete destruction.



Figure 4-12: The newer composite panel construction is visible on the left while the older traditional CMU construction is shown on the right.

Masonry construction with engineered lumber performed poorly at Cancryn Middle School on St., Thomas (Figure 4-13). The engineered wooden elements appeared to be in advanced stages of decay.





Figure 4-13: Cancryn Middle School in St. Thomas performed poorly due to extensive decay in the engineered wood roof.

The wood-framed roof system (utilizing sawn lumber) performed well at Addelita Cancryn Junior High School in St. Thomas, despite impacts to the metal jalousie windows (Figure 4-14).





Figure 4-14: View of Addelita Cancryn Junior High School. The building has metal louvered windows (left). The common framed roof system performed well even after debris impacts to the windows (right).

Gifft Hill School in St. John is a Metal Building System (MBS) school and was constructed in 2006-2007 (Figure 4-15 and 4-16). This type of construction was formerly known as pre-engineered metal building. It was originally intended to be a gymnasium, but classroom modules were ultimately constructed inside the building (Figure 4-17). There was no apparent damage to the MWFR, though many solar panels did blow off the roof, some of the gutters and rake flashing were blown off, and all six skylights leaked. The distribution of the wall louvers resulted in a partially opened enclosure, as defined in ASCE 7-16. There was significant water infiltration at these wall louvers, which damaged the portioned classroom ceilings. (Figure 4-16). The school reopened in early January 2018. Abrupt change in topography at the left side of the building, shown in Figure 4-15 resulted in wind speed-up during Hurricane Irma. A wood trellis structure was severely damaged, and all of the guttering was blown off the eave of the roof.



Figure 4-15: Front view of Gifft Hill School. The red arrow indicates the area where the solar panel damage occurred.



Figure 4-16: View of damaged wood trellis. The red arrow indicates wall louvers. Gutters were also torn from the upper building edge as indicated by green arrow.



Figure 4-17: Interior view of the Gifft Hill School gymnasium. The yellow arrow indicates a skylight that was damaged by the storm. The red arrows indicate classroom modules. The classroom ceilings were damaged by water infiltration from the louvers.

#### 4.2.2 Building Envelope Damage

General observations of damage to building envelopes due to water intrusion are followed by considerations involving particular building elements.

#### 4.2.2.1 Water Intrusion

Damage to rooftop equipment, gutters, roofing, and flashing provides avenues for water to enter buildings from above. The Pearl B. Larsen Elementary School experienced water infiltration through these avenues during the hurricanes. Figure 4-18 shows the damaged vents, gutters, and flashings that allowed water intrusion into the classrooms.



Figure 4-18: Roof of the Pearl B. Larsen School showing vent blown off indicated by red arrows, gutter damage and missing gutters indicated by blue arrow, downspout damage indicated by magenta arrow, and flashing damage indicated by green arrow.

#### 4.2.2.2 Roof Coverings

A variety of school roof coverings were observed including metal panels, liquid-applied membranes over concrete roof decks, and single-ply and modified bituminous membranes. Metal panels included exposed-fastener systems (corrugated metal panels and R-panels) and standing-seam panels with concealed clips. In many instances, corrugated roof panels were not attached securely or in accordance with details from *Construction Information for a Stronger Home Guide* (Figure 4-19). Significant corrosion of corrugated panels was observed at some schools. Portions of roofs were tarped at the time of the MAT observations, so it was not possible to determine the cause of damage in these areas. The MAT observed that membrane roofs were not blown off but were commonly punctured by wine-borne debris.



Figure 4-19: The R-panels on this school roof had significant corrosion and inadequate fastener spacings indicated by red arrows.

Figure 4-20 is a view of the Ulla F. Muller Elementary School after Hurricane Marilyn. A steel truss superstructure had been installed as part of a steep-slope conversion. A steep-slope conversion adds a pitched roof structure on top of a low-slope roof. Several of the trusses blew off because of inadequate attachment. Rather than replace the trusses, a liquid-applied membrane was applied to the existing precast double tee roof panels. Liquid-applied membrane over concrete decks was observed to provide reliable wind performance. However, instances of leakage were observed where the membrane had not been maintained by recoating (Figure 4-21).



Figure 4-20: View of the steel truss superstructure in the Muller courtyard after Hurricane Marilyn. (FEMA P-424, Figure 6-122).



Figure 4-21: View of the underside of precast double tee roof panels in a Mueller classroom. The liquid-applied membrane had ruptured over a panel joint, allowing rain to enter the building.

The damage to MBS buildings varied from minor to major. The building performance often suffered when louvers were placed in the end walls, which allowed the buildings to pressurize, causing the deck and coverings to fail even when extra support purlins were installed. See Figure 4-22, in which the roof was torn free from extra supports.



Figure 4-22: School in St. Croix with metal roof covering torn free from supports.

#### FEMA P-1000, SAFER, STRONGER, SMARTER: A GUIDE TO IMPROVING NATURAL HAZARD SAFETY

This 2017 Guide provides up-to-date, authoritative information and guidance that schools can use to develop a comprehensive strategy for addressing natural hazards. It is intended to be used by administrators, facilities managers, emergency managers, emergency planning committees, and teachers and staff at K through 12 schools. It can also be valuable for state officials, district administrators, school boards, teacher union leaders, and others that play a role in providing safe and disaster-resistant schools for all. Parents, caregivers, and students can also use this Guide to learn about ways to advocate for safe schools in their communities.

https://www.fema.gov/media-library/assets/documents/132592

#### 4.2.2.3 Windows

Pearl B. Larsen Elementary had laminated glass installed at the courtyard sometime around 1984, improving on the circa-1956 complex (Figure 4-23). With mid-1950s construction, windows are usually not laminated, pressure-rated, or impact-resistant. The newer windows had an ANSI Z97.1 impact rating. This is not the same rating for windows in hurricane debris zones, yet the windows withstood the elements fairly well, with only minor leaks and a few panes that broke. Most of the water entered from the roof and from the flooded courtyard.



Figure 4-23: Corridor window at Pearl B. Larsen Elementary School with etched note of date and name of manufacturer indicating 1984 date of manufacture.

At Addelita Cancryn Junior High School, most of the classrooms were observed to have metal jalousie window systems to allow air circulation. These jalousies served to keep debris out even after the substantial impacts that left the louvers damaged but intact (Figure 4-24). However, metal jalousies are typically not tested to meet the wind-borne-debris criteria given in ASTM D1996. Metal jalousies breached by wind-borne debris were observed at other buildings.





Figure 4-24: View of metal jalousies that had wind-borne debris impacts but stayed intact.

The Ulla F. Muller Elementary School also had metal jalousies. Panels glazed with plastic were mounted inside of the jalousies for energy conservation. Some of the glazed panels were blown away during the storms. Even when the panels remained in place, wind-driven rain reportedly entered rooms because the panels were not sealed to the jalousie frames (Figure 4-25).



Figure 4-25: Glazed panels indicated by red arrow, were mounted to the inside of the jalousies. Such panels were typically ineffective in preventing entry of wind-driven rain.

#### 4.2.2.4 Doors

The doors at the interior courtyards of Pearl B. Larsen School leaked when they were inundated by stormwater runoff from the roof. Attempts were made to abate the flow with sandbags. Other exterior doors leaked and allowed the entry of localized site flooding from nearby surfaces. The thresholds and perimeters typically did not have weather stripping. Even if weather stripping had been in place, it likely would have been unsuccessful in stopping water with even moderate pressure, as was the case in these conditions. Weather stripping helps with infiltration of low to moderate wind-driven rain but is typically not intended as a gasket or seal for flood waters (Figure 4-26).



Figure 4-26: Door to interior courtyard at Pearl B. Larsen showing the sandbagging effort against the rising waters and the damaged door itself after the storm.

#### 4.2.3 Long Span Roof System

Long-span roofs had variable performances for the school systems in the USVI. The Pearl B. Larsen Elementary School gym and Gifft Hill School (Figures 4-27 and 4-28) performed well, while the Charlotte Amalie High School in St. Thomas (Figure 4-29) had substantial loss of metal roof panels, and the Arthur A. Richards Jr. High School gym in St. Croix (Figures 4-30 and 4-31) suffered dramatic and large-scale failures.



Figure 4-27: The Pearl B. Larson Elementary School gym survived with some minor damage to secondary elements.







Figure 4-28: The left image shows movement between the steel frame and infill CMU wall, as indicated by red arrow. Similarly, the middle image shows daylight between the frame and the infill wall, as indicated by red arrow. The image on the right shows broken bracing straps that restrain the roll over effects on the light gage purlins, as indicated by red arrows. Pearl B. Larsen Elementary School Gym.





Figure 4-29: Long-span roofs at Charlotte Amalie High School that lost large sections of metal roof panels.



Figure 4-30: A classroom at Arthur A. Richards Junior High School showing heavy damage. The metal roof panels and steel framing were blown off, exposing the room contents to the full effects of the hurricane.



Figure 4-31: E. Benjamin Oliver after Hurricane Marilyn. The red arrows indicate blownoff HVAC units. The yellow arrow indicates blownoff roof decking.

#### 4.2.4 Rooftop Equipment

Poor wind performance of rooftop equipment was common during Hurricane Marilyn (1995) and during the 2017 hurricanes. At the E. Benjamin Oliver Elementary School, several heating, ventilation, and air conditioning (HVAC) units<sup>1</sup> were blown off their curbs (Figure 4-31) during Hurricane Marilyn. Several of the cementitious wood-fiber roof deck panels were also blown off the roof. Figure 4-32 indicates similar conditions after the 2017 hurricanes.



Figure 4-32: E. Benjamin Oliver Elementary School after the 2017 hurricanes. The red arrows indicate blown off HVAC units and condensers. One condenser unit is on the ground adjacent to the building, having fallen from its rooftop location. The yellow arrows indicate blown-off cementitious woodfiber roof decking.

<sup>1</sup> HVAC units are also knows as "rooftop units" (RTU).

Common failures included condenser and HVAC units displaced due to lack of attachment or inadequate attachment to equipment curbs, HVAC unit access panels torn off, HVAC sheet metal unit enclosures (cabinets) ruptured and torn open, and displaced condensate drain lines. Examples of these types of failures are shown in USVI Recovery Advisory 2, *Attachment of Rooftop Equipment in High-Wind Regions* (Appendix D). When HVAC units blow off their curbs, rain can freely enter the building. Wind-borne rooftop equipment, including access panels, sheet metal unit enclosures, and condensate drain lines can puncture and tear roof membranes (Figure 4-33) and metal roof panels. Entire condenser units that may fall from rooftop elevations can hurt people or damage windows and structures at ground-level. Some of the punctures on the roof shown in Figure 4-34 had been repaired, however four punctures were still unrepaired weeks after Hurricane Maria.



Figure 4-33: The single-ply roof membrane on this school was punctured in several locations by HVAC access panels and/or sheet metal unit enclosures. An ink pen shows the scale of the large tear.



Figure 4-34: Rooftop gravity air vent with protective cover blown off. This failure was common on the roof of the school.

#### 4.3 Sheltering and School Facilities

It is common for public and municipal buildings, and specifically school facilities, to be identified for use as event-specific or post-event/recovery shelters. During Hurricanes Irma and Maria, many existing public buildings and schools were used as hurricane evacuation shelters, best available refuge areas, post-event shelters, etc., across the USVI. While these types of facilities provide support to the community, the success of these endeavors depends on the damage experienced by the shelters. The MAT was not able to identify a public building or school used as a shelter before, during, or after the hurricanes that was designed and constructed to provide near-absolute protection from hurricanes <sup>2</sup>. Further, the MAT was not able to verify the level to which existing buildings were evaluated to provide best available refuge areas during a hurricane. FEMA guidance recommends that buildings used as best available refuge areas, as post-event shelters, or for any other purpose for which people will congregate in response to a hurricane should be

<sup>2</sup> FEMA uses the term "near-absolute protection" to describe the level of protection afforded by a building (or portion thereof) that has been designed specifically to protect individuals from injury or death during an extreme wind event such as a hurricane or a tornado when designed to FEMA P-361. Note, the ICC 500<sup>®</sup> storm Shelter Standard did not use that same term; rather, it uses the language "life safety protection" (ICC 500<sup>®</sup>, 1) from the hurricanes and tornadoes.

evaluated by a registered design professional using guidance from FEMA P-361 *Safe Rooms for Tornadoes and Hurricanes: Guidance for Community and Residential Safe Rooms, 3rd Edition* and FEMA P-431 *Tornado Protection: Selecting Refuge Areas in Buildings* to identify the best available refuge areas to be used.

Prior to Hurricane Irma impacting the USVI, Governor Mapp, the Virgin Island Territory Emergency Management Agency (VITEMA), and the USVI Department of Human Services announced that shelters were available for residents if they did not want to stay in their homes (South Florida Caribbean News 2017). The list of shelters identified as available on September 4, 2017, represented the cross section of buildings for use as shelters or refuge areas before, during, or after the hurricanes passed. See Chapter 2 for additional discussion on shelters and saferooms. This list included the following facilities, with school facilities *italicized*.

#### **Shelters on St. Croix**

- St. Croix Education Complex
- Herbert Grigg Home for the Aged
- Claude O. Markoe School

#### Shelters on St. John

Bethany Methodist Church

#### Shelters on St. Thomas

- E. Benjamin Oliver School
- Lockhart Elementary School
- Nisky Moravian Church
- Knud Hansen Complex
- Sugar Estate Head Start



Figure 4-35: Interior view of Lockhart Elementary School shelter still in use in mid-October 2017 after Hurricanes Irma and Maria.

Community Health Center (supporting special-needs residents)

While the USVI provided information to their residents on where to go if they did not want to stay in their homes, the MAT was not able to identify a formal program that outlined how the USVI assesses and evaluates these facilities for vulnerabilities to high winds, flooding, or seismic events. Safe rooms or storm shelters should be designed as buildings or spaces that afford shelter occupants near-absolute life-safety protection. If the availability of these spaces is unknown, a design professional should be retained to perform an assessment of facilities for use as refuge areas. Damage observed to school buildings during the hurricanes shows the vulnerabilities of these buildings which included the following:

- Damage to structural elements of roof beams, roof purlins, and wall systems (Figures 4-30)
- Damage to infill walls between structural elements
- Loss of roof covering, leading to water intrusion and damage
- Loss or damage to windows, including glazed windows and metal panel jalousies, leading to water intrusion and damage
- Damage to mechanical/ventilation systems
- Loss of primary and backup power
- Loss of communication systems

#### SHELTERS AND AREAS OF REFUGE

Chapter 2 presented the terms Safe Rooms and Storms Shelters as purpose-built buildings (or portions thereof) designed to provide life-safety protection during hurricanes. However, there are many different uses of the word shelter in emergency preparedness and emergency response. In the USVI, VITEMA and other government entities work together to identify buildings to be used by residents if they do not want to stay in their homes during a storm event and to come to after a storm event if their homes have been damaged.

While these buildings will provide an organized location to take refuge from the storm with some emergency services such as food, water, and cots to sleep on, it should be noted that the buildings identified as shelters were not designed or constructed to provide life-safety protection from flood or wind events. Further, these facilities were not evaluated for their vulnerability or susceptibility to damage from flood waters, extreme winds, or wind-borne debris. The presumption that larger buildings, or public buildings, will perform better during hurricanes and tropical storms may be incorrect for several reasons. If the building has not been evaluated for its ability to resist flood and wind loads without damage or collapse, the ability of the shelter to provide a safe area of refuge cannot be defined or confirmed prior to being impacted by a storm event.

These emergency shelters, recovery shelters, and post-event shelters are simply a place of refuge and should not be considered to be able to provide the same level of protection as by a FEMA P-361 Safe Room or an ICC 500<sup>©</sup> complaint storm shelter. Guidance from FEMA can be applied to evaluate buildings proposed for use as shelters or at least to provide a best available refuge area when a storm approaches.

### HURRICANES IRMA AND MARIA IN THE U.S. VIRGIN ISLANDS

# Performance of Hospital Facilities

All three of the primary hospitals/healthcare facilities in the USVI experienced damage and service losses from the impacts of Hurricanes Irma and Maria.

Damage at the hospital facilities was primarily due to wind forces and wind-driven rain that damaged one or more elements of the building envelope. The MAT visited each of the primary facilities during October and November 2017 field assessments, which included:

- Roy Lester Schneider Hospital at the Schneider Regional Medical Center (St. Thomas)
- Myrah Keating Smith Health Center (St. John)
- Governor Juan F. Luis Hospital and Medical Center (St. Croix)

The structural systems of the large hospital facilities on St. Croix and St. Thomas and the health center on St. John did not experience structural failures or significant damage from the storms. Damage to the facilities on St. Thomas and St. John was caused by winds and rains associated with both hurricanes, while damage to the hospital on St. Croix was attributed almost completely to Hurricane Maria. Most damage observed was due to the failure of building envelope systems at the hospital facilities. While some roof covering remained in place during the storms, several roofs experienced partial or complete roof covering blow-off. Rooftop equipment failures also led to significant water intrusion into the facilities. Punctures and tears to roof membranes intensified water intrusion issues. Windows were hardened or protected at the facilities, resulting in only isolated failures or window damage caused by wind pressure or wind-bornedebris impact, though water intrusion around window systems was observed in numerous locations.

#### 5.1 Roy Lester Schneider Hospital at the Schneider Regional Medical Center

The Roy Lester Schneider Hospital, built in 1982, is a 200,000-square foot facility located in St. Thomas a short distance north of Long Bay. In December 2006, the 24,000-square-foot addition called the Charlotte Kimelman Cancer Institute was constructed. At the time of the hurricane, the hospital was operating as a 169-bed acute care facility.

The Schneider facility is a steel-frame structure with a reinforced concrete floor supported by metal joists. The roof structure is a metal deck system supported on metal joists. The roof deck is topped with insulation and is mostly covered with a mechanically-attached singleply membrane. By contrast, the Kimelman facility is a reinforced concrete and steel-frame structure.

Schneider sustained minor damage during Hurricane Hugo (1989), but in Hurricane Marilyn (1995) the facility suffered major damage to the roof system, rooftop equipment, and window systems. Significant interior damage from water intrusion led to much of the facility being shut down. A field military hospital was temporarily set up on-site to

#### COORDINATED MITIGATION EFFORTS

The MAT investigates the performance of structural systems and building envelopes to determine what caused damage to buildings, whether it was related to design or construction, and whether known mitigation strategies could have been employed to reduce or prevent the damage. The MAT was one of many entities that performed assessments at the hospitals. FEMA Public Assistance support teams, the US Department of Health and Human Services (HHS), and the US Army Corps of Engineers (USACE) were a few of the other entities who also were actively providing support to the hospitals. The MAT coordinated this assessment through the JFO with the other teams to improve the implementation of mitigation goals at these important facilities.

assist the hospital in providing emergency services. Extensive repairs were required, including new roof systems, reinforcement of exterior wall panel connections, and replacement of all windows with impact-resistant glazing systems.

#### 5.1.1 Performance Relative to Flood (Coastal, Riverine)

The Schneider and Kimelman facilities are located outside the SFHA in a Zone X, as noted on FIRM 780000027G, dated April 16, 2007. This location is advantageous, as the facility is located well outside of any storm surge inundation zone, main roads accessing the site are not susceptible to flooding, and the site has reasonable vertical (elevation) and horizontal (distance) separation from the nearest Zone A SFHAs. No drainage issues were reported to the MAT during the site visits. Large drainage ditches are located to the east and along the south side of the property, aiding in the removal of rainwater from the site.

#### 5.1.2 Performance Relative to Wind and Wind-Driven Rain

The Schneider and Kimelman facilities were heavily impacted by Hurricane Irma, and to a lesser degree, by Hurricane Maria. Wind forces caused extensive damage to roof coverings and rooftop equipment, which resulted in water leakage into the building. The main structural systems at Schneider, the 5-story hospital core (tower) and the 2-story wings, did not appear to experience damage during the event. The main structural systems of the 2-story Kimelman facility did not sustain structural damage. A wall cladding failure at the Kimelman addition was initially reported as being a structural failure when it was not. While

the exterior windows and wall covering of Schneider were mitigated to improve wind resistance after Hurricane Marilyn, failure of the roof covering occurred on several portions of the facility. Water intrusion at windows resulted in damage to the building interior. A single window failure due to wind pressures was observed.

#### 5.1.2.1 Main Wind Force Resisting System

The structural systems of the Schneider and Kimelman facilities performed well during the hurricanes. No structural damage was observed in the MWFRS. Based on the limited visual observations performed by the MAT in October and November 2017, there was no observed structural damage to the roof decks from the hurricanes despite the complete loss of the roof covering from the lower (second-floor) portion of the facility.

#### 5.1.2.2 Roof Coverings

The roof coverings performed with varying levels of success across the different roof levels, though elevation of the roof did not appear to be a contributing factor to poor performance. The fourth- and fifth-floor roof coverings (Figure 5-1) generally performed well. Some punctures of the membrane did occur from wind-borne debris (Figure 5-2) and there were areas where the lightning protection system (LPS) conductors broke free from their connectors (see yellow arrow in Figure 5-1).



Figure 5-1: Roof covering on upper roof on Schneider. This portion of the fifth-floor roof covering performed well; the red lines indicate the location of the rows of roof membrane fasteners. The yellow arrow indicates displaced LPS.



Figure 5-2: View of a roof membrane tear caused by wind-borne debris at an upper-level roof. The instrument in the photo is shown for scale. The lower roof coverings on the east and west side of the facility performed very differently. The lowerlevel west side roof covering performed similarly to the fifth-floor roofs noted above. However, the lower-level roof covering on the east side of Schneider experienced complete failure and loss of the roof membrane, including loss of some polyisocyanurate insulation boards beneath the roof covering itself. Figure 5-3 show the portion of the roof where the roof covering was lost. The clean, white roof covering over the entire area outlined in red was damaged and had to be replaced. This same section of the facility lost its roof during Hurricane Marilyn (1995) (Figure 5-4).



Figure 5-3: Aerial view of the Schneider Regional Medical Center after Hurricane Irma. The red arrows indicate where the roof membrane blew off (Figure 5-5). The blue X indicates where the roof over the Kimelman facility blew off (Figure 5-7). The yellow arrow indicates the roof over the mechanical equipment room (Figure 5-9). The red circles indicates areas of damaged ductwork. The green arrows indicate where duct insulation was blown off. The yellow circle indicates temporary facilities brought in after Hurricane Irma. (Photo by NOAA).



Figure 5-4: Lower roof of Schneider that lost roof covering in both Hurricanes Marilyn and Irma.



Figure 5-5: View of the roof shown in Figure 5-3 after Hurricane Marilyn.
Kimelman facility experienced major roof covering damage during Hurricane Irma. Figure 5-6 shows a portion of the roof that lost its covering; a mechanically-attached single-ply membrane was over gypsum roof board over polyisocyanurate insulation over a steel deck. With no secondary membrane over the steel deck, water leaked into the interior of the building. The facility was shut down at the time of MAT observation, 44 days after Hurricane Irma made landfall.



Figure 5-6: Roof of the Kimelman addition that was heavily damaged (yellow arrows) resulting in significant water intrusion within the facility. At the HVAC unit within the red circle, portions of the sheet metal unit enclosure cabinet blew off.

### 5.1.2.3 Rooftop Equipment

The rooftop equipment of both facilities was impacted by wind and wind-borne debris. Damage occurred to the ductwork on the top of the Schneider tower despite being behind a screen wall. Wind forces and possibly debris impacts resulted in the failure of the end of the intake unit (Figure 5-7). This failure resulted in water intrusion into the building. Additional rooftop equipment was damaged, including fan cowlings being blown off. HVAC units, including the unit within the red circle in Figure 5-8, sustained damaged to portions of their sheet metal unit enclosures (cabinet). Windborne rooftop equipment debris was a primary cause of roof membrane punctures and tears (Figure 5-8).

After Hurricane Marilyn, FEMA provided roof and rooftop equipment mitigation recommendations to the hospital. The recommendations included installation of a secondary roof membrane. The recommendations were not implemented.

Figure 5-7: View of damage at air intake. The red arrow indicates the screen wall.



Figure 5-8 shows rooftop equipment damage at the mechanical equipment room roof. Figure 5-9 shows the same area after Hurricane Marilyn.



Figure 5-8: One of the boiler stacks toppled indicated by red arrow. A fan indicated by blue arrow and fan cowling indicated by green arrow were blown off. The lightning protection system also detached.



Figure 5-9: View of the roof shown in Figure 5-8 after Hurricane Marilyn. Three of the five stacks that did not have guy-wires were blown down indicated by red arrows.

### 5.1.2.4 Building Envelope: Exterior Walls, Windows and Doors

The exterior wall of Schneider Hospital consists of exterior wall panels secured to the supporting structural frame through cold-rolled steel studs and C-shaped struts. The wall framing supporting the exterior panels also supports the windows. After Hurricane Marilyn (1995), the exterior walls were retrofitted to address vulnerabilities from wind, and the windows were replaced with units designed for wind pressure and wind-borne-debris resistance. The wall panels have been further retrofitted with additional screws to improve wind resistance (screws were installed at a spacing that varied from 6 inches to 10 inches o.c.). This approach proved effective, as no panels were observed to have been completely removed by wind.

In many instances, soffit panels above the windows were blown out of place (Figure 5-10, yellow circle). While some windows had solid soffits and others had a combination of soffit and fresh air intake above the window for the ventilation of an individual room, these parts of the cladding experienced varied performance. When the soffits or soffit/vent areas failed, it created a large opening where wind-driven rain entered the building and contributed to the water damage present on all building levels. Damage was not observed to the low roof parapets around the roof perimeter; however, there was minor damage to support struts of the screen walls around the rooftop mechanical systems atop the fifth-floor roof.



Figure 5-10: Exterior wall on the 5-story tower (east side) at the Schneider facility. The missing soffit/vent area is identified with the yellow circle. The inset illustrates how the exterior wall panels were retrofitted with additional fasteners and caulked along the seams to improve resistance to high winds and wind-driven rain.

The windows of Schneider were impact-resistant windows installed after Hurricane Marilyn (1995). These glazing systems protected the facility against damage from wind-borne debris. However, many of these windows were unable to withstand the wind-driven rain from both Irma and Maria and water intrusion occurred both through and around the window frames throughout the facility. During Irma, a single window failed due to wind pressures. Figure 5-11 shows (in the yellow circle) where a portion of a larger window bank on the fourth floor was blown into the building. Both the window and its frame were blown into the facility, indicating the failure point was at the connection of the window system to the supporting wall.



Figure 5-11: Location of window systems blown-in during Hurricane Irma indicated by yellow circle. This was the only window system where the frame separated from the supporting wall structure. Some soffits near the main entry also failed (Figure 5-12). The primary failure was detachment of the gypsum board from the metal framing.

Some of the exterior wall signs blew off (Figure 5-13) during Irma. The primary concern with soffit and sign failure is that people arriving at a hospital during a hurricane may be injured by the wind-borne debris.



Figure 5-12: Soffit failure, as indicated by red arrows.

Figure 5-13: View of a sign failure, which could potentially fall and/or become wind-borne debris during or after a storm.

The Kimelman addition experienced major damage to the wall cladding at the rear of the facility (Figure 5-14). The exterior wall system was an exterior insulation and finish system (EIFS) on a light-gauge steel frame constructed against a reinforced concrete portion of the facility, extending upward past the structural roof deck to create a short parapet. This wall system failed and pulled away from the reinforced concrete and structural steel frame wall systems due to lack of connections to the structural systems.



Figure 5-14: View of the eastern side of the Kimelman addition EIFS that failed during Hurricane Irma.

# 5.2 Myrah Keating Smith Health Center

The Myrah Keating Smith Community Health Center is a comprehensive primary healthcare facility located on St. John. The center provides 24-hour emergency services and outpatient clinics. The Health Center offers high-risk OB/GYN, well-woman examinations, and many other services, including adult medicine, pediatrics, radiology, ophthalmology, a laboratory, and nutrition counseling. Figures 5-15 and 5-16 are general views of the facility.



Figure 5-15: General view of the facility. The doors were protected by rolling metal doors, shown by red arrows. (The labels did not indicate a wind pressure rating). A flag pole is leaning against the building, indicated by yellow arrow.



Figure 5-16: View of the emergency generator building. The cowling was blown off the exhaust fan, indicated by red arrow.

The facility's emergency generator was placed in a separate building (Figure 5-17). Placing a generator within a wind- and wind-borne-debris-resistant building (as recommended in FEMA P-577) helps ensure that a generator will not be damaged during a hurricane. If generator repairs are needed during a hurricane, they can be performed, which is not the case if the generator is exposed outdoors.

# 5.2.1 Performance Relative to Flood (Coastal, Riverine)

The Health Center facility is located outside the SFHA in a Zone X, as noted on FIRM 7800000033G, dated April 16, 2007. This location is advantageous, as the facility is located well outside of any storm surge inundation zone, main roads accessing the site are not susceptible to flooding, and the site also has reasonable vertical (elevation) and horizontal (distance) separation from the nearest Zone A SFHAs.

### 5.2.2 Performance Relative to Wind and Wind-Driven Rain

Wind- and wind-driven-rain damage to the Health Center was extensive and primarily involved the roof covering and rooftop equipment.

### 5.2.2.1 Main Wind Force Resisting System

There was no apparent structural damage to the MWFRS. The structural systems at the Health Center performed well during the hurricanes.

### 5.2.2.2 Roof Covering

The mechanically-attached single-ply membrane was placed over insulation over steel deck. Because it was not adhered, once the membrane was punctured or torn by wind-borne debris, water was able to readily enter the roof system. With no secondary membrane over the steel deck, water easily leaked into the interior of the building (Figures 5-18 and 5-19). Rooftop equipment blew off and tore the roof membrane, which caused extensive interior water damage. The facility was shut down at the time of the MAT observation, 45 days after Hurricane Irma made landfall.



Figure 5-17: Aerial view of the Myrah Keating Smith Community Health Center after Hurricane Irma. The yellow arrow indicates the emergency generator building. The red line indicates the approximate location of the roof membrane tear shown in Figure 5-19. The roof membrane did not blow off. (Photo by NOAA).



Figure 5-18: View of Health Center roof system. The red lines indicate membrane tears caused by wind-borne rooftop equipment debris (see also Figure 5-20). The tear was approximately 18 feet long. The black areas at the lower left and upper right of the figure are self-adhering modified bitumen that had been installed over the singleply membrane for temporary protection.



Figure 5-19: Close-up view of the red area in Figure 5-18.

# 5.2.2.3 Rooftop Equipment

Rooftop equipment failures due to inadequate load paths caused interior water infiltration that required the facility to be shut down. The HVAC unit shown in Figure 5-20 was adequately anchored to its support stand; however, the unit itself had inadequate wind resistance.



Figure 5-20: The sheet metal enclosure (cabinet) blew off this HVAC unit. An access panel was also blown off. It appeared that wind-blown enclosure debris caused some of the roof membrane tears. Figure 5-21 shows an exhaust fan that blew off its curb because it was attached with only two screws. This is less than the recommended number of fasteners in FEMA P-577. Water was able to enter the facility at the curb opening. Further design guidance is provided in USVI Recovery Advisory 2, *Attachment of Rooftop Equipment in High-Wind Regions* (Appendix D).



Figure 5-21: This exhaust fan was attached to its curb with only two fasteners as indicated by red circles.

Figure 5-22 shows displaced LPS conductors. Conductors that become detached during a storm can puncture and tear roof membranes. The conductors were attached with common pronged connectors, which are susceptible to failure during high winds. FEMA P-577 provides recommendations for enhanced attachment. Further design guidance is provided in USVI Recovery Advisory 2, *Attachment of Rooftop Equipment in High-Wind Regions* (Appendix D).



# Figure 5-22: Detached LPS conductors as indicated by red arrow.

### 5.2.2.4 Exterior Windows and Doors

Windows were protected by permanently mounted wind-borne-debris-resistant screens (Figure 5-23). As noted earlier in Figure 5-15, the doors were protected by rolling metal doors. No screen damage was observed.



debris resistant screens.



Figure 5-24: The screen had a label indicating that it was a tested assembly, but the label did not indicate the level (i.e., the mass and speed) of the test missile.

# 5.3 Governor Juan F. Luis Hospital and Medical Center

The Juan F. Luis Hospital (previously called the St. Croix Hospital) is located in Christiansted in the center of St. Croix, south of the downtown area. The hospital was first constructed in 1982 as a 240,000-square-foot facility with a 250-bed capacity. It experienced extensive envelope damage in 1989 during Hurricane Hugo and was repaired and renovated, reopening in 1994 as the Juan F. Luis Hospital and operating with a 188-bed capacity. The hospital offers a wide variety of primary, tertiary, and specialty healthcare services, including emergency, rehabilitative, and ambulatory care. In December 2008, a new addition, the Virgin Islands Cardiac Center, opened at the hospital (Figure 5-25).

The facility is a steel frame structure with reinforced concrete floors supported by metal joists. The roof structure is a metal deck system supported on metal joists. The roof deck is topped with insulation and is mostly covered with a white mechanically-attached single-ply membrane.



Figure 5-25: Main entrance photo of Juan F. Luis Hospital in St. Croix. Storm shutters and impactresistant screens indicated by red arrows, were used to protect glazed doors and windows respectively, at the front entrance of the facility. The inset shows more detail of the large shutter systems.

# 5.3.1 Performance Relative to Flood

The facilities at the Governor Juan F. Luis Hospital are located outside the SFHA in a Zone X, as noted on FIRM 780000081G, dated April 16, 2007. This location is advantageous as the facility is located well outside of any storm surge inundation zone, main roads accessing the site are not susceptible to flooding, and the site has reasonable vertical (elevation) and horizontal (distance) separation from the nearest Zone A SFHAs. The primary flooding issue at the hospital is stormwater. Interviews with staff indicated that flooding from stormwater is a chronic issue. The stormwater issue is complex as it affects both the storm drains and sanitary sewer. When heavy rain events occur, the drainage system at the south (lower elevation) end of the site is overwhelmed and the storm and sanitary sewers back up within the building. The backup and interior building flooding occurs in the emergency rooms and operating rooms along the south and southeast portions of the facility impacting and sometimes halting services offered from these two units of the hospital. The affected areas are highlighted in Figure 5-26 in yellow circles.



Figure 5-26: Aerial view of the Juan F. Luis Hospital in St. Croix. Yellow circles identify building areas that experience interior flooding during rain events. (Photo by NOAA).

# 5.3.2 Performance Relative to Wind, Wind-Driven Rain, and Wind-Borne Debris

The hospital is divided into two distinct structures: the original 1982 hospital structure and the 2008 cardiac center addition. Both buildings are steel frame structures with concrete decks. The different wings of the original hospital vary in height from 1-3 stories, while the addition is a combination of 1- and 2-story areas.

### 5.3.2.1 Main Wind Force Resisting System

The structural systems of both the original hospital and the addition performed well during the hurricanes. Neither building experienced structural or element failures in the MWFRS. Based on the visual observations by the MAT in October and November 2017, there was no apparent structural damage to the roof decks from the events. Damage was observed to the top of the parapets around the roof perimeter, however, no parapets were observed to be toppled or compromised, and as a result, no related failure of the roof deck was observed.

### 5.3.2.2 Roof Coverings

The membrane roof on the cardiac center clinic performed well and damage was limited to small punctures and isolated areas of damage. By contrast, the modified bitumen membrane roof on the original hospital sustained major damage. The most damage was at the parapets where coping and parapet base flashing blew off. This damage occurred in isolated locations on lower roof sections, but failure was wide-spread on the third-floor roofs (Figure 5-27). When the parapet flashing was lost, it peeled back and left the roof membrane exposed to wind, which resulted in a further peeling of the roof membrane. The LPS attached to the top of the parapet through the flashing was also released when the flashing failed. This impacted the ability of the LPS to function properly while components of the LPS also punctured the roof membrane.



Figure 5-27: Loss of coping and parapet base flashing on the third floor of the original hospital led to significant water intrusion into the hospital Emergency Operating Center (EOC) located below. The LPS is also displaced. Water intrusion occurred through numerous roof punctures caused by wind-borne debris. There were several locations where the roof covering had lost its bond at the seams, allowing water to penetrate through the roof covering and into the facility below (Figure 5-28). With no secondary membrane over the steel deck, water easily leaked into the interior of the building.



Figure 5-28: Unbonded roof seams contributed to water infiltration through the roof covering behind the parapet.

### 5.3.2.3 Rooftop Equipment

The hospital had limited rooftop equipment on the upper roofs. Most equipment (air handlers, vent hoods, etc.) were located on lower roofs of the original and addition to the hospital. While some of the equipment experienced damage from the wind forces and led to water intrusion, the most significant damage was associated with an elevator vent hood (Figure 5-29). When the elevator vent hood was lost, the elevator shaft (one of three at the facility) was inundated with rainwater, resulting in a failure of the enclosed elevator and damage to the adjacent elevator. During the initial MAT field visit (4 weeks after the event), the elevators were still out of service.

The lightning protection systems were impacted by wind forces and building component failure. As noted in the previous section, the lightning protection system on the original hospital was compromised by the flashing failure on the wall parapets. Failure of the system occurred at the parapet (Figure 5-27) and at the connectors in the center of the roof. The lightning protection system on the cardiac center addition performed well and remained in place.



Figure 5-29: Loss of the elevator vent hood, indicated by red arrow, led to significant water intrusion into the hospital EOC located below elevator shafts resulting in loss of elevator service in two elevator systems.

# 5.3.2.4 Building Envelope: Exterior Walls, Windows, and Doors

The exterior walls, windows, and doors at the hospital experienced varied performance during the storms. The exterior wall system on the original hospital is primarily an EIFS, while the cardiac addition utilizes a panelized exterior wallboard system. Except for one area on the rear exterior stairwell, the wall cladding remained in place (Figure 5-30). While the cladding remained in place, there was a significant amount of water intrusion at and around the windows. During interviews, the staff mentioned that the facility experienced water intrusion issues even when the roof covering remained in place during smaller storms.

This indicates that the wall systems may require additional maintenance or be reaching the end of their useful lives, as water may be entering the building at the interface between the windows and the wall cladding systems.



Figure 5-30: View of the exterior cladding systems, windows (with protective screens), and a lower roof of the original hospital.

Glazing on the original hospital consisted primarily of double-hung windows protected with impactresistant screens (Figure 5-31). The screens are rated to provide debris impact resistance for both large and small wind-borne-debris impacts and have a label identifying that they are Dade County Approved (Florida). However, the large missile test could have been conducted with a 9-lb, 2x4 wood member impacting the shutter at either 33 mph or 50 mph, but the specific test criteria that was used was not able to be provided to the MAT. The screens performed well with no failures. The front of the hospital had multiple fixed windows and large, glazed doors. These glazed systems were protected from impact by large accordion shutter systems which performed well and protected the glazing from damage. By contrast, the cardiac center addition had fixed windows and glazed doors around the facility. The glazing was not impact-resistant nor was it protected with impact-resistant shutters. While these systems were not damaged during the hurricane, to be compliant with the latest building code requirements for wind-borne-debris protection, the windows should be protected with shutters or be replaced with code-compliant assemblies.

An additional impact from the storms was water intrusion through and around the double-hung windows in the original hospital. Figure 5-32 shows one of the many areas in the facility where water intrusion was significant. This resulted in standing water throughout the facility and created concern about the moisture level of the exterior wall system. The water intrusion was observed on all floors of the existing hospital, while the cardiac center addition experienced little to no water intrusion through its fixed windows.



Figure 5-32: Typical windows along a corridor in the original hospital facility. These windows experienced water intrusion significant enough to damage the floor covering below them.



HURRICANES IRMA AND MARIA IN THE U.S. VIRGIN ISLANDS There were several locations where large, louvered systems failed from wind forces. The louvers appeared to fail due to inadequate attachment to the supporting wall framing (Figure 5-33). Two louver panels that failed were 5-section wide louvers (the widest configuration at the hospital). The 3- and 4-section wide louvers notably performed better with a similar exposure to wind. The roof mounted PV-systems in this area experienced minor damage.



Figure 5-33: View of large louver systems that failed due to wind pressure.

# 5.4 Emergency Operations after Hurricanes

The ability to provide standard and emergency services at the hospitals and health centers in the USVI was impacted by Hurricanes Irma and Maria. The Juan F. Luis and Roy Lester Schneider Hospitals remained functional during both events. However, the Health Center and the Kimelman addition sustained major damage (primarily due to roof leakage) and have remained non-functional since the storms.

# 5.4.1 Impacts to Operations Due to Physical Damage to Facilities

The impacts of the failures of the building envelope and other systems had a profound effect on the operations of the two hospitals. Both hospitals were forced to evacuate inpatient and outpatient clients. Based on the paths of the hurricanes, the Schneider Regional Medical Center facilities in St. Thomas and St. John were impacted first and ceased normal operations and evacuated patients to their homes or other islands during Hurricane Irma. While there was a reduction in operations during Irma at Juan Luis hospital in St. Croix, the facility was not forced to halt normal operations until it was impacted by Hurricane Maria, at which time the hospital evacuated all inpatient clients.

At the time of November 2017 field assessments, both hospitals were operating at about one third of their pre-storm capacity for inpatient services. Due to the complex nature of reimbursement for repairs, only temporary repairs have been performed at each facility.

### 5.4.2 Impacts Due to Loss of Power

The most significant impact of power loss was at the Health Center on St. John. During Hurricane Irma, the facility lost primary power from WAPA and operated on generator power for approximately 2 weeks, providing basic emergency services. However, the fuel pump on the generator failed and by late September the facility had no power and was forced to shut down completely. Because there was no air conditioning to cool and dry the facility, hospital facilities staff determined that, for at least through the end of 2017, the facility could not be reopened due to mold and other air quality issues. At the time of this report, the facility remained closed due to the environmental damage (e.g., mold) caused by having been without power for an extended period of time. Services have since been relocated to a new location nearby.

Schneider was occupied during Irma by hospital leadership and operations staff, and those who stayed were concerned whether the facility would survive the hurricane. The water infiltration through the damaged roof coverings, windows, and other building penetrations resulted in the hospital shutting down all normal operations and evacuating patients immediately after the event.

For the first week after Irma, the facility operated on backup (generator) power. After approximately five days, shore power from WAPA was restored to the facility but on some days operated on generator power due to intermittent power losses as WAPA worked to restore power across the island. Throughout the cleanup, the Kimelman facility was shut down and did not return to service due to damage. The Schneider facility remained open for emergency services but shut down all non-emergency services to support cleanup operations. After several weeks, the ability to support normal inpatient services was in the process of being restored and 65 of the 188 beds were returned to provide inpatient services.

The Juan F. Luis Hospital was occupied during Hurricanes Irma and Maria. It was notable that during both storm events the facility did not lose shore power. However, due to the instability of the grid and the pulsating nature of the power being supplied (primarily power surges), the hospital elected to disconnect from grid power several times for a few hours at a time. This action was done to protect the equipment at the hospital from surge impacts.

# 5.4.3 Potable Water

The Schneider and Juan F. Luis facilities both are equipped with water storage systems that have a capacity of approximately 1 million gallons each. Neither hospital reported issues with their potable water supply for operations during the storms. The water is stored on-site and water pumps for the system are connected to the backup power generators.

# HURRICANES IRMA AND MARIA IN THE U.S. VIRGIN ISLANDS

# Performance of Critical Facilities

Critical facilities are the first line of response to severe weather events and provide necessary public services that are required before, during, and immediately after a hurricane.

First responders utilize these facilities to manage emergency operations, provide healthcare, and ensure

the active safety and security of residents. Even minor damage to buildings such as hospitals, fire stations, police stations, and communications infrastructure hubs can render them inoperable and inhibit the provision of services in part or in whole. During Hurricanes Irma and Maria, high winds and wind-driven rain had varying impacts on these facilities. Some buildings suffered little damage and exhibited resiliency, allowing critical functions to operate throughout the storms. Others were severely impacted and did not reopen for several months.

## **CRITICAL FACILITIES DEFINITION**

FEMA defines critical facilities as those buildings and facilities that are essential for the delivery of vital services or protection of a community (FEMA 2007a).

The MAT identified critical facilities to evaluate on all three islands in an array of geographical and functional areas. These included hospitals, health clinics, fire stations, police stations, and the control tower at the airport in St. Croix. Hospitals are addressed in a separate chapter due to their importance, the magnitude of damage they encountered, and the impact they can have on the community. Other facilities were chosen without specific regard to their performance, but rather by their importance to essential services on the islands. This methodology provides examples of both good and bad performances. Assessments were completed as soon as possible following the storms to determine the scope of impaired services, beginning with extensive review during the Pre-MAT visit. Because critical facilities have an inordinate impact on public welfare, returning them to service is a priority. The MAT stressed prompt data collection,

recognizing that a quick clean-up of these facilities would take place. The team also drew conclusions and provided recommendations as quickly as possible for these facilities to assist in the rebuilding process.

An important component of a critical facilities assessment is evaluation of the continuity of operations. In the moment, critical facilities are only as valuable as the functions they can provide. For example, a hospital that loses all utility and backup power typically cannot provide complete medical services. Similarly, a fire station that cannot adequately protect equipment not only threatens the engines and supplies but residents throughout the area with fire and rescue needs. The MAT gathered these operational details through a combination of in-person interviews, electronic communications, and official reports and used them to qualify the physical damage observed.

The MAT did not evaluate the electrical or water utilities of the islands beyond the performance and operations of systems within individual facilities. While FEMA is concerned with the resilience of the electrical grid and water networks, such evaluations were beyond the scope of FEMA's Building Science Branch and the MAT process. As mentioned in Chapter 1, the MAT focuses on the evaluation of building impacts to inform the thoughtful assessment and adoption of building mitigation strategies. For critical facilities, this process looks at the practices building owners and operators can use to protect essential services and the policies officials can use to encourage them.

# 6.1 Fire Stations

The MAT visited fire stations on St. Thomas, St. Croix, and St. John which sustained various levels of damage. The hurricanes caused major damage to some fire stations, including Romeo Fire Station at Coral Bay, St. John, whereas other stations, such as Omar Brown on St. Thomas, sustained only relatively minor damage. In some cases, fire stations lost communication capabilities and were unable to proceed with operations. Common problems included power loss, flooding, apparatus bay door failure, and glazing and roof covering damage. In several facilities, damage to the building envelope led to water intrusion and interior damage.

# 6.1.1 Performance Relative to Flood (Coastal, Riverine, Storm Water Sheet Flow)

The fire stations suffered little damage from coastal and riverine flooding. Siting and the limited storm surge associated with the 2017 hurricanes helped minimize these impacts. Localized stormwater runoff did create sheet flow that could penetrate buildings due to poor site drainage. The Captain Robert O'Connor Sr. Fire Station on St. John and the Hotel Company Omar Brown Fire Station on St. Thomas sustained water infiltration under doors and into the interior areas of the buildings (Figure 6-1).



Figure 6-1: Water in lobby of Hotel Company Omar Brown Fire Station, St. Thomas. (Photo by the USVI Department of Public Works).

# 6.1.2 Performance Relative to Wind and Wind-Driven Rain

The Captain Robert O'Connor Sr. Fire Station located at Cruz Bay, St. John experienced major roof damage. Debris impacts from high winds damaged large portions of the wood sheathing of the roof (Figure 6-2). The structure is comprised of masonry load-bearing walls supporting wood beams and wood roof joists. The structure lacks apparatus bay doors, and high winds could easily access the interior areas of the apparatus bays. This caused additional uplift pressure on the roof from the interior side of members, as well as exerting uplift pressures on the exterior side of members. The duel effect resulted in roof joists exhibiting twisting action from the high winds. Damage was also observed at the roof where a concrete pole adjacent to the building fell and impacted the masonry wall.





# 6.1.2.1 Coral Bay Fire Station (St. John)

The Coral Bay fire station is an older building with concrete walls and a concrete gable roof with a liquidapplied roof membrane. It is located adjacent to a facility that was previously used as a school (Figure 6-3); that facility was being used as a community center prior to Hurricane Irma and was not occupied during the hurricanes. The fire station is the only medical/fire facility on the east side of the island. It serves about 1,000 people and was occupied during Hurricanes Irma and Maria.



Figure 6-3: Aerial view of Coral Bay Fire Station indicated by red arrow. The buildings within the yellow oval are the community center (previously a school). The building within the blue oval collapsed (Figure 6-3). The red oval indicates the emergency generator. The yellow arrow indicates the ambulance shown at Figure 6-4 inset. (Photo by NOAA). Figure 6-4 is a general view of the fire station. The two apparatus bays were not equipped with bay doors and vehicles within the bays were susceptible to wind-borne debris. An ambulance was parked across the street under a car port which was blown away and was damaged by wind-borne debris (Figure 6-4, inset). Figures 6-5 and Figure 6-6 provide different views of the damage.

The emergency generator was exposed outdoors and a large tree fell on the fire station and the generator. The tree fall did not cause structural damage due to the robustness of the concrete wall and roof structure but the generator was heavily damaged, along with the electrical service, transfer switch, and condensers. FEMA P-543 recommends that emergency generators be placed inside wind-borne-debris-resistant buildings so that they are not susceptible to damage from debris or tree falls (specific recommendations are given in the publication).



Figure 6-4: General view of the fire station. The red arrow indicates the tree that fell on the generator and the roof. A temporary canopy in front of the station provided shade for residents seeking recovery assistance. The inset shows the damaged ambulance.



Figure 6-5: View of the fire station, shown in the red oval, from the community center. The primary wind direction during Hurricane Irma was to the east, i.e., from the community center towards the fire station.



Figure 6-6: View of the west side of the fire station (the primary windward side during Hurricane Irma). The red arrow indicates where a tree struck the generator. The blue arrow indicates tree debris on the roof. The yellow arrow indicates a room being used for patient treatment.

# 6.1.2.2 Hotel Company, Omar Brown, Sr. Fire Station (St. Thomas)

This was a new building that was in the final stages of construction at the time of Hurricane Irma (Figure 6-7). Although it experienced building envelope damage and subsequent water infiltration, it was used as a FEMA Disaster Recovery Center for several weeks after Hurricane Maria. In addition to building damage, there was some erosion of the slope near the building from Hurricane Maria's heavy rains.

The exterior windows and glass doors were laminated glass and did not have labels indicating a wind pressure or wind-borne-debris rating. They did not appear to have been struck by damaging wind-borne debris.



Figure 6-7: View of the fire station. The red arrow indicates the apparatus bay. The blue arrow indicates the roof shown in Figure 6-8. Rain was driven between the door to the roof and its frame during Hurricane Irma. Water flowed down the stairs all the way to the first floor. At the second floor of the facility, rooms adjacent to the balcony experienced water infiltration underneath doors that lacked weather stripping. As high winds developed, water accumulating on the balcony deck was forced towards the building and seeped underneath these doors.

Figure 6-8 is a general view of the main roof. It had a single-ply roof membrane adhered to insulation that was adhered to a concrete topping over steel deck. The membrane was punctured in a few locations by wind-borne debris. Solar panel debris from the fire station site was found on the roof after Hurricane Irma. Vegetation debris was also blown onto the roof, which partially clogged the roof drain domes and resulted in several inches of rooftop water accumulation.

Several ceiling tiles were water damaged, but there was no widespread interior damage below the roof. The lack of widespread damage was likely due to the roof membrane being adhered rather than mechanically-attached, and the presence of a concrete topping over the steel deck, which somewhat served as a secondary membrane. When a single-ply membrane is mechanically-attached and is punctured or torn, water can readily spread laterally until it reaches an insulation board joint, where it can then migrate toward the building's interior. When the membrane is adhered, if a puncture or tear occurs somewhere other than at a board joint (which is likely), water is inhibited from migrating towards the interior.



Figure 6-8: General view of the main roof. The red arrows indicate patches where the roof membrane was punctured by debris.

Figure 6-9 shows a roof puncture (likely caused by solar panel debris) that had been previously identified but not patched. This photo was taken 86 days after Hurricane Irma.



Figure 6-9: View of a roof membrane puncture that had not been patched.

Attention at this site was given to anchoring the condensers (Figure 6-10). The anchoring was similar to the type recommended in FEMA P-543; however, recommendations for enhanced attachment of the LPS were not incorporated. In one area, the LPS conductor connector spacing was substantially greater than standard recommended spacing.



Figure 6-10: The base of the condenser was bolted to the curb indicated by the blue arrows and had tie-down cables indicated by red arrows. The support for the disconnect switch was bolted to the curb. The lightning protection system conductor was no longer secured by the pronged connector indicated by green arrow.

There were six rolling doors at the apparatus bay that had a label that indicated pressure and impact resistance testing in accordance with Florida test standards, rather than the American National Standard Institute (ANSI) and Door & Access Systems Manufacturers Association International (DASMA) Standard Method for Testing Sectional Garage Doors: Determination of Structural Performance Under Missile Impact and Cyclic Wind Pressure (ANSI/DASMA 115, 2017). ANSI/DASMA 115 is more stringent than the applicable Florida test standards. The design pressure rating on the label exceeded the calculated pressure from Irma's estimated wind speed and ASCE 7-10 criteria. Despite this rating, one door had several slats disengaged from their track (Figure 6-11) and two other apparatus bay doors were not operational. Closely-spaced, bolted connections, however, were used for the attachment of the door tracks to the structure and bolstered the strength of this component (Figure 6-12).

Figure 6-11: View of slats that disengaged from the rolling door track, indicated by the red oval.



The emergency generator was mounted outdoors (Figure 6-13). Generators located outdoors are susceptible to damage from wind-borne debris (Figure 6-6). If an outdoor generator malfunctions during a hurricane, it is problematic to attempt repair during the storm.



Figure 6-12: View of rolling door tracks on either side of a column. The tracks were bolted to the column with closelyspaced bolts.



Figure 6-13: View of the emergency generator. FEMA P-543 recommends placing emergency generators within a building.

## 6.1.3 Emergency Operations

Emergency operations for the USVI fire stations were at times impaired by the severe weather of the hurricanes. Communications became inoperable, vehicles were damaged by wind-borne debris, and critical damage to facilities created buildings that were unsafe for occupancy or emergency operations. Damage was severe enough on St. Thomas and St. Croix to prohibit on-going operations for some fire stations. High winds and wind-borne debris caused apparatus bay door failure, broken windows, and roof system damage. The newly created breaches in the building envelopes and water accumulation on roofs provided opportunities for water to infiltrate into the interior of buildings, resulting in the loss of communication.

Four stations were evacuated in the district of St. Thomas and St. John: Old Hotel Company (Fort Christian), Tango Company (Bordeaux Fire Station), Zulu Company (Captain Robert O'Connor Sr. Fire Station), and Romeo Company. Communications were sporadic between St. Thomas and St. John. Numerous communication towers, radio repeaters, and local landlines were damaged during both Hurricanes Irma and Maria, making it difficult to communicate with fire department personnel on St. Thomas and St. John. Lack of power also contributed to loss of service to local businesses, governmental agencies, and residents. Wireless communication networks were almost non-existent, and many calls were dropped due to dead zones throughout the district. Certain fire stations within the district had difficulty receiving/ transmitting via telephone or radio. For example, communication between Zulu Company and Romeo Company were practically not present due to the mountainous terrain and loss of power. Firefighters communicated with each other using their own cellular telephones.

Between the St. Thomas/St. John district, numerous pieces of apparatus were taken out of service because of damage during the storms. On the island of St. John, Unit 205 received damage during Hurricane Irma. The Deputy Fire Chief's vehicle (FS-10) also sustained damage with a broken front radiator grill, cracked windshield, cracked windows, and damage to the body of vehicle. On the island of St. Thomas, Unit 203 received damage to both rear tires during Hurricane Irma while responding to a structural fire at the Miller Manor Hotel. Unit 204 received damage to both the turbo and exhaust system and was taken off-line. The Fire Chief's vehicle (FS-2) sustained water damage to the electronics and interior of the vehicle.

# 6.2 Airports

The MAT visited the main airports for St. Thomas and St. Croix. These airfields provide critical links to the outside community and impacts to their operations can be outsized and far reaching. The airports serve as a primary conduit for services and transportation and are the key to tourism, the main industry of the Virgin Islands. Both airports had damage and reduction in capabilities due to storm impacts on the building envelopes and interior damage.

# 6.2.1 Cyril E. King Airport

The Cyril E. King Airport Terminal Building in St. Thomas opened in 1990. It experienced significant building envelope damage during Hurricane Marilyn (1995) and again during Hurricane Irma. Many ground-mounted solar panels were adjacent to one of the taxiways (Figure 6-14), and a few of the panels were damaged by wind-borne debris. The framing that supported the panels failed in several areas (Figures 6-14 and 6-15).





Figure 6-15: View of failed solar panel support framing.

### 6.2.1.1 Performance Relative to Flood (Coastal, Riverine, Storm Water Sheet Flow)

While the Cyril E. King Airport on St. Thomas sits relatively low at 24 feet above sea level and is immediately adjacent to the water, with the main runway extending over one-half mile into the Caribbean Sea, it did not experience flooding or inundation from coastal, riverine, or sheet flow flooding during the 2017 hurricanes.

Figure 6-16 is a view of a portion of the standing seam metal roof. The seams were 16 inches on center. The hip flashing was attached by hemming, rather than by exposed screws. Screws provide more reliable attachment while hems are susceptible to deformation and unlatching during high winds. Blown off hip flashings can become damaging wind-borne debris and water can get underneath the metal panels at flashing breaches.

Figure 6-17 is a view of an office area below the damaged metal roof. Water leakage caused the ceiling boards to collapse.



Figure 6-16: View of blown-off hip flashing.



Figure 6-17: View of interior damage below blownoff metal roof panels.

## 6.2.1.2 Performance Relative to Wind and Wind-Driven Rain

The Cyril E. King Airport Terminal Building has a single-ply membrane at the low-slope roof and metal standing seam panels at the higher-sloped roof. Several of the metal roof and wall panels blew off during Hurricane Irma and the single-ply membrane was punctured/torn in several areas (Figure 6-18). Several exterior windows and some skylights were also broken.



Figure 6-18: Aerial view of the Cyril E. King Airport Terminal Building after Hurricane Irma. The metal panel roofs are red; yellow arrows indicate where panels blew off. The white area is the single-ply membrane. The red arrows indicate damaged areas (see blue tarps, Figure 6-17). The blue arrow indicates a row of skylights. (Photo by NOAA).

Figure 6-19 is a view after Hurricane Maria. The area covered by the blue tarps at the metal roof is much larger than the apparent damage shown in Figure 6-18. Additional panels were possibly damaged during Hurricane Maria, or there may have been damage that is not visible in Figure 6-18 (such as opening of panel seams).

The MAT observed the terminal building 44 days after Hurricane Irma. In the field of the roof, the mechanically-attached single-ply membrane fastener rows were approximately 10 feet 2 inches on center. At portions of the perimeter zone, there were two rows at approximately 5 feet on center. At other perimeter areas there were three rows at this spacing. As shown in Figures 6-19 and 6-22 portions of the perimeter were tarped. The tarps precluded determining the type and cause of the membrane damage.



Figure 6-19: Aerial view after Hurricane Maria. The red arrows indicate tarps at the single-ply membrane roof. (Photo by the Civil Air Patrol).



Figure 6-20: View of the low-sloped roof area (yellow area on right side) and the metal roof panels after Hurricane Marilyn. The red arrow indicates a tarp over metal panels.



Figure 6-21: View of a portion of sloped roof after Hurricane Marilyn. The yellow arrow indicates the steel roof deck. The green arrow indicates the roof insulation. The red arrow indicates a metal panel clip.



Figure 6-22: View of one of the tarped areas at the roof perimeter. The red arrows indicate the membrane fastener rows. The blue arrow indicates a lightning protection system conductor.

The roof membrane was punctured/torn in a few hundred locations (Figures 6-23 through 6-25 The membrane was placed over insulation over the steel deck. Because it was not adhered, once the membrane was punctured or torn by wind-borne debris, water was able to readily enter the roof system. With no secondary membrane over the steel deck, water easily leaked into the interior of the building. Water also leaked into the building where rooftop equipment blew off its curbs.

After Hurricane Marilyn, FEMA provided roof and rooftop equipment mitigation recommendations for the airport terminal building. The recommendations included installation of a secondary roof membrane. Most of the recommendations were not implemented.



Figure 6-23: The blue tarps are over broken windows. A large number of temporary patches are shown on the roof. Several of the roof membrane punctures/tears were likely caused by glass shards.

A large number of skylights exist on the east side of the building (the leeward side of the primary wind during Hurricane Irma). They appeared to be adequately attached to their curbs, although some of the screws were corroded. A few of the skylights were broken by wind-borne debris (Figure 6-22), illustrating the importance of specifying skylights that have been tested to meet wind-borne-debris criteria.



Figure 6-24: Skylight damaged by wind-borne debris. The red arrows indicate patches.



Figure 6-25: A large number of roof membrane patches are shown within the red oval. The red arrow indicates a tarp at a piece of rooftop equipment.

Several condensers were not attached to the roof (i.e., there was lack of a continuous load path, Figure 6-26).



Figure 6-26: None of these condensers were attached. The blue tarp is covering broken windows.

The exhaust fan in Figure 6-27 was attached to the curb with two screws at each side of the curb. This is less than the number of fasteners recommended in FEMA P-543 and USVI-RA2, *Attachment of Rooftop Equipment in High-Wind Regions* (Appendix D). The fan cowling was strapped to the curb. Strapping is recommended in FEMA P-543 and USVI-RA2, *Attachment of Rooftop Equipment in High-Wind Regions*; however, for the USVI basic wind speed, strapping to all four sides of the curb is recommended, rather than to just two as shown in Figure 6-27. Installation of the tie-down straps was the only post-Hurricane Marilyn mitigation observed at this building.

Figures 6-27 and 6-28 show detached LPS conductors. Conductors also detached at the metal roofs and were attached with common pronged connectors (Figure 6-28). Displaced LPS was likely a major cause of roof membrane punctures/tears. Guidance for enhanced attachment of LPS is given in FEMA P-542 the USVI RA 2, Attachment of Rooftop Equipment in High-Wind Regions.



Figure 6-27: This fan cowling had a tie-down strap on two sides of the curb. One of the straps indicated by red arrow was damaged by debris impact. The blue arrow indicates a lightning protection system conductor.

# 6.2.2 Henry E. Rohlsen Airport



Figure 6-28: Several temporary patches were made after the hurricane. The LPS inidicated by red arrow also detached during Hurricane Marilyn (1995).

The MAT visited the Henry E. Rohlsen airfield control tower on St. Croix. The tower itself belongs to the Virgin Island Port Authority and is used by the Federal Aviation Administration (FAA). The facility, built in 2004, was constructed to withstand the effects of environmental hazards while providing shelter and continued operations to support the airfield (Figure 6-29).



#### Figure 6-29: Henry E. Rohlsen airfield control tower on St. Croix.

### 6.2.2.1 Performance Relative to Wind and Wind Driven Rain

The St. Croix control tower was occupied during the hurricanes to help support its mission, though this was not a requirement of the FAA. Tower personnel often find that the tower complex is more sturdy and secure than other places and chose to remain on-site at their own risk. The level of expected damage to roads, widespread power outages, and other travel challenges contributed to the decisions of many who chose to remain on-site during the storm. The tower experienced some leaks from upper levels down the core to the elevator pits, which managed to soak the drywall at the ground floor lobby (Figure 6-30).

Water entered the lower level bathrooms from the lower roof. The bathroom on the ground level became unusable due to the backflow through the toilets. It appears that the storm-force winds, possibly combined with the plumbing vent location, created a substantial pressure differential. The ensuing waste water contamination on a majority of the bathroom interior surfaces required a large clean-up effort (Figure 6-31).





Figure 6-30: Lobby and elevator shaft with drywall removed. A fire alarm pull station on this wall had wire damage.

Figure 6-31: View of the bathroom where water leaked down the interior walls. The drywall was removed to facilitate drying and the blue foam insulation can be seen.

The tower has a steel frame core and uses exterior upper mezzanines to house air conditioning condensers for upper floors. The exterior mezzanines have bar-grating floors to aid air flow and utilize fans to exhaust the hot air from the mechanical platforms. During the storm, loose materials were lifted from the bar-grating floors and entered the exhaust fan Thousings that are interlocked with the fire control system. The exhaust fans failed and placed the fire alarm system into alert. This was partially why the use of the tower was lost. (Figure 6-32).



Figure 6-32: Exterior elevated open floor used to house HVAC condensers. The exhaust fans above the condenser units were damaged from debris on the floor that was lifted into the fan housing by the high winds.



Figure 6-33: Image of generator room and door that opened during the hurricane allowing wind-driven rain into the generator room.



Figure 6-34: View of the airfield facing west for the control tower. A shipping container, indicated by red arrow, was rolled from the base of the tower by the hurricane-force winds.



Figure 6-35: Equipment pads and displaced condensers above the mechanical and electrical rooms.

# HURRICANES IRMA AND MARIA IN THE U.S. VIRGIN ISLANDS

# Wind Performance of Solar Panel Systems

Solar power in the USVI is a rapidly growing industry, providing both distributed and utility scale electricity for all three islands.

With ample sunshine and advantageous sun angle, the islands leverage solar panels (also known as photovoltaic [PV] panels) to reduce utility dependence on more traditional energy sources, such as diesel fuel. Due to the islands' low latitude, the sun is high throughout the day and year, allowing for high solar power production. The USVI has a goal of reducing fossil fuel consumption 60 percent by 2025. Pursuant to this goal, the government of the USVI has been encouraging renewable energy technologies through incentives and net-metering programs. As of 2015, approximately 15 megawatts (MW) of generation potential, or about 13 percent of USVI Water and Power Authority's (WAPA's) peak demand, was being produced by distributed rooftop systems through WAPA's net-metering program (DeCesaro 2015, Business View Caribbean 2016). Homeowners are increasingly turning to rooftop solar panel systems for some or all of their monthly usage, recognizing that they can both save money and potentially mitigate outages caused by storm-induced conditions. However, many ground- and rooftop-mounted solar panel systems (also known as arrays) were damaged during Hurricanes Irma and Maria. Likewise, mitigating the loss of service during outages requires additional batteries and inverters that are less common at present. The MAT observed a variety of solar panel arrays to determine relative performance, develop recommendations for future action, and encourage resilient rebuilding efforts.

At the utility scale, the number of ground-mounted solar arrays has increased, providing more centralized production of PV power. One of the largest ground-mounted solar projects in the USVI, Estate Spanish Town, has a production capacity of 4 MW and was included in the MAT's observation for its relative success during the storms (WAPA 2014). Projects like this help the USVI achieve another one of its goals of generating 30 percent of peak capacity from renewables by 2025 (U.S. National Renewable Energy Laboratory 2015). However, as with roof-mounted systems, performance of ground-mounted systems during Hurricanes Irma and Maria varied significantly.

# 7.1 Performance of Ground-Mounted Solar Panel Arrays

The MAT observed very large solar arrays (farms) as well as small arrays. Observations were conducted with a focus on the differences in array performance. Even when exposed to relatively similar conditions, the observed arrays performed dramatically differently. On St. Croix, a comparison between the performance of the arrays in Estate Spanish Town and the array at the U.S. federal district courthouse in Christiansted showed a vast difference in resilience, despite both projects being completed in the last several years. The comparison of performance is detailed in the following subsections and highlights the relative areas of improvement and success in the ground-mounted solar sector. See Section 6.2.1 for a ground-mounted solar array at Cyril E. King Airport on St. Thomas.

# 7.1.1 U.S. Federal Courthouse Solar Array

Located on the eastern side of the island near the town of Christiansted, this solar array is located adjacent to the U.S. Federal District Court of the USVI (Figure 7-1 and 7-2). The array was built and managed by the General Services Administration (GSA) and was recently opened before the 2017 hurricanes. The general location of the array is approximately one third of a mile from the coastline. The array is made up of 10 rows of 4 frames and an 11th row with 3 frames, each with 5 rows of 7 panels, for a total of 1,505 solar panels. The array was designed for solar exposure, with panels angled from southwest (low side) to northeast (high side). The frame design consists of open-section (C-shaped) beams supported by single metal posts with poured concrete foundations and small diagonal braces (Figures 7-3 – 7-5). Lateral open-section (C-shaped) metal rails run perpendicularly between the cantilevered beams. On top of these rails are open-section (hat-shaped) metal support arms, to which the panels themselves are directly attached with screws. The support arms are attached to the rails with light-gauge clips made of pressed steel that act as clamps and can be tightened with fasteners. Diagonal struts also connect the support arms to the rails at regular intervals, using screws at each end.



Figure 7-1: Aerial view of U.S. Federal District Courthouse solar array project after Hurricane Maria. (Photo by NOAA)



Figure 7-2: Aerial view of site of U.S. Federal District Courthouse solar array project indicated by yellow oval with the shoreline in the distance indicated by yellow arrow, Christiansted, St. Croix.

Almost the entire solar array was damaged during the hurricanes. At the time of the MAT observations, the array was not operational, with the components in a state of disarray, scattered as debris. The MAT observed that the cantilever design and open-section supports may have contributed to significant fluttering and vibration of the panels due to wind uplift. This exerted cyclical loading on the clips and frame, leading to failure of these components. While this wind loading pattern cannot be verified, the damage suggests that flutter was likely.

The estimated wind gusts in the area were approximately 115 mph (exposure C, at 33 feet above grade) during Hurricane Maria. Generally, it appeared that the clip attachment and bracing hardware proved inadequate for these loads. The clips, their fasteners, and the diagonal struts were not strong enough to hold the support arms to the rails against the various forces exerted on the panels. Once the support arms were loose and twisted, individual panels were cracked and pulled from them. The MAT observed numerous clip and fastener failures, which allowed the support arms and panels to break loose and turn into wind-borne debris that threatened the rest of the array (Figure 7-3).



Figure 7-3: View of the failed damaged solar array at the U.S. federal district courthouse. The yellow arrow indicates the shoreline in the distance. Christiansted, St. Croix.
Similarly, the lateral rails between the beams frequently failed. As panels fluttered and the support arms were eventually pulled from the rails of the frames, many of these rails were bent or pulled from the rest of the frames themselves (Figure 7-4).





Figure 7-4: View of failed clip and fastener, as still attached and highlighted by the yellow circle (left), and separated from the rails (right). As the edges of the panels detached from the frame, they loosened and exposed nearby panels and damaged the frame in the process.



Figure 7-5: Single self-tapping screws used to attach the diagonal strut and rail-to-beam clamps were both a source of failure during Hurricane Irma at this PV system on St. Croix (photo by Andy Walker, National Renewable Energy Laboratory).

#### **DESIGN GUIDANCE FOR GROUND-MOUNTED PV:**

ASCE 7-16 does not provide criteria for determining wind loads on ground-mounted PV systems. However, some guidance is provided in PV2-17.

FM Global Loss Prevention Data Sheet 7-106 provides guidelines and recommendations for the design, installation, and maintenance of ground-mounted PV systems.

### 7.1.2 Estate Spanish Town Solar Array

This large solar array is located on an inland hillside in the central part of St. Croix. The 4 MW facility was constructed in 2014 as a joint agreement between Toshiba, NRG Energy, and WAPA and produces 14 percent of St. Croix's current power demand. It is located approximately 1.4 miles north of the southern coast of the island and immediately north of an old industrial plant. To the site's eastern and southeastern sides is a large wooded area. Estimated winds in this area were near 120 mph (exposure C, at 33 feet above grade), according to Figure 1-8). The array is made up of 16,748 panels in 50 rows of long frames of varying length, the longest row of which is nearly 875 feet long. Each frame is made up of two rows of panels and is angled for solar exposure from southwest (low side) to northwest (high side). Supporting electrical equipment for the facility is housed in a CMU building in the middle of the site, which was not significantly damaged by the hurricanes.

The frame design consists of a cantilevered metal beam supported by a metal post driven into the ground (Figure 7-6). The array has a total of 3,044 posts with 5 to 6 feet of embedment, and according to the facility operators, were push/pull tested upon installation. A diagonal beam runs between the top of each post and the cantilevered beam. Four lateral rails run perpendicular to these beams and are attached with clamps that can be tightened. The beams and rails are closed-section metal construction of various shapes and gauges. The panels themselves are attached with metal clips made of extruded aluminum that hold them to the rails and can also be tightened. According to the facility managers, these clips were torqued to design specifications upon installation.



Figure 7-6: View of the mostly intact solar array at Estate Spanish Town, St. Croix, after the hurricanes (left) and the design of beams, posts, and rails of its framing system (right).

The array sustained minor damage, with most frames and panels remaining completely intact. At the time of the MAT observation, the site appeared mostly unharmed, but was not operating due to limited repairs and tests needed to bring it back into service. This lack of service shows that even for minor damage to utility-scale PV arrays, disruptions to production can still last several months following a storm. (WAPA 2017).

In total, 106 panels were damaged, with 64 blown partially off their frame. Most of the damage was observed in a single location along the eastern edge of the array. The edge was the most susceptible area, where uplift forces from wind could get up and under the panels. Unlike at the federal courthouse site, the panels often stayed attached to the rails as the rails pulled away from the rest of the frame. A primary point of failure was the bolts connecting the closed section beam to the post (Figure 7-7). These bolts were not self-locking and became loosened by the cyclical loading associated with wind gusts during hurricanes. When the bolts failed, a portion of the rails and connected panels were separated from the rest of the frame, creating a cascading effect. As the edge section began to lift, subsequent forces caused a failure of the clamps connecting the rails to the diagonal beams further down the array. The panels stayed mostly attached to the rails as this occurred. This cascading damage was limited and only extended to several immediately adjacent panels. Such cyclical loading occasionally bent or twisted the supporting posts throughout the array as well. Only about 400 posts were damaged, of which less than 50 were identified by the facility operators as needing replacement.



Figure 7-7: Overturned solar panels at the edge of the array at Estate Spanish Town. Failed bolts, shown missing in the yellow box, allowed the rails and panels to pull loose and lift additional sections of the array (left image). The wind load-loosened bolts were found immediately adjacent to the damage.

The robustness of the closed-section beams, posts, and rails could explain why damage was limited; even where uplift forces on the panels were extensive and where portions of the rails pulled away, this extra support may have mitigated flutter and vibration and limited the damage caused by it. The clips, clamps, and other associated hardware were generally more robust and proved superior to those at the courthouse site. These components were made of a thicker, extruded aluminum as opposed to the thinner, stamped steel used at the courthouse. As mentioned, all the clips that held the panels to the rails (Figure 7-8) were reportedly torqued to design specifications and all posts were push/pull tested upon installation. In the case where the posts proved inadequate to this testing, they were re-installed. This attention to installation and testing protocols likely played a role in the survival of most of the array.





Figure 7-8: Close-up view of clips that held the PV panels to the rails of the array at Estate Spanish Town. These clips were used at the end of frame sections (left) and in-between panels within a frame section (right), as indicated by the yellow circles. Their design of extruded aluminum was robust and performed well; even in one section where the rails detached from the rest of the frame, the panels mostly remained clipped to the rails.

#### 7.1.3 Estate Donoe Solar Array

This large solar panel array is located on an inland hillside in the central part of St. Thomas. The 5 MW solar power generation facility at Estate Donoe was constructed in 2014-2015 as a joint agreement between the Main Street Power Company, Morgan Stanley, and WAPA to provide 10 percent of the demand on the island. At the time of the 2017 hurricanes, it was an AES Corporation Distributed Energy project called USVI Solar I. The site (Figure 7-9) is located on the eastern side of St. Thomas approximately 1.5 miles north of the southern coast of the island in a very hilly and rough terrain area that was previously undeveloped. Estimated winds in the area were near 150 mph (exposure C, at 33 feet above grade) (Figure 1-8). The array itself is situated on the south face of the hillside off Donoe Road. Solar panels were deployed in rows on frames that followed the terrain of the hillside and were not "benched" or leveled into the hillside. Two rows of panels are placed along each run of frames; however, specific details related to the number of panels deployed could not be verified by the MAT due to the extensive damage across the site and the inability to obtain site plans. At the time of publishing of this report, the solar array was unrepaired and not operational.



Figure 7-9: Aerial view of the Estate Donoe Solar Array on St. Thomas. (Photo by Civil Air Patrol).

The frame design consists of a series of cantilevered metal Z-purlins supported by metal, square tubular beams, where each beam is supported by a pair of metal H-shaped columns that are welded to base plates, which in turn are bolted into concrete foundation elements. A diagonal strut extends upward out from the column base plates to support the cantilevered square tubular beams at each end of the frames. The beams and purlins are a combination of closed- and open-shaped sections. On each frame assembly, there are two sets of Z-purlins aligned parallel to each other and perpendicular to the square tubular members. The panels span across two purlins, creating two rows of panels on each individual frame assembly. One complete frame assembly typically supports either 10 or 14 solar panels. The panels themselves have a perimeter, light gauge metal frame that supports the panels and connects them to the Z-purlins with bolts. The bolts are inserted through pre-cut holes in the light gauge metal frames for the panels and the Z-purlins These holes were too large when compared to the size of the bolts used to connect the panels, and almost all connectors used two to three washers on each side of the connection (bolt head and nut) to keep the fasteners from pulling through the pre-cut holes in the frames and supporting structural members.

The array sustained significant damage with roughly 50 percent of panels being damaged or blown from the frames. The array was not operational during the MAT visit and remains offline at the time of this report. While topography appeared to play a role in protecting large portions of the array from experiencing maximum winds, other areas were heavily damaged. The combination of closed and open sections that made up the supporting structure experienced varied performance. The lower portion of the frame assemblies (columns and square tubular beams) generally performed well; however, the Z-purlins and the light-gauge metal frames supporting the solar panels experienced the most damage (Figure 7 10).



# Figure 7-10: View of the framing for the Estate Donoe Solar Array.

The frames had a notable amount of flexibility. Even frames that were fully intact (those that lost no solar panels) could be easily moved by hand resulting in several inches of displacement of the frame assembly. This flexibility, as opposed to rigidity, was notable, but no analysis was performed to evaluate if this contributed to the failure of the Z-purlins and the loss of panels due to dynamic or vibrational movements during the event. The Z-purlins experienced deformation and failures when the solar panels were exposed to the storm winds. Many of the "leading edge" purlins (the purlins on the lower row of a frame pulled up the hillside by winds from the south as Irma passed to the north of the island) failed and were missing

from the frame assemblies. When the purlins separated from the square tubular beams, or when they deformed due to overloading, the solar panels were broken or damaged (Figure 7-11).



Figure 7-11: Damaged purlings and solar panels at the Donow Solar Array indicated by red arrows.

Based on the brief field visit and aerial photos, about half of the solar panels experienced damage and failures. The failures of the panels occurred across all portions of the frames and at different locations across the hillside. While many panels themselves were damaged, the MAT was not able to determine if the damage to the panels themselves initiated failure and separation from the supporting frames, or if the failure occurred with the panels intact due to a failure of the connectors securing the panels to the frames. While the failures at Donoe were similar to those at the federal courthouse site in that the panels separated from the supporting frames, the primary failure point at Donoe was at the connectors (bolts). Only four bolts were used to secure the panels (via the panel's metal frame) to the Z-purlins. Failure modes included pull-over from the solar panel frame over the bolt/washer connector, tearing of the solar panel frame at the bolt connection, and bolt pull-through at the Z-purlin (Figure 7-12). Further, where the bolts did not fail, they were observed to be missing nuts and washers, as the bolts were not self-locking and became loosened by the cyclical loading; this is a typical failure mode caused by wind gusts during hurricanes. Most connection failures were between the solar panels and the Z-purlins. But while most Z-purlins remained in place, many were damaged, bent, and deformed.



Figure 7-12: View of failure of the metal frames supporting the solar panels. Only four bolts were used to connect the panels to the supporting frame through the light gauge metal frame on the panel itself. Red circles identify failure points.

As noted at the other sites, the greater robustness of the lower portions of the frame, which used closedsection beams, could explain why damage to these portions of the frames was limited, even where uplift forces on the panels were extensive and where portions of the Z-purlins pulled away, this extra support may have mitigated flutter and vibration and limited damage caused by it. However, it is unlikely that many of the frames experienced full wind loading, because the loss of solar panels from the frame would result in the wind loads being dissipated when the panel failed and was blown off the frame. It should be noted that of the three larger ground solar sites presented in this chapter, only the Donoe site anchored the solar panels through its light gauge metal frame and did not employ the use of clips, clamps, or other external fasteners to anchor the panels.

#### 7.1.4 Small Ground-Mounted Arrays

Two small ground-mounted arrays were observed on St. Thomas. The array shown in Figures 7-13 and 7-14 had approximately 76 panels. The array was located in Exposure D, in an area with an abrupt change in topography; therefore, wind speed-up likely occurred. The panels were attached with compression clamps to extruded aluminum rails. The rails were attached to wood beams which were attached to concrete columns.

A perimeter beam was broken (Figure 7-14). This failure was likely caused by wind-borne debris which caused the beams that were supported by the perimeter beam to drop, and resulted in progressive failure of rails and panels.



Figure 7-13: View of a small ground-mounted array.



Figure 7-14: The broken perimeter beam is within the red oval. The red arrow indicates one of the beams that dropped after the perimeter beam failed. The yellow circles indicate panel clamps.

Figure 7-15 shows a panel clamp and rail. The rail was attached to the beam with a clip and lag bolt. Figure 7-16 shows a panel clamp that was not damaged.



Figure 7-15: View of a panel clamp, rail, and connection of the rail to the beam.



Figure 7-16: View of undamaged panel clamp. The clamp connects two adjacent panels. The red arrow indicates the rail underneath the panels.

The arrays shown in Figures 7-17 and 7-18 had approximately 120 panels. They were located in Exposure D. The panels were attached with compression clamps to extruded aluminum rails. The rails were attached to concrete columns. Limited access precluded making detailed observations. However, it appeared that the damage was primarily caused by wind-borne debris.



Figure 7-17: The panels within the red oval and the panels indicated by the red arrows had been damaged by wind-borne debris. Six panels to the left of the panels with the red arrows detached from the rails. The yellow arrows indicate panels that lifted. There was no apparent damage at the array shown by the blue arrow.



Figure 7-18: In addition to the windborne debris damage to panels and rails in the foreground, some panels beyond were damaged. A few panels detached from the rails but did not blow away (similar as shown at the yellow arrows in Figure 7-17).

Figure 7-19 shows panel clamps. The clamps near the end of a rail only connected one panel.



Figure 7-19: View of panel clamps. The red circles indicate end clamps. The yellow circles indicate clamps that connect two panels. The red arrow indicates a concrete column. The two panels to the left had been broken by wind-borne debris.

# 7.2 Performance of Rooftop-Mounted Solar Panel Arrays

At the time of Hurricane Marilyn (1995), many buildings had rooftop solar hot water heaters, but PV panels were not observed. The 2017 USVI MAT observed a few rooftop hot water heaters (Figure 7-20), but they were not nearly as prevalent as in 1995. The MAT noticed a large number of rooftop PV arrays on all three islands. Most of the arrays were on residences, but arrays also occurred on non-residential buildings. Some had only two panels, while others had more than 100 panels. The MAT made observations at several arrays, as shown and described below and in USVI Recovery Advisory 5, *Rooftop Solar Panel Attachment: Design, Installation and Maintenance* (Appendix D). None of the observed arrays had wind deflectors.



Figure 7-20: View of solar hot water heaters. The red arrow indicates windborne debris damage. The yellow arrow indicates PV panels beyond.

Some of the observed arrays were connected to standing seam metal roof panels with external seam clamps; however, the majority of the solar panels were attached with panel clips that were attached to extruded aluminum rails with stainless steel T-bolts that had a single flanged nut. The underside of investigated nuts had a flange that was serrated (the serrations are intended to prevent loosening). T-bolts and panel clamps from three different manufacturers were examined. One of the damaged arrays had stainless steel panel clamps. All the other arrays had extruded aluminum clamps.

The rails were attached to the roof support structure and/or the roof deck with clip angles or posts (support stands). Rail blow-off was observed at only two arrays. The panels shown in Figure 7-21 were much longer than most of the observed panels. A rail near the rake was blown away (Figure 7-22). The rails were attached with clips that were anchored through the corrugated metal roof and into the roof support structure.



Figure 7-21: Blow-off of panels adjacent to the rake was initiated by failure of a rail connection, indicated by red arrow (Figure 7-22). The yellow arrow indicates a panel that lifted but did not blow off. The adjacent up-slope panel did blow off, indicated by orange arrow.



Figure 7-22: View of damaged rails. The red arrow indicates a rail that is still attached. The red line indicates where a rail blew off. It was attached with two clip angles. The bolts connecting the angles to the rail pulled out of the rail.

Figures 7-23 and 7-24 show a private school on St. John where 126 solar panels were installed in April 2015. Only nine panels (7 percent) remained on the roof. The building was in an area with an abrupt change in topography; therefore, wind speed-up likely occurred. The rails were attached with clips that were anchored through the metal R-panel roof and into the roof support structure. One or more rails blew off, but lack of access precluded determining the failure mode.



Figure 7-23: View of the severely damaged solar panel array indicated by yellow arrow. The nine panels that remained on the roof are indicated by the red arrow.



Figure 7-24: Aerial view. The yellow arrow indicates the array. The red arrow indicates the nine panels that remained on the roof. The blue arrow indicates skylights at the ridge. The orange arrow indicates a damaged wood trellis structure. The green arrow indicates the primary wind direction during Hurricane Irma. The hillside slopes up towards the school. The severity of the tree damage was typical of the hurricane impacts. (Photo by NOAA)

Three arrays were observed that were attached to standing seam metal roof panels. The solar panels were attached with panel clamps attached to external seam clamps at two of the buildings (Figure 7-25). At the third building, the panels were clamped to rails that were attached to external seam clamps. Use of rails resulted in overstressing the concealed clips that attached the metal panels to the roof deck; several roof panels and the attached PV panels blew off. Special attention is needed when attaching panels to standing seam metal roofs, as discussed USVI Recovery Advisory 5, *Rooftop Solar Panel Attachment: Design, Installation, and Maintenance* (Appendix D).

#### USVI RECOVERY ADVISORY 5 ROOFTOP SOLAR PANEL ATTACHMENT: DESIGN, INSTALLATION, AND MAINTENANCE (USVI-RA5)

In addition to providing examples of various levels of PV array performance and failure modes observed after the 2017 hurricanes, USVI RA-5 provides design and construction mitigation guidance and an overview of codes, standards, and guidelines that pertain to attachment of PV arrays.

https://www.fema.gov/media-library/assets/documents/158123

Solar panels that are operational after a hurricane can be extremely beneficial if they can provide power to the building even if the municipal power is not operational. The residence shown at Figure 7-26 had wind-borne debris damage to the array, but it was quickly repaired. At the time of the MAT observation (86 days after Hurricane Irma), municipal power had not been restored in this area, which was high on a mountain. However, the array provided the family's electrical power needs, except for the clothes washer and dryer, and the house did not have an air conditioner.



Figure 7-25: View of damaged panel clamps. The red arrow indicates a panel clamp. The yellow arrow indicates an external seam clamp. Clamps were not installed at each seam as indicated by yellow circle, which can lead to overstressing.



Figure 7-26: View of residential rooftop. The red arrow shows a small portion of the array that is on the backside of the roof. The yellow arrow indicates an area where the liquid-applied membrane had peeled away.

# HURRICANES IRMA AND MARIA IN THE U.S. VIRGIN ISLANDS

# Conclusions and Recommendations

The conclusions and recommendations 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 Territory and local officials and other interested parties.

They are intended to assist the USVI, 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 Hurricanes Irma and Maria. Section 8.1 is a summary of the conclusions and recommendations observed during the MAT. Section 8.2 discusses general conclusions and recommendations. Section 8.3 discusses conclusions and recommendations related to building codes, standards, and regulations. Section 8.4 discusses conclusions and recommendations related to general building considerations. Section 8.5 includes conclusions and recommendations related to residential buildings. Section 8.6 includes conclusions and recommendations for manufactured housing. Section 8.7 includes conclusions and recommendations and recommendations related to solar panel systems. Section 8.10 discusses conclusions and recommendations related to solar panel systems. Section 8.10 discusses conclusions and recommendations on FEMA Technical Publications and Guidance. Section 8.12 provides a summary of the conclusions and recommendations in a tabular format.

# 8.1 **Overview of Conclusions and Recommendations**

The recommendations are presented as guidance to the Territory and those who are involved with the design, construction, and maintenance of the built environment across the islands. The government of the USVI and the entities involved in reconstruction and mitigation efforts should consider these recommendations in conjunction with their existing priorities and resources when determining how they can or will be implemented.

Overall, improved performance was seen across all roof systems in homes and other buildings that were constructed post-Marilyn that were designed to the 2003 *International Building Code* or newer or where the design followed the Third Edition of the *Construction Information for a Stronger Home* guidance. The structural plans with details regarding design codes were unavailable for review at time of field assessment.

Many of the conclusions and recommendations center on encouraging DPNR to assess its code development and enforcement programs and implement a code and standards program that will withstand the elements over time. In addition, the conclusions and recommendations provide guidance on ensuring that the buildings provide robust systems to withstand wind, flood, and seismic events. This not only includes the roof systems but the glazing, doors, and energy systems as well.

The MAT Conclusions and Recommendations are prioritized within each section as those that may be of most important to implement by the Territory, community or interested party. Specifically, recommendations of note include, in order of recommended immediate action to those that may take longer to implement:

**Recommendation USVI-1a: USVI should adopt the latest hazard-resistant building codes and standards on a regular update cycle.** 

**Recommendation USVI-8: DPNR should consider hiring additional code enforcement staff.** 

**Recommendation USVI-14b:** Homeowners should consider protecting the glazed window and door systems on their existing homes.

**Recommendation USVI-19: Develop and support a wind retrofit programs across USVI.** 

**Recommendation USVI-34a:** Add specific design criteria for ground-mounted PV solar arrays and connections to ASCE 7-22 and reference them in other select codes.

#### **4TH EDITION OF CONSTRUCTION INFORMATION FOR A STRONGER HOME**

DPNR recently published the 4th Edition of *Construction Information for a Stronger Home*. This edition provides clear guidance for the homeowner to design to the most recent codes and standards at the time of this publication.

The previous edition of this document was released in 1996 and did not reflect natural-hazard-resistant provisions (requirements) of the building codes and standards developed over the past 20-plus years. This edition provides details specifically addressing framing or MWFRS connections that create a continuous load path from the roof to the foundation to address forces quantified in the building codes from flood, wind, and seismic events, details which should be updated and released in new guidance. These revisions include but are not limited to higher ultimate design wind speed criteria, higher wind roof pressures for components and cladding because of higher pressure coefficients, wind topographic effects that include wind speed-up, considerations for seismic design as stipulated in ASCE 7-16, and current references to the latest structural wood connectors.

# 8.2 General Conclusions and Recommendations

#### **Conclusion USVI-1**

The most heavily damaged buildings lacked a continuous load path: Most of the buildings that experienced partial or total failure of their structural systems, particularly roof systems, lacked a continuous load path. In some instances, a continuous load path was present, but members or connections within the load path were unable to carry the loads experienced during the storms. While some buildings experienced failures when structural members failed, the failure of the individual structural member was not the most commonly observed failure. The most common type of failure occurred when a connection between two structural members failed. When guidance from the Third Edition of the USVI Stronger Home Guide was followed, most roof systems withstood the high wind.

The Department of Planning and Natural Resources (DPNR) is the entity within the USVI that administers the USVI Building Code, issues building and construction permits, and provides interpretations on the codes and standards in force on the islands.

**Recommendation USVI-1a: USVI should adopt the latest hazard-resistant building codes and standards on a regular update cycle.** To help enable new buildings to better resist the impacts of hurricanes, floods, and seismic events, the latest editions of the hazard-resistant building code (and reference standards) should be adopted by the USVI on a regular basis. Currently, the USVI automatically adopts the latest edition of the model building codes (I-Codes) six months after publication. Any amendments to the USVI Building Code (*Virgin Islands Code, Title Twenty-Nine, Public Planning and Development, Chapter 5. Building Code*) must go through legislation. The charge language (*Virgin Islands Code, Title Twenty-Nine, Chapter 5. Building Code*, § 292. *General purposes, application, and scope*) in the USVI Building Code lacks clarity, and written notification of updates and amendments does not always take place.

**Recommendation USVI-1b: DPNR should continue to update** *Construction Information for a Stronger Home* (The Stronger Home Guide) as the International Building Code and International Residential Code are updated. Prescriptive design and construction guidance have long been helpful to building officials, designers, contractors, and owners of residential construction, especially one- and two-family dwellings. As the IRC© and IBC© change, DPNR should ensure that the most recent and up-to-date guidance and design loads are provided for in the guide.

#### **Conclusion USVI-2**

**Numerous temporary facilities are vulnerable to wind hazards and have been installed for longer than their intended purpose:** Many facilities used by schools and other public entities were designed and constructed for temporary use after Hurricanes Hugo or Marilyn or other storm events. These temporary facilities were critical in allowing public functions to return to service; however, these facilities were not replaced or upgraded with structures or retrofits to meet the hazard-resistant provisions of the building code at the time of their construction. Many of the temporary buildings installed after Hurricanes Hugo and Marilyn were still in use almost 20 years later during Hurricanes Irma and Maria and were damaged by wind forces, rain, and other loads they were not designed or constructed to resist.

Recommendation USVI-2: The permitted use of temporary buildings should be limited to 180 days, as set forth in the International Building Code. DPNR issues permit for and regulates temporary buildings per Section 108 of the IBC© which states that building officials are permitted to issue permits for temporary buildings and temporary use of those buildings. However, this section limits the time of service these buildings may be used before needing to be taken out of service or brought into compliance with the requirements of a permanent building under the building code. DPNR should monitor the temporary facilities that have been permitted during the 2017 recovery efforts and either require removal of temporary buildings after the allotted time or enforce the code requirement that buildings or structures installed as temporary use structures be brought into compliance with the building codes should they transition to permanent-use structures. If the expected length of use is uncertain, DPNR can require the temporary structures to be constructed or installed per the current building code; this was the requirement DPNR implemented for temporary classrooms being installed in the summer of 2018. DPNR should develop a process for which the temporary facilities are closely monitored, and removal is encouraged over time.

#### TERMINOLOGY

Temporary Facility refers to a building, structure, or facility that is designed and constructed to serve a shortterm life expectancy. These facilities, though used by the public, are not required by code to comply with the structural strength, fire safety, means of egress, accessibility, light, ventilation, and sanitary requirements of the IBC© as necessary to ensure public health, safety, and general welfare. There are appropriate applications to permit a temporary building for use over a short duration after a disaster while a more permanent structure is being constructed. Examples of these buildings may include (but are not limited to) portable school buildings, post offices, or medical clinics.

#### **Conclusion USVI-3**

**Some building owners have a limited awareness of hurricane hazard risks and vulnerabilities:** The quality of planning and preparedness for Hurricanes Irma and Maria at the buildings visited by the MAT varied greatly. This variance of planning may have been due to the information sources used to identify the risks and vulnerabilities to wind and flood events, as well as local government recommendations about whether to close the facilities during the event. Many building managers and owners may not have been aware of the higher risks to their buildings from such severe hurricane events.

Recommendation USVI-3: Perform vulnerability assessments. Prior to a disaster and on a regular schedule, facility and building owners should consider a vulnerability assessment conducted by a team of knowledgeable professionals to help determine options available to mitigate hazards and risks for buildings; critical facilities and key assets; and other structures that may be heavily impacted by a flood, wind, or seismic event. Owners should identify vulnerabilities and include mitigation measures in short- and long-term facility maintenance and capital improvement programs to realistically address the vulnerabilities over time, where possible. Facility owners and operators should work with key internal staff and design professionals to analyze their facilities, key systems and components, operational assumptions, and operation plans to determine a path forward for developing project priorities and funding capital improvements that maximize facility and operational resiliency. FEMA P-424 Design Guide for Improving School Safety in Earthquakes, Floods, and High Winds (FEMA 2010x), FEMA P-543 Design Guide for Improving Critical Facility Safety from Flooding and High Winds (FEMA 2007) and FEMA P-577 Design Guide for Improving Hospital Safety in Earthquakes, Floods, and High Winds: Providing Protection to People and Buildings (FEMA 2007) are building-use-specific guidance documents that include multi-hazard vulnerability assessment checklists for schools, critical facilities, and hospitals, respectively.

# 8.3 Building Codes, Standards and Regulations

#### 8.3.1 USVI Code

#### **Conclusion USVI-4**

The local USVI Building Code amendments conflict with some of the requirements and referenced standards in the latest edition of the International Codes (I-Codes): In response to Hurricane Marilyn (1995), the USVI adopted the 1997 *Unified Building Code* (UBC) and then the 2003 I-Codes (with local amendments) to be the referenced building code for the USVI, with local

#### TERMINOLOGY

USVI Building Code refers to Title 29, Chapter 5 of the USVI Code.

Referenced Code means the I-Codes, which are model codes referenced in the USVI Building Code.

amendments (*Virgin Islands Code, Title Twenty Nine, Public Planning and Development, Chapter 5. Building Code, §292 General purposes, application, and scope*). Since that time, new I-Codes have been developed, new referenced standards included, and others updated to provide improved technical guidance. The USVI Building Code refers to the guidance document which provides information on local amendments and charging language. Language in the USVI Building Code takes precedence over what is in the referenced or adopted standard unless certain specific conditions apply, such as the I-Codes providing more stringent design loads.

In addition, the USVI Building Code is interpreted to automatically adopt the latest edition of the I-Codes six months after publication (*Virgin Islands Code, Title Twenty Nine, Public Planning and Development, Chapter 5. Building Code, §292 General purposes, application, and scope*). However, there is no Legislative action or trigger to review and update local amendments to ensure that the most recent edition of the I-Codes, or referenced codes and standards, if automatically adopted, do not conflict with the current USVI Building Code. Currently, there are several conflicts between the local amendments presented in the USVI Building Code and the most recent edition of the I-Codes.

**Recommendation USVI-4a: The USVI should consider updating and clarifying local amendments and specify a recurring code update cycle.** The USVI should consider an update and clarify local amendments to the USVI Building Code that are appropriate for the construction methods and materials most suitable for construction on the islands. When the USVI Building Code adopts the latest edition of the I-Codes, DPNR should ensure that any update does not result in conflicts with the locally adopted building code amendments.

**Recommendation USVI-4b: Provide published process for stakeholders to suggest amendments to the USVI Building Code.** A published process should be provided to allow for stakeholders to suggest amendments to the building code. This can be accomplished through legislative action or Executive Orders, as was previously done for the adoption of the 2003 I-Codes, or it may be achieved through other means, such as through the establishment of a building code commission.

#### **Conclusion USVI-5**

The referenced building code is not clearly presented or defined (named code, edition, and year) with the local amendments: In response to Hurricane Marilyn in 1995, the USVI adopted the 1997 Unified Building Code (UBC) and then the 2003 I-Codes (with local amendments) to be the referenced building code for the USVI. There is not a summary or interpretation of the legislated USVI Building Code amendments available for distribution via print, web, or other media.

**Recommendation USVI-5: DPNR should use multiple means of media (print, website, etc.) to identify the current edition of the I-Codes that is being referenced as the USVI Building Code (including appendices) and list all local amendments.** While the USVI Building Code is currently adopted through the legislature, it is implemented and enforced by DPNR. To support the legislature with the development, implementation, and enforcement of the USVI Building Code, DPNR should support the program through the development of an online information portal. When DPNR begins the enforcement of a new edition of the I-Codes, a summary document should be prepared and released to summarize the update that has taken place, to address (generally) the codes or standards that have been updated and identify if any local amendments have been updated. Further, this portal could provide downloads or enable access to the USVI Building Code, relevant DPNR policies, the latest edition of the prescriptive design guides for the USVI (i.e., *Stronger Home Guide*), procedures, forms, permits, USVI statutes or other information through an up-to-date online website for residents, design professionals, construction contractors, building owners or any other interested party.

#### **Conclusion USVI-6**

**The signing and sealing of construction documents is too permissive in USVI Building Code:** Currently, the USVI Building Code states that registered engineers and architects as well as certified draftsmen may sign construction drawings (*Virgin Islands Code, Title Twenty Nine, Public Planning and Development, Chapter 5. Building Code, §298 Supervision and Certification*). Due to changes in the IRC© since 2003, the design of residential structures to provide better wind, flood, and seismic hazard resistance has become more involved. The building codes require more engineering calculations, professional judgement, and technical documentation to show compliance. Prescriptive design options provided by the IRC© in high wind, hurricane-prone geographies such as the USVI do not meet the design criteria identified for the USVI. Therefore, the design of new residential buildings, along with repairs to substantially damaged buildings, falls under the IBC©, which details specific construction documents that are to be prepared and submitted and limits the individuals who can sign and seal those documents to professional engineers and registered architects.

**Recommendation USVI-6: Amend the USVI Building Code and restrict the signing and sealing of construction documents to registered design professionals.** To ensure compliance with the design and construction requirements of the 2018 I-Codes, DPNR should revise its permitting and approval process to only allow professional engineers and registered architects to stamp and seal construction documents (*Virgin Islands Code, Title Twenty Nine, Public Planning and Development, Chapter 5. Building Code, §298 Supervision and Certification*).

#### **Conclusion USVI-7**

**Building damage/repair triggers in the USVI Building Code based solely on financial replacement costs for buildings/systems can be simplified:** The USVI Building Code provides a clause for when repairs are required to comply with the latest edition of the requirements of the USVI Building Code (*Virgin Islands Code, Title Twenty Nine, Public Planning and Development, Chapter 5. Building Code, §310 Applications to Existing Buildings*). These requirements are triggered when more than 25 percent of the value of a building or portion of a building (such as a roof system) is damaged, or at the discretion of the Commissioner of DPNR. However, the standard of practice in the USVI has moved to a trigger based on the percentage of area of a building element being repaired (or that was damaged) versus the value of the damage or repair.

**Recommendation USVI-7: DPNR should amend the current code for percent damage repair triggers.** DPNR should amend current code to allow for the current practice of using percent damage to an existing building or existing structural systems within the building to determine if compliance with the latest I-Codes (under the USVI Building Code) is necessary. The USVI should update the Building Code to also document in writing its current practice based on percentage of area being repaired (or that was damaged) as the trigger for new code compliance; to include the measure of damage based on percent of building systems or percent damage to a discrete building element or system (*Virgin Islands Code, Title Twenty Nine, Public Planning and Development, Chapter 5. Building Code, §310 Applications to Existing Buildings*).

#### 8.3.2 DPNR

#### **Conclusion USVI-8**

**DPNR Lacks adequate staffing to enforce the latest building codes and standards:** The requirements of the latest building codes necessitate that knowledgeable, trained staff be available to review and issue permits, evaluate design and construction packages, and inspect and enforce the building code. The building code requirements (including for residential construction) require new construction, and repairs past an identified threshold, to be permitted and accompanied by signed and sealed design and construction documents. The current staffing allocation within DPNR of three full-time staff limits the resources available to perform the compliance and enforcement activities set forth by the referenced code adopted by the USVI – the IBC© and the IRC©.

**Recommendation USVI-8: DPNR should consider hiring additional code enforcement staff.** DPNR should hire, train, and support additional staff for permit, inspection, and code enforcement efforts during the post-Irma and -Maria reconstruction activities. After an initial surge of support is provided through EMAC, DPNR can determine the number of staff that is be retained for long-term support of the building code and use the current EMAC and Hazard Mitigation Grant Program (HMGP) grant opportunities to bring in building officials for a short duration.

#### **Conclusion USVI-9**

**Training is needed for local code enforcement staff on the latest building codes and standards:** Building codes cannot be effectively implemented and enforced without adequately trained staff. When new codes and standards are being adopted, code enforcement staff should be provided adequate training on the content and relevant code changes being made when compared to the existing codes. This training should take place in advance of the new codes being implemented.

**Recommendation USVI-9: Provide training to building code enforcement staff on the latest edition of the referenced code that has been adopted.** DPNR should work with ICC© and FEMA to provide access to training on the 2018 I-Codes to ensure all code enforcement staff are adequately trained and up-to-date on current changes to the building code and standards and on associated local amendments.

#### **Conclusion USVI-10**

**DPNR does not provide a list of specific notes and design criteria for design professionals to include on construction drawings:** The IBC© and IRC© provide some guidance for minimal information that should be included on construction documents to clarify design information and criteria. However, the minimum guidance provided in the code is much less than requirements set forth to be included on construction drawings in other areas prone to hurricanes, for example, by many county building departments in South Florida.

**Recommendation USVI-10: DPNR should consider requiring that construction documents list critical design parameters, including seismic design loads, and to show load path connections.** To implement and enforce the new codes, DPNR staff charged with permitting, plan review and inspections should require a more exhaustive

list of the flood, wind, and seismic design criteria used for the home or building. The design professional responsible for the design and construction of new residential buildings (as well as repairs to existing buildings) should be made aware of the high seismic design criteria for the USVI. In the permitting process, DPNR should ensure the design professional checks wind loads against seismic loads; these are dependent upon the site condition, the geometry of the house and foundation, and the weight of materials used for construction. In addition, the criteria would include not only design criteria that can be verified to ensure the design professional is starting with the correct parameters, but also testing information related to debris impact protection systems for glazing, water intrusion, flood-resistant materials, corrosion-resistant materials, and other performance-based building components.

#### **Conclusion USVI-11**

**USVI lacks key resources to help DPNR enforce codes:** DPNR currently does not have a list of hazardresistant materials or hurricane products and components that have already been tested and approved for use by other entities (e.g., registered laboratories, counties, or states in hurricane-prone regions) to provide certifications or ratings for wind and flood hazards. Two jurisdictions with such lists include Dade County, Florida, and the Texas Department of Insurance.

**Recommendation USVI-11a: Maintain a list of select tested and approved hazardresistant materials for key systems.** DPNR should consider maintaining a list of select building products that are tested and approved to address vulnerabilities and help provide protection from wind and flood events. DPNR does not need to develop its own product certification program but rather maintain a cadre of lists from jurisdictions with similar hazards of known approved products to assist designers, contractors, and code enforcement staff in identifying products that are already tested or certified for appropriate natural hazard load application. A list of products and materials complying with hazardresistant codes and standards including items such as shutters, impact-resistant glazing, other window assemblies rated for high-wind pressures, or various connectors used to establish a continuous load path would be helpful for builders and design professionals.

**Recommendation USVI-11b: Work with local construction material suppliers to ensure that tested and approved materials are available in store for homeowners and building owners for rebuilding.** DPNR should consider working directly with the construction material suppliers on the islands to ensure that they have the tested and approved materials in stock or have a plan in place to quickly receive these materials after a disaster event. This ensures that homeowners can rebuild with disaster resistant materials immediately after an event instead of waiting for local stores to provide adequate stock.

#### RESOURCES

Jurisdictions with lists of tested and approved hazard-resistant materials for consideration:

Miami-Dade product control requirement:

http://www.miamidade.gov/building/pc-search\_app.asp

The Florida Product approval system:

<u>https://www.floridabuilding.org/pr/pr\_app\_srch.aspx</u>

The international code council uses the ICC-ES reports as their basis for hazard resistant products.

<u>http://www.icc-es.org/reports/index.cfm?search=search</u>

The Texas Department of Insurance also has a list of approved products.

http://www.tdi.texas.gov/wind/prod/index.html

#### **Conclusion USVI-12**

**Staged construction performance varied:** The performance of structures with staged or phased construction varied. Some instances were observed where structural and building envelope performance was impacted by partially constructed elements of single family homes.

**Recommendation USVI-12a: Limit extended open permit periods for staged or phased construction.** Staged and phased construction is not addressed with specific time durations within the IRC©. DPNR should consider providing guidance on permits for construction that is left incomplete (i.e., extended rebar through roof sections for future second stories, partially completed additions, etc.).

**Recommendation USVI-12b: Protect material during staged construction.** Where extended open permit periods exist for staged construction, DPNR should provide requirements for ensuring that the materials used in the construction of the home maintain their original strength (i.e., capping rebar).

#### 8.3.3 NFIP and the USVI Floodplain Management Ordinance

#### **Conclusion USVI-13**

**The USVI Floodplain Management Ordinance is old and out of date:** The USVI Floodplain Management Ordinance was drafted in 1993 and amended in 1998. While the 1998 update produced an Ordinance that was reasonably well-linked to the 2003 I-Codes for floodplain management purposes, the existing Ordinance no longer properly coordinates with the many changes that have been made over the past 15 years to the 2018 I-Codes. This will result in vulnerable development that will not meet NFIP requirements and construction that will be susceptible to unnecessary damage during future storm events. Although efforts have been made since 1998 to update the Ordinance, no changes have been formally adopted.

**Recommendation USVI-13: Update the USVI Floodplain Management Ordinance and integrate with the IBC**<sup>©</sup> and IRC<sup>©</sup>. The USVI Floodplain Management Ordinance should be updated and integrated with the flood-resistant provisions currently included in the 2018 I-Codes. This ordinance needs to be properly integrated with IBC<sup>©</sup> Section 1612, IBC<sup>©</sup> Appendix G, and IRC<sup>©</sup> Sections R301, R322, and R401 (and other sections), enabling effective compliance for all development with the flood-resistant provisions of the I-Codes and the NFIP. The flood-resistant provisions of the IBC<sup>©</sup> and IRC<sup>©</sup> and their reference standards, primarily ASCE 24, provide improved criteria for flood-resistant construction. DPNR should utilize FEMA's model floodplain ordinance to help them develop and adopt its own that seamlessly integrates with the I-Codes.

# 8.4 General Building Considerations

#### **Conclusion USVI-14**

Windows (glazed openings) on most existing buildings are vulnerable to damage and failure from wind pressures and wind-borne debris: The MAT observed that buildings of all types with unprotected windows (glazing) on exterior walls are vulnerable to failure from wind pressures and wind-borne debris. When these glazed openings fail, the buildings are exposed to additional internal wind pressures, and the building interior also becomes exposed to the wind and rain associated with the events. These failures were observed in all building types visited by the MAT, including residential homes, businesses, schools, hospitals, and critical facilities.

**Recommendation USVI-14a: Existing critical facilities should protect their windows.** Existing critical facility owners and operators should protect windows and glass doors with rated opening protection systems (i.e., storm shutters) or retrofit the structures with impact-resistant glazing. Perform a vulnerability assessment as set forth in the general recommendations section. USVI Recovery Advisory 4, *Design, Installation, and Retrofit of Doors, Windows, and Shutters* (Appendix D) provides guidance on the installation and protection of windows and doors.

**Recommendation USVI-14b: Homeowners should consider protecting the glazed window and door systems on their existing homes.** Existing residential home owners should consider protecting glazed (glass) window systems and doors with rated opening protection systems (i.e., storm shutters); retrofitting the home with impact-resistant glazing; or using prescriptive plywood shutter panels as allowed by the building code. USVI Recovery Advisory 4, *Design, Installation, and Retrofit of Doors, Windows, and Shutters* (Appendix D) provides guidance on the installation and protection of windows and doors. When those options are cost prohibitive, consider constructing and maintaining plywood panels that are cut and sized to cover each window or glass door at the home (per the wood panel design criteria for opening protection set forth in the IRC© and *The Stronger Home Guide*.

**Recommendation USVI-14c: Building owners and property managers of commercial and large, multi-unit residential buildings should consider protecting the windows on existing buildings.** Existing non-residential buildings owners and property managers should consider protecting windows and glass doors with rated opening protection

systems (i.e., storm shutters) or retrofitting the structures with impact-resistant glazing. USVI Recovery Advisory 4, *Design, Installation, and Retrofit of Doors, Windows, and Shutters* (Appendix D) provides guidance on the installation and protection of windows and doors.

#### **Conclusion USVI-15**

Water intrusion through and around existing windows (glazed openings) and metal panel jalousie systems was pervasive: Water infiltration into buildings occurred both at glazed openings and through metal panel jalousie window systems. Metal panel jalousies were the least effective in keeping wind-driven rain and water out of buildings. These issues were observed in most building types visited by the MAT, including residential homes, businesses, schools, and critical facilities.

**Recommendation USVI-15a: Replace older glazed (glass) openings in existing buildings with new windows designed and tested to resist water intrusion**. To address water intrusion issues around glazed openings on existing buildings, replace and re-flash existing windows with windows designed to meet the pressure testing requirements set forth in ASCE/SEI E1105, *Standard Test Method for Field Determination of Water Penetration of Installed Exterior Windows, Skylights, Doors, and Curtain Walls*, by Uniform or Cyclic Static Air Pressure Difference (ASCE/SEI E1105 2015). Where conditioned space exists behind the glazed window system, consider use of impact-resistant glazing or glazed openings that are protected with impact-resistant (opening protection) systems such as shutters. Note, opening protection systems that protect from wind and wind-borne debris are not rated to reduce water intrusion for the windows and openings they protect.

**Recommendation USVI-15b: Consider using water damage resistant materials to address water intrusion for interior spaces that have exterior jalousie window systems.** When using jalousie window systems, designers and contractors should consider the use of materials resistant to damage from wind-driven rain within the occupied space where these jalousie windows are used. Although these systems provide some benefits of shading, privacy, minimal non-rated impact resistance, they are not typically sealed systems and enable significant amounts of wind-driven rain to enter the building's interior spaces, with associated potential damages. See *FEMA Technical Bulletin 2 (TB-2), Flood Damage-Resistant Material Requirements (2008).* (https://www.fema.gov/media-library/assets/documents/2655)

#### **Conclusion USVI-16**

**Excessive water intrusion through existing exterior doors was observed:** It was observed that many existing exterior doors had excessive water penetration from wind-driven rain intrusion and often lacked weather stripping.

**Recommendation USVI-16: Mitigate exterior doors with improved water intrusion resistance.** For new construction, design and install a vestibule using flood- and waterresistant materials at each door to provide additional protection from wind-driven rain as set forth in ASCE/SEI E1105, *Standard Test Method for Field Determination of Water Penetration of Installed Exterior Windows, Skylights, Doors, and Curtain Walls, by Uniform or Cyclic Static Air Pressure Difference*. This test method helps to simulate a wind driven rain event under severe rainfall conditions. For existing construction, consider replacing old doors and retrofit the building with new weather stripping. See USVI Recovery Advisory 4, *Design, Installation, and Retrofit of Doors, Windows, and Shutters* (Appendix D) for guidance on the installation and protection of windows and doors.

# 8.5 Residential Buildings

#### 8.5.1 Conventional, Site-Built Homes

#### **Conclusion USVI-17**

**Roof panels (coverings) often lacked structural roof decks beneath them:** The MAT observed many homes with metal panel roof coverings that performed poorly. These roof coverings were often blown off by the hurricanes. In most cases observed, these homes did not have a wood deck beneath the metal panels. The absence of a structural deck below the roof panels, the absence of any secondary roof element below the panel to remain in place if the covering be blown off, and the lack of adequate anchorage for the panel coverings led to reduced stability of the roof structure and full exposure of the building interior and its contents when the metal panels failed.

**Recommendation USVI-17: Require the use of wood decks below roof coverings.** For new and existing homes, DPNR should consider requiring the use of wood structural panels, wood boards, or other panel system capable of carrying loads and supporting the panel roof systems above. These systems provide adequate stability, a load path, and a solid roof deck beneath the roof covering and comply with the requrements of the building code. A roof deck should be required unless calculations are provided to DPNR demonstrating the adequacy of the open wood or metal frame (or composite frame) system to address wind loads or other applicable site hazard loads. *Construction Information for a Stronger Home*, 4th Edition and USVI Recovery Advisory 3, *Installation of Residential Corrugated Metal Roof Systems* (Appendix D) provide guidance on improving wind and water intrusion performance of the roof covering and its structural system and establishing an adequate load path from the metal covering all the way down through the foundation.

#### **Conclusion USVI-18**

**Key wind vulnerabilities remain in many undamaged homes:** The MAT observed several homes that experienced little to no structural damage from Hurricanes Maria and Irma yet remain vulnerable to the effects of high winds. These homes may not have experienced the highest winds because of their locations on the islands, however, hurricanes could impact the homes in the future. In most cases, the connections between the structural members and the unprotected glazed openings are the weakest links in the load path and are vulnerable to failure.

**Recommendation USVI-18: Homeowners should consider evaluating and retrofitting existing homes for wind vulnerabilities.** Homeowners should consider hiring design professionals to evaluate their existing roof structure to determine if it can carry at least 75 percent of the design load (per the 2018 *International Existing Building Code* [IEBC]). If it cannot, perform wind retrofits using design guidance found in FEMA P-804 *Wind Retrofit Guide for Residential Buildings* (FEMA 2010x). Also, apply other wind retrofit techniques described for the different protection levels of P-804 to holistically improve the hazard resistance of homes.

#### **Conclusion USVI-19**

Home Protection Roofing Program (HPRP) roof design, when implemented correctly, performed well: The MAT observed that roof systems and designs compliant with HPRP standards appeared to perform well across the USVI during Hurricanes Irma and Maria.

**Recommendation USVI-19: Develop and support wind retrofit programs across USVI.** DPNR and the USVI should consider developing a new retrofit program to address roofing, structural, and building envelope issues in a comprehensive approach to wind mitigation. This work can build on the design and retrofit guidance developed in FEMA P-804 and combine it with guidance provided in the *Stronger Homes Guide*.

#### **Conclusion USVI-20**

**Utility service mast roof penetrations through roof coverings performed poorly:** Where utility service masts penetrated the existing roofs, localized roof failure and water intrusion damage often occurred. Because most roofs have overhangs or porches, when the power feed is extended up from the wall (where the meter is located) the mast typically is extended up through the roof covering.

**Recommendation USVI-20: Avoid penetrating roof coverings, including porches and overhangs, with utility service masts.** New construction and most major renovations are required by the USVI Water and Power Authority (WAPA) to install new meter pedestals at homes for power and utility connections. Where existing homes are being repaired or renovated, installation of a new meter pedestal will prevent the need to penetrate the roof with a utility service mast. The area where the mast penetrates the roof introduces weakness in the panel, requires repair when damaged to prevent water intrusion and creates unnecessary vulnerabilities to the structure and its contents.

## 8.6 Manufactured Housing

#### **Conclusion USVI-21**

Many manufactured housing units (MHUs) experienced near-total damage from a wind event that was at or below design levels for the USVI: Very few, if any, MHUs visited by the MAT were designed to comply with the current USVI wind speed and wind-borne-debris protection requirements. On St. Croix, MHUs in each of the three MHU communities sustained numerous failures of large sections of walls and roof framing, with a higher percentage further impacted by significant loss of siding, loss of roof covering, and roof deck damage. This is more damage than would be expected from a design-level event for MHUs that should be HUD Zone III units (designed for 110 mph fastest mile wind speeds [approximately 163 mph, 3-second gust wind speeds]). The observed and expected damage is more consistent with Zone I and II homes not designed to resist these wind speeds.

**Recommendation USVI-21: Ensure MHUs are properly designed and installed for their given HUD wind zones throughout USVI.** MHUs should have wind ratings capable of resisting specific USVI wind performance criteria for their given HUD zones. DPNR should ensure that any MHU proposed for installation in the USVI be provided with the same permit and sealed construction drawings addressing wind, flood, and seismic loads as site-built homes are required to submit for compliance with the USVI Building Code. MHUs installed in the USVI should be designed and installed to resist the same flood, wind, and seismic loads—and the same debris impacts—as traditional, site-built homes.

#### HUD INSTALLATION STANDARDS FOR MANUFACTURED HOMES

HUD Installation Standards are published in 24 CFR 3285. The standards provide requirements for wind, seismic and flood. These can be found at: <u>https://www.ecfr.gov/cgi-bin/text-idx?SID=a2c5655a37054c584f7dd6a0ed240fb8&node=pt24.5.3285&rgn=div5%20-#se24.5.3285\_1405</u>

#### **Conclusion USVI-22**

**MHU labeling had often been removed, making it difficult to identify units:** FEMA MAT members had difficulty identifying the age and design criteria used for many MHUs. Interior and exterior labels and plates were often removed during renovations of MHUs or after they sustained damage during Hurricanes Irma and Maria.

**Recommendation USVI-22a: DPNR should require MHU labels or placards to be maintained on all MHUs regardless of age or the renovation of the unit.** DPNR should enforce a requirement that all MHU installed and maintained in the USVI retain the HUD label or placards to ensure that new units are appropriate for the wind hazards and that existing unit are properly identified.

**Recommendation USVI-22b: HUD should consider location of MHU labels or placards such that any renovation of the exterior material, sun damage, or water damage does not cover the label.** HUD should consider the placement of the exterior MHU label in the wake of this season's flooding and natural disasters to determine if a better placement location exists, or placement in multiple locations, to ensure that these labels remain visible throughout the life of the product.

# 8.7 Schools, Hospitals, and Critical Facilities

#### **Conclusion USVI-23**

**Buildings having their main or first floor levels at or near adjacent grade can be very vulnerable to localized flood damage:** Several schools, fire stations, and other critical facilities were damaged as localized flooding occurred at the building sites, even where the mapped flood hazard area was identified as Zone X. Although individual site conditions led to localized flooding in many cases, had the elevation of the main or first floor of these buildings been constructed several inches higher than the adjacent grade, less flood damage to the facilities would likely have occurred.

**Recommendation USVI-23: Elevate main (primary) floors of buildings above adjacent grade.** Designers and contractors should provide a differential of at least 8 inches between the top of the finished floor elevation of the main (primary) floor and the surrounding grade. As a best practice, buildings should be built with the finished floor elevated above surrounding grade. A common practice is to make the grade difference one stair height or 8 inches above grade at its lowest point. Local practice may call for this elevation to be higher or lower. This allows easy accommodation for access and egress by use of a single stair, ramp, or pad.

#### **Conclusion USVI-24**

Internal pressures were not adequately addressed through open/louvered window assemblies and metal jalousie window systems: Many multi-use and gymnasium school facilities with long-span roofs were damaged during the hurricanes. While the larger, structural members of the MWFRS did not fail, intermediate structural members, roof decking, roof coverings, and exterior walls systems were all observed to experience failure indicative of internal pressurization of the building.

**Recommendation USVI-24: Designers must consider and adequately address internal wind pressures.** For new construction, and for repairs to existing buildings, use of louvered openings that allow free passage of air into facilities, especially in long-span buildings, must properly account for and address internal wind pressures and the effects they have on building components.

#### **Conclusion USVI-25**

**Design and installation of wind-resistant roof coverings was often inadequate:** Although the MAT observed examples of good roof covering performance, the number of roof covering failures at schools, hospitals, and critical facilities that resulted in a significant impact or complete loss of functionality was notable, especially at hospitals and critical facilities. Failures observed started with roof flashing and continued through the different roof covering attachment methods.

**Recommendation USVI-25a: Design and install new and replacement roof coverings for critical facilities to resist high winds in accordance with ASCE 7-16**. Identify roof coverings that are vulnerable to high winds and design new roof systems in accordance with ASCE 7-16 wind loads.

**Recommendation USVI-25b: Avoid the use of single-ply roof membranes.** Avoid the use of single-ply roof membranes for critical facilities; these systems are vulnerable to puncture, tearing, and blow-off.

#### **Conclusion USVI-26**

**Maintenance of roof coverings was often inadequate:** Many of the schools and public buildings observed by the MAT had roof coverings that were inadequately maintained or past their useful life. When impacted by the storms, these roof coverings failed even though the roof decks supporting them did not, resulting in significant damage and loss of function. Further, when roof coverings did remain in place, many roofs (including those at hospitals, an airport, and schools) were punctured by wind-borne debris.

**Recommendation USVI-26: Regularly assess, adequately maintain, and repair or replace roofs when needed.** Building owners and operators (both public and private) should develop maintenance programs for their building exteriors, specifically for roof coverings and roof systems. Much of the damage and loss of function to schools, critical facilities, and hospitals could have been limited or avoided if roof coverings were properly installed, maintained, and replaced when worn out. The maintenance programs should include a section to address punctures of the roof coverings (membranes, systems, etc.) for when roof coverings remain in place but are damaged.

#### **Conclusion USVI-27**

**Inadequate anchoring of rooftop equipment caused unnecessary damage to roof systems and building contents:** At several locations visited by the MAT, debris that punctured roof coverings (at the airport, both hospitals, several schools, and public buildings) was generated from the building itself. The punctured roof coverings led to water intrusion even when the roof covering remained in place. Roof mounted equipment of any type should be designed to adequately resist being displaced by (design level) wind speeds for the given location. Where HVAC components were not adequately anchored on flat roof systems, some of the HVAC elements were blown off, causing portions of the roof covering to be unnecessarily removed or damaged.

Recommendation USVI-27: Adequately anchor HVAC and other equipment to roofs.

Design professionals and building managers should adequately anchor HVAC systems to resist high wind loads; this applies to both new and existing buildings and equipment. USVI Recovery Advisory 2, *Attachment of Rooftop Equipment in High-Wind Regions* (Appendix D) and FEMA P-543 provide specific guidance for anchoring HVAC and other equipment to the roof, roof structure, or parapets. If the equipment cannot be adequately mounted on the roof, then consideration should be given to moving the equipment elsewhere on-site.

#### **Conclusion USVI-28**

**Equipment penthouses and elevator equipment vents on roofs notably failed:** The MAT observed the failure of rooftop equipment, penthouses, and vent structures that resulted in impacts to mechanical systems and vertical conveyance systems that caused buildings to lose important functions and operational capacity. The hospital in St. Croix was most notably affected when vent hoods were blown off the roof and allowed wind-driven rain to enter the hospital, causing a failure of the elevators' mechanical systems. This damage resulted in the loss of operations within the facility.

**Recommendation USVI-28: Design mechanical penthouses and equipment housing to resist high winds.** After a vulnerability assessment has been completed, mitigation to reinforce existing elevator penthouse structures, other mechanical and equipment penthouses, and to secure rooftop equipment should be designed per ASCE 7-16 wind load requirements.

#### **Conclusion USVI-29**

Some facilities had insufficient protection for backup power generators, switches, and equipment, including fire alarm systems: The airport and several fire stations lost backup and emergency power when their generators were damaged as a result of the failure of their protective enclosures. Additionally, damage to fire alarm systems at the airport in St. Croix caused FAA to shut down the control tower.

**Recommendation USVI-29: Protect backup and emergency generator systems and equipment to requirements of ASCE 7.** Emergency generators and back-up power should be designed in accordance to the requirements of ASCE 7-16 and other applicable codes and standards dependent on their use.

#### **Conclusion USVI-30**

Large, overhead roll-up doors failed under wind loading and debris impact at critical facilities: The MAT observed that wind forces and wind-borne debris damaged large overhead doors that were intended to protect apparatus bays and vehicles at several fire stations. While many fire stations had buildings in which to store fire apparatus, some of these buildings experienced damage from wind forces and many of the large, overhead doors also were damaged by wind and wind-borne debris. Damage occurred to the doors themselves, resulting in door failures that left the door unusable and preventing equipment from being able to be deployed from the facilities. In other instances, the failure of the large doors resulted in damage to the buildings themselves and vehicles housed inside the buildings.

**Recommendation USVI-30: Use only large overhead doors that have been tested and certified for wind loads and debris impact associated with the design criteria for the site.** Vulnerability assessments of existing fire stations should be performed as provided in Recommendation USVI-3. Fire station facilities and vehicles housed therein are vulnerable to damage from wind pressures and wind-borne debris. If buildings are constructed to protect these vehicles, the large overhead doors through which the vehicles enter and leave the facility should be designed and constructed to resist wind loads and wind-borne debris as required by ASCE 7-16. Designers should also address the seismic design of doors and frames to prevent racking and non-functionality immediately after an earthquake. Building owners and operators should install new garage/apparatus bay doors rated for wind loading and debris impact resistance. Installing new doors will help protect the integrity of the building envelope by reducing the vulnerability of the large doors being breached. This breach increases internal wind pressures and loads increasing the possibility of building failure.

## 8.8 Sheltering

#### **Conclusion USVI-31**

There are currently no public Safe Rooms designed to FEMA P-361 criteria or Storm Shelters designed as per ICC 500<sup>©</sup> in the USVI for protection of residents during hurricanes: Safe rooms and storm shelters provide buildings or portions of buildings that have been designed and constructed to provide life-safety protection from high wind events such as hurricanes. Storm shelters, and their associated design criteria, are identified and defined in the IBC<sup>©</sup> if they are to be constructed in a

jurisdiction, but they are not currently required to be constructed in the USVI. There are currently no public safe rooms or storm shelters in the USVI that have been constructed to the criteria of FEMA P-361 or the ICC 500<sup>©</sup> Standard. The USVI has limited capability to evacuate residents from the path of hurricanes and tropical storms and no public safe rooms or storms shelters to offer residents.

**Recommendation USVI-31a: The USVI should consider a local amendment to the building code to require Storm Shelters designed to ICC 500© for select Educational and First Responder Facilities.** The USVI should consider a local amendment to the USVI Building Code to require that some new facilities constructed across the USVI have a storm shelter. This requirement would be limited to a number of facilities, including:

- Any new facility constructed for Group E occupancies with an aggregate occupant load of 50 or more (including public and private schools, but excluding Group E day care facilities or Group E occupancies accessory to places of religious worship)
- 911 call stations
- Emergency operations centers, fire, rescue, ambulance, and police stations

In addition, fire, rescue, ambulance, and police stations shall comply with the IBC© Table 1604.5 as a Risk Category IV structure.

**Recommendation USVI-31b: VITEMA should consider registering public Storm Shelters designed to ICC 500**<sup>©</sup> when they are constructed. VITEMA should consider registering all public ICC-compliant<sup>©</sup> shelters when constructed in the Territory for use in helping to plan and implement measures to help protect citizens of the USVI from hurricanes or other high wind events. Encourage the public to register private shelters with VITEMA. Registering shelters is important because knowing the location after a disaster allows first responders to provide aid to occupants.

**Recommendation USVI-31c: Encourage residents to build in-residence storm shelters.** The IBC© and IRC© reference the ICC 500©, which provides design criteria for in-residence storm shelters. VITEMA and DPNR should consider developing specific guidance consistent with FEMA P-361, FEMA P-320, and ICC 500© and outreach materials to encourage residents to construct storm shelters or safe rooms in their homes when it is appropriate to do so. These will help protect them against high wind events, such as hurricanes or tornadoes. FEMA has developed prescriptive design and construction plans (FEMA P-320) to construct a safe room in or near a home or small business that comply with the design criteria of the ICC 500© along with criteria and guidance in FEMA P-361 for situations that fall outside of the prescriptive designs in FEMA P-320.

#### TERMINOLOGY

As noted in Chapter 4, any building (or portion thereof) not designed and constructed to meet the criteria of FEMA P-361/FEMA P-320 or the requirements of the ICC 500<sup>©</sup> as a safe room or storm shelter, respectively, has not been designed to provide a safe place to go and provide life-safety protection during a hurricane. Any other name used to describe a building such a shelter, recovery shelter, refuge area, etc. are buildings that were not designed to protect people, and that may or may not have been evaluated for their vulnerabilities to damage or collapse from a hurricane or tropical storm.

#### **Conclusion USVI-32**

Many buildings currently being used as shelters and refuge areas were not evaluated by design professionals for flood, wind, and seismic vulnerabilities: Many buildings used during Hurricanes Irma and Maria as shelters were not evaluated by design professionals prior to the hurricanes. A consistent methodology to identify vulnerability for flood, wind, and seismic was not utilized to assess the shelters in the USVI.

**Recommendation USVI-32: VITEMA and DPNR should consider developing a "best available refuge area" assessment program. VITEMA, DPNR, and other stakeholders should consider collaborating to develop a program to evaluate existing buildings for determining "best available refuge areas" for use by occupants before, during, and after storm events.** During severe weather, building occupants should utilize the location in the building that is least susceptible to collapse or failure. Guidance from FEMA for evaluating buildings for use as hurricane or tornado refuge areas is presented as an appendix to FEMA P-431, *Tornado Protection: Selecting Refuge Areas in Buildings* (FEMA 2009x). This guidance, for both hurricanes and tornadoes, provides an assessment methodology. FEMA recommends these evaluations be performed by licensed design professionals (engineers or architects) experienced in performing building design and vulnerability assessments for wind, flood, and seismic loads and can be used to identify areas of buildings that may be less vulnerable to damage from impacts of hurricanes. Such areas may be used by VITEMA and the USVI if needed to support residents in response to hurricanes.

# 8.9 Solar Panel Systems

#### **Conclusion USVI-33**

**Damaged ground-mounted solar panel systems hindered the full return of electrical utility service:** In a few cases, catastrophic failure of ground-mounted, grid-connected photovoltaic (PV) solar facilities impacted the restoration of power to residents. Damage to the PV facilities, forced the islands to rely on fuel imports. The damages to PV facilities added additional demand on the already delicate grid, affecting restoration time and/or price of their power supply.

**Recommendation USVI-33: Incorporate mitigation and preparedness aspects into PV system repairs.** Incorporate mitigation and preparedness best practices into groundmounted PV solar facilities connected to the utility grid.

#### **Conclusion USVI-34**

**Current design standards do not provide recommended design loads specific to ground-mounted PV solar arrays:** ASCE 7-16 and SEOC PV2-17 *Wind Design for Solar Arrays* (SEOC 2017) specify design wind loads and procedures for rooftop PV solar arrays but do not provide similar guidance for ground-mounted PV solar arrays. The overall lack of design criteria available for ground-mounted PV solar arrays furthered the variable performance of PV systems in the USVI and raises concerns over the ability of new systems to adequately withstand high wind events. Following Hurricanes Irma and Maria, the lack of guidance for designers became evident through the multiple means of failures observed across the islands. This helped confirm that gaps exist in current design standards for ground-mounted PV solar arrays.

**Recommendation USVI-34a: Add specific design criteria for ground-mounted PV solar arrays and connections to ASCE 7-22 and reference them in other select codes.** New and appropriate design standards for ground-mounted PV solar arrays included in ASCE 7-22 should be referenced by SEOC PV2-17, the I-Codes, and the USVI Building Code to provide for more consistent performance of such systems in high wind events. Any new standards would require the focused coordination of researchers, industry professionals, and code officials to ensure that such criteria are adequate without being overly prescriptive.

**Recommendation USVI-34b: Assign Risk Category affecting design for groundmounted PV.** It is recommended that the Risk Category assigned to and guiding the design of ground-mounted PVs not be less than that for the building to which the PV serves. (Note: this is similar to rooftop PVs in ASCE 7-16, C29.3.1).

#### **Conclusion USVI-35**

**Insufficient sizing of structural members and connections contributed to damage and failures of ground-mounted PV solar arrays:** Damage ranging from significant to catastrophic failure was observed at ground-mounted PV solar arrays due to probable insufficient sizing of structural members and the frames supporting the panels. The degree and type of failures were typically caused by load path discontinuity and indicated that structural support systems, clips, and other connections were inadequately designed to meet the anticipated high wind magnitude and cyclical loading for the given sites.

**Recommendation USVI-35: Designers should improve the sizing of structural systems, frames, and connections for ground-mounted PV solar arrays.** When designing ground-mounted PV solar arrays, designers should consider the design wind speeds that are used for other building types on the islands and size members and connections adequate to withstand the anticipated wind load magnitudes and cyclical loading regimes. Generally, stronger structural systems were needed at numerous facilities; these can be achieved in a variety of ways through a comprehensive design process with reference to appropriate related standards.

#### **Conclusion USVI-36**

**Current design standards for ground-mounted PV solar arrays do not provide for dynamic testing:** Design standards specified by entities such as UL and FM Global do not currently include dynamic wind load testing. Much of the damage observed in the USVI to ground-mounted PV solar arrays resulted in part from the cyclical loading of dynamic wind loads.

**Recommendation USVI-36: Consider research into dynamic testing of groundmount PV solar arrays.** Standards developers, system manufacturers, and university and government-based researchers should consider further research into the effects of dynamic testing on structural performance. Wind-tunnel-based research will allow investigation into how connections are loosened over time and structural members fail under conditions more correlated to actual storm events. Without further research into the necessary design criteria for such impacts, engineers and owners will lack the detailed performance-based standards necessary to ensure the adequacy of their systems to realworld events.

#### **Conclusion USVI-37**

**Ground-Mounted PV open-cross-section framing members performed poorly when compared to similarly sized closed-cross-section members:** In a comparison between multiple ground-mounted PV solar arrays on the islands, structural systems that featured similarly-sized framing members performed significantly better when they utilized closed sections instead of open sections in their designs. Members such as C-section beams did not provide adequate torsional strength when exposed to high wind events and the cyclical loading and flutter associated with them. Sections that had closed ovular or rectangular shapes provided more resistance and allowed for a consistent transfer of loads throughout the rest of the system.

**Recommendation USVI-37: Designers should consider using closed-shape crosssections for the design of ground-mounted PV solar array structural framing members.** Designers should consider the use of closed ovular- or rectangular- section framing members for ground-mounted PV solar arrays, whenever possible, instead of open-section members. These provide improved torsional resistance to better withstand the unique wind loads exerted by high-wind-speed events.

#### **Conclusion USVI-38**

**Vibrations from dynamic, cyclical loading caused failure of bolted connections of ground-mounted PV solar arrays:** The high wind loads experienced by the framing systems for ground-mounted PV solar arrays caused nuts to back out of their bolt connections. This resulted in the failure of the connection and a discontinuity in the system's load path. Without connections in place, framing members and attached PV panels are easily lifted from their bases by high speed winds, causing further damage. One observed array performed notably well except where bolts backed out and caused weakness. This system did not have any type of locking mechanism to prevent back-cycling of the connector.

**Recommendation USVI-38: Designers should utilize a stainless-steel locking nut with a nylon insert for all bolted structural connections of ground-mounted PV solar arrays.** Designers should include a stainless-steel locking nut with a nylon insert

to prevent back-cycling for any bolted connection that supports the wind loads of the framing system. These nuts provide resistance to the vibrations caused by dynamic wind loading and will not significantly loosen during a high wind event.

#### **Conclusion USVI-39**

**Bolt checks are generally not performed on PV solar arrays after initial construction/installation occurs or through normal maintenance protocol cycles:** The installation procedures from the manufacturers and developers of ground-mounted PV solar arrays do not currently include specifications for the appropriate torque levels of bolted connections. An observed array that included this procedure experienced only minor damage due to loosening of bolt connections, which bolster the continuity of the load path. Further, after construction of ground mounted PV solar arrays occurs, annual torque checks and checks following high wind events are generally not in written protocols performed by building owners or operators.

**Recommendation USVI-39: Ground-mounted PV solar installation and operation and maintenance (O&M) procedures should account for proper bolt torque specifications and checks.** PV solar array installation contractors should tighten and check all bolted connections for the appropriate level of torque, as specified by the design requirements for high wind events. These torque levels should be, at minimum, checked regularly and following high wind events. Any loose connections should be tightened accordingly to ensure adequate design performance.

# 8.10 Topographic Effects on Wind Speeds

#### **Conclusion USVI-40**

**Buildings generally lacked designs that considered topographic effects, thereby increasing damage:** The MAT observed the effects of topography on wind speeds across the islands. Many locations, both inland and coastal, were observed to have experienced higher wind speeds due to the channeling of wind through the mountains; these increased wind speeds damaged homes and buildings with more severity than where topography is flat. Designing for these effects involves a complicated method for estimating wind speed in ASCE 7 (incorporated by reference in the IBC©). Most building locations observed by the MAT and impacted by these storms did not appear to have buildings designed to resist the higher wind loads due to topographic effects.

**Recommendation USVI-40a: DPNR should work with the Legislature to incorporate revised basic wind speed maps into the USVI Building Code that consider topographic effects as an option for determining wind pressures on buildings.** To assist design professionals with correctly addressing wind speed-up due to topography, the USVI should include revised basic wind speed maps that consider topographic effects, presented in Appendix E of this report, as an alternative process to calculate the wind pressures on buildings and other structures. The maps were produced as part of a study to provide a more useful approach for designers to address wind speed-up appropriately in building design. The maps provide a simplified alternative to determining the wind speedup effects represented by K<sub>zt</sub> in the calculation of design wind pressures using ASCE 7-16. The revised basic wind speed maps present alternative basic wind speeds to be used with the ASCE 7 design process that already consider the  $K_{zt}$  factor for wind speed up over rough terrain as required for design across the islands. Similar maps were developed for the State of Hawaii and are currently included in ASCE 7-16. The maps can be adopted into the USVI Building Code as an alternative to the existing basic wind speed maps to simplify the procedure to determine wind pressures on buildings.

**Recommendation USVI-40b: DPNR should consider developing guidance to assist designers when applying the revised basic wind speed maps.** DPNR should consider collaborating with FEMA and other stakeholders to develop and include new guidance for design professionals to incorporate topographic effects into their designs through the USVI Building Code.

**Recommendation USVI-40c: The revised basic wind speed maps developed for the USVI should be proposed for inclusion in the next edition of ASCE 7.** The wind engineering research community that supported the development of the revised basic wind speed maps for the USVI should submit these maps to the ASCE 7 Wind Committee for final evaluation and consideration for inclusion into the next edition of ASCE 7. The revised USVI maps would then be evaluated by the ASCE 7 Wind Committee under the same process used to incorporate the wind speed maps that considered topographic effects for the State of Hawaii into the standard.

# 8.11 FEMA Technical Publications and Guidance

#### **Conclusion USVI-41**

**FEMA Building Science technical guidance publications should be updated to ensure congruence with current building codes and incorporate lessons learned from the MAT:** The Building Science Branch at FEMA HQ develops and maintains over 200 publications and resources that provide technical guidance on how to assess risk; identify vulnerabilities; better understand the NFIP and the regulatory environment with respect to building codes and standards; and provide best practices and mitigation measures that can be taken to reduce vulnerabilities to flood, wind, and seismic hazards. The 2017 hurricane season brought landfalling hurricanes on the island territories and the continental United States. There are many valuable and important damage observations and lessons learned from this and other events, and the observed damage might have been avoided if the guidance from these documents had been incorporated at different building locations. However, while the approaches and theory in these publications are still accurate, many of the building codes have been updated in the last 8-10 years and may impact the current approach outlined in these documents.

#### **Recommendation USVI-41a: Update select FEMA Building Science Publications.**

FEMA's Building Science Branch, in the Risk Management Directorate, should consider updating its key hurricane technical guidance publications to include lessons learned from the 2017 hurricane season and update to current building codes. These publications might include but not necessarily be limited to the following:

- FEMA P-55 Coastal Construction Manual (FEMA 2011x)
- **FEMA P-499 Home Builder's Guide to Coastal Construction (FEMA 2010x)**
- FEMA P-762 Local Officials Guide for Coastal Construction (FEMA 2009x)
- FEMA P-804 Wind Retrofit Guide for Residential Buildings (FEMA 2010x)

**Recommendation USVI-41b: Update the FEMA Risk Management Series guidance publication for natural hazards.** FEMA's Building Science Branch, working with other FEMA and DHS entities, should consider updating select technical documents from the FEMA Natural Hazard Risk Management Series to include lessons learned from the 2017 hurricane season and update to current building codes. These publications might include but not be limited to the following:

- FEMA P-424 Design Guide for Improving School Safety in Earthquakes, Floods, and High Winds (FEMA 2010x)
- FEMA P-543 Design Guide for Improving Critical Facility Safety from Flooding and High Winds (FEMA 2007x)
- FEMA P-424 Design Guide for Improving School Safety in Earthquakes, Floods, and High Winds (FEMA 2010x)

#### NATIONAL DISASTER RECOVERY FRAMEWORK AND RECOVERY SUPPORT FUNCTIONS

FEMA has developed the National Disaster Recovery Framework (NDRF) to create a common platform and forum for how the whole community builds, sustains, and coordinates delivery of recovery capabilities. FEMA guidance states "Resilient and sustainable recovery encompasses more than the restoration of a community's physical structures to pre-disaster conditions. The primary value of the NDRF is its emphasis on preparing for recovery in advance of disaster. The ability of a community to accelerate the recovery process begins with its efforts in pre-disaster preparedness, including coordinating with whole community partners, mitigating risks, incorporating continuity planning, identifying resources, and developing capacity to effectively manage the recovery process, and through collaborative and inclusive planning processes. Collaboration across the whole community provides an opportunity to integrate mitigation, resilience, and sustainability into the community's short- and long-term recovery goals."

The Recovery Support Functions (RSFs) comprise the coordinating structure for key functional areas of assistance in the National Disaster Recovery Framework (NDRF). Their purpose is to support local governments by facilitating problem solving, improving access to resources and by fostering coordination among State and Federal agencies, nongovernmental partners and stakeholders.

The list of Recovery Support Functions and the leading coordinating agency is presented below and available on line at:

#### https://www.fema.gov/recovery-support-functions

- Community Planning and Capacity Building (CPCB) Recovery Support Function (See FEMA's page for CPCB)
- Economic Recovery Support Function (U.S. Department of Commerce)
- Health and Social Services Recovery Support Function (U.S. Department of Health and Human Services)
- Housing Recovery Support Function (U.S. Department of Housing and Urban Development)
- Infrastructure Systems Recovery Support Function (U.S. Army Corps of Engineers)
- Natural and Cultural Resources Recovery Support Function (U.S. Department of Interior)

#### 8.12 Summary of Conclusions and Recommendations

Table 8-1 is a matrix showing a list of the conclusions and recommendations cross-referenced to the sections of the report that describe the supporting observations. The recommendations provided in the table have also been cross-referenced to Recovery Support Functions (RSFs) supported by FEMA through the National Disaster Recovery Framework (NDRF). FEMA developed the RSFs with the objective of facilitating the identification, coordination and delivery of Federal assistance needed to supplement recovery resources and efforts by local, State, Tribal and Territorial governments, as well as private and nonprofit sectors. The MAT has identified RSFs with the recommendations provided in this report to assist the USVI with accelerating the process of recovery, redevelopment and revitalization.

Observations	Conclusions	Recommendations	Recovery Support Function
Section 2.1	USVI-1 – The most heavily damaged buildings lacked a continuous load path.	USVI-1a. USVI should adopt the latest hazard- resistant building codes and standards on a regular update cycle.	CPCB, Housing
Sections 2.1, 2.3		USVI-1b. DPNR should continue to update <i>The Stronger Home Guide</i> as the IBC© and IRC© are updated.	CPCB, Housing
Chapters 2, 4	USVI-2 – Numerous temporary facilities are vulnerable to wind hazards and have been installed for longer than their intended purpose.	USVI-2. The permitted use of temporary buildings should be limited to 180 days, as set forth in the IBC.	CPCB, Infrastructure
Chapters 2, 3, 3, 5, 6, 7	USVI-3 - Some building owners have a limited awareness of hurricane hazard risks and vulnerabilities.	USVI-3. Perform vulnerability assessments.	Housing, HSS
Section 2.1	USVI-4 - The local USVI Building Code amendments conflict with some of the requirements and referenced standards in the latest edition of the I-Codes.	USVI-4a. Review and update local building code amendments and specify a recurring code update cycle.	СРСВ
Section 2.1		USVI 4b. Provide published process for stakeholders to suggest amendments to the USVI Building Code.	СРСВ
Section 2.1	USVI-5 – The referenced building code is not clearly presented or defined (named code, edition, and year) with the local amendments.	USVI-5. DPNR should use multiple means of media (print, website, etc.) to identify the current edition of the I-Codes that is being referenced as the USVI Building Code (including appendices) and list all local amendments.	СРСВ
Section 2.1	USVI-6 – The signing and sealing of construction documents is too permissive in the USVI Building Code.	USVI-6. Amend the USVI Building Code and restrict the signing and sealing of construction documents to registered design professionals.	СРСВ
Section 2.1	USVI-7 – Building damage/repair triggers in the USVI Building Code based solely on financial replacement costs for buildings/ systems can be simplified.	USVI-7. DPNR should amend the current code for percent damage repair triggers.	СРСВ
Section 2.1	USVI-8 – DPNR lacks adequate staffing to enforce the latest building codes and standards.	USVI-8. DPNR should consider hiring additional code enforcement staff.	СРСВ
Chapter 2	USVI-9 – Training is needed for local code enforcement staff on the latest building codes and standards.	USVI-9. Provide training to building code enforcement staff on the latest edition of the referenced code that has been adopted.	СРСВ

#### Table 8-1: Summary of Conclusions and Recommendations

Observations	Conclusions	Recommendations	Recovery Support Function
Chapter 2	USVI-10 – DPNR does not provide a list of specific notes and design criteria for design professionals to include on construction drawings.	USVI-10. DPNR should consider requiring construction documents to list critical design parameters, including seismic design loads, and show load path connections.	CPCB, Housing
Chapters 2, 3, 4, 5, 6	USVI-11 – USVI lacks key resources to help DPNR enforce codes.	USVI-11a. Maintain a list of select tested and approved hazard-resistant materials for key systems.	СРСВ
Chapters 2, 3, 4, 5, 6		USVI-11b. Work with local construction material suppliers to ensure that tested and approved materials are available in store for homeowners and building owners for rebuilding.	CPCB, Housing
Chapter 3	USVI-12 – Staged construction performance varied.	USVI-12a. Limit extended open permit periods for staged or phased construction.	CPCB
Chapter 3		USVI-12b. Protect material during staged construction.	Housing
Section 2.2	USVI-13 – The USVI Floodplain Management Ordinance is old and out of date.	USVI-13. Update the USVI Floodplain Management Ordinance and integrate with the IBC© and IRC©.	СРСВ
Chapter 3	USVI-14 – Windows (glazed openings) on most existing buildings are vulnerable to damage and failure from wind pressures and wind-borne debris.	USVI-14a. Existing critical facilities should protect their windows.	Infrastructure
Chapter 3, 4, 5		USVI-14b. Homeowners should consider protecting the glazed window and door systems on their existing homes.	Housing
Chapters 5, 6		USVI-14c. Building owners and property managers of commercial and large, multi- unit residential buildings should consider protecting the windows on existing buildings.	Housing, Economic
Chapters 3, 4, 5,6	USVI-15 – Water intrusion through and around existing windows (glazed openings) and metal panel jalousie systems was pervasive.	USVI-15a. Replace older glazed (glass) openings in existing buildings with new windows designed and tested to resist water intrusion.	Housing, HSS, Infrastructure
Chapters 3, 4, 5, 6		USVI-15b. Consider using water damage resistant materials to address water intrusion for interior spaces that have exterior jalousie window systems.	Housing, HSS, Infrastructure
Chapters 3, 4, 5,6	USVI-16 – Excessive water intrusion through existing exterior doors was observed.	USVI-16. Mitigate exterior doors with improved water intrusion resistance.	Housing, HSS, Infrastructure
Chapters 3, 4, 5, 6	USVI-17 - Rood panels (coverings) often lacked structural roof decks beneath them.	USVI-17. Require the use of wood decks below roof coverings.	Housing, HSS, Infrastructure

Observations	Conclusions	Recommendations	Recovery Support Function
Chapter 3	USVI-18 - Key wind vulnerabilities remain in many undamaged homes.	USVI-18. Homeowners should consider evaluating and retrofitting existing homes for wind vulnerabilities.	Housing
Chapter 3	USVI-19 – HPRP roof design, when implemented correctly, performed well.	USVI-19. Develop and support a wind retrofit programs across USVI.	Housing
Chapter 3	USVI-20 – Utility service mast roof penetrations through roof coverings performed poorly.	USVI-20. Avoid penetrating roof coverings, including porches and overhangs, with utility service masts.	Housing
Chapter 3	USVI-21 – Many manufactured housing units (MHUs) experienced near-total damage from a wind event that was at or below design levels for the USVI.	USVI-21. Ensure MHUs are properly designed and installed for their given HUD wind zones throughout USVI.	Housing
Chapter 3	USVI-22 – MHU labeling had often been removed, making it difficult to identify units.	USVI-22a. DPNR should require MHU labels or placards to be maintained on all MHUs regardless of age or the renovation of the unit.	Housing
Chapter 3		USVI-22b. HUD should consider location of MHU labels or placards such that any renovation of the exterior material, sun damage, or water damage does not cover the label.	Housing
Chapter 4	USVI-23 - Buildings having their main or first floor levels at or near adjacent grade can be very vulnerable to localized flood damage.	USVI-23. Elevate main (primary) floors of buildings above adjacent grade.	HSS, Infrastructure
Chapters 4, 5, 6	USVI-24 - Internal pressures were not adequately addressed through open/louvered window assemblies and metal jalousie window systems.	USVI 24. Designers must consider and adequately address internal wind pressures.	HSS, Infrastructure
Chapters 4, 5, 6	USVI-25 – Design and installation of wind-resistant roof coverings was often inadequate.	USVI-25. Design and install new and replacement roof coverings for critical facilities to resist high winds in accordance with ASCE 7-16.	HSS, Infrastructure
		USVI-25b. Avoid the use of single-ply roof membranes.	HSS, Infrastructure
Chapters 4, 5, 6	USVI-26 – Maintenance of roof coverings was often inadequate.	USVI-26. Regularly assess, adequately maintain, and repair or replace roofs when needed.	HSS, Infrastructure
Chapters 4, 5, 6	USVI-27 – Inadequate anchoring of rooftop equipment caused unnecessary damage to roof systems and building contents.	USVI-27. Adequately anchor HVAC and other equipment to roofs.	HSS, Infrastructure
Chapters 4, 5, 6	USVI-28 – Equipment penthouses and elevator equipment vents on roofs notably failed.	USVI-28. Design mechanical penthouses and equipment housing to resist high winds.	HSS, Infrastructure

Observations	Conclusions	Recommendations	Recovery Support Function
Chapters 4, 5, 6	USVI-29 – Some facilities had insufficient protection for backup power generators, switches, and equipment, including fire alarm systems.	USVI-29. Protect backup and emergency generator systems and equipment to requirements of ASCE 7.	CPCB, HSS, Infrastructure
Chapter 6	USVI-30 – Large, overhead roll-up doors failed under wind loading and debris impact at critical facilities.	USVI-30. Use only large overhead doors that have been tested and certified for wind loads and debris impact associated with the design criteria for the site.	HSS, Infrastructure
Chapter 3	USVI-31 – There are currently no public Safe Rooms designed to FEMA P-361 criteria or Storm Shelters designed as per ICC 500 in the USVI for protection of residents during hurricanes.	USVI-31a. The USVI should consider a local amendment to the building code to require Storm Shelters designed to ICC 500© for select Educational and First Responder Facilities.	HSS
Chapter 3		USVI-31b. VITEMA should consider registering public Storm Shelters designed to ICC 500 when they are constructed.	HSS
Chapter 3		USVI-31c. Encourage residents to build in- residence storm shelters.	Housing
Chapter 3	USVI-32 – Many buildings currently being used as shelters and refuge areas were not evaluated by design professionals for flood, wind, and seismic vulnerabilities.	USVI-32. VITEMA and DPNR should consider developing a "best available refuge area" assessment program.	CPCB, HSS
Chapter 7	USVI-33 - Damaged ground- mounted solar panel systems hindered the full return of electrical utility service.	USVI 33. Incorporate mitigation and preparedness aspects into PB system repairs.	Infrastructure
Chapter 7	USVI-34 – Current design standards do not provide recommended design loads specific to ground-mounted PV solar arrays.	USVI-34a. Add specific design criteria for ground-mounted PV solar arrays to ASCE 7-22 and reference them in other select codes.	Infrastructure
Chapter 7		USVI-34b. Assign Risk Category affecting design for ground-mounted PV.	Infrastructure
Chapter 7	USVI-35 – Insufficient sizing of structural members and connections contributed to damage and failures of ground- mounted PV solar arrays.	USVI-35. Designers should improve the sizing of structural systems, frames, and connections for ground-mounted PV solar arrays.	Infrastructure
Chapter 7	USVI-36 - Current design standards for ground-mounted PV solar arrays do not provide for dynamic testing.	USVI-36. Consider research into dynamic testing of ground-mount PV solar arrays.	Infrastructure
Chapter 7	USVI-37 - Ground-mounted PV open-cross-section framing members performed poorly when compared to similarly sized closed-cross-section members.	USVI-37. Designers should consider using closed-shape cross-sections for the design of ground-mounted PV solar array structural framing members.	Infrastructure

Observations	Conclusions	Recommendations	Recovery Support Function
			Function
Chapter 7	USVI-38 – Vibrations from dynamic, cyclical loading caused failure of bolted connections of ground-mounted PV solar arrays.	USVI-38. Designers should utilize a stainless- steel locking nut with a nylon insert for all bolted structural connections of ground- mounted PV solar arrays.	Infrastructure
Chapter 7	USVI-39 - Bolt checks are generally not performed on PV solar arrays after initial construction/installation occurs or through normal maintenance protocol cycles.	USVI-39. Ground-mounted PV solar installation and operation and maintenance (O&M) procedures should account for proper bolt torque specifications and checks.	Infrastructure
Chapter 8	USVI-40 – Buildings generally lacked designs that considered topographic effects, thereby increasing damage.	USVI-40a. DPNR should work with the Legislature to incorporate revised basic wind speed maps into the USVI Building Code that consider topographic effects as an option for determine wind pressures on buildings.	СРСВ
Chapter 8		USVI-40b. DPNR should consider developing guidance to assist designers when applying the microzoning wind maps.	СРСВ
Chapter 8		USVI-40c. The revised basic wind speed maps developed for the USVI should be proposed for inclusion in the next edition.	СРСВ
Chapters 2, 3, 4, 5, 6	USVI-41 – FEMA Building Science technical guidance publications should be updated to ensure congruence with current building codes and incorporate lessons learned from the MAT.	USVI-41a. Update select FEMA Building Science Publications.	СРСВ
Chapters 2, 3, 4, 5, 6		USVI-41b. Update the FEMA Risk Management Series guidance publications for natural hazards.	СРСВ

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# Acronyms

ABFE	Advisory Base Flood Elevation
ANSI	American National Standards Institute
ARA	Applied Research Associates, Inc.
ASCE	American Society of Civil Engineers
ASTM	ASTM International
CFR	Code of Federal Regulations
CMU	Concrete Masonry Unit
DHS	Department of Homeland Security
DPNR	Department of Planning and Natural Resources (U.S. Virgin Islands)
EMAC	Emergency Management Assistance Compact
FAA	Federal Aviation Administration
FEMA	Federal Emergency Management Agency
FIRM	Flood Insurance Rate Map
FIS	Flood Insurance Study
GIS	Geographic Information System
HHRF	Hawaii Hurricane Relief Fund
HHS	Health and Human Services
HMGP	Hazard Mitigation Grant Program
НМТАР	Hazard Mitigation Technical Assistance Program

#### ACRONYMS

Home Protection Roofing Program
U.S. Department of Housing and Urban Development
Heating, ventilation, and air conditioning
Joint Field Office
Lightning Protection System
Limit of Moderate Wave Action
Metal Building System
Manufactured housing unit
Megawatt
Main Wind Force Resisting System
National Design Specification
National Flood Insurance Program
National Institute of Standards and Technology
National Oceanic and Atmospheric Administration
National Ocean Service
National Research Council
On Center
Photovoltaic
Special Flood Hazard Area
Subject Matter Experts
Uniform Building Code
U.S. Army Corps of Engineers
U.S. Virgin Islands
Virgin Islands Territory Emergency Management Agency

WAPA Water and Power Authority

# Recovery Advisories for Hurricanes Irma and Maria in the USVI

FEMA has prepared new Recovery Advisories (RAs) that present guidance to engineers, architects, homeowners, and local officials on mitigation measures that can be taken to minimize building damage in a hurricane event. Five advisories are referenced in this appendix:

- USVI RA 1: Rebuilding Your Flood-Damaged House
- USVI RA 2: Attachment of Rooftop Equipment in High-Wind Regions
- USVI RA 3: Installation of Residential Corrugated Metal Roof Systems
- USVI RA 4: Design Installation and Retrofit of Doors Windows and Shutters
- USVI RA 5: Rooftop Solar Panel Attachment: Design, Installation, and Maintenance

These advisories are online at https://www.fema.gov/media-library/assets/documents/158123.

# Basic Wind Speed Maps for the USVI

The American Society of Civil Engineers (ASCE), in association with the Structural Engineering Institute (SEI) develop and maintain the engineering Standard Minimum Design Loads and Associated Criteria for Buildings and Other Structures (ASCE/SEI 7-16) to provide requirements for general structural design. This standard includes means for determining dead, live, soil, flood, snow, rain, atmospheric ice, earthquake, and wind loads, as well as their combinations, which are suitable for inclusion in building codes and other documents.

As part of the technical criteria provided for the wind design of buildings and structures, ASCE 7 provides basic wind speed maps for selecting a design wind speed that is based on flat, open terrain. Further, ASCE 7 provides guidance for design professionals to use to properly incorporate the effects of topography on the basic wind speed when calculating design wind pressures on a building. This guidance is required to be applied when the topography is not flat, using a site coefficient called  $K_{zt}$  to adjust the basic wind speed values from the maps to consider topographic effects. The design professional is required to perform a series of calculations to calculate 3 additional values called multipliers (which are identified as K1, K2, and K3) in order to determine the value of  $K_{zt}$  that is used in the calculation of wind pressures acting on a building at a particular site on a hill or slope. This is important to determine, as the value of  $K_{zt}$  increases from unity ( $K_{zt} = 1.0$ ) to a value between 2.0 and 4.0 depending on the size of the hill, ridge, or escarpment over which the wind is flowing and the location of the building atop that topographic feature.

However, as an alternative to the design professional calculating K<sub>zt</sub>, it is possible to have wind speed maps developed that include topographic effects; i.e., considering the effects of wind speed-up across terrain when hills, ridges, and escarpments are in an area where the basic wind speed is being determined. Wind speed maps that consider topographic effects can be developed using the same models and approaches used to develop the current maps in ASCE 7, but would show higher wind speeds because they reflect anticipated wind speeds due to the wind interacting with mountainous terrain. Using revised basic wind speed maps that include the effects of the specific topography, the design professional who is determining loads and pressures on a building can simply select wind speeds for a building on a site from the revised maps rather than calculate them.

In 2016, ASCE 7 provided revised basic wind speed maps that consider topographic effects for the State of Hawaii. In response to the 2017 hurricane season, FEMA worked with the wind research community (Applied Research Associates) to develop revised basic wind speed maps for the USVI using the methodologies of ASCE 7 (full report can be found at <u>https://www.fema.gov/media-library/assets/documents/158123</u>). The model was developed using empirical equations whose parameters were determined through comparisons with wind speed-up data obtained from wind tunnel tests measured on topographic models of Oahu and Kauai. As a result, revised basic wind speed maps that consider topographic effects have been developed for the USVI to illustrate wind speeds that can be used in the calculation of wind pressures where  $K_{zt} = 1.0$ . Maps have been developed for the 700-year return period, 3-second gust, for Risk Category II building design (residential and most non-residential building).

The USVI can evaluate the wind speeds from these revised basic wind speed maps that consider topographic effects for use as a simplified alternative method to determine wind loads and pressures (using a  $K_{zt}$ =1.0 during calculations) on a building or structure. The revised basic wind speed maps do not change the design wind criteria of ASCE 7. Rather, if these wind speed maps are adopted for use as an alternative method for calculating design wind pressures, they will enable a designer to more quickly determine wind loads and pressures on a building where topographic effects must be considered without requiring design professionals to perform additional, and complex, calculations.









