Final Report:

Survey and Investigation of Buildings Damaged by Category II, III, IV and V Hurricanes in FY 2017-18 – Hurricane Irma 2017

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Florida Department of Business and Professional Regulation
Mo Madani, Program Manager
Building Codes and Standards
1940 North Monroe Street
Tallahassee, Florida 32399

Prepared by:

David O. Prevatt, Ph.D., PE (MA)
Principal Investigator
Associate Professor (Structures)

Kurtis R. Gurley, PhD.
Co-Principal Investigator
Professor (Structures)

David B. Roueche, Ph.D.
Assistant Professor (Auburn University)

Gabrielle Wong-Parodi, Ph.D.
Social Science Consultant
Assistant Research Professor (Carnegie-Mellon University)

Research Assistants:
Rohit Tallur, Jason Lopez, Rodrigo Castillo-Perez, Quinten Ozimek (University of Florida)
Courtney Hodges (Auburn University)

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Engineering School of Sustainable Infrastructure and Environment
Department of Civil and Coastal Engineering
University of Florida
365 Weil Hall
P.O. Box 116580
Gainesville, FL 32611-6580

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EXECUTIVE SUMMARY

The Florida Building Commission retained the University of Florida to conduct a damage survey and document hurricane-related damage to residential structures caused by the 2017 Hurricane Irma. We were tasked to assess the impact of the Florida Building Code (FBC) on residential building performance. The FBC was first enacted on 1 March 2002, and so we analyzed our database in two categories; houses built BEFORE, and houses built AFTER 1 March 2002. In our report, we designate these categories as pre-2002 and post-2001 respectively. The research team inspected over 800 single-family houses from the Florida Keys to Jacksonville, FL, cataloguing effects of strong winds and storm surge on these structures. As a part of our study, we conducted interviews of homeowners to determine the extent of interior damage and losses, and homeowner response and behavior to evacuation and approach to recovery

Since Hurricane Irma was not a design-level hurricane, few structural failures should be expected in code-compliant houses. In our assessments we found no systemic failures of structural systems in single-family houses built in accordance to the 2001 Florida Building Code (i.e. houses built after March 2002). Conversely, we observed many structural failures in the pre-Florida building code houses (i.e. homes built before March 2002). Nearly 40% of the pre-2002 houses surveyed in the Florida Keys had structural damage (defined as damage to roof or wall structural members and roof sheathing). We also found the widespread occurrence of damage to roof and wall cladding systems in both pre-2002 and post-2001 houses. Failed soffits were observed to be a prevalent component failure mechanism that provided significant water leakage paths resulting in costly interior damage. Elevated houses generally performed well against storm surge and flood inundation. Breakaway walls in lower enclosures were often damaged as expected. There is evidence that the combined back-to-back impact of hurricanes in two consecutive years may have exacerbated more severe damage and losses to houses in North-east Florida.

Our scope included recruitment and interviews of homeowners selected from among our surveyed houses whose homes had experienced damage. Water leakage (wind-driven rain through soffits, damaged roofs, windows and doors, and wall siding) was the most common source of interior damage noted by the interviewed homeowners, and the magnitude of damage from water was of a similar order of magnitude as damage from strong winds or storm surge. When comparing homeowner reported damage to our independent field assessments of damage, several homes experienced significant interior water damage despite no visible exterior damage being noted.

The research team made three recommendations; a) investigate prevalence of premature failure of vinyl siding systems occurring in post-2001 houses; b) implement recommendations to mitigate soffit failures that were responsible for extensive water damage to houses; and c) address the aging effects on the wind uplift performance of roofing systems. Prior research by the Principal Investigators and others had identified these issues as causative of damage and some solutions have already been proposed. Given the damage patterns observed from Hurricane Irma it is likely that the aggregate repair costs from damage to Florida houses in a design-level wind event will be significantly larger than what was experienced throughout the state in 2017.

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1 HURRICANE IRMA

Hurricane Irma made its first landfall in the continental US at Cudjoe Key in southern Florida on September 10, 2017, with Category 4 winds reaching 58 m/s (130 mph). The National Hurricane Center (NHC) downgraded Irma to a Category 3 storm as it made its second landfall later that afternoon on Marco Island, just south of Naples on the Florida's Gulf Coast, with sustained winds near 54 m/s (120 mph). It weakened further to a Category 2 once inland.

The storm's large wind field resulted in strong winds across much of Florida. The highest reported sustained wind speed was 50 m/s (112 mph) on Marco Island, while the strongest observed wind gust was 64 m/s (142 mph), recorded near Naples, though wind gusts of 67 to 72 m/s (150 to 160 mph) likely occurred in the Middle Florida Keys. Generally, heavy amounts of rainfall were recorded to the east of the Irma's path, including a peak total of 550 mm (21.66 in) in Fort Pierce. Heavy precipitation – and storm surge, in some instances – overflowed at least 32 rivers and creeks, causing in significant flooding, particularly along the St. Johns River and its tributaries. The highest recorded storm surge was 8.31 ft NAVD88 near Everglade City. A complete synopsis of Hurricane Irma and its impacts is available through the National Hurricane Center (NOAA, 2018).

2 OVERVIEW AND SCOPE OF WORK

The University of Florida's Wind Hazard Damage Assessment Group in collaboration with other researchers at several universities (Florida International University, Florida Institute of Technology, Notre-Dame University and Auburn University) captured preliminary damage observations in communities throughout Florida. The teams made observations in the Florida Keys, Everglade City, Chokoloskee, Miami, Naples and Marco Island. The University of Florida's Professor David O. Prevatt presented summary observations to the Florida Building Commission on 9 October 2017. Wind damage occurred throughout the length of the state, consisting mainly of minor to moderate roofing damage, damage to wall cladding systems, garage doors, flooding and damage from fallen trees. Many houses in coastal, low-lying areas were damaged by the storm surge (for example, houses in Big Pine Key, Everglade City and the Chokoloskee community).

The scope of this task is divided into two phases which are as follows:

Phase 1 Scope:

- Maintain data collection and transport equipment as necessary for measuring intensity of land-falling hurricanes and documenting damage.
- Perform field data collection preparation to include: purchase and organize data collection and recording equipment; documenting equipment and software for database construction.
- Deploy wind monitoring assets in the event of a land-falling hurricane.
    - Wind monitoring equipment training was conducted by the preliminary program field program manager (Masters) and his staff. However. This did not incur cost to this budget.
- Provide an initial triage assessment of damage to the residential infrastructure, including approximate extent of visible water depths, where evident.
    - The damage assessment effort conducted within five days after landfall, included contracting with a licensed supplier of unmanned aerial vehicles to take photographs above the damaged areas.
    - UF leveraged the FBC damage assessment by working with a National Science Foundation – supported RAPID research project (bit.ly/2xxO5iu), which enabled the surveying and the recording of building performance for over 1000 structures.

- Data collection training of participating personnel was conducted by the PIs (Prevatt, Gurley) in-situ and via Zoom remote meetings, in coordination with the survey application (Fulcrum) that was used by the leadership team of the NSF RAPID grant (PI: Kijewski-Correa) that supported a statewide damage assessment response.

The following tasks were not performed: Conduct one deployment training exercise (Thunderbolt Drill) in the field to ensure personnel are trained and familiarized with wind monitoring equipment and data collection procedures.

Phase 2 Scope:

The work had been divided into two tasks:

Task 1:

The study will focus on building types regulated by the Florida Building Code, i.e. site-built residential structures and structures built in accordance with Florida's Manufactured Buildings Programs. We will separate the damage by the Year Built, into two groups, based on date of approval of building plans by Before and After 1 March 2002. We propose to conduct this scope using existing publicly available data from the county property appraisers and the Florida Department of Revenue.

- Using our photographic database (from the post event survey work) we will count observed exterior damage patters and rank them in order from most to least prevalent damage satisfied by estimated wind speed experienced at each location (Zip Code).
- Identify the metadata characteristics on each community or subdivision surveyed, including: Year Built, materials used, building codes at force during time of construction, number of homes surveyed in each subdivision or community, changes made to the home during construction and whether the work was done via permitting.
- Document the peak wind speed and the wind direction at peak wind speed due to Hurricane Irma at each community using reliable data sources, including the FCMP towers and wind swath hind-cast maps from modelers contracted via NSF RAPID grant.
- Document the potential storm surge elevation at each house based upon USGS provided data as well as field observations of high water marks.

Task 2:

It is our expectation that any exterior building envelope damage that results in a breach of the building envelope may allow wind-driven rain to enter the interior and cause additional damage. The extent of this hidden damage cannot be ascertained by an exterior survey alone. Therefore, task 2 proposes to conduct structured interviews with a subset of homeowners from task 1, to quantify the damage and repair costs (if available at the time) that occurred inside their houses.

- Develop structured interview questions and obtain the approval of Carnegie Mellon University's Internal Review Board to conduct interviews via telephonic methods, to be determined
    - Elicit extent of interior damage and costs due to water leakage, including documentation of source of cost information collected from homeowner.
    - Elicit extent of storm-surge height, damage caused and costs from building interior and contents.
    - Collect information on their evacuation patterns and tendencies.
    - Assess homeowners' opinions about doing structural retrofits to their home in light of their recent experience with Hurricane Irma and performance of their home.
- Recruit a sample set of homeowners from our database (approximately 50 to 100) roughly distributed equally among the six areas surveyed.
    - Identify the year built of the house
    - Identify demographics of the homeowner or occupant
    - Identify improvement made since the home was first constructed.
    - Identify whether retrofit/repair work was done through local permitting and inspection
- Transcribe responses of homeowners and analyze the data into Before/After 1 March 2002 categories.
- Present conclusions of the survey supported by graphs and figures to the Florida Building Commission by 30 June 2018 including information on whether the retrofit/repair work was done through local permitting and inspection.

3 DAMAGE ASSESSMENT METHODOLOGY

The objective of these assessments was to document the performance of single family residential (SFR) buildings during the hurricane with respect to the building code in place at the time the building was constructed. Specifically, the Florida Building Commission is interested in a comparison of the wind and surge performance of homes built before and after the enactment of the 2001 Florida Building Code in March 2002.

3.1 Overview of Assessment Efforts

Due to the breadth of the damage incurred from Hurricane Irma, the PIs leveraged involvement in a complimentary, multi-institution damage assessment effort funded by an NSF RAPID grant (CMMI-1761461, PI: Tracy Kijewski-Correa, University of Notre Dame) to expand the scope of the damage assessment sponsored by the Florida Building Commission. As part of the larger, multi-storm reconnaissance effort, regional nodes were established at the University of Florida (UF, led by PI Kurt Gurley), Florida Institute of Technology (FIT, led by Jean-Paul Pinelli), and Florida International University (FIU, led by Ioannis Zisis), from which local reconnaissance was organized to respectively document damage along the Gulf Coast, Atlantic Coast and Southern Tip of the state. Each regional node engaged faculty and affiliated partners to assemble a team to assess their assigned geography, with the objective of swiftly deploying the initial wave of teams within a week of the storm's landfall. The organization and scope of the various efforts are summarized in Table 1.

Table 1. Summary of main post-Irma damage assessment efforts

Geographic Region	Team Lead	Key Assessment Locations	Assessment Dates
Gulf Coast (Tampa to Keys)	Kurt Gurley (University of Florida)	Naples, Marco Island, Goodland, Everglade City	9/12/2017 – 9/17/2017
Atlantic Coast (Jacksonville to Miami)	Jean-Paul Pinelli (Florida Institute of Technology)	Ponte Vedra Beach, St. Augustine	9/13/2017 – 9/15/2017
Miami metro and Florida Keys	Ioannis Zisis (Florida International University)	Miami, Marathon, Cudjoe Key, Key West	9/18/2017 – 9/25/2017

3.2 Assessment Methodology

Teams documented damage to structures, delineating the effects of wind and coastal hazards (where visible) with a standardized damage assessment instrument created and programmed using the Fulcrum mobile smartphone application (Spatial Networks 2017) for door-to-door implementation, providing an enhanced workflow compared to what the team used for Hurricane Matthew (Prevatt et al. 2017). Fulcrum supports in-line capture of geotagged photos directly from the user's mobile device, extracts all device-supplied metadata (date, time, etc.), and automatically geocodes local addresses based on GPS coordinates. The customized app then steps through major assessment categories defined by the team, beginning with classification of the structure including number of stories, occupancy and typology (roof shape, etc.). Any visible mitigation measures such as storm shutters, roof-to-wall connections, etc are also noted. Assessment teams assign an overall damage rating, attribute damage cause (wind, surge/wave, rain damage/water penetration, freshwater flooding, tree fall) and post-event functionality, followed by component-level damage ratings to roof cover, roof sheathing, roof structure, wall cladding, wall sheathing, wall structure, doors and windows. Table 2 defines the total damage rating scale for low-rise (less than 3 stories), single- and multi-family residential structures – the focus of the FBC study. Assessments relied on direct exterior observations accompanied by geotagged photos and statements from eyewitnesses to establish failure sequences, high water marks and interior damage. Typically the assessment teams did not have access to the interior of homes and were only able to document exterior damage.

At select locations, professional Unmanned Aerial Surveys (UAS) generated additional geolocated aerial imagery for subsequent creation of photogrammetric products like point clouds, 3D models, digital elevation models, and orthomosaics. A deliberate pre-programmed flight plan captured all data to achieve a targeted ground sample distance (resolution) of 3 centimeters or less.

Field assessment teams typically did not have access to the interior of homes to document interior damage from wind-driven rain, storm surge inundation or flooding. To supplement the field assessment data, homeowners were solicited post-hurricane to participate in online interviews to answer questions with regards to interior damage and economic losses. Initial and follow-up recruitment letters were sent out to 784 of the homes in the field assessment database, resulting in 32 responses – 31 of which were linked to homes in our field assessment database. The recruitment methodology is described in more detail in Section 5, along with the detailed responses to the survey.

Table 2. Quantitative guidelines for assigning overall damage rating

Damage State	Damage Description	Roof/Wall cover failure	Window/ door failures	Roof/ deck	Roof structure failure	Wall structure failure[1]	Interior water damage
0	No visible damage	0%	No	No	No	No	None
1	Minor damage	> 2% and ≤ 15%	1	No	No	No	Minor rainwater ingress, no evidence of flood.
2	Moderate damage	> 15% and < 50%	> 1 and ≤ the larger of 3 and 20%	1 to 3 panels	No	No	Water marks 0-2 ft above first floor. Significant rainwater ingress. Interior damage ≤ 30%.
3	Severe Damage	> 50%	> the larger of 3 and 20% and ≤ 50%	> 3 and ≤ 25%	≤ 15%	No	Water marks 2-4 ft above first floor. Interior damage > 30% and ≤ 60%
4	Destruction	> 50%	> 50%	> 25%	> 15%	Yes	Water marks > 4 ft above first floor. Interior damage > 60%.

Notes:
[1] Wall structure refers to walls in living area only. The ground level of elevated structures often have breakaway walls that can be easily damaged by storm surge. This damage should be classified as Damage State 2 (Moderate Damage).
[2] A building is considered to be in the damage state if any of the shaded damage indicators in the corresponding row occurs.

3.3 Data Processing

Following the field work, damage assessments underwent a rigorous quality assurance/quality control (QA/QC) process, detailed in Kijewski-Correa et al. (2018), to improve the accuracy and consistency of the field-obtained data. This process was divided into two stages, each with a detailed procedure. Most critical was Stage 1 -- verifying basic building attributes, geolocation details including site address, and overall damage state; and Stage 2 -- adding or updating relevant property details and verifying or adding overall/component damage ratings, respectively, using public sources such as county property appraiser websites and post-event aerial imagery from NOAA. Once the dataset completed its QA/QC process it was curated in NHERI DesignSafe (Rathje et al., 2017).

The consistency of the final database, particularly in regards to the association of building attributes to the damage observations, depended in part upon the data availability in the various counties and the quality of the available photographs taken by the teams. Table 3 summarizes the attributes available from Collier, Monroe, Miami-Dade and St. Johns Counties, which include 98% of the sites assessed. Of the four, St. Johns and Monroe Counties had detailed attributes recorded for each home that were then associated with homes assessed post-Irma, while Collier and Miami-Dade counties had only the year built. In addition to the building attributes, the various counties also maintained online public records of building permits associated with homes within the county. However, although requests were made to each county, only St. Johns was able to provide permit information for the addresses that were assessed post-Irma directly in bulk. For the remaining counties, individual addresses had to be looked up and permit information sifted through to evaluate whether any major repairs or retrofits had been completed since the home was constructed. The process was completed for 31 homes, but collecting the data for all assessed homes was beyond the scope of this study.

Table 3. Attributes available from the counties in which assessments were performed.

County	Collier	Monroe	Miami-Dade	St. Johns
Year Built	Y	Y	Y	Y
Effective Year Built	N	Y	N	N
Ext. Wall Cladding	N	Y	N	Y
Ext. Wall Structure	N	Y	N	Y
Roof Shape	N	Y	N	Y
Roof Cover	N	Y	N	Y
Number of Stories	N	Y	N	Y
First Floor Elevation	N	Y	N	Y
Foundation Type	N	Y	N	Y

UAV Data Processing

Photographic imagery from the UAV is collected and processed using a specialized software PIX4D (pix4d.com/) that was developed for this purpose. The specific software was Pi4Dmapper version 4.2 which is a freely available online program. The program used input of individual photographic images taken from the overhead drone, either as individual images or the software can extract still images from videos. Prior to processing each project is established by the pre-programmed flight path and frequency of images taken. In our case we used the images to corroborate the damage observations made during our ground surveys and to validate the percentage damage to roofs. Four locations within our survey had over flights of the UAV and from which we created 3D Point Clouds. An example of the data input and processing is illustrated for the Little Torch Key North area, below:

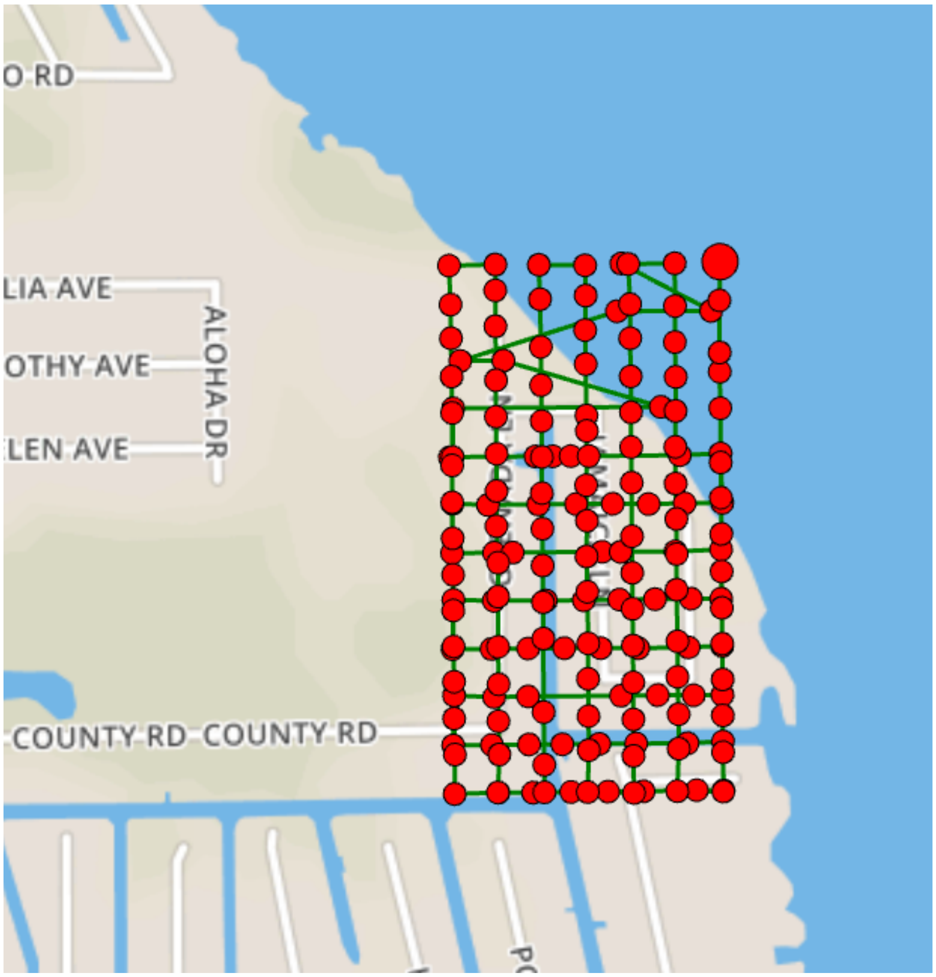


Figure 1. Flight Path of the UAV taken over Little Torch Key North. The red dots indicate locations where photographs were taken. The photographs and metadata (including GPS location of the camera, height etc.) are input to Pix4DMapper to produce the 3D Point Clouds.

The processing of all images within the Pix4DMapper software creates a 3D Point Cloud that within color enhancements represents the terrain, trees and buildings within the scanned area. There are many manipulations that can be done using this processed data including meshing of surfaces, fly-through animation and some editing. Figure 2(a) and Figure 2(b) shows two images of extracted from within the 3D Point Cloud.

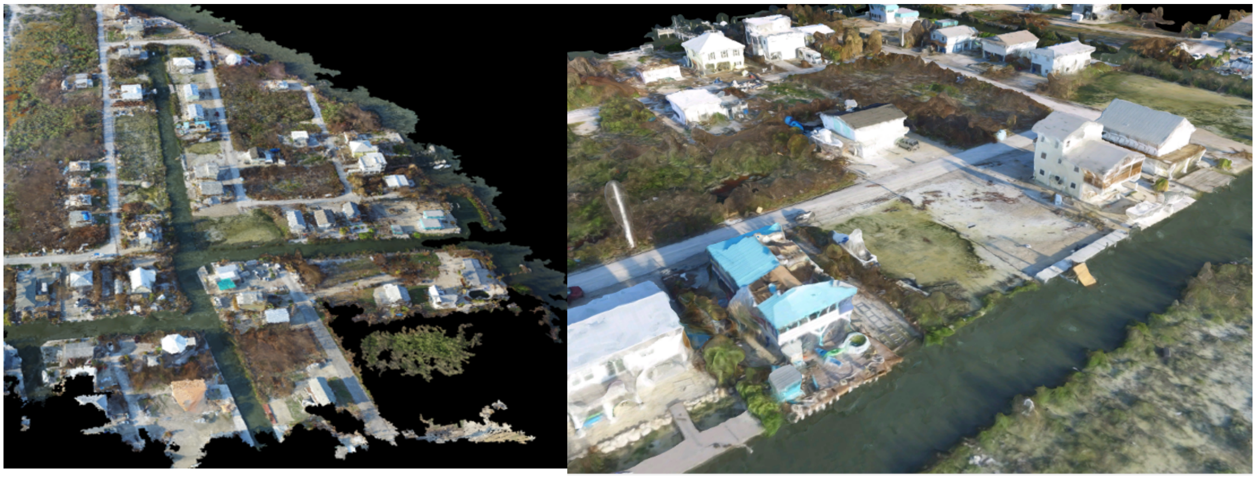


Figure 2. Two images extracted from 3D Point Cloud created for Little Torch Key North. Figure 2(a) shows the complete area created using still images captured by the UAV, and Figure 2(b) is a partial view showing damage to the metal roof Dutch-hipped roof house at 756 Jamaica LN.

The 3D Point Clouds are a valuable tool enabling the surveyors to zero in on a structure and identify major damage on many surfaces. In Figure 3 it is obvious more than 50% of the roof structure has failed, and details of the failed structures can be observed in high-resolution still images.

Figure 3. Details of roof damage to structure at 756 Jamaica LN, Little Torch Key North. Figure 3(a) is a still-image taken from the drone overflight and Figure 3(b) is a photograph taken during the damage surveyor from the ground, showing the metal roofing blown over the north side of the building with some battens still attached.

3.4 Hazard Intensity Estimates

3.4.1 Peak Gust Wind Speeds

Hurricane Irma achieved a maximum 1-minute sustained wind speed of 167 mph (Category 5 on the Saffir-Simpson Hurricane scale) as it made landfall near Cayo Romano, Cuba on September 9, 2017. Interaction with land caused the hurricane to weaken slightly, but it reintensified to a Category 4 hurricane over the Florida straits as it turned northwest towards Florida. When Hurricane Irma made landfall near Cudjoe Key on September 10, 2017, the maximum surface gust wind speed observation was 121 mph at 20 ft above ground level by the Key Deer National Wildlife Refuge RAWS station (NOAA 2018). Assuming open exposure and using the boundary layer wind speed conversion method outlined in Simiu and Scanlan ((1996), the 121 mph gust wind speed measurement corresponds to 129 mph at 33 ft (10 m), the standard height used in wind engineering.

After making landfall in Cudjoe Key, Hurricane Irma continued northward and made a second landfall near Naples, FL. The official intensity at landfall near Marco Island is estimated at 115 mph (1-minute sustained wind speed). The FCMP towers recorded a peak 3-second gust wind speed of 106 mph at 10 m height in Naples.

While individual wind speed observations provide valuable information, the spatial resolution remains limited and the observations require standardization to common height, gust averaging time and upwind terrain conditions. As such, for the purpose of relating wind speeds to observed damage, it is typically necessary to use the wind speed observations to condition a numerical hurricane wind field model and use the conditioned model to estimate wind speeds at discrete points throughout the hurricane path. For this study, we use the Hurricane Irma wind speed distribution map provided by ARA (Vickery et al. 2017), which was developed by fitting the Vickery et al. (2009) hurricane wind field model to standardized surface observations. The peak wind speed contours estimated by the model are shown in Figure 4, and correspond to 3-second gust wind speeds at 33 ft height above ground level in open terrain. For buildings located in terrain other than open, and at mean roof heights other than 33 ft, adjustments would need to be made to obtain the local wind velocity. The exact adjustments necessary are different for each building. The fine-scale evaluation of the adjusted, local wind speeds is outside the scope of this study.

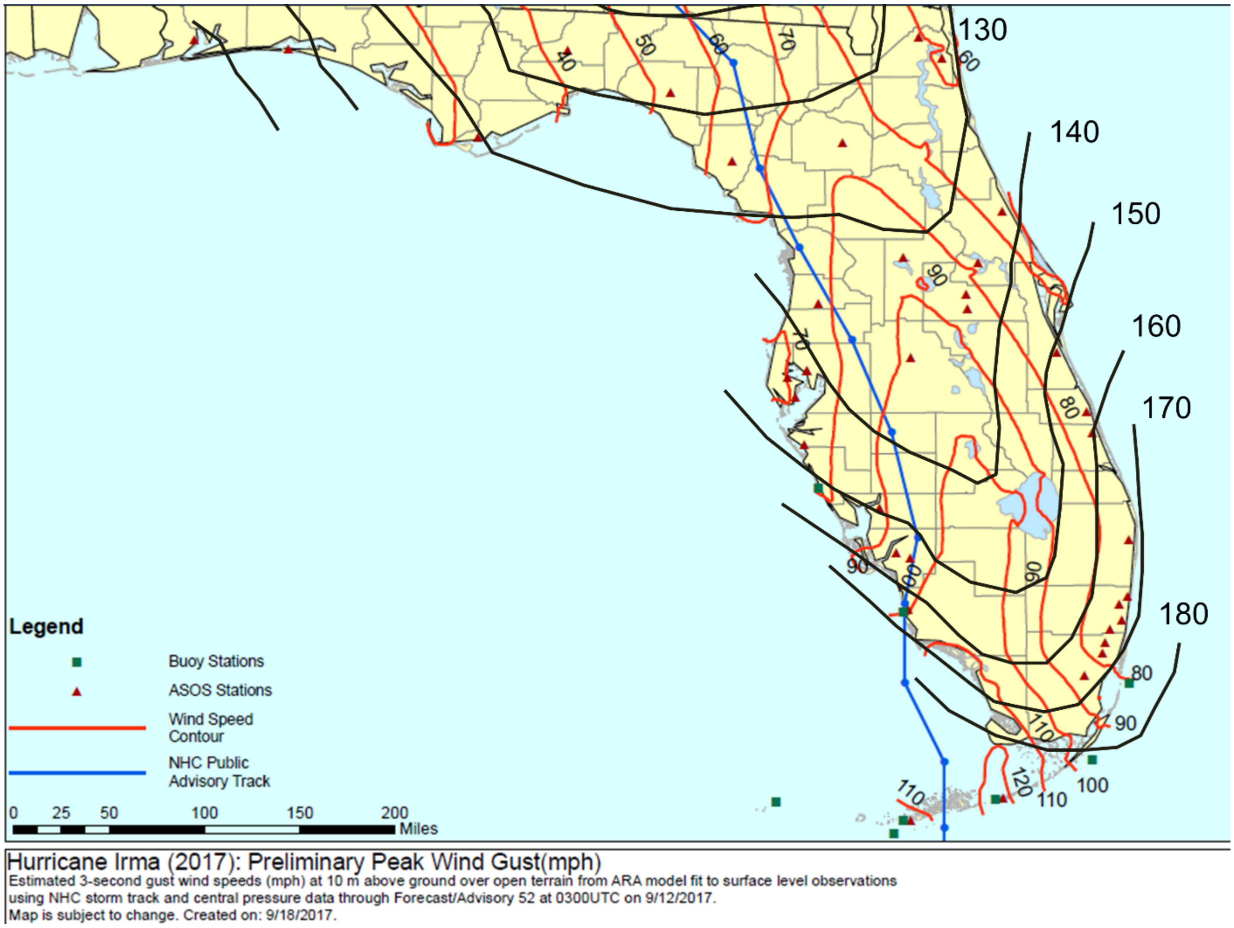


Figure 4. Comparison of design wind speeds in FL compared to estimated wind speeds from Hurricane Irma. Black lines correspond to design wind speeds for Category II structures from ASCE 7-10. Red lines correspond to estimated peak 3-second wind gusts at 33 ft height in open terrain across the state of Florida during the passage of Hurricane Irma, from Vickery et al. (2017).

Based on the ARA hurricane wind maps, the highest gust wind speeds in Florida were just above 120 mph and occurred in and around Marathon, FL, near the middle of the FL Keys. Peak gust wind speeds in Marco Island were estimated near 110 mph.

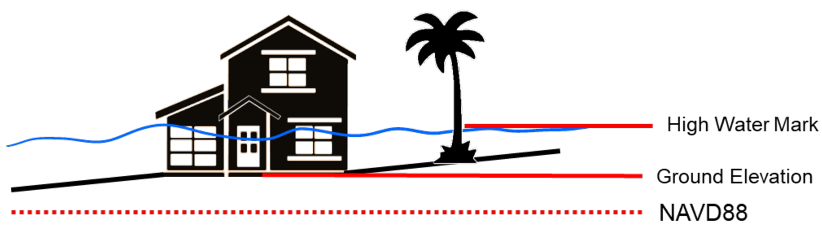
3.4.2 Storm Surge Inundation and Flooding

Storm surge inundation for each surveyed home was estimated using a combination of high water mark (HWM) measurements, obtained by the United States Geological Survey (USGS), and Digital Elevation Model (DEM), obtained from a 2013 Florida DEM database (UF Geoplan 2013) hosted through the Florida Geographic Database Library (FGDL).

The USGS HWM database provides the elevation of observed HWMs relative to the NAD88 vertical datum (Koenig et al. 2016), essentially a common vertical reference point. High water marks include seed lines, mud lines, debris lines, and more. To estimate the water depth at locations other than the HWM observations, it is necessary to couple the HWM elevations relative to NAVD88 with a DEM, referenced to the same NAD88 vertical datum. The DEM establishes the height of the land surface (not including buildings and vegetation) relative to the datum. The difference between the HWM elevation and the land surface elevation results in the water height above ground level. In equation form,

$$h_{water,AGL} = (HWM_{xy} - NAVD88) - (DEM_{xy} - NAVD88) \quad 1$$

where HWM_{xy} is a high water mark at a given location with GPS coordinates x longitude and y latitude, $NAVD88$ is the common vertical datum, and DEM_{xy} is the surface elevation at a given location with longitude x and latitude y. For this study the DEM used was a 5-meter composite DEM published by the University of Florida Geoplan Center, which sourced the Northwest Florida Water Management District DEM, the NOAA FLIDAR DEM, the Florida Fish and Wildlife Conservation Commission DEM, and a contour derived DEM. The provided elevation data is available at 16 ft (5 meter) resolution. More details of the dataset (*Florida Digital Elevation Model (DEM) Mosaic – 5-meter cell size – elevation units inches*) are available at https://www.fgdl.org/metadataexplorer/explorer.jsp.



$$Water\ Height\ AGL = (High\ Water\ Mark - NAVD88) - (Ground\ Elevation - NAVD88)$$

Figure 5. Illustration of the process for estimating the water height at each structure using the USGS high water marks and a digital elevation model.

A limitation of this approach is similar to that of the point wind speed observations – namely, that there is a lack of spatial resolution. For this study, the water elevation at a structure is taken as the height of the nearest HWM above ground level, using the local ground elevation at the structure, obtained from the DEM model, in Equation 1. An alternative approach is to use the output of surge models such as ADCIRC (Hope et al. 2013), coupled with the height of the ground surface at each surveyed building, relative to NAVD88, to estimate the water height at each structure. The simulation and incorporation of such models are beyond the scope of this study, but in the future such data may be publicly available through NSF NHERI Design-Safe cyber-infrastructure (Rathje et al. 2017) and could improve the quality of the water height estimates.

During the field surveys, teams estimated high water marks above ground level at a handful of structures, providing a means of comparing the estimated water heights at ground level (USGS + DEM) to the direct observations at the same geographic location. The results of the comparison are shown in Figure 6 for the 36 homes with high water mark estimates. The correlation is generally positive, but the data is highly scattered, demonstrating the need for further improvements in the methodology.

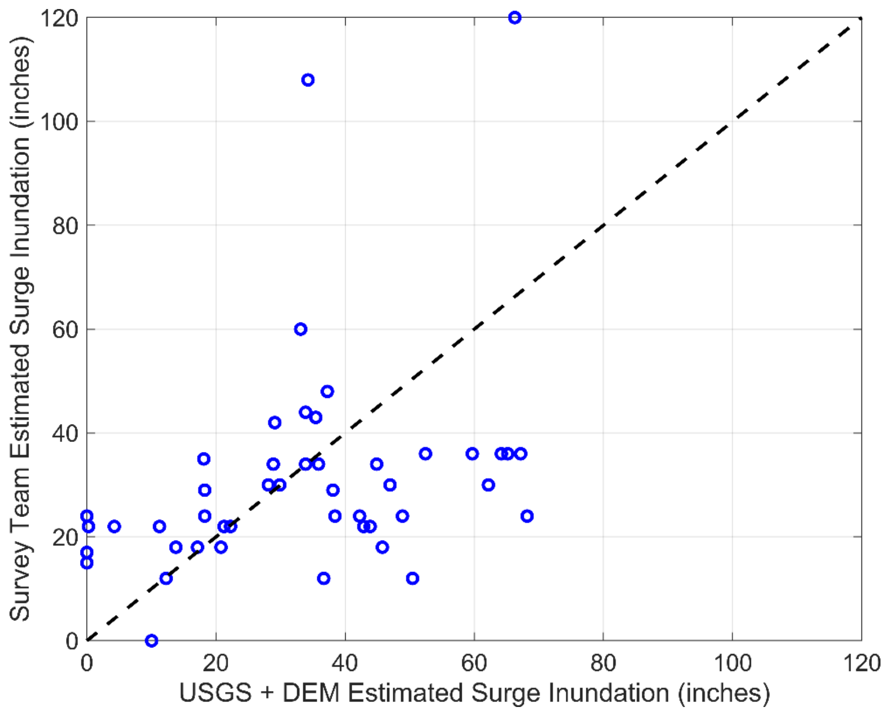


Figure 6. Comparison of Hurricane Irma storm surge inundation estimated by the field teams and storm surge inundation estimated using the USGS HWM and the FL DEM database. The dashed line is the unity line with proximity to the line indicating the level of agreement between the two sources of surge inundation height estimates.

Figure 7 shows the distribution of estimated storm surge inundation above ground level for homes with inundation greater than 0 (i.e., homes potentially exposed to surge inundation). Of the homes that were potentially exposed to storm surge inundation, the majority experienced an inundation less than 6 ft above ground level based on the analysis using USGS HWM and the FL DEM.

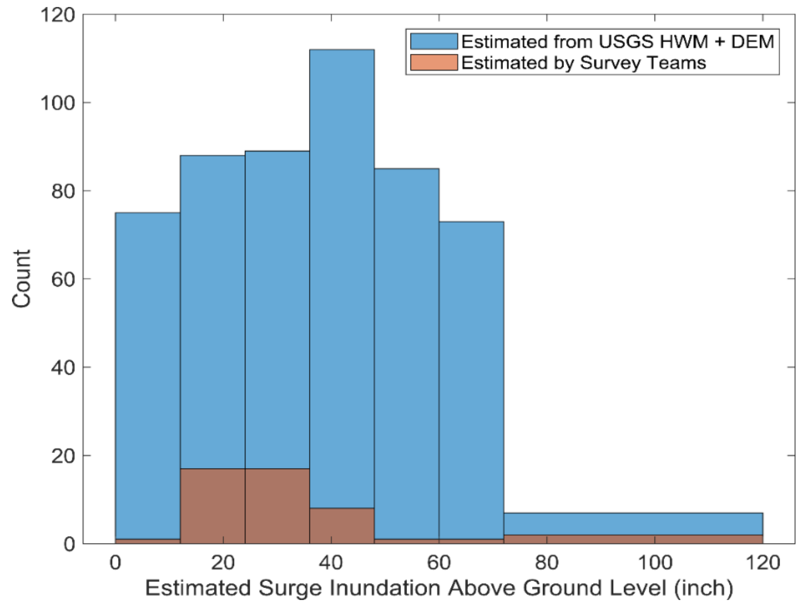


Figure 7. Histogram of surge inundation depths above ground level as observed by the survey teams and as estimated using the USGS HWM and the DEM data.

3.5 Characteristics of Buildings in the Damage Assessment Dataset

The complete dataset collected following Hurricane Irma by the assessment teams contains 1121 structures, but 86 of the structure records have missing or incomplete information that render them unsuitable for analysis. The remaining 1035 records are summarized by use in Table 1. This report focuses primarily on Single Family Residential structures. Of the 800 SFR structures, 81% were constructed prior to 2002, the year the 2001 edition of the Florida Building Code was enacted statewide. Statewide, approximately 80% of SFR were constructed prior to 2002, indicating the collected dataset is a reasonable sample of the state population of SFR.

Table 4. Summary of assessments by building use

Building Use	Number of Assessments	% Year Built < 2002
Single Family Residence (SFR)	800	81%**
Mobile/Manufactured Home	147	90%
Apartment/Condo	28	94%
Church	8	100%
Retail Store	7	100%
Hotel/Motel	6	100%
Institutional	7	29%
Other	32	75%
Total	**1035***	**83%**

*Excludes 86 records with missing or incomplete information
** Statewide, approximately 80% of FL SFR built < 2002 (American Housing Survey, 2015)

The geographical distribution of the SFR are shown in Figure 8 in relation to the estimated peak gust wind speeds. Over 92% of the assessments were made of homes in Collier County or Monroe County, where impacts from Hurricane Irma were most severe. To facilitate comparisons between the performance of pre- and post-2002 homes, the assessed homes were grouped geographically based on exposure to similar hazard intensity levels.

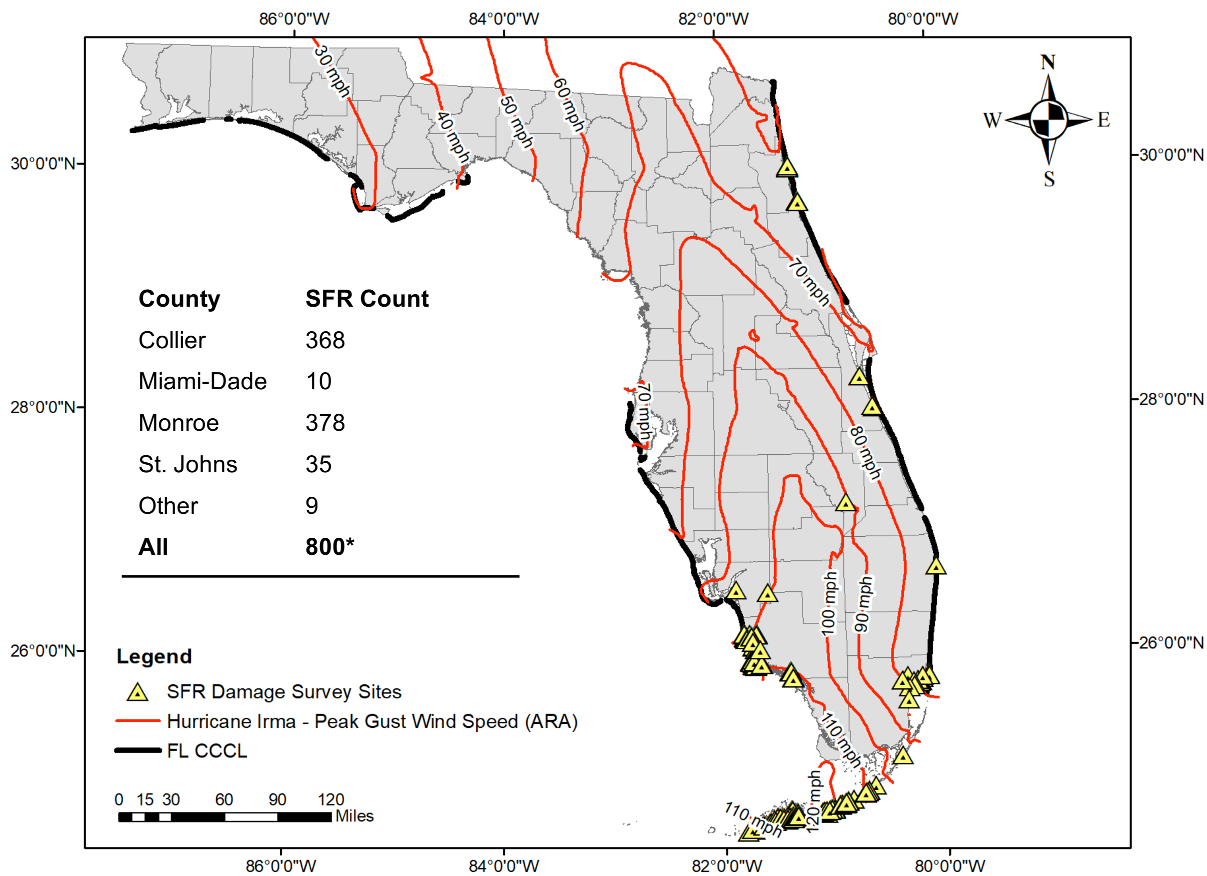


Figure 8. Geographical distribution of SFR assessments in relation to estimated peak gust wind speeds. Gust wind speed contours are courtesy of ARA (Vickery et al. 2017).

Figure 9 shows the specific geographic regions used in our analysis in relation to the peak gust wind speed contours and the Florida Coastal Construction Control Line (CCCL). The CCCL is not present in Monroe County. In each geographic region where the CCCL was present, our assessed homes were inland of the CCCL, except for the Ponte Vedra homes in northeast FL.

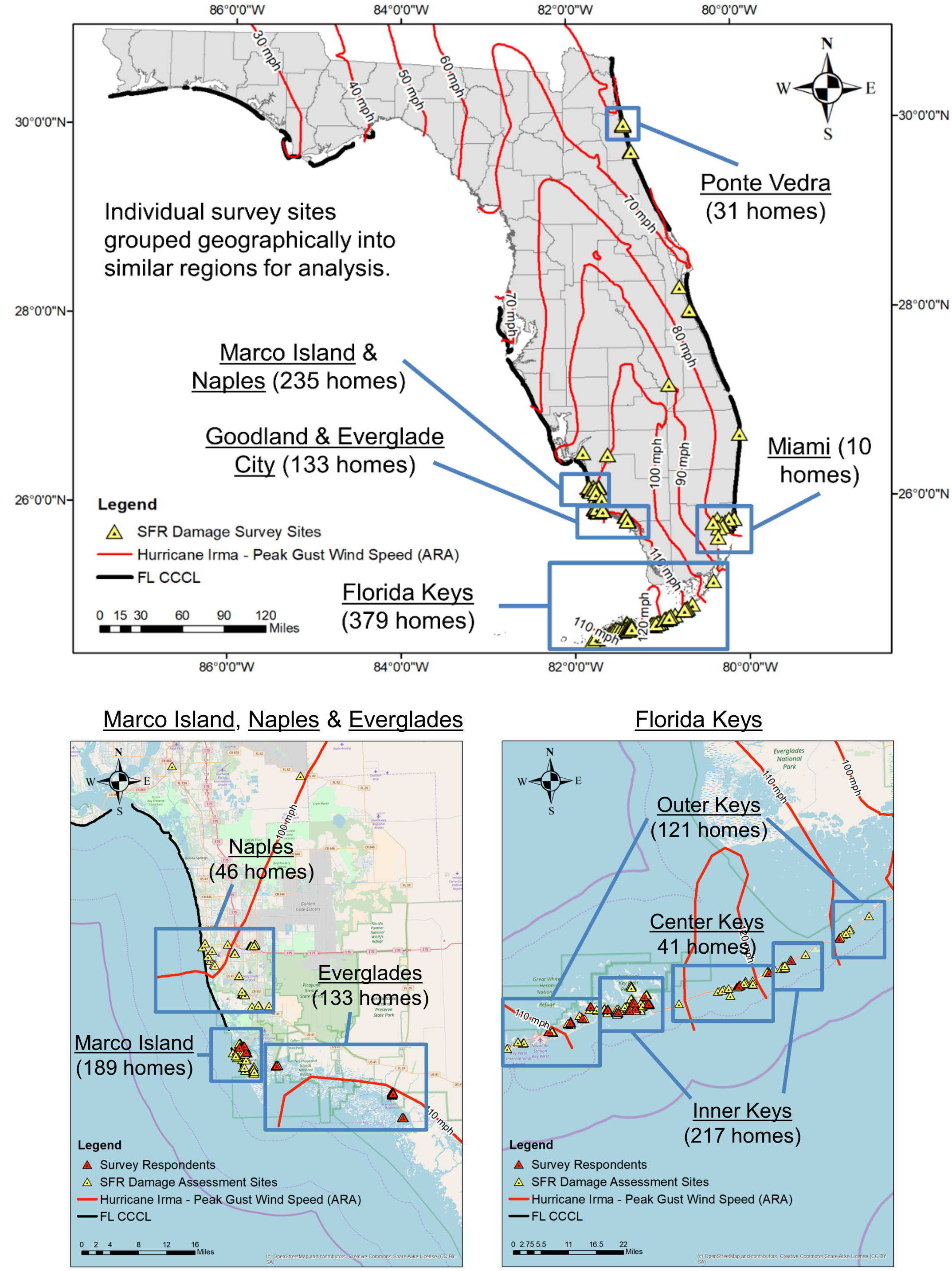


Figure 9. (Top) Overview of the primary geographic regions into which the assessments were divided. (Bottom) Closer views of sub-regions used in the Florida Keys and near Marco Island with locations associated with homeowner interviews shown in red.

The objective of grouping the SFR assessments was to provide a means of analyzing pre-2002 and post-2002 SFR performance under exposure to similar hazard conditions, while simultaneously ensuring a sufficiently large number of SFR within each geographic region for statistical robustness.

Table 5 summarizes the number of SFR assessments within each region in relation to the estimated hazards – peak gust wind speed (WS), surge inundation above ground level (HWM) – and key structural design parameters including the ASCE 7-10 design wind speed and location within a wind-borne debris region. The ratio of the square of the estimated gust wind speed (spatially averaged across each of the assessed homes in the region) from Hurricane Irma to the design wind speed is also provided as an indication of how close estimated wind loads were to design wind loads. The highest wind speeds are estimated to have occurred in the Center Keys, which primarily consists of Marathon, FL, while the lowest wind speeds in our assessments were estimated to have occurred in the Ponte Vedra region. Note that this excludes a handful of homes just south of Ponte Vedra that were damaged by a cyclone-induced tornado estimated at EF2 intensity (~130 mph). Surge inundation was greatest in the Center Keys, Inner Keys (including Ramrod Key, Little Torch Key, Summerland Key, Big Pine Key and others), and the Everglades (including Everglades City, Goodland and Chokoloskee) regions. All assessed structures were within the wind-borne debris region as specified in the 2001 FBC, but SFR structures constructed prior to 2002 may not have been subject to these provisions.

The following sections summarize some of the key building attributes within each of the geographic regions listed in Table 5, specifically characterizing year built, number of stories, roof shape, roof cover type, wall cladding type and structural system.

Table 5. Summary of SFR assessments, hazard exposure, and design parameters within each geographic region

Region	Year Built	SFR	Home-owner Interviews	Mean WS (mph)	Mean HWM (inch)	ASCE 7-10 Design Wind Speed (mph)	Wind-Borne Debris Region	(Mean WS)^2 / (Design Wind Speed)^2
Center Keys	**All**	**41**	**3**	122	32	182	Yes	0.45
	< 2002	31	3					
	>= 2002	10	0					
Inner Keys	**All**	**217**	**9**	116	41	182	Yes	0.41
	< 2002	169	8					
	>= 2002	48	1					
Outer Keys	**All**	**121**	**9**	112	23	181	Yes	0.38
	< 2002	96	7					
	>= 2002	25	2					
Ever-glades	**All**	**133**	**4**	110	43	167	Yes	0.44
	< 2002	119	3					
	>= 2002	14	1					
Marco Island	**All**	**189**	**5**	106	1	170	Yes	0.39
	< 2002	151	3					
	>= 2002	38	2					
Naples	**All**	**46**	**0**	101	2	166	Yes	0.37
	< 2002	31	0					
	>= 2002	15	0					
Miami	**All**	**10**	**1**	79	6	170	Yes	0.22
	< 2002	10	1					
	>= 2002	0	0					
Ponte Vedra	**All**	**31**	**0**	62	0	130	Yes	0.23
	< 2002	29	0					
	>= 2002	2	0					
	Total	**788***	**31**					

* Total excludes 12 homes from a variety of inland locations with minor or no damage

3.5.1 Year Built

Figure 10 shows the distribution of year built for SFR within each of the primary geographic regions. The total number of SFR is reduced to 800 due to the inability to confirm the location or year built data for 50 of the SFR structures assessed. For all regions but Ponte Vedra and Miami, approximately 20% of the SFR structures assessed were constructed in or after 2002. The Everglades and Miami had greater proportions of pre-1960's SFR structures that were assessed. In the Keys, Marco Island, and Naples regions, the majority of the assessed SFR structures were constructed between 1980 and 2001.

3.5.2 Number of Stories

Figure 11 shows the distribution of elevated and non-elevated single and multi-story SFR assessed in each region. Elevation was estimated or measured in the field or was estimated based on the photographs taken by the team of each structure. When the elevation was estimated using photographs, engineering judgment was used. Recognizable features with reasonably standard heights such as entry doors and garage doors were helpful in these estimations, but there is uncertainty in the estimated values. In these assessments, care was taken to correctly identify what was an elevated 1-story structure versus a 2-story structure, as many times the space under an elevated structure was enclosed and used as a garage or storage which would result in a structure that appears to be a 2-story non-elevated structure from the exterior. The photographs and county property appraiser databases were helpful for correctly identifying elevated structures. For example, if exterior stairs leading to the floor of an elevated story were visible in the photographs, this was an indication that the bottom enclosure was not part of the living area and thus the living area was elevated above the ground level. Also, if two enclosed floors were visible but the property appraiser records indicated a one-story structure with additional storage space, this also indicated an elevated structure. Figure 12 shows an example of the homes mentioned above.

3.5.3 Structural System

The most common structural systems observed were wood-frame and some form of masonry block, as shown in Figure 13. In the Keys, some homes were identified with masonry block ground floors and wood-frame construction in upper flows. Identification of the structural system and its reinforcement or connections was challenging when there was no major structural damage to the walls. In those cases, the team relied upon county property appraisal records to identify at least the basic structural system. Unfortunately, Collier County and Miami-Dade County do not maintain records of the structural system and so in the Everglades, Marco Island and Naples regions the structural system typically remained unknown. Examples of these structural systems can be seen in Figure 13.

3.5.4 Roof Shape

Figure 15 shows that the majority of the assessed SFR contained gable roofs, particularly in the Keys. In Marco Island and Naples, hip roofs and complex roofs (with multiple gable and/or hip structures present in the roof) were most common.

3.5.5 Roof Cover

Overall, asphalt shingle roofs were most commonly observed in the dataset as shown in Figure 16. However, there was a significant proportion of metal roofs in the Keys and Everglades regions (approximately 50% combined), and a dominance of tile roofs in Marco Island and Miami (60% and 90% respectively). Tile roofs were infrequently observed in the Keys.

3.5.6 Wall Cladding

Figure 17 shows that wall cladding systems in the dataset primarily consisted of vinyl siding or stucco. However it was often difficult to differentiate vinyl siding from horizontal wood (or engineered material) siding from the photographs. If the information was not input during the field by the surveyor, the county property appraiser records were relied upon for guidance. Wall cladding records were only maintained in Monroe and St. Johns Counties. In some homes there were multiple cladding types present. When this occurred, the dominant wall cladding system was used to classify the structure.

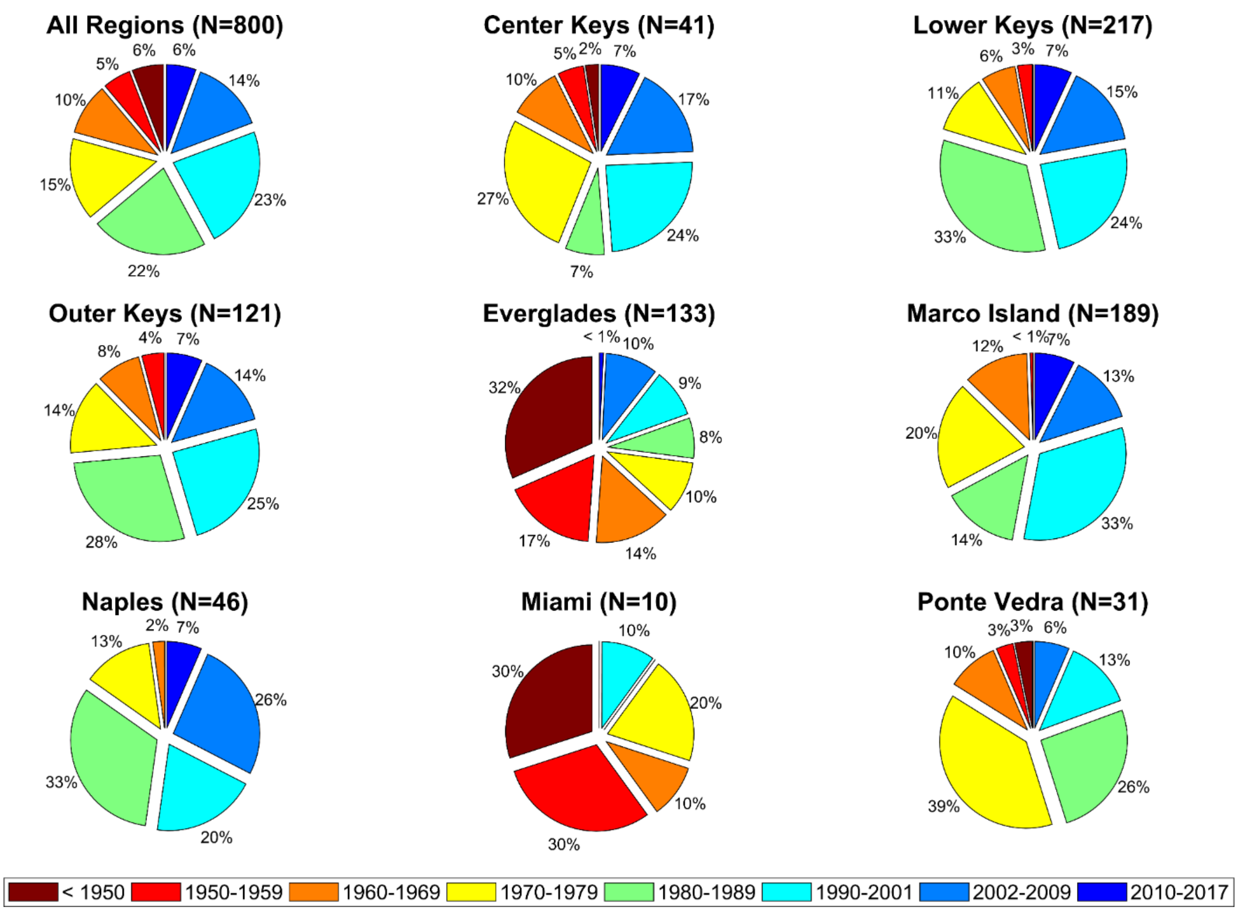


Figure 10. Distribution of year built for SFR within each of the primary geographical regions.

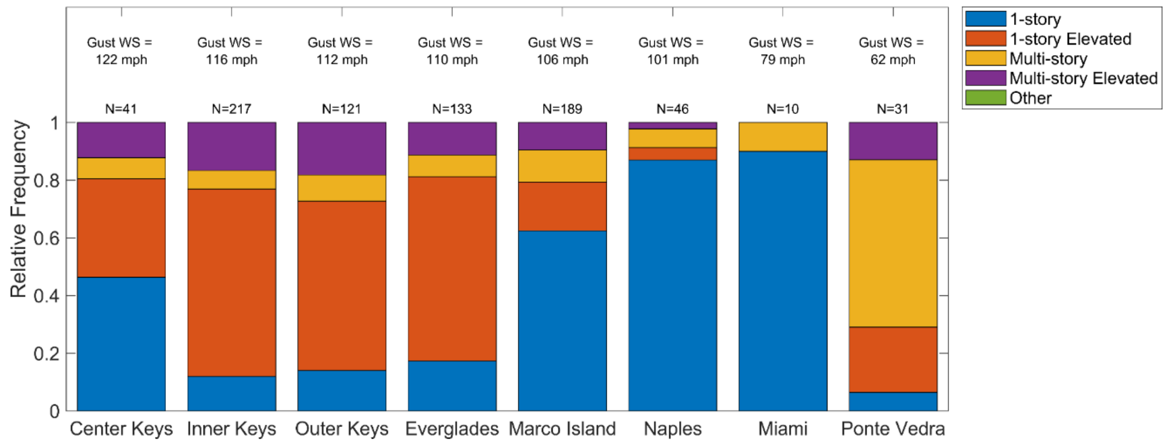


Figure 11. Proportions of single and multi-story, elevated and non-elevated SFR.

Figure 12. Examples of (left) multi-story non-elevated and (right) multi-story elevated homes.

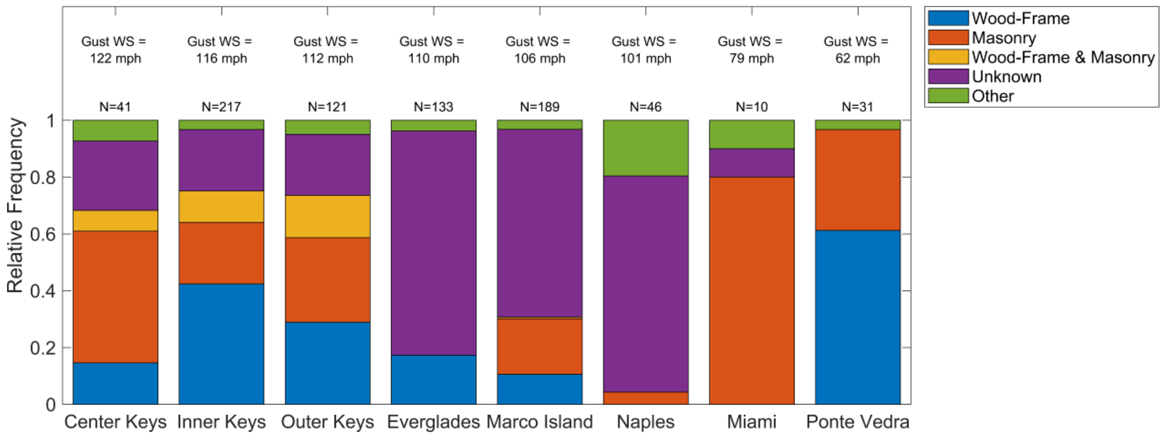


Figure 13. Proportions of structural systems observed in SFR assessments

Figure 14. Examples of (top-left) wood framed home; (top-right) home with masonry block first floor and wood framed second floor; and (bottom-left) home with masonry block.

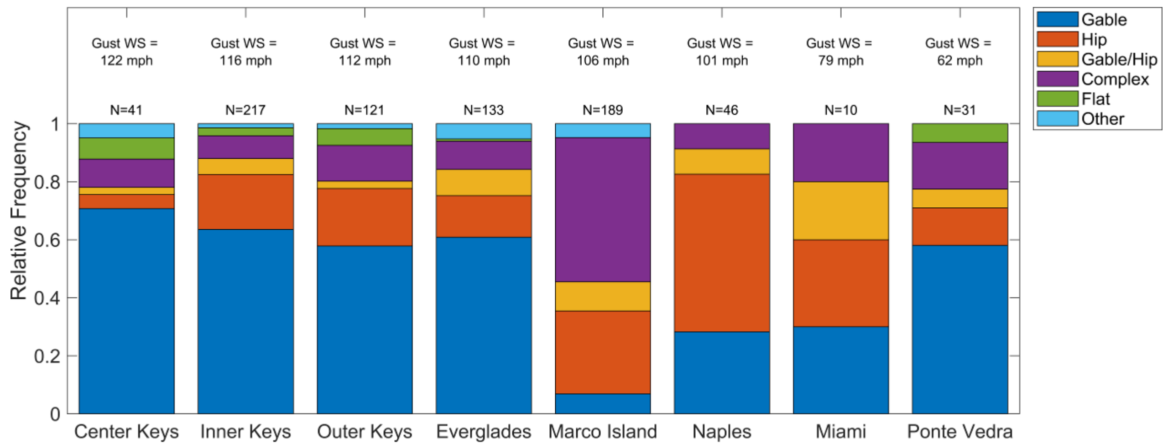


Figure 15. Proportions of roof shapes observed in SFR assessments.

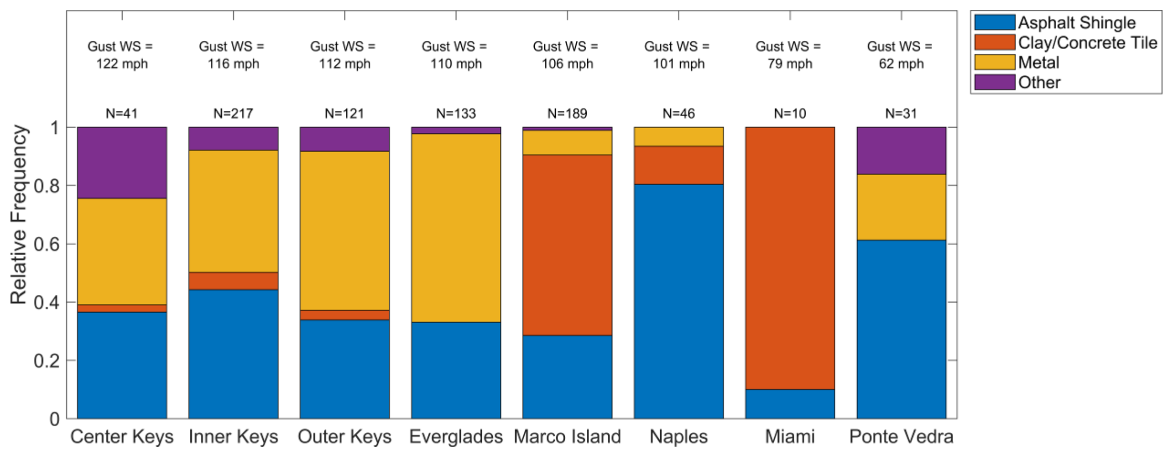


Figure 16. Proportions of roof cover types observed in SFR assessments.

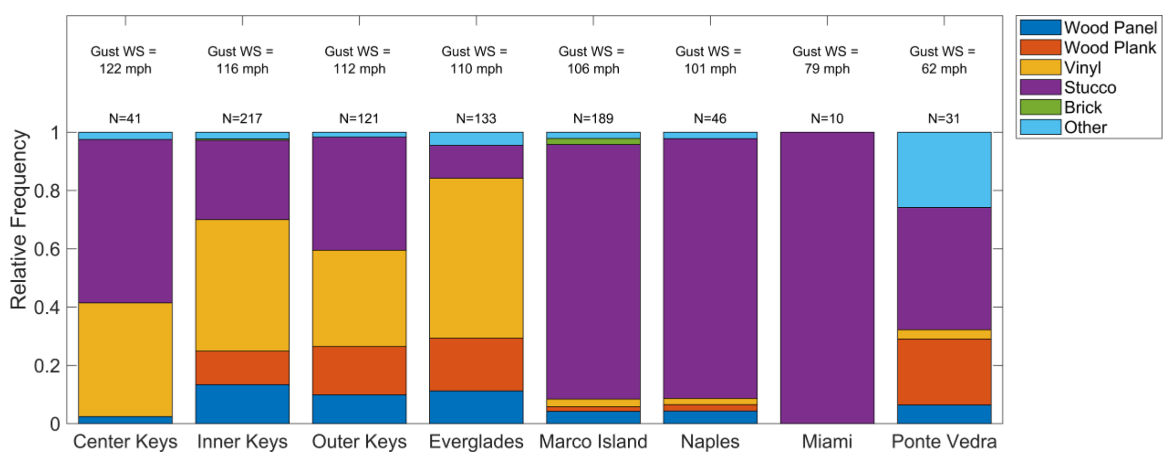


Figure 17. Proportions of primary wall cladding systems observed in SFR assessments.

4 DAMAGE ASSESSMENT FINDINGS

The following sections present the analysis of the assessment data with regards to the performance of pre- and post-2002 homes, major findings, and a few case studies to demonstrate the different issues highlighted. Exterior damage findings are primarily based on the post-Irma field assessment dataset of 840 homes and are stratified into the geographic sub-regions identified in Section 3.5 to normalize for hazard exposure. Interior damage findings are primarily based on 32 post-Irma homeowner interviews described in Section 5.

4.1 Exterior Wind Damage

Exterior wind damage varied from minor cladding failures to complete destruction of some buildings. Structural systems generally performed well, but component and cladding failures frequently occurred, even in post-2002 homes. The following sections summarize the overall exterior wind damage and damages to specific building components.

To provide a visual assessment of the damage caused by Hurricane Irma, four UAV 3dPoint Clouds were produced covering Little Torch Key South, South Ponte Vedra Beach, FL, St. Augustine FL and Little Torch Key North (already shown in Figure 3). The following images provide three areas.

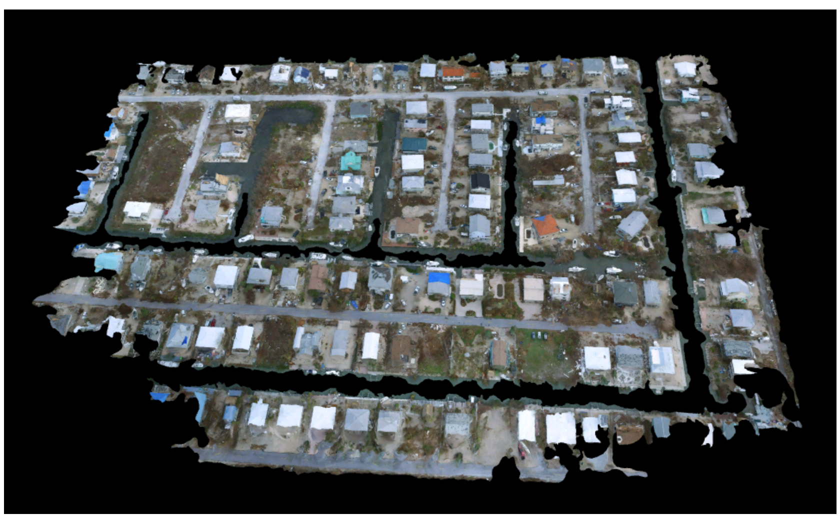


Figure 18. Little Torch Key South

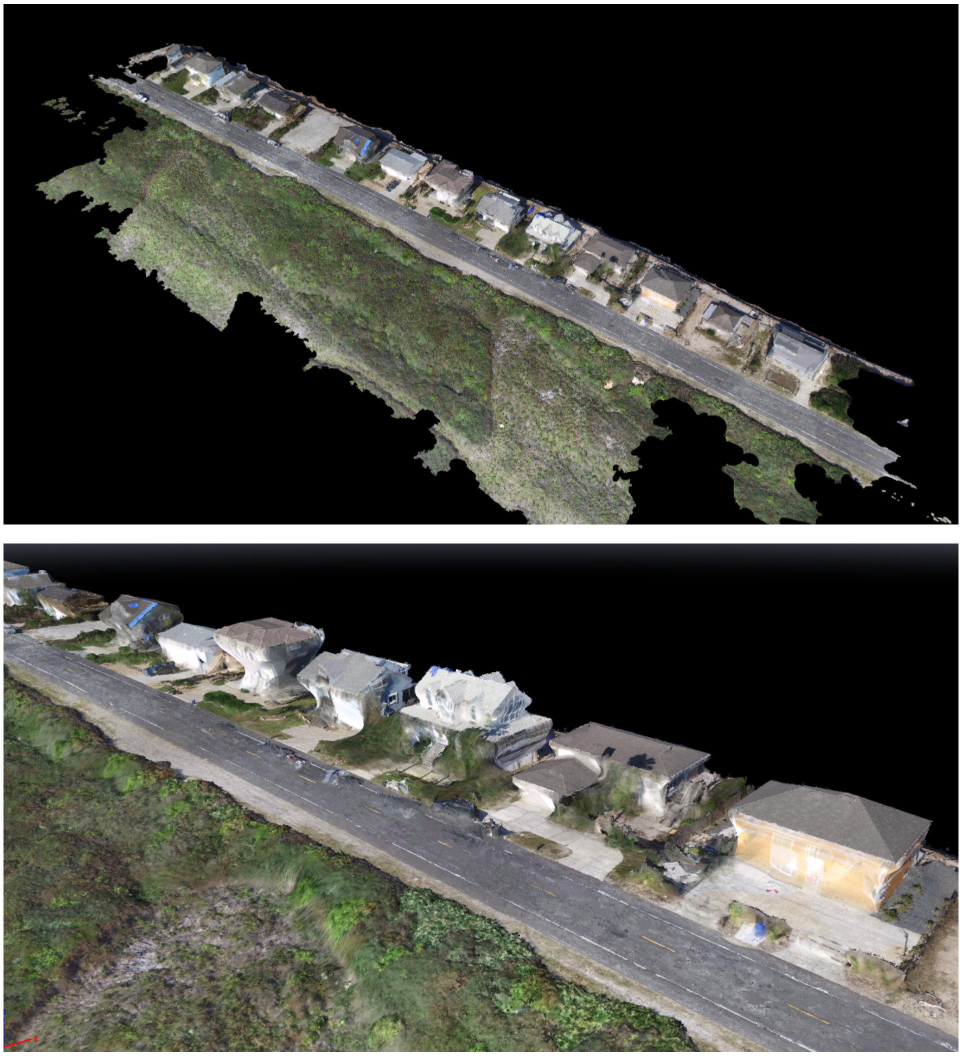


Figure 19. South Ponte Vedra, FL. While the view from steep angle Figure 19(a) provides good resolutions of roofs, when a lower viewpoint is used, some of the detail on the houses is lost due to artifacts made during the processing.

Figure 20. Townhouses in St. Augustine, FL damaged by a hurricane-induced tornado rated EF2 by the National Weather Service.

Figure 21. Townhouses in St. Augustine, FL By increasing the number of still images and manipulating the grid size, greater resolution is possible from the 3D Point Cloud in which even the conditions and damage to walls and vertical surfaces can be identified.

4.1.1 Overall damage

Each assessed home was assigned an overall damage rating of No Damage, Minor, Moderate, Severe, or Destroyed as defined in Table 2. Figure 22 shows that only 26% of post-2001 homes experienced Moderate or greater damage as compared to 38% for pre-2002 homes.

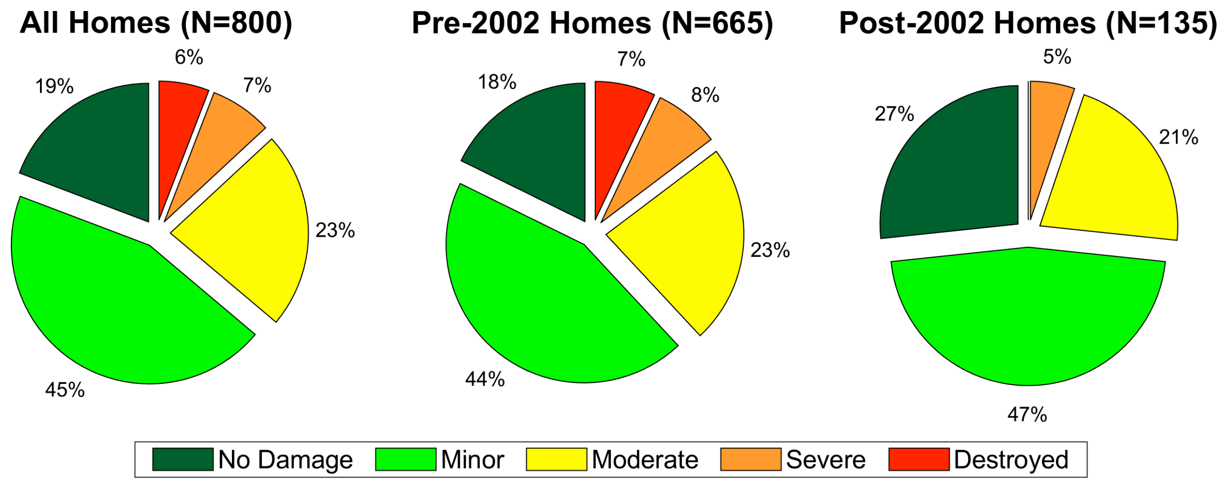


Figure 22. Distribution of overall damage ratings for all structures, pre-2002 and post-2001 structures.

Broken down regionally, Figure 23 shows that the overall trend of higher rates of Moderate or greater damage states in pre-2002 homes holds across all regions and all ranges of hurricane wind speeds. Interestingly, the highest proportion of destroyed homes occurs in the Inner Keys, which is not where the highest gust wind speeds were estimated to have occurred. The anomalous rate of severe and destroyed homes in the Ponte Vedra region is also of interest as the gust wind speeds were only estimated at 62 mph, meaning wind loads were just 23% of the ASCE 7-0 design wind loads for a Category II structure as indicated in Table 5.

The National Weather Service reported weak tornadoes had touched down a couple miles south of where the destroyed homes were located, but no reports aligned with the observed damage. Further, the destroyed homes were separated by several homes with very little or no visible wind damage. Moderate or greater damage was only observed in the pre-2002 homes.

Figure 24 plots the mean damage rating for pre-2002 and post-2001 homes in each region. Damage ratings were converted to numerical values (No Damage = 0, Minor = 1, etc.) to facilitate the analysis, which assumes there is a continuous damage scale underlying the damage ratings. Statistical inference as to the differences between pre-2002 and post-2001 homes is made using 84% confidence intervals. Where confidence intervals do not overlap, the differences are statistically significant at a p-value of 0.05. Payton et al. (2003) show that using 84% confidence intervals for statistical inference matches well with the use of a p-value of 0.05 in the unpaired student t-test to infer differences between sample means. The statistical analysis indicates that pre-2002 homes have a statistically-significant higher mean damage rating than post-2002 in three of the five regions in which there is sufficient data to conduct the test. In every region containing both pre-2002 and post-2001 homes, the post-2001 homes have a lower mean damage rating. Thus the analysis clearly supports the hypothesis that homes built after the Florida Building Code was enacted statewide are overall less likely to experience wind damage than those built prior.

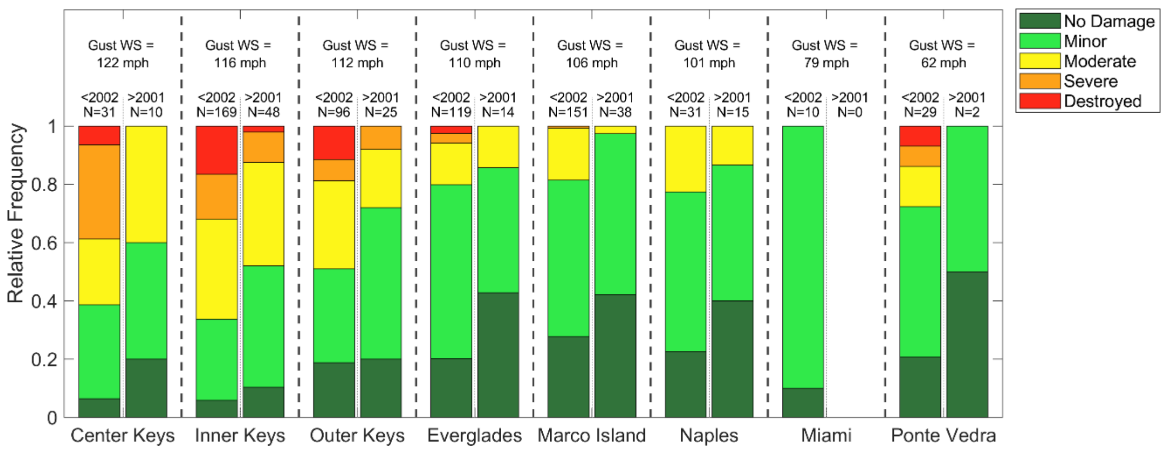


Figure 23. Distribution of damage ratings in pre-FBC and post-FBC

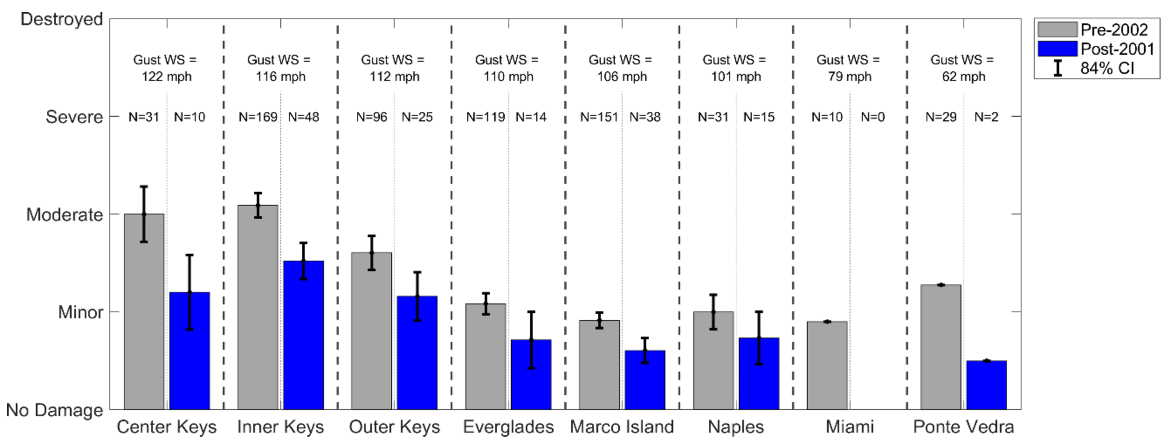


Figure 24. Median overall damage rating in pre-FBC and post-FBC SFR with confidence intervals for each region.

4.1.2 Roof structure performance

In a typical Florida home, roof structure refers to the wood rafters or trusses spanning between walls to support the roof sheathing and roof cover. Regardless of whether a home is concrete or masonry construction, or wood-frame, the roof structure is typically wood. The safe performance of the roof structure is necessary to protect the interior from rain inundation and to support the lateral displacement of the walls. The 2001 Florida Building Code and subsequent versions specified that for homes in the High Velocity Hurricane Zone, metal straps must be used to connect wood rafters or trusses to the wood or concrete walls, with a minimum design uplift resistance of 700 lbs. Prior to the enactment of the 2001 Florida Building Code, no statewide code was in effect and local jurisdictions had varied requirements and enforcement levels. Some pre-2002 homes may have been designed and constructed, or later retrofitted, in accordance with or exceeding requirements of the 2001 Florida Building Code for roof structure attachment. However structural design drawings are not publicly available for review for individual homes.

Field observations indicated roof structure performance was excellent in post-2001 homes as demonstrated in Figure 25, with only one apparent failure, which is discussed in more detail below. In pre-2002 homes, roof structure failures most frequently occurred in the Keys. Exact connection details were often not visible, but H2.5 or similar metal straps were observed in 14 of the roofs that experienced structural damage. Exact details of each connection were not accessible.

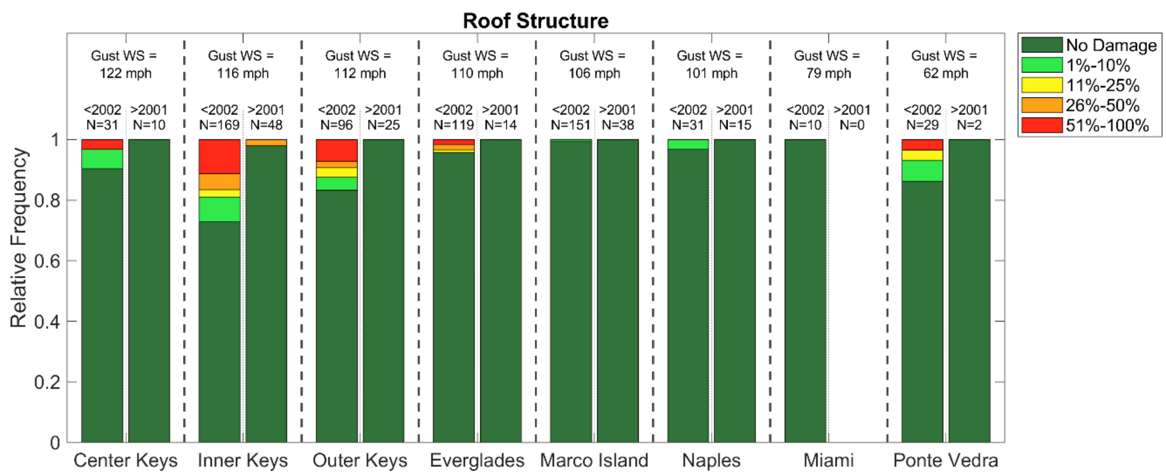


Figure 25. Frequency of roof structure damage occurring by region relative to FBC adoption.

The one post-2001 roof structure failure occurred to a wood-frame, two-story, elevated home located at 491 W Indies Drive in Ramrod Key, FL. The home experienced the collapse of a portion of the second story walls and lost approximately 30% of the roof structure. Metal straps anchoring the roof structure to the walls are visible in the post-hurricane photographs, but the exact connections were inaccessible in the field. The Monroe County property appraiser indicates the home was built in 2002, but permit records show that the construction permit application was made in 1999, prior to the enactment of the 2001 Florida Building Code. The ASD design wind speed was given in the permit application as 155 mph, which would correspond to a 200 mph ultimate design wind speed in ASCE 7-10. If properly designed and constructed, the home should have had residual capacity to resist the wind loads. The sequence of failure is unclear from the post-hurricane photographs.

Figure 26. Wood-frame, two-story, elevated home located at 491 W Indies Drive in Ramrod Key, FL showing collapse of second story walls and portions of the roof structure.

4.1.3 Roof sheathing performance

Figure 27 shows the frequency of roof sheathing damage in pre-2002 and post-2001 homes stratified by region. Overall, roof sheathing performance was better in post-2001 homes. However, roof sheathing failures were indicated in nine post-2001 homes, in regions of the Keys that experienced the highest wind speeds. Further review of these homes does not reveal any systemic issues with roof sheathing performance in post-2001 homes. All but two experienced 10% or less damage. Of those that experienced 10% damage, most cannot be definitively confirm with the available aerial imagery. In one of the homes where damaged sheathing is visible, the damage appears to have been due to wind-borne debris impact punching through the panel, not a wind-induced uplift failure. Of the two that experienced greater than 10% roof sheathing damage, one was the 491 W Indies home which had approximately 30% roof structure damage.

When the roof structure is damaged, we also considered the overlaying roof sheathing to be damaged. Several panels outside of the region with roof structure damage did fail. The other home was an elevated, 1-story home at 27315 St Lucie Lane in Ramrod Key which lost approximately 20% of its roof sheathing as shown in Figure 28, all in the edge and corner regions of the roof where the highest wind suction pressures would be expected. The home was built in 2015 according to Monroe County property records. No failed panels were found by the field assessment team from which fastening details could be determined.

In pre-2002 homes, roof sheathing damage was more widespread, with failures being indicated in 124 homes. Out of these 124 homes, 44 (35%) had 10% or less roof sheathing damage and there was typically uncertainty as to whether there was roof sheathing damage or not. Fastening details for the remaining sheathing panels was typically not visible to the field assessment teams, but in a few cases failed sheathing panels were found nearby, showing plywood panels with staples or 6d common nails at variable spacing.

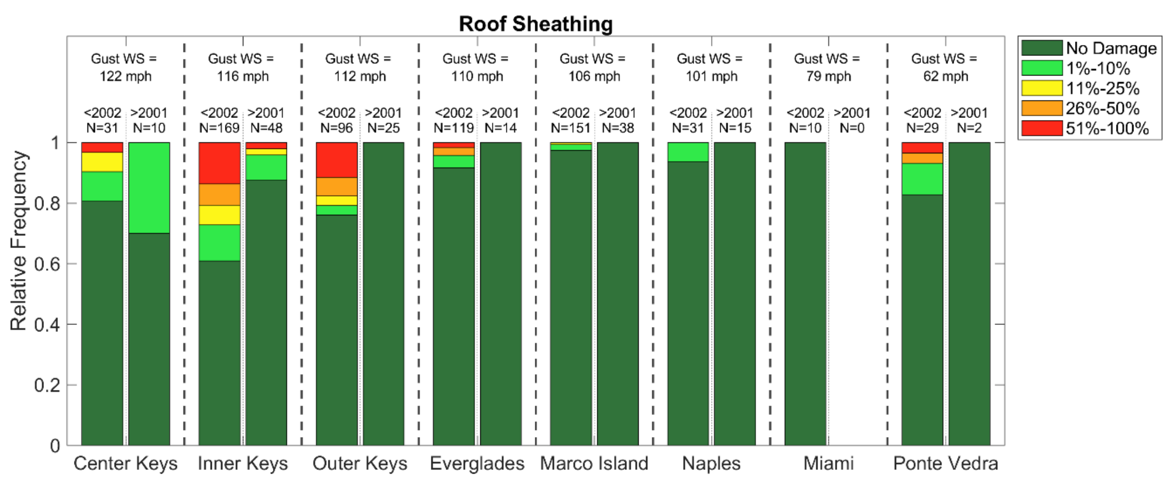


Figure 27. Frequency of roof sheathing damage occurring by region relative to FBC adoption.

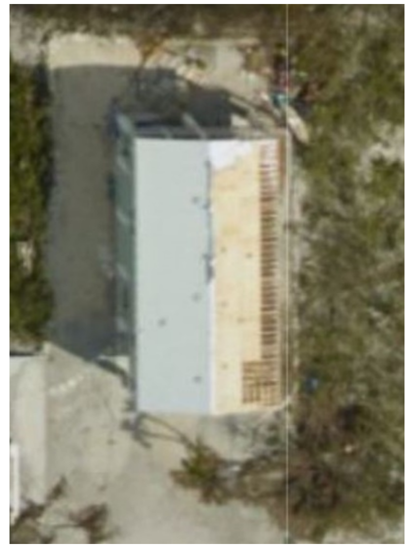


Figure 28. Roof sheathing failure in a post-2001 home (Year Built = 2005) on Ramrod Key, FL. Multiple sheathing panels along one eave and in a corner region of the roof uplifted.

4.1.4 Roof cover performance

Roof cover damage was widespread throughout the affected regions, for both pre-2002 and post-2001 homes. While the severest damage (> 50% roof cover loss) was mostly restricted to the Florida Keys, more than half of the surveyed homes had roof cover damage to some degree. No significant differences are apparent between pre-2002 and post-2001 homes, but the comparison here has little value for two reasons:

1) A large proportion of roofs that were assessed used asphalt shingles, which do not maintain their capacity over the entire service life. Dixon et al. (2014) show that vulnerability to extreme winds may accelerate after as little as 6 years, depending upon maintenance and other factors. As such, in homes built after 2001 with asphalt shingle roofs, the roofs are facing reductions in capacity. Homes built prior to 2002 may have had a shingle roof recently replaced, making it more resilient to extreme winds than a post-2001 home with an older roof.
2) The age of the home is generally not a suitable proxy for the age and performance of the roof. The older the home, the less likely it is to have its original roof still installed. Any replacement roof would be installed to the current building code, so year built of the home is typically not going to be a suitable indicator of the performance of the roof itself. A comparison of roof cover damage by age is needed, stratified by estimated gust wind speeds. Reroofing information is sometimes available in county building permit records,

but obtaining it is time-consuming as it must be obtained individually for every home. The analysis was not able to be completed in time for this report.

Figure 31 shows roof cover damage rates stratified by type and region. These results are presented as is, but caution should be taken in interpreting too much from any apparent trends as they have not been normalized by the age of the roof. It is possible in certain regions or overall that newer roofs may be biased towards a particular roof cover type, resulting in improved performance that may or may not be material driven.

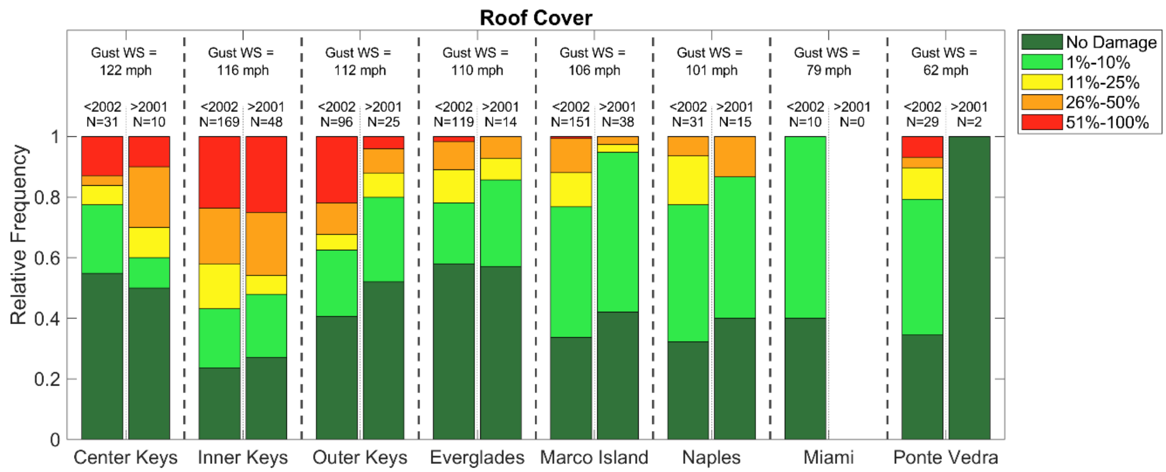


Figure 29. Frequency of roof cover damage occurring by region relative to FBC adoption.

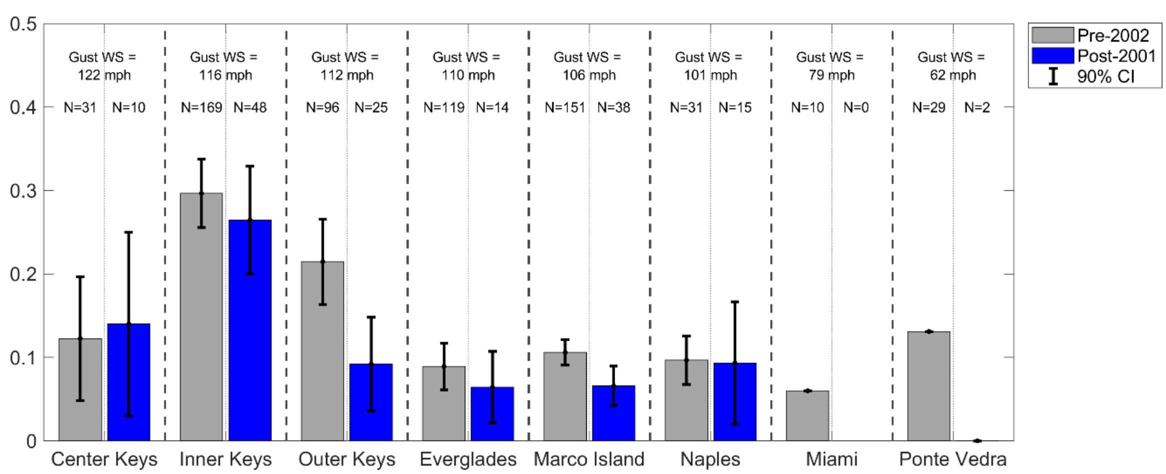


Figure 30. Mean roof cover damage ratio by region relative to FBC adoption.

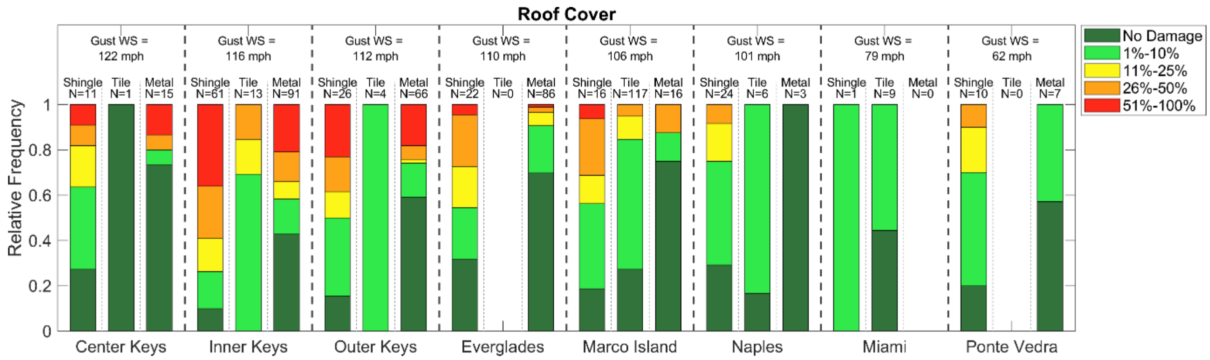


Figure 31. Roof cover damage stratified by roof cover type and region. Note that biases may exist in these results due to the age of the roof being unknown.

4.1.5 *Wall structure performance*

Structural wall failures were infrequently observed, and nearly exclusively occurred in wood-frame, pre-2002 homes. All but two of the 47 homes with wall structure failures also occurred in regions with exposure to direct surge inundation, and the two that were not directly exposed to surge inundation were on the Atlantic coastline in Ponte Vedra, where storm surge washout restructured the shoreline and caused the collapse of several walls of homes. Note that we did not consider damage to breakout walls or other walls around lower level enclosures as wall structure failures, because these are typically not constructed to code.

All but 8 of the homes with wall structure failures also experienced roof structure failure, demonstrating the correlation often found between roof structure failure and subsequent wall structure failure due to the removal of the lateral support along the top edge of the wall.

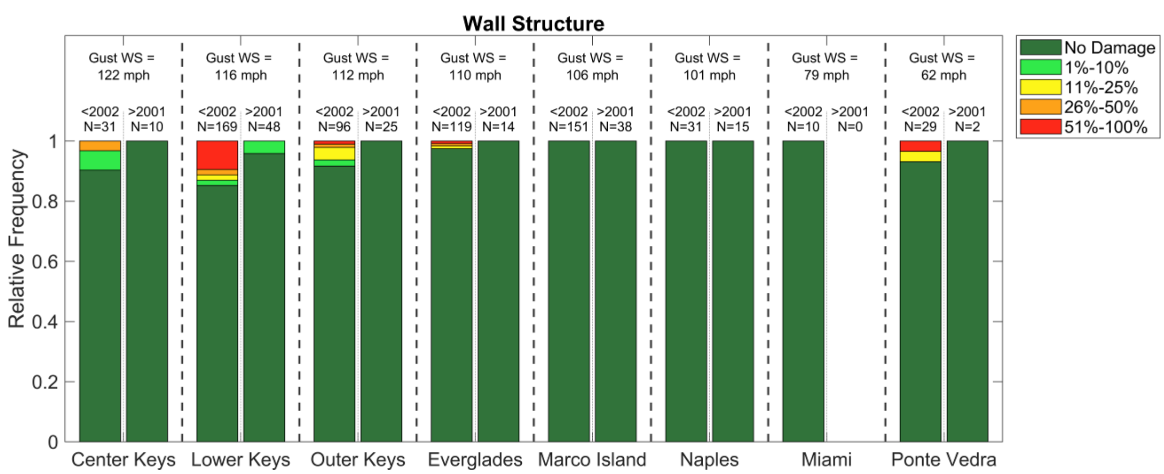


Figure 32. Frequency of structure wall failures occurring by region relative to FBC adoption. Percentages refer to the percentage of the wall structure that collapsed.

4.1.6 Wall cladding performance

Wall cladding damage was commonly observed, but not as frequently as roof cover damage. Wall cladding damage of some level was observed in 278 homes (35%) compared to 495 homes (62%) for roof cover. The majority of the wall cladding failures were observed in the Keys, due in large part to the prominence of vinyl siding cladding in these regions. Just over half (53%) of the wall cladding failures were associated with homes that used vinyl siding. The FEMA MAT report (FEMA 2018) provides a detailed examination of some specific design and installation failures in vinyl siding that were also observed by the field assessment teams in this study. For example, Figure 34 shows a home at 44 Pelican Ln on Big Pine Key that was constructed in 1993. No building permits were issued following construction that were related to wall cladding, so it is assumed that the failed vinyl siding was the original installed material. Approximately 40% of the wall cladding, including the underlying moisture barrier, was removed. Close-up photos of the failed siding show that it had a standard (single) hem and narrow locking area, which are features of standard siding, not high-wind rated siding.

Vinyl siding failures occurred in post-2001 homes as well, with 17% of the homes that experienced more than 10% failure of the vinyl siding being built post-2001. Figure 35 shows two homes constructed in 2017 and 2007 in Marathon, FL and Stock Island, FL respectively that experienced significant vinyl siding failures. Unfortunately, details of the nail spacing and/or siding type were not captured during the field assessment. The moisture barrier underlayment in both homes remained mostly intact and attached to the structure.

One of the challenges in this study with regards to wall cladding performance is related to many homes containing more than one cladding type. During the field assessment, if multiple cladding systems were present, each was noted on the digital survey form, but there was not a way to associate wall cladding damage to a specific wall cladding type. A further complication was that there was not a separate field in the survey form for soffit damage – it was categorized as wall cladding failure. Future studies should be more specific in defining wall cladding types and associated failures, and have a separate category for soffit damage, particularly given the prominence of wall cladding failure in hurricanes.

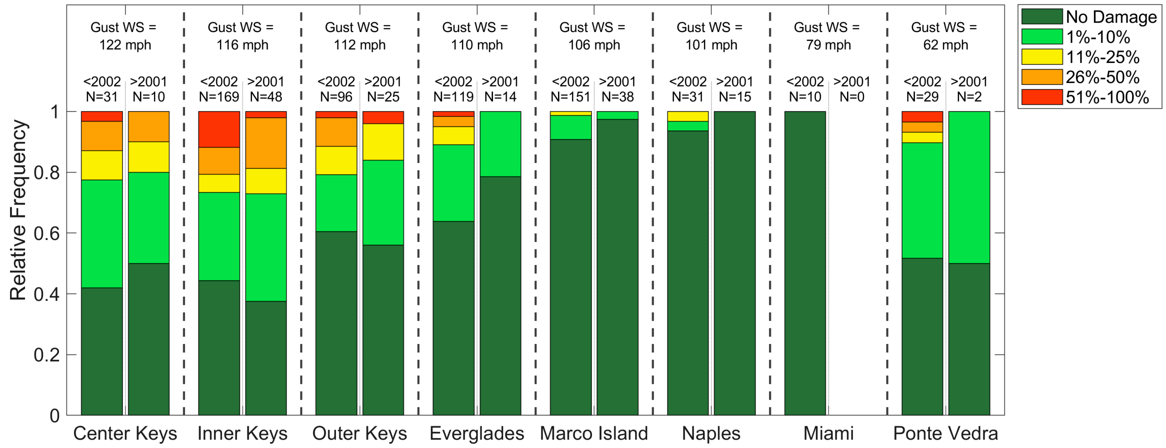


Figure 33. Frequency of wall cladding failures occurring by region relative to FBC adoption. Percentages refer to the percentage of the wall cladding that failed.

Figure 34. (Left) Damage to vinyl siding at 44 Pelican Ln in Big Pine Key, built in 1993 (estimated peak gust wind speeds of 114 mph at 33 ft height). (Right) Close-up of damaged siding indicating non high-wind rated siding was used.

Figure 35. Vinyl siding damage to post-2002 homes. (Left) a 2017 home in Marathon, FL (estimated gust wind speed of 122 mph; ASCE 7-10 design wind speed of 180 mph); (right) A 2007 home on Stock Island (estimated gust wind speed of 109 mph at 33 ft from Hurricane Irma; ASCE 7-10 design wind speed of 180 mph).

4.1.7 Doors and windows

Window failures were observed in just 71 of the 800 homes (9%) assessed in the field survey, and this includes homes where walls containing windows collapsed. Figure 36 shows the frequency of observed window failure rates broken down for each of the major geographic regions. The vast majority (97%) of window failures occurred in pre-2002 homes, but, similar to the issue with roof cover damage, demarcating by year built ignores any retrofitting that may have occurred since the home was built. Anecdotally, we found that building permits were issued fairly often to replace windows or add hurricane shutters in the limited dataset we obtained building permit information for. For example, in the 31 homes that were the subject of the homeowner interviews that we had addresses for, nine of the 31 (29%) had building permits issued prior to Hurricane Irma to either replace windows with impact resistant windows or to install hurricane shutters. All of the nine homes were constructed prior to 2002 and none had window or door damage noted in the field survey or the homeowner interviews.

Figure 37 shows shattered windows in a 2012 home on Ramrod Key. Building permit records indicated a modular home constructed to a design wind speed of 175 mph. The window failures occurred on the east face of the building, facing an adjacent home that was destroyed during Hurricane Irma and was likely the source of the damaging debris that impacted the windows and caused failure. Notes by the field assessment team indicated confirmation that the failed windows were debris impact resistant.

Hurricane shutters were observed in 38% of the assessed homes and generally were found to have performed well. Two of the 31 homeowners interviewed as part of this study indicated they had hurricane shutters blown away during the hurricane. One was a mobile home on Conch Key. The other was a single-family home on Little Torch Key, but the missing shutters were not visible in the photographs of the home taken by the assessment team. Three other assessments indicated shutters had failed – two for pre-2002 homes and one for a post-2001 home. Examples are shown in Figure 38 and Figure 39.

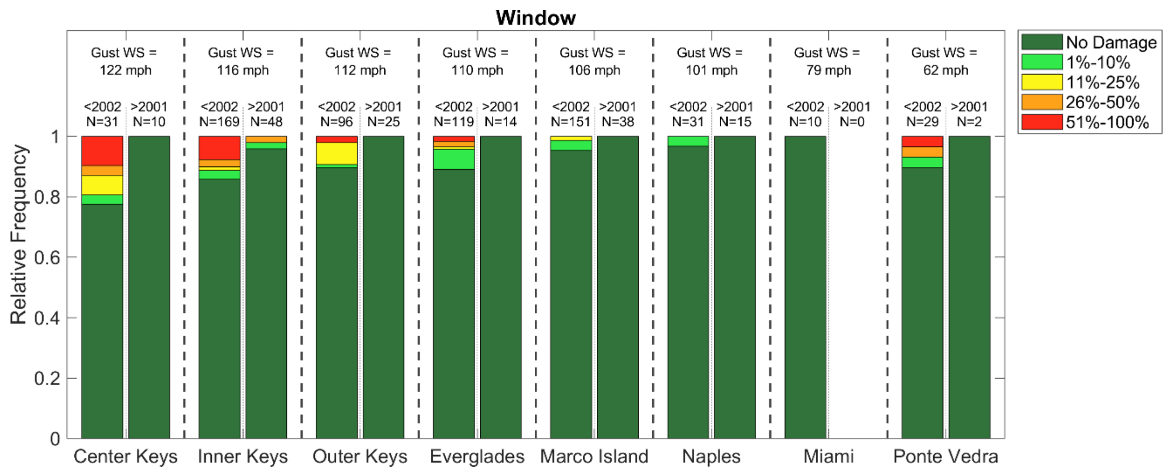


Figure 36. Frequency of window failures occurring by region relative to FBC adoption. Percentages refer to the percentage of visible windows observed to have failed.

Figure 37. Shattered windows in a 2012 home on Ramrod Key (estimated peak gust wind speeds in Hurricane Irma of 117 mph). The windows were confirmed to be impact resistant during the field assessment. The left image shows the damaged windows (circled in red) in relation to a destroyed building adjacent to the house which was the likely source of the damaging debris.

Figure 38. Home in Islamorada, FL (built in 1972) with damaged accordion-style hurricane shutters. Gust wind speeds at the home were estimated at 110 mph with approximately 1-2 ft of storm surge. No building permits are on file for this location.

Figure 39. Home on Big Coppit Key (built in 2005) with a damaged accordion-style hurricane shutter. Wind gusts were estimated at 116 mph.

Door failures were only observed in pre-2002 homes and many appeared to be surge-related, although it was difficult to determine in some cases whether the damage was wind- or surge-induced. Eight homes were observed with apparent damage to garage doors, with all but one in areas of the Keys exposed to storm surge inundation. The one failure in Marco Island appears to have been caused by impact from a downed tree. Surge-related door failures are discussed further in Section 4.2.

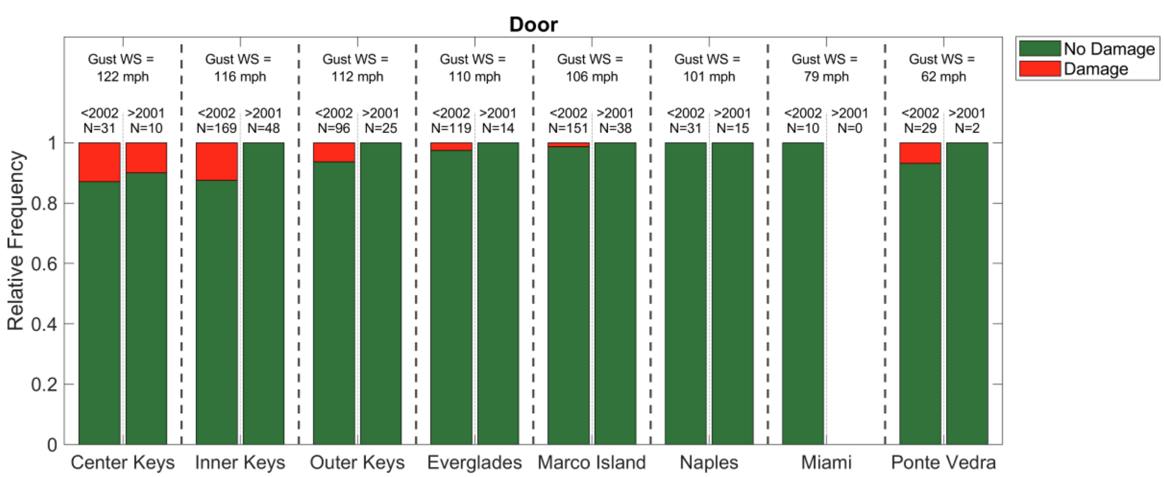


Figure 40. Frequency of door failures occurring by region relative to FBC adoption.

4.1.8 Soffits

Field assessment teams specifically indicated soffit damage in 55 assessments. More cases of soffit damage may have occurred, but were categorized as wall cladding damage in assigning damage ratios. Future survey efforts should separate out these damage types more distinctly. Of the 55 assessments that explicitly mentioned soffit damage, 15% occurred in post-2001 homes, all of which were vinyl soffits. Figure 41 and Figure 42 show damaged soffit on homes in Marco Island and Little Torch Key respectively. The home in Little Torch Key also lost portions of the fascia which can facilitate soffit blowout.

Figure 41. Soffit damage to a home in Marco Island (built in 2003).

Figure 42. Soffit damage to a home on Little Torch Key (built in 2008).

4.2 Exterior Surge Damage

The field assessment teams observed many homes with exterior surge-induced damage. Examples of surge damage included collapsed walls of non-elevated structures, collapse of breakaway walls in elevated structures, stripping away of wall cladding elements, surge washout undermining foundations and more. Figure 43 shows a sliding glass door that was failed by apparent surge inundation. Inspection of the interior of the home indicated water heights of approximately 2.5-3 ft above the floor level. The home was built in 1959 and was not in compliance with the current base flood elevation standards at the time of the hurricane. Figure 44 shows a home apparently destroyed by surge that was built in 1968. This home also was not in compliance to current base flood elevation standards.

Figure 45 shows wall cladding failures that may have been induced by storm surge and waves. The location of the home has a 10 ft base flood elevation according to FEMA flood maps. Scour on the porch posts and stair treads indicate storm surge inundation near the base flood elevation. However it is unlikely that all of the cladding damage is surge-induced given the context of the damage and height of the wall cladding on the front wall, so we cannot conclusively determine whether the damage is wind-induced, surge-induced or a combination of both.

Figure 43. Surge-induced failure of a door system in a home in Islamorada, FL.

Figure 44. Surge-induced collapsed walls in a home in Big Pine Key, FL.

Figure 45. Possible surge-induced wall cladding failure to a home in Big Pine Key (built in 2004; current Base Flood Elevation of 10 ft) exposed to storm surge inundation. Actual surge inundation or waves may have reached higher than 10 ft based on scouring of porch posts and stairs and cladding damage, but some cladding damage may have been wind-induced.

Surge-induced damage was commonly observed to lower level enclosures, as shown in Figure 46. These failures are not unexpected, particularly in pre-2002 homes as they are not intended to resist such forces. Most enclosures are not constructed to code requirements and are only to be used for storage, not as living spaces. Habitation is not allowed and all plumbing and electrical must be installed above the base flood elevation.

Figure 46. Surge-induced collapse of breakaway walls in lower level enclosure of a home in Cudjoe Key. Wind gusts of 114 mph were estimated at this location along with surge inundation of 45 inches.

Surge-inducted washout of the foundation was primarily observed in Ponte Vedra along S. Ponte Vedra Blvd. A series of homes there, constructed on the coast seaward of the FL Coastal Construction Control Line, had extensive volumes of sand washed out from beneath the foundations, causing the full or partial collapse of multiple homes. In one instance, an entire home was washed out to sea. This same area had been previously impacted by Hurricane Matthew in 2016. Storm surge during Hurricane Matthew had washed out portions of Florida State Road A1A just south of this region. Figure 47 and Figure 48 suggest the combination of the Hurricanes Matthew and Irma in back-to-back years may have exacerbated the observed failures. Hazard impacts at the building scale are typically assumed to be independent events, but the damage patterns here, both wind and surge, indicate that this may not be true. Figure 49 shows additional views of homes with foundations potentially compromised due to surge washout.

Figure 47. (Left) Seaward view of a home from 2013, courtesy of Google Streetview; (right) Seaward view of the same home after Hurricane Irma showing the collapsed foundation caused by washout of sand under slab foundation.

Figure 48. Views from (left) January 2014, (middle) January 2017, and (right) September 2017 of a home along S. Ponte Vedra Blvd in St. Johns County. In addition to the wind damage, surge inundation washed out the foundation causing collapse of the seaward exterior walls. Note the progression of the shoreline from 2014 to 2017. Hurricane Matthew impacted the same region in 2016. Imagery sourced from the St. Johns County property assessor.

Figure 49. Surge washout inland to the foundations of several homes along Ponte Vedra Blvd in St. Johns County.

4.3 Interior damage and economic losses

Field assessment teams typically did not have access to the interior of homes to document interior damage from wind-driven rain, storm surge inundation or flooding. To supplement the field assessment data, homeowners were solicited post-hurricane to participate in online interviews to answer questions with regards to interior damage and economic losses. The recruitment methodology is described in more detail in Section 5, along with the detailed responses from the 32 respondents to the survey.

Out of the 32 homeowner interviews, 14 mentioned interior damage and economic losses due to wind-driven rain and/or storm surge inundation or flooding. Nine of the respondents defined wind damage repair cost, including seven that also experienced wind-driven rain or storm surge losses. Figure 50 plots the repair cost due to interior leaks (i.e., wind-driven rain or water ingress through breached openings) against the exterior damage rating assigned by the field assessment teams. The $500,000 repair cost was reported by a homeowner on Marco Island whose home had a value of around $3M. Sources of the water leak-induced damage was indicated as water leaks through the roof and flying roof tiles. Figure 51 plots the repair cost due to storm surge inundation or flooding against the exterior damage rating assigned by the field assessment teams. Figure 52 plots the repair cost due to wind damage against the exterior damage rating assigned by the field assessment teams.

From each of these plots, a general trend of increasing interior repair costs with increasing exterior damage rating is observed. Some of the high repair costs were associated with homes rated as having No Damage or Minor Damage in the field assessments.

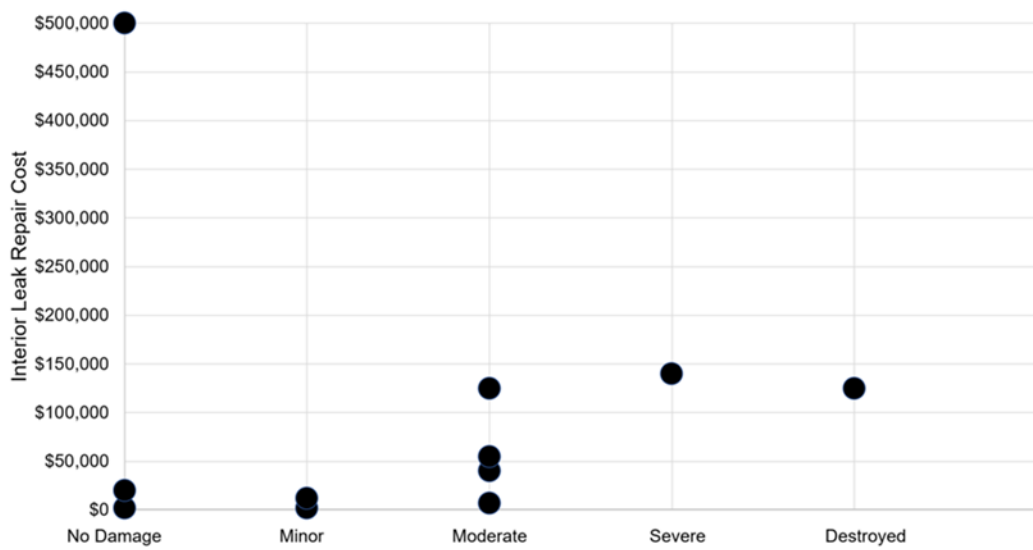


Figure 50. Exterior damage rating assigned by assessment teams and homeowner-indicated repair costs due to water leaks.

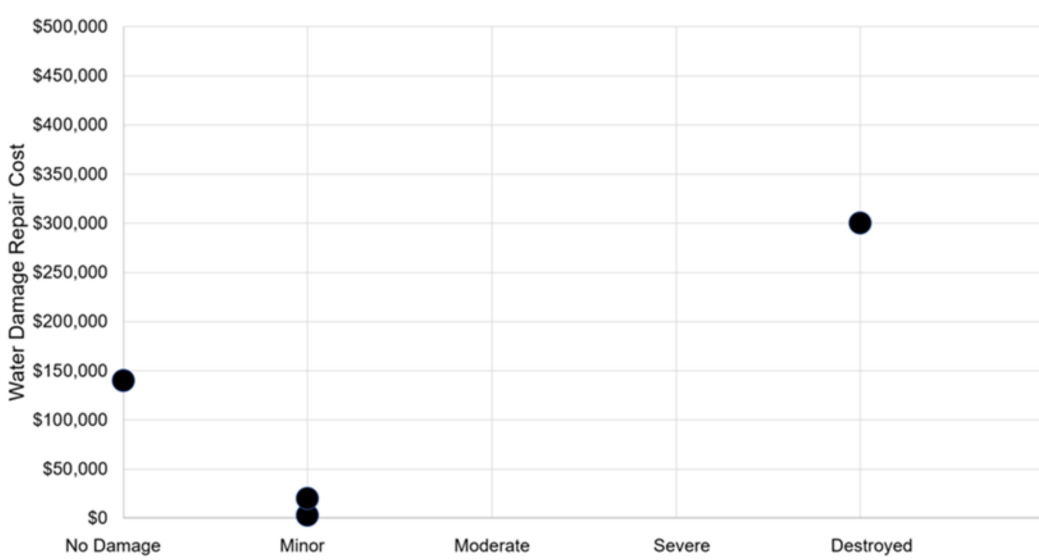


Figure 51. Exterior damage rating assigned by assessment teams and homeowner-indicated repair costs due to storm surge inundation or flooding.

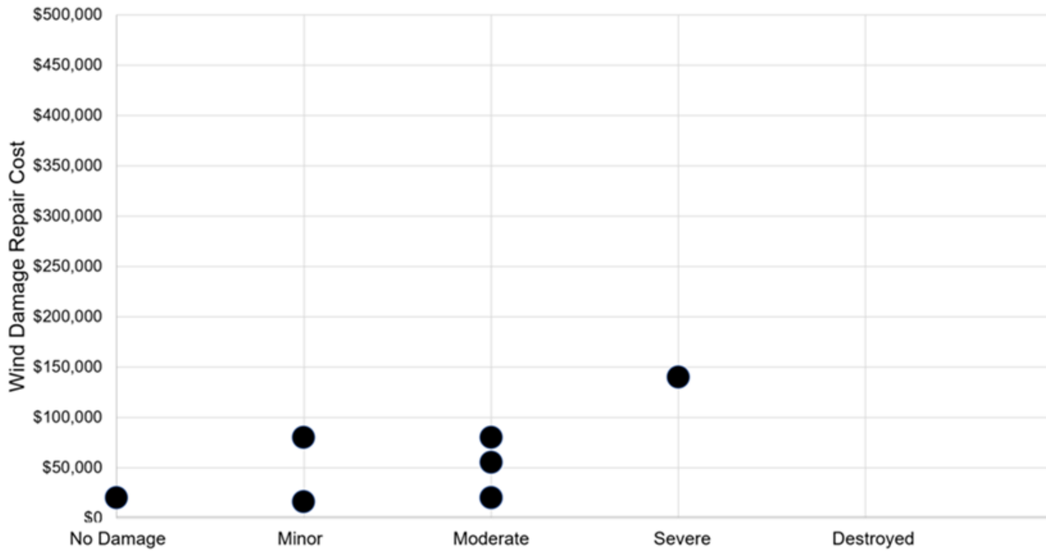


Figure 52. Exterior damage rating assigned by assessment teams and homeowner-indicated repair costs due to wind damage.

4.4 Summary of Findings

The following summarizes the major findings from our assessment of building performance following Hurricane Irma in September 2017:

- Structural systems of single-family homes built to the 2001 Florida Building Code or its subsequent revisions performed well, albeit in a below design wind event, with no systemic issues related to design or construction observed by the team. This included roof truss/rafter performance, roof sheathing performance, and wall structure performance.
- Structural failures were commonly observed in pre-2002 homes (as much as 40% of homes in the Keys), even in a below design wind event. The legacy stock of pre-2002 buildings will likely continue to be a source of major structural failures in subsequent events without more widespread implementation of effective mitigation strategies.
- Roof and wall cladding failures were widespread in both pre-2002 and post-2001 homes. Shingle roofs were observed with the highest number of failures, but tile and metal roofs experienced damage to more than 10% of the roof in nearly 30% of homes in the Keys. While for roofs, additional analysis of damage as a function of roof age is needed, the evidence demonstrates that in-service performance of many roofs are not meeting design requirements.
- Several instances of shattered impact-resistant windows were observed by the team or in the homeowner interviews, typically adjacent to a home with significant structural or roofing damage.

- Soffits continue to be a source of costly water intrusion, with several homeowners pointing to this mode of water entry as causing thousands of dollars in repairs.
- Water leaks (through the roof, doors, soffits, and even wall siding) was the most common source of interior damage noted by the interviewed homeowners.
- Elevated homes generally performed well against storm surge and flood inundation. Breakaway walls in lower enclosures were often damaged as expected, but the main living spaces did not appear to be visibly affected by the storm surge. No homeowners that we interviewed in post-2001 homes indicated surge-related interior damage to their homes. A few homeowners in pre-2002 homes, not meeting current Base Flood Elevation requirements, indicated surge-related interior damage.
- The repeated impacts of hurricanes in two consecutive years exacerbated damage in northeast FL, particularly with regards to surge-induced damage but possibly for wind damage as well.

5 HOMEOWNER INTERVIEWS

We conducted online and telephone surveys with homeowners living in buildings in which we observed exterior damage. This approach allowed us to gauge the extent of the damage to the interior of the home, and ensuing economic losses due to water leaks, storm surge, and wind. We also recognized the opportunity to learn about the impact of Hurricane Irma on mental health and well-being, as well as about the perceptions and behaviors of Florida residents towards hurricane risk, evacuation, mitigation, and building resiliency against future events.

5.1 Literature Review

Previous studies have shown that few homeowners take adaptive measures to enhance their resilience to high impact storm events such as hurricanes voluntarily (Kunreuther, 1996; Kunreuther & Pauly, 2004) and they are often underprepared when disaster strikes (Donahue et al. 2013). However, recent research also suggests that those with recent direct experience are more open to taking such protective measures (Bubeck, Botzen, & Aerts, 2012). Most of this literature review focuses on intentions to take smaller protective measures (e.g. sandbags, evacuation plans, flood provisions, etc.) rather than more substantive protective steps (e.g., additions of metal roof, wind-resistant shingles, impact resistant windows, etc.). Hurricane Irma offers a unique opportunity to conduct an exploratory study examining how direct experience, and the nature of that experience, influences these decisions and the potential role for policy.

5.2 Methodology

5.2.1 Recruitment

Participants were recruited from homes identified with visible damage from onsite assessment. A personalized recruitment letter was sent to each of the 784 identified homes on April 6, 2018, resulting in 19 completed surveys. Follow-up recruitment postcards were sent out to all participants on April 24, 2018, resulting in a total of 32 completed surveys. Participants were informed about the nature of the study, provided with links to take the survey online and contact information should they desire to take the survey by phone, and offered $20 in compensation via an Amazon giftcard and were enrolled into a lottery for a chance to win an Apple IPad Mini®. A total of 76 mailers were returned, indicating that the homeowner is no longer receiving mail at the residence. Thus, we obtained a total response rate of 4.5%, which is higher response rate than obtained in previous studies with similar recruitment methods (Wong-Parodi & Klima, 2017). See Appendix B for examples of the personalized recruitment letter and postcards.

5.2.2 Institutional Review Board

Before any research involving human subjects can be conducted, federal regulations stipulate the research scope must receive approach from the Institutional Review Board (IRB) at the Investigator's institution. The IRB reviews such research to ensure that the welfare and rights of the participants are protected in accordance with federal regulations. Description of the research project objects, survey protocol, and recruitment materials were submitted to Carnegie Mellon University's IRB on March 12, 2018, with approval granted on April 3, 2018. See Appendix C for a copy of the approval letter.

5.2.3 Survey Protocol

After a brief introduction to the study, screening for age (must be age 18 or older to participate), and obtaining informed consent, participants entered in their unique participant ID and provided their email address to receive their compensation. They then were asked questions related to mental health and well-being with respect to their experience regarding Hurricane Irma and its aftermath, and in general. Then they answered questions related to their evacuation behavior, including where they went and how long they remained there. This was followed by questions related to their risk perceptions, storm-related beliefs, and the extent to which they prepared for Hurricane Irma. Next, they were asked a series of questions about interior home damage specifically as related to water leaks, storm surge, and wind. They then answered questions with respect to major home structural retrofits that they had undertaken, as well as ones that they plan to do in the future. Finally, they answered basic demographic questions. See Appendix D for a complete copy of the survey.

5.3 Results

5.3.1 Participants

Our participants reported being on average 62.5 years old (range: 33-89, SD=10.4) and 38.7% female. Most reported having a household income between $50 and $100K (24.8%), followed by $0-50K (19.4%), $100-150K (19.4%), prefer not to answer (19.4%), and greater than $150K (16.1%). People moved into their homes ranging from 1988 to 2017, with a median move in year of 2003. They reported that their homes were built ranging from 1956 to 2016, with a median construction year of 1988. Most people reported that they owned their home (93.6%), followed by prefer not to answer (3.23%) and other (3.23%). More than half (51.6%) of the participants reported living in a household with at least one adult over the age of 65; whereas no participants reported that they lived in a household with a child under the age of 5. Some of the participants reported having been diagnosed with depression (9.7%) and/or anxiety (9.7%) previously. Most participants reported having completed at least some college or higher (93.6%). Finally, most participants reported being retired (54.8%), followed by employed full time (29.0%), employed part time (9.7%), and unemployed looking for work (6.45%).

5.3.2 Mental health and well-being

As shown in Figure 1, our participants are not feeling overly stressed about Hurricane Irma and its aftermath at this point in time. The highest level of reported behavior is avoidance, where participants indicated that they have ‘rarely’ “tried hard not to think about the hurricane or gone out of [their] way to avoid situations that reminded them of it” (M=2.28, SD=1.33). General levels of stress were reportedly higher, however, as shown in Figure 2. Participants reported that ‘sometimes’ “worried about experiencing financial stress or strain” (M=3.19, SD=1.12).

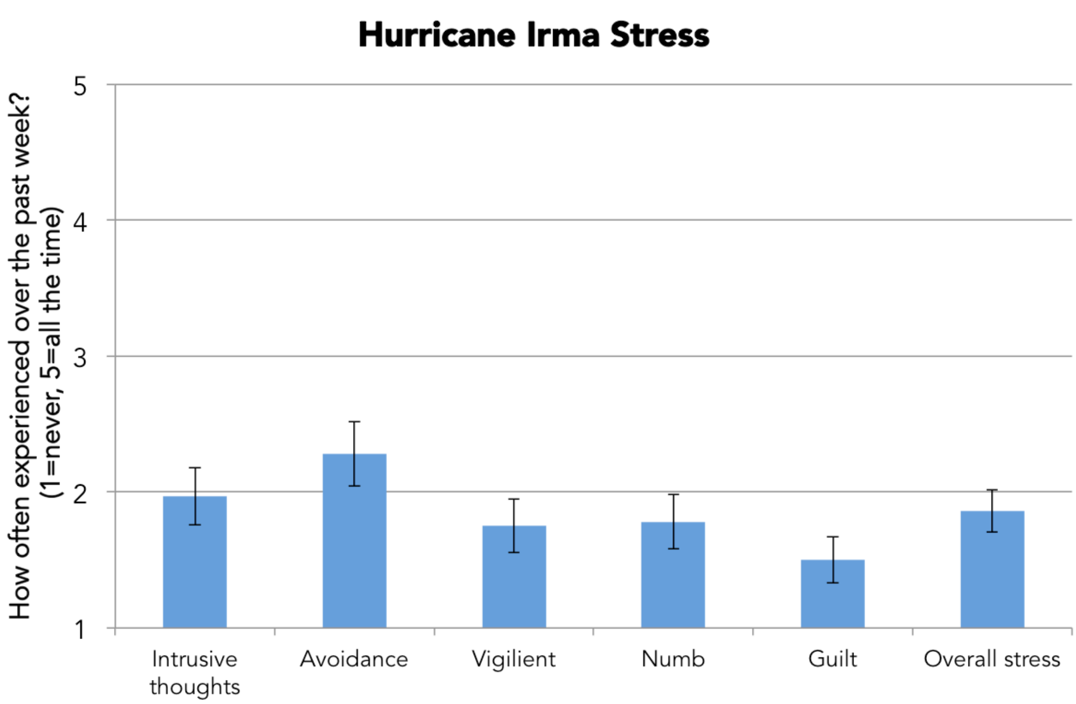


Figure 53. Mental health and well-being as a result of Hurricane Irma and its aftermath

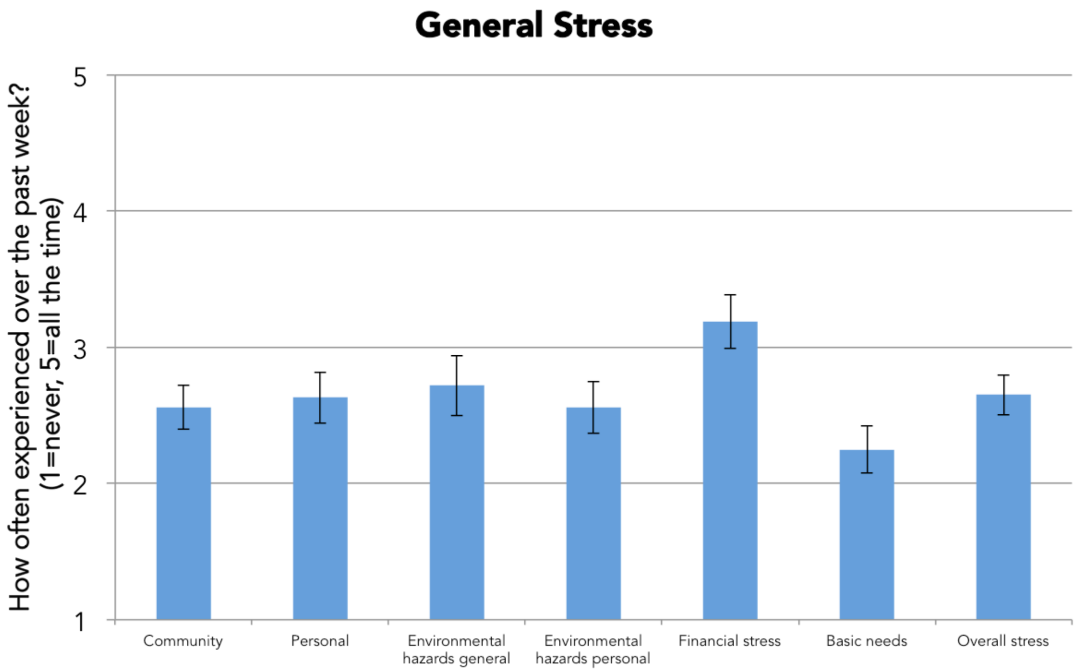


Figure 54. General mental health and well-being

5.3.3 Evacuation Behavior

As shown in Figure 3, nearly all of our participants decided to evacuate in the days before or during Hurricane Irma (91%). Figure 4 shows the reasons given for evacuating with the primary reason being that they were located in an evacuation zone (79%), followed by feeling at risk (69%), they could afford to evacuate (52%), they had somewhere to go (48%), they could take their pets with them (48%), and other reasons (25%). Other reasons included that they were already away from their home (e.g., “We were in Ohio for my son’s wedding at the time of the hurricane”) and a further underscoring of the unfamiliar risk they were facing (e.g., “predicting a 15 foot storm surge and I don’t swim”). Figure 5 shows the reasons given for not evacuating with the primary reason being other (67%), followed by not being located in an evacuation zone (33%). The reasons given for not evacuating was that these participants said that they were already in another location (e.g., “I was in my house in NJ”). Most people evacuated only once (89%), followed by twice (7%) and five times (4%) (Figure 6). As shown in Figure 7, most people evacuated to locations in Florida (46%), however people evacuated to other locations as well including places in the Midwest and along the Atlantic coast. Figure 8 shows that people evacuated anywhere between 2 and 45 days, with the majority evacuating at some point between

12 and 21 days. Finally, as shown in Figure 9, most people (87%) report that they are currently back in their homes.

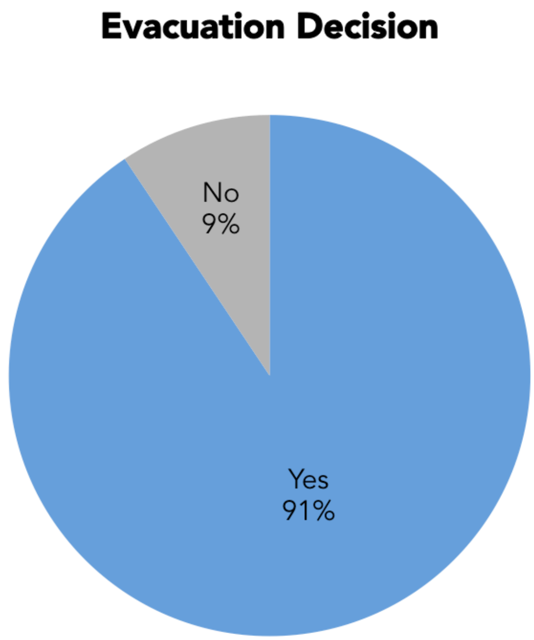


Figure 55. Participant evacuation decision before or during Hurricane Irma

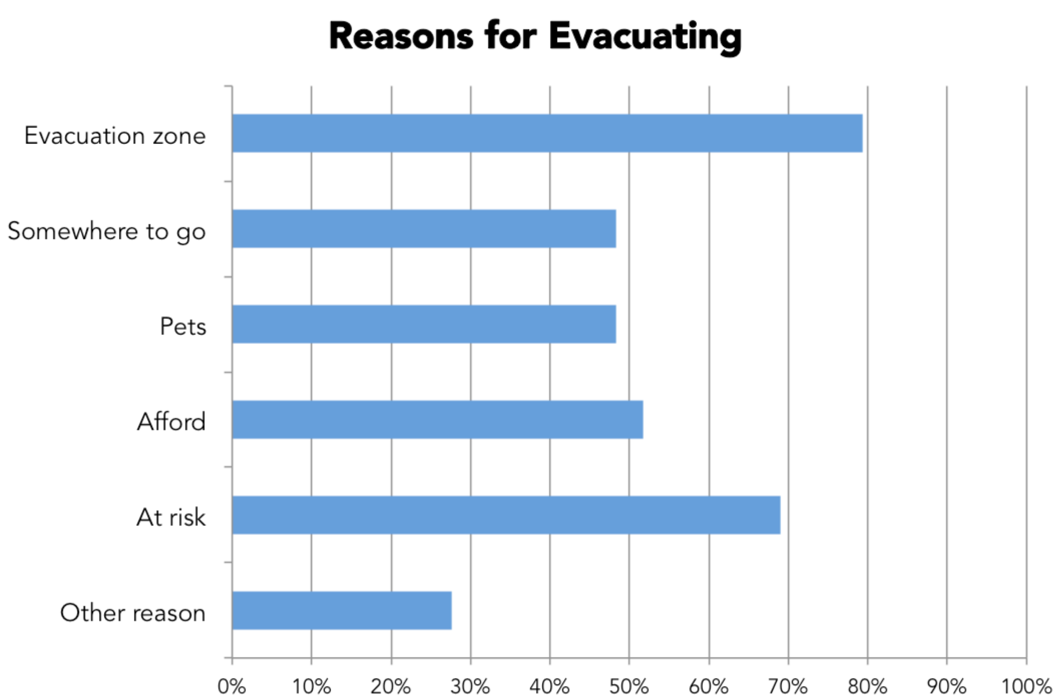


Figure 56. Reasons for evacuating among those who evacuated before or during Hurricane Irma

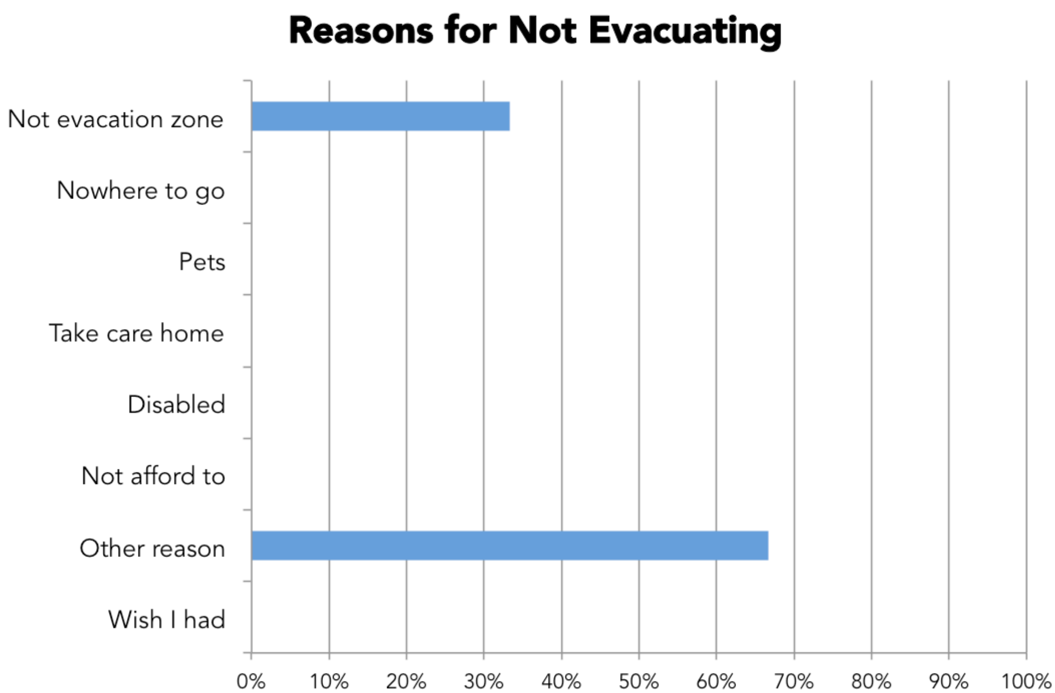


Figure 57. Reasons for not evacuating among those who did not evacuate before or during Hurricane Irma

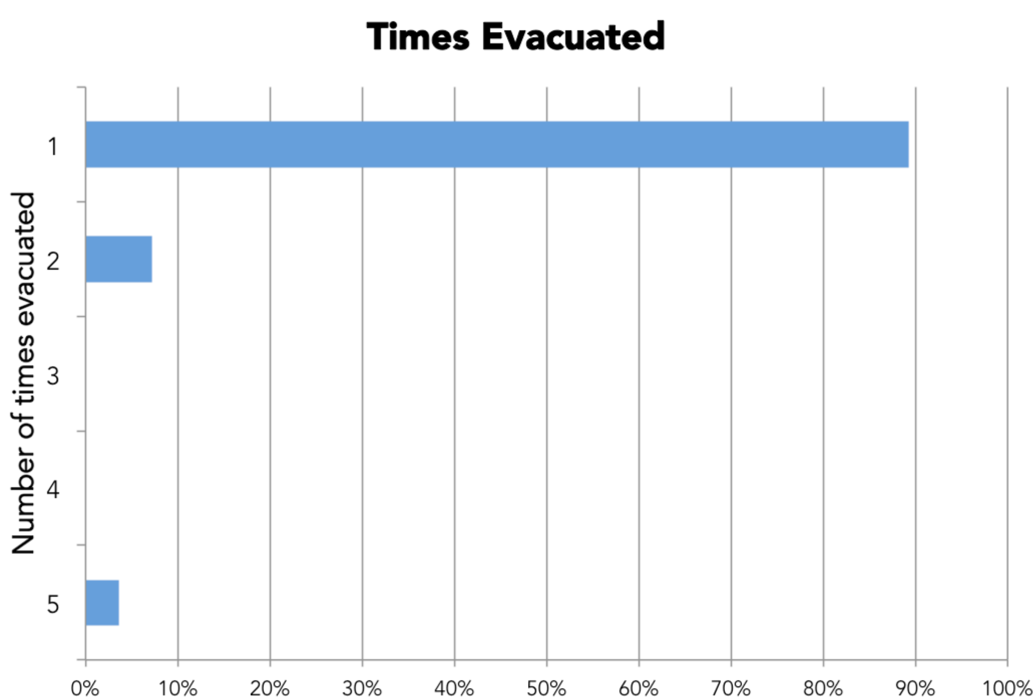


Figure 58. The number of times participant evacuated as a result of Hurricane Irma

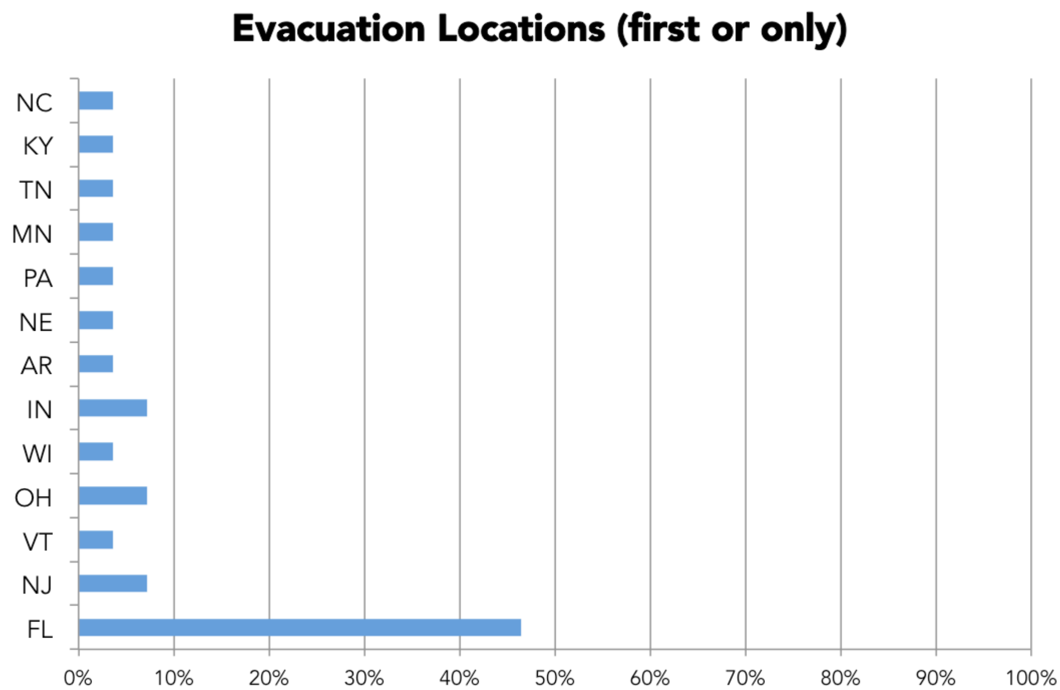


Figure 59. The states participants evacuated to as a result of Hurricane Irma

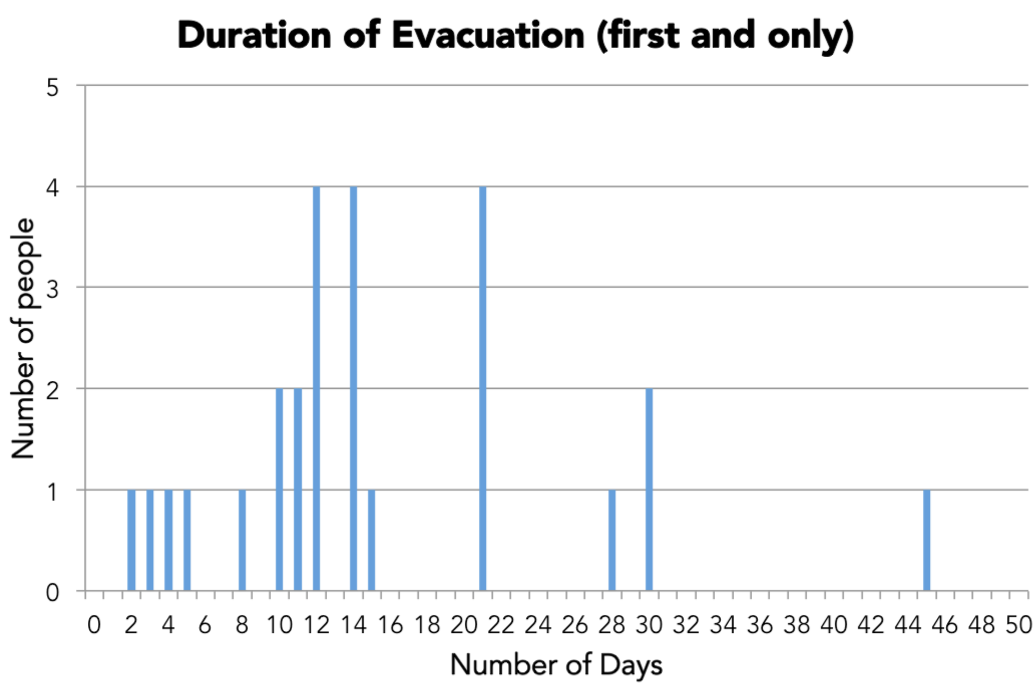


Figure 60. The duration of evacuation for the first and/or only location among those who decided to evacuate as a result of Hurricane Irma

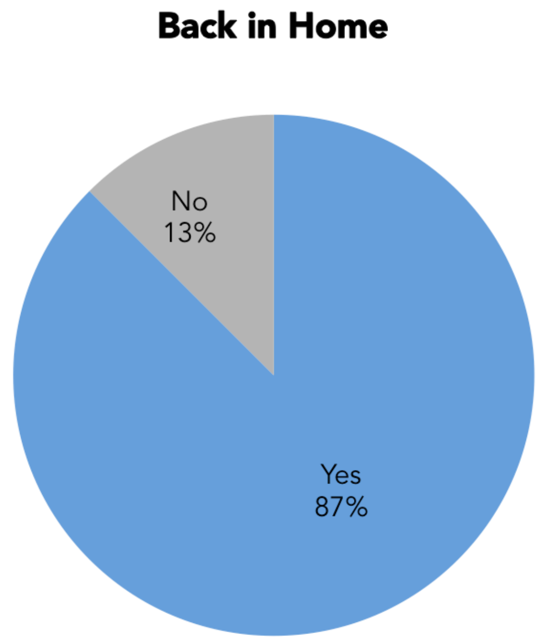


Figure 61. Participants who are currently (as of April/May 2018) back in their home

5.3.4 Risk Perceptions

As shown in Figure 10, participants thought the chances that any damages that resulted from the storm would be covered by insurance (M=57.5%, SD=31.3%) were somewhat good. They also thought the chances of their home being damaged or destroyed by the storm were pretty high (M=50.1%, SD=26.6%). They thought that the chances they would never be able to return to their home due to damages was lower (M=34.5%, SD=31.6%). They thought that the chances that someone they know would be seriously injured was higher (M=19.9%, SD=23.4%) than their own chances (M=5.8%, SD=8.1%).

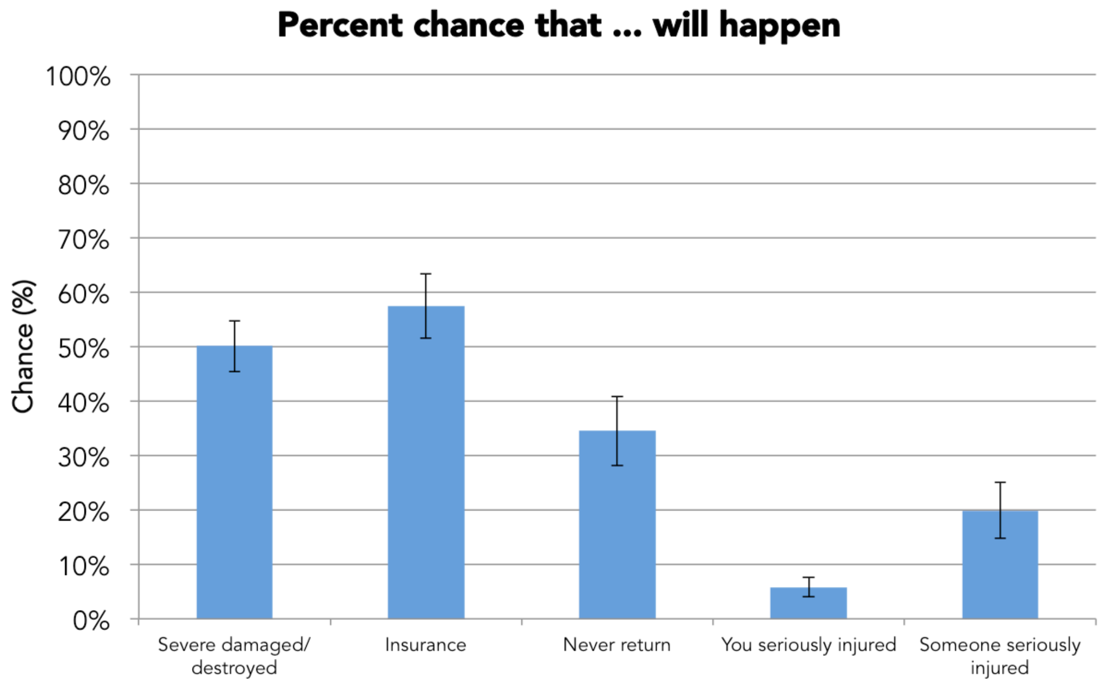


Figure 62. Reported perceived risk as a result of Hurricane Irma

5.3.5 Storm related beliefs

On balance, participants felt like they experienced high levels of social support (M=4.4, SD=.7) (Figure 11). Views with respect to responsibility for the storm were, however, mixed. As shown in Figure 12, with respect to federal government intervention, participants strongly agreed that the federal government should provide disaster relief for people whose lives are disrupted by the hurricane or its aftermath (M=3.9, SD=1.3). However, they disagreed that the federal government should pay to rebuild homes that are destroyed by a hurricane or its aftermath (M=2.3, SD=1.2) with some participants expressing the view that they didn't want to be responsible for paying for other people's homes. They expressed the strong view that they did everything that they could do to prepare for Hurricane Irma and its aftermath (M=4.4, SD=1.0). They were ambivalent about whether climate change made the 2017 hurricane season so strong (M=3.0, SD=1.5).

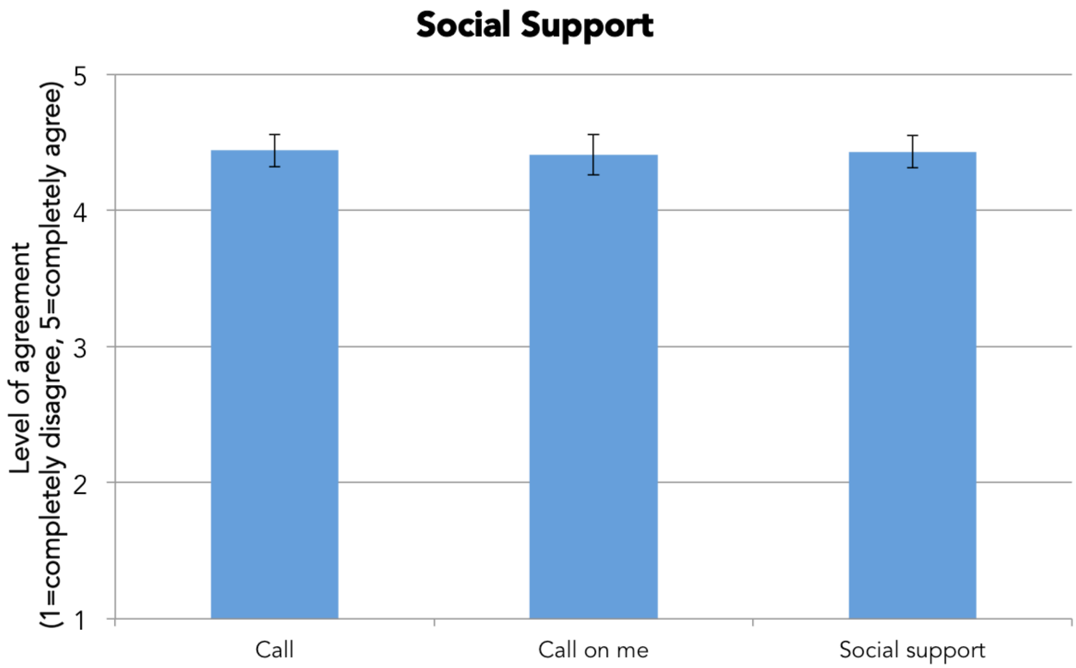


Figure 63. Reported social support during and after a hurricane event

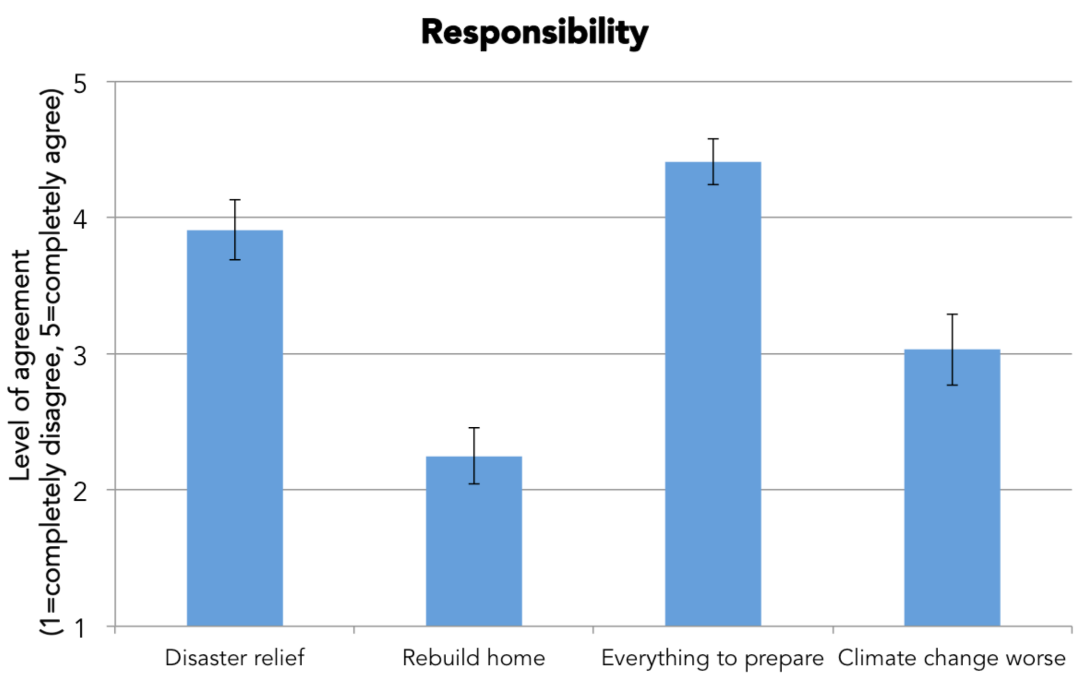


Figure 64. Reported views on responsibility for damages related to Hurricane Irma and similar events

5.3.6 Preparation

As shown in Figure 13, people performed a variety of actions to prepare for Hurricane Irma including learning about the risks from hurricanes and how to prepare for them (88%), making the home more hurricane proof (84%), moving vehicles to a safe location (81%), putting together an emergency kit (78%), having flood insurance (72%), copying important documents (e.g., birth certificates, driver's licenses) (63%), developing and practicing an emergency plan (44%), identifying shelter location in the event of an evacuation (41%), other actions (22%), and getting a row boat or inflatable raft (13%).

Figure 14 shows that participants see no difference in terms of the intensity and frequency of hurricanes between the 2017 and 2018 hurricane season.

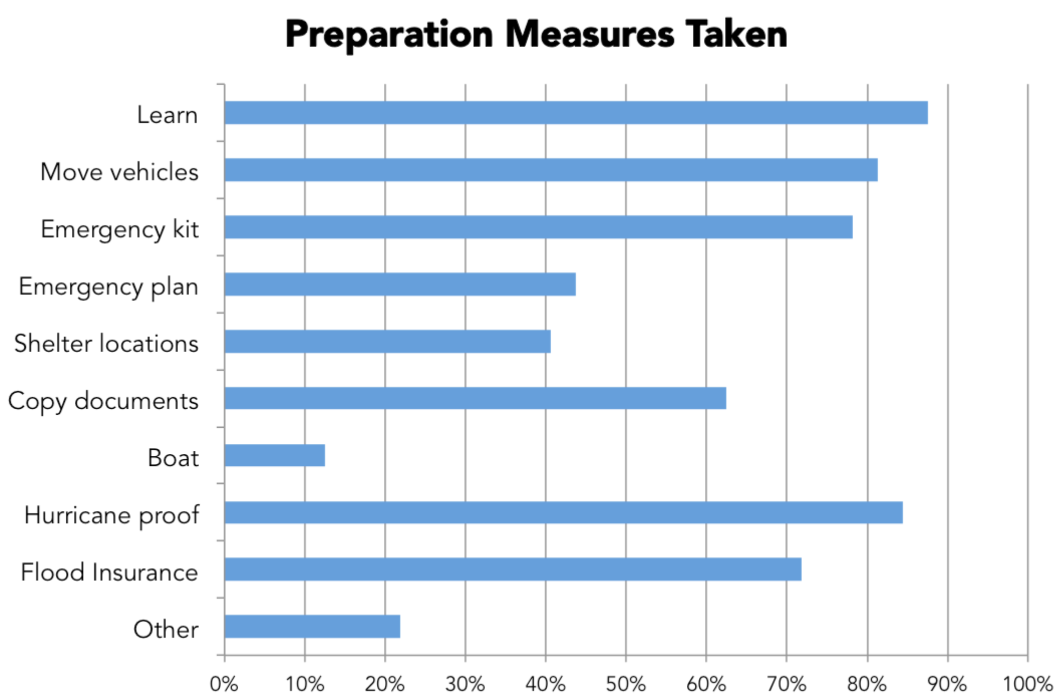


Figure 65. Preparation measures taken before Hurricane Irma

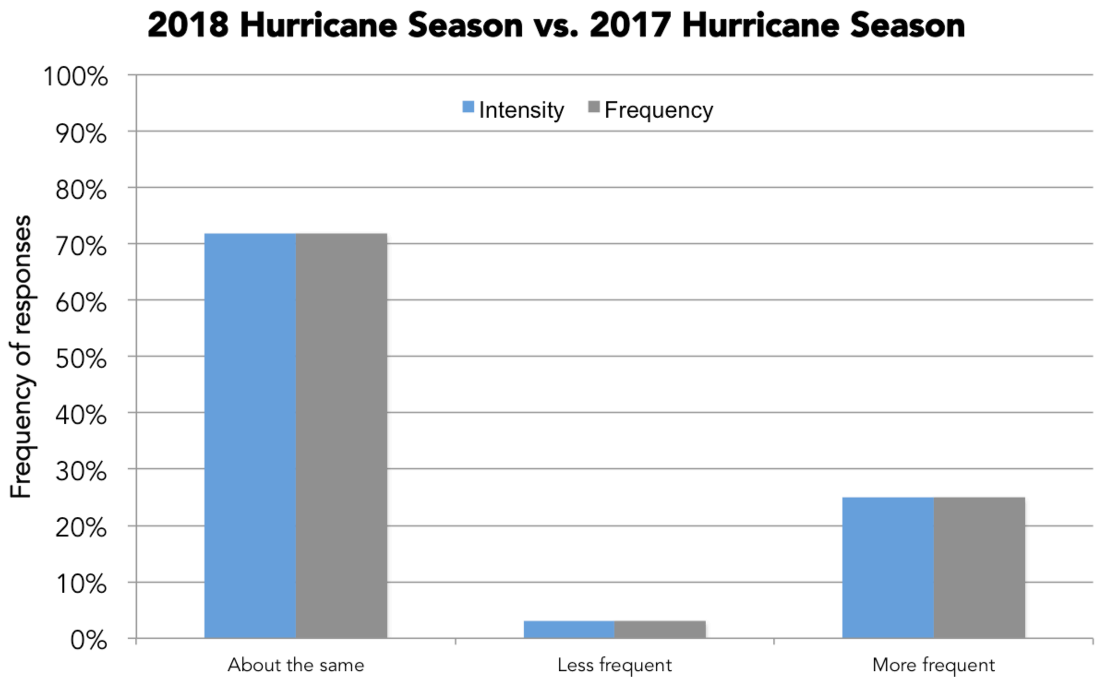


Figure 66. Views on the intensity and frequency of hurricanes during the 2017 versus 2018 season

5.3.7 Interior Home Damage

The most frequent type of interior damage reported by the participants was from water leaks (66%), followed by wind (56%), storm surge (34%), and other (19%) (Figure 15). Most people reported that the 'other' damage they experienced came from mold, which was due to water leaks (e.g., "mold from roof leak"). Therefore, in this section, we only present the results from water leaks, storm surge, and wind. Figure 16 shows the estimated costs of repair across all types of damage. Note that some participants reported the same amount and had difficultly estimating the costs for just one type of damage since repairs were done at the same time. Here we see estimated costs are highest for water leak repairs (n=12, M=$106,500.00, SD=$145,373.81), followed by storm surge (n=5, M=$93,200.00, SD=$129,022.09), and wind (n=9, M=$81,222, SD=$91,861.01).

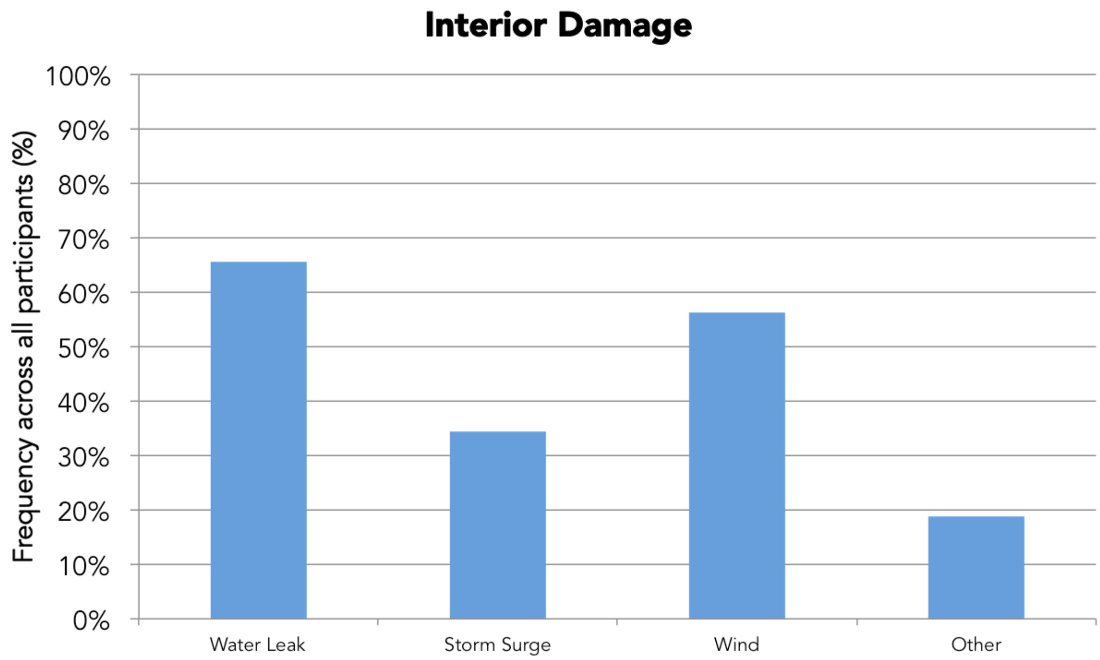


Figure 67. Frequency of reported interior damage across all participants

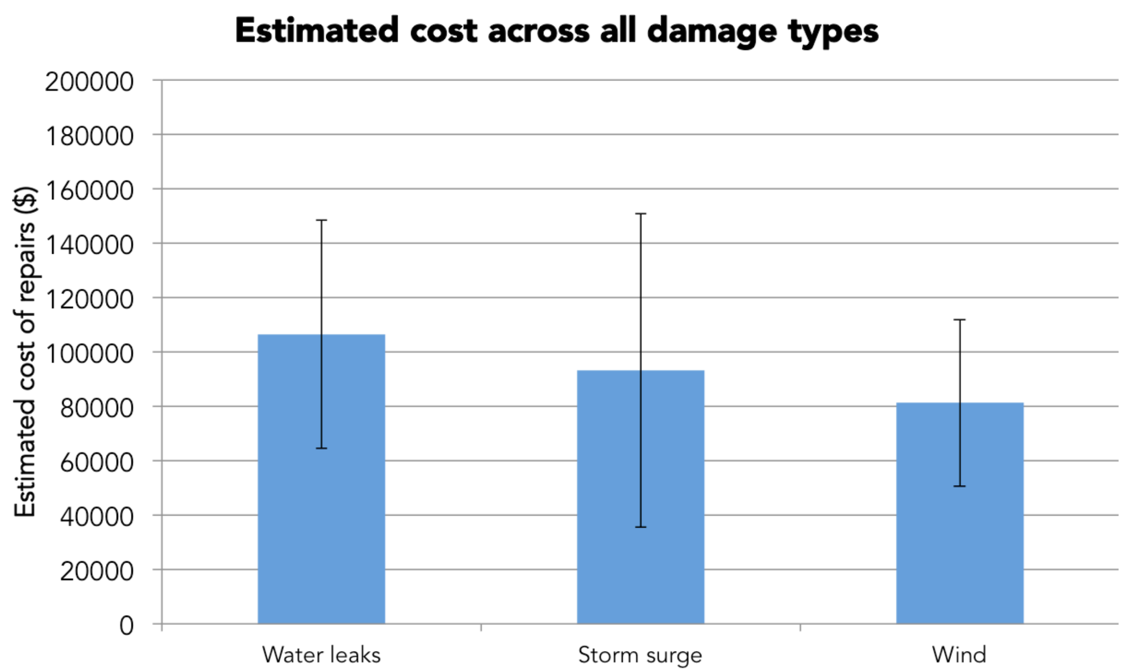


Figure 68. Reported estimated repair cost across all damage types

5.3.7.1 Water Leaks

Figure 17 shows that water came in from a variety of places in people's homes, with the dominant locations being from the roof (29%), soffit (10%), and walls (10%). Participants reported that the majority of the damage occurred in bedrooms (19%), living rooms (14%), and upstairs in general (14%) (Figure 18).

As shown in Figure 19, about 60% of the participants who experienced interior damage from water leaks reported having repaired that damage with nearly all (92%) hiring a professional contractor for the repairs (Figure 20). Among those who experienced damage but have made repairs, many reported that repairs will happen in the future (38%) however all (100%) reported some other reason for not making repairs now (Figure 21). Reasons given for not making repairs included: unable to get a building permit, still waiting for insurance claim to come through, need to make a final decision about an engineer, not enough contractors available in the area, and that the job seemed too small to fix to be worth it. Figure 22 shows a wide range of estimated costs for repairs among those who have already made them, ranging from $2,000 to $500,000.

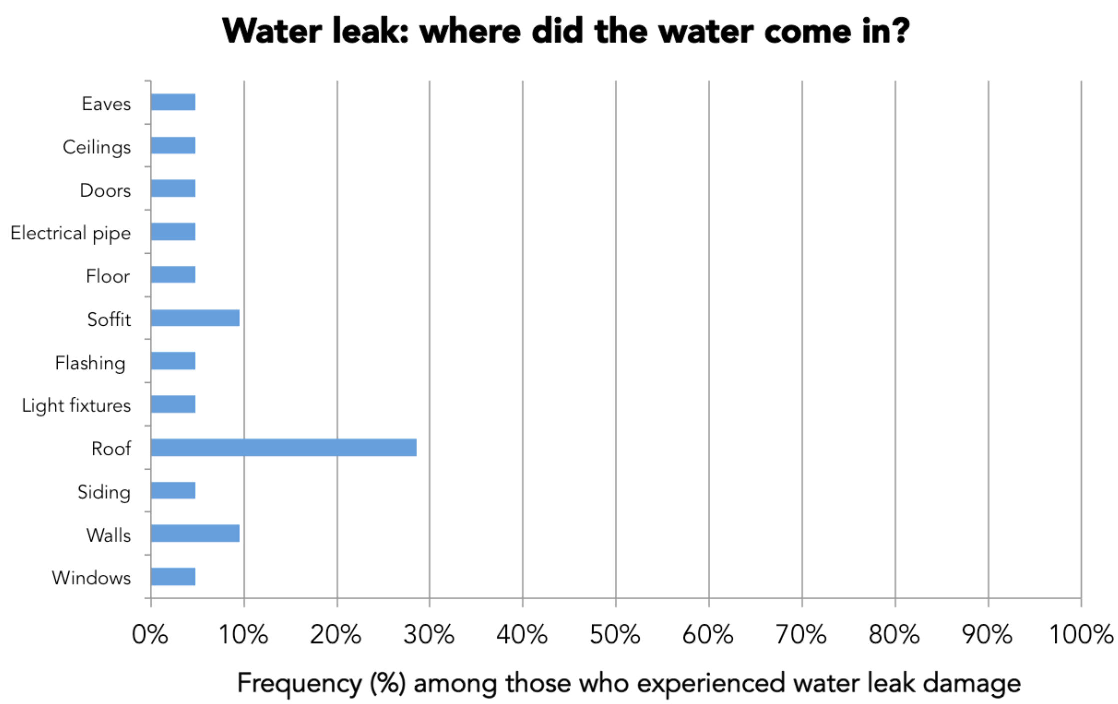


Figure 69. Where the water came in as a result of Hurricane Irma for those reporting water leak damage

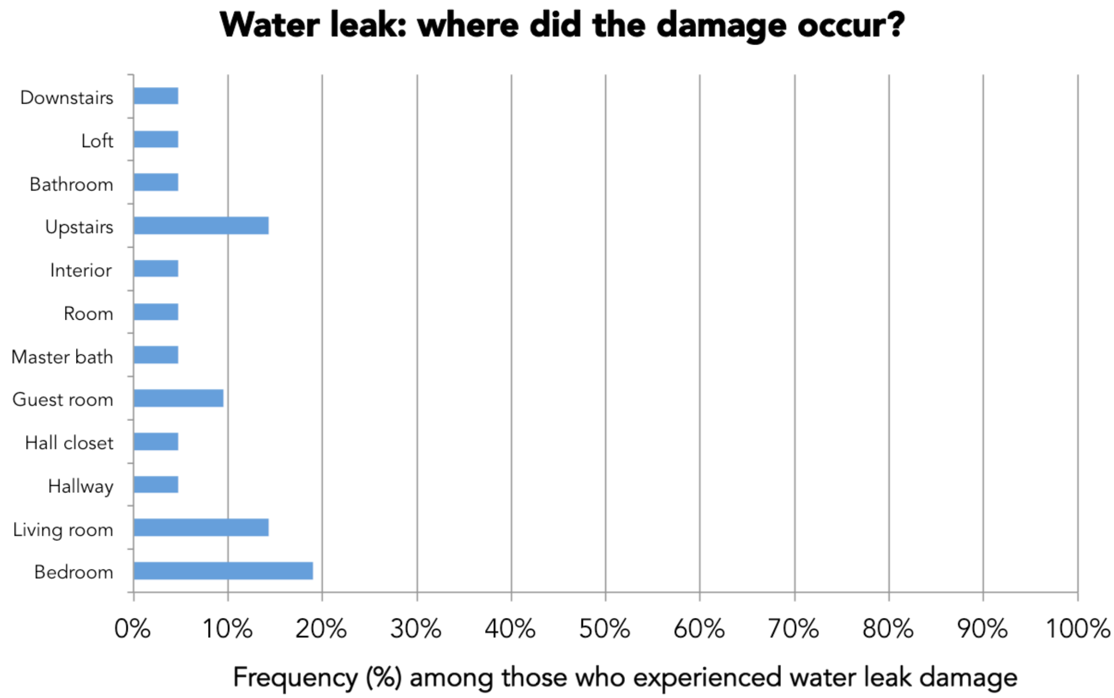


Figure 70. Location in the home where the water damage occurred

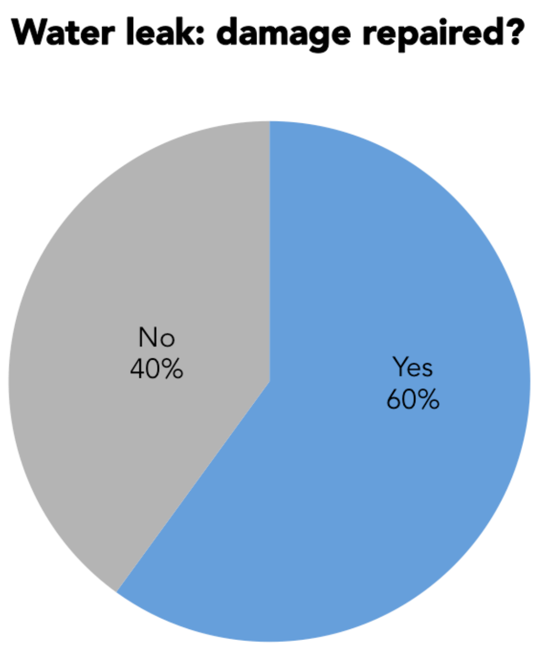


Figure 71. Whether the water leak damage has been repaired

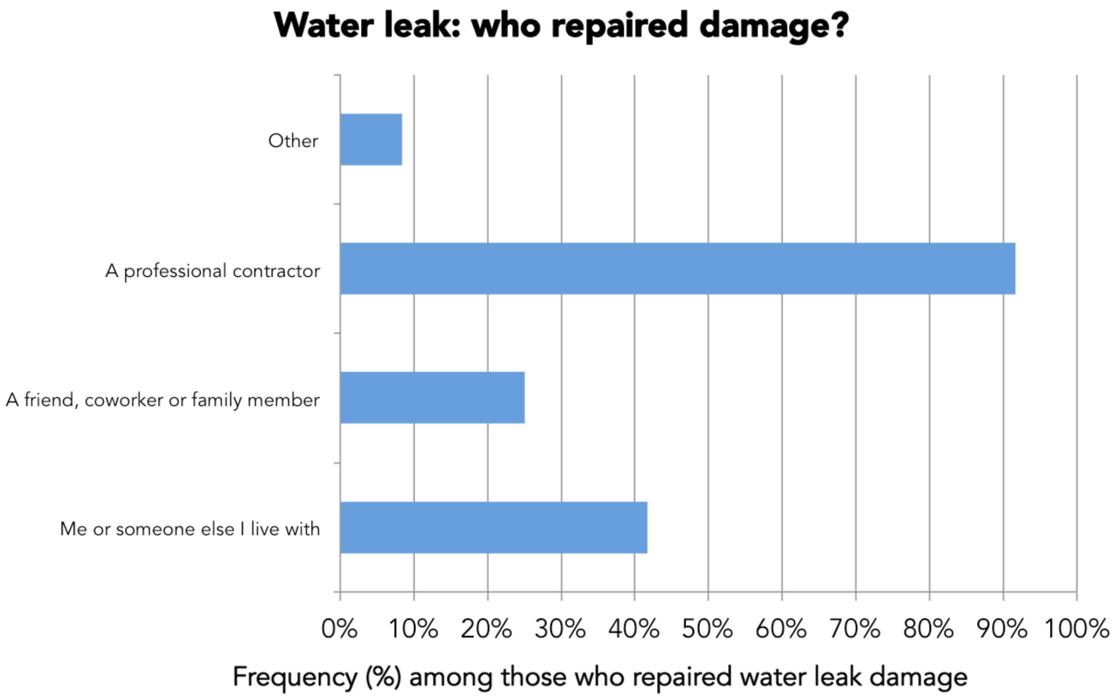


Figure 72. Among those who repaired the water leak damage, who did the repairs

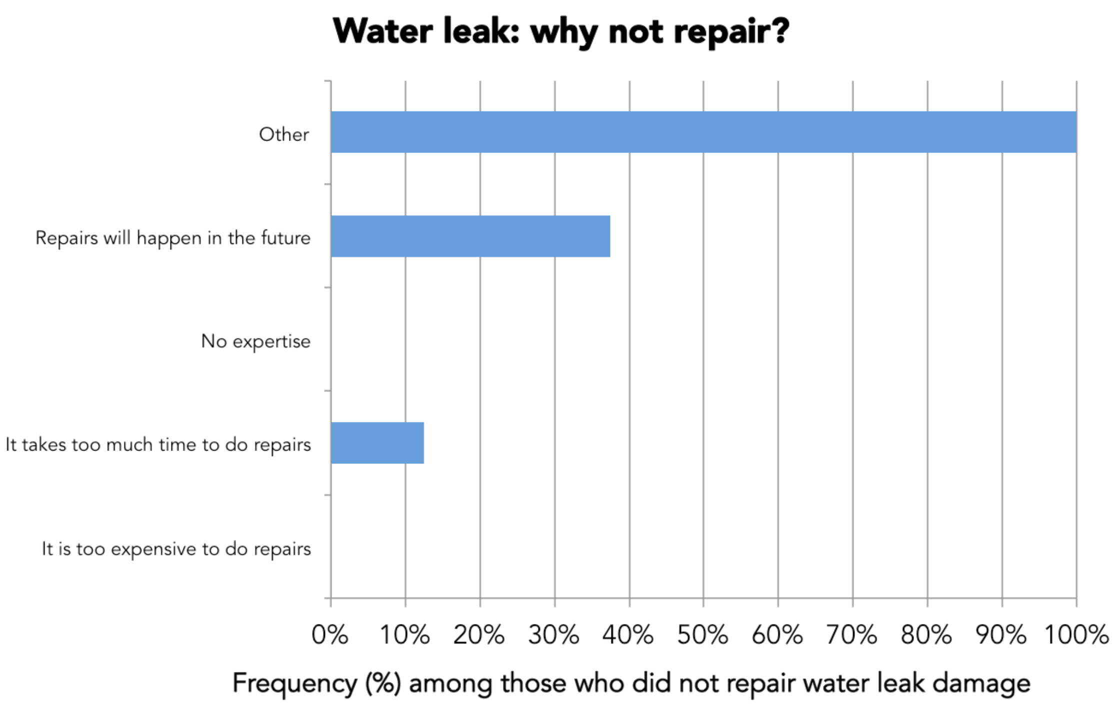


Figure 73. Among those who did not repair the water leak damage, the reason given

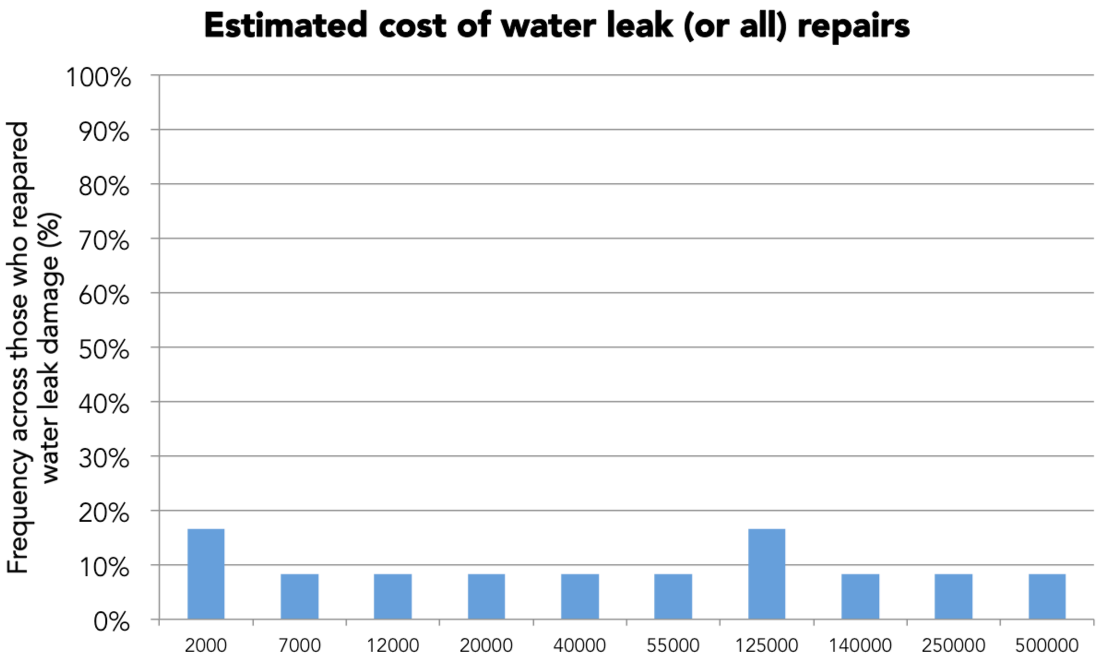


Figure 74. Range of estimated cost of repairing water leak damage among those who did repairs

5.3.7.2 Storm Surge

Figure 23 shows the estimated height of water in the main living area of people's homes, ranging from 0 to 5 feet. Figure 24 shows that water came in from a variety of places in people's homes, with the dominant locations being from the ceiling (18%) and garage (18%). Participants reported that the majority of the damage occurred downstairs in general (14%) (Figure 25).

As shown in Figure 26, 50% of the participants who experienced interior damage from storm surge reported having repaired that damage with most (80%) hiring a professional contractor for the repairs (Figure 27). Among those who experienced damage but have made repairs, many reported that repairs will happen in the future (60%) however most (80%) reported some other reason for not making repairs now (Figure 28). Reasons given for not making repairs included: only minor things were damaged, there is a limited number of contractors available, medical reasons not associated with Hurricane Irma, waiting for a roof permit, and the homeowner decided to sell the home As-Is. Figure 29 shows a wide range of estimated costs for repairs among those who have already made them, ranging from $3,000 to $300,000.

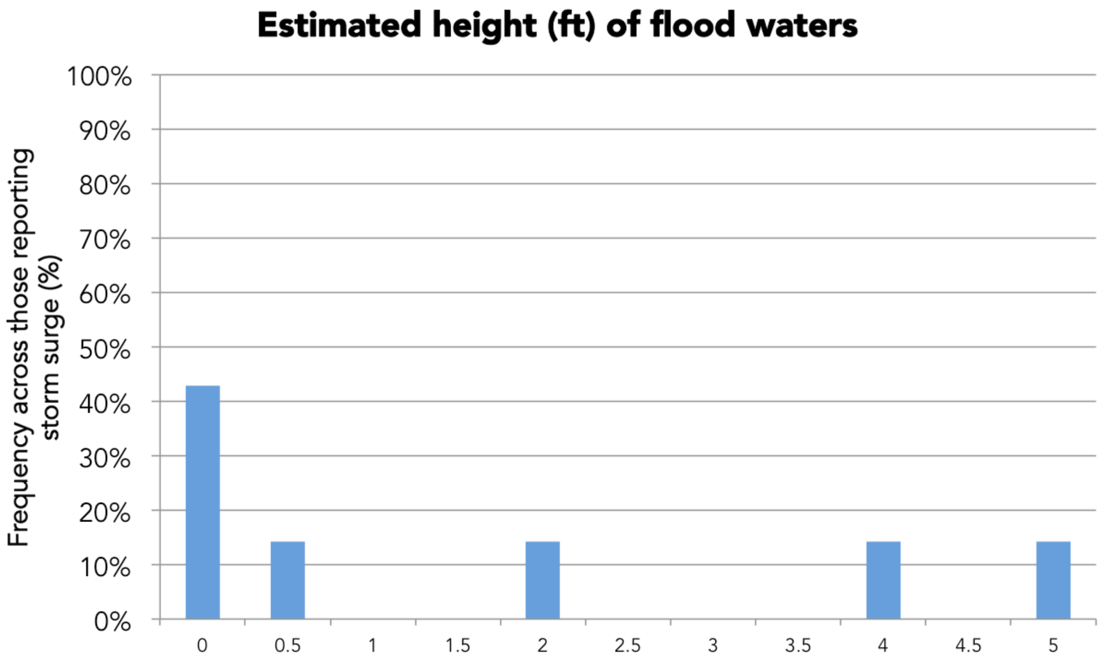


Figure 75. Reported estimated height of storm surge in home

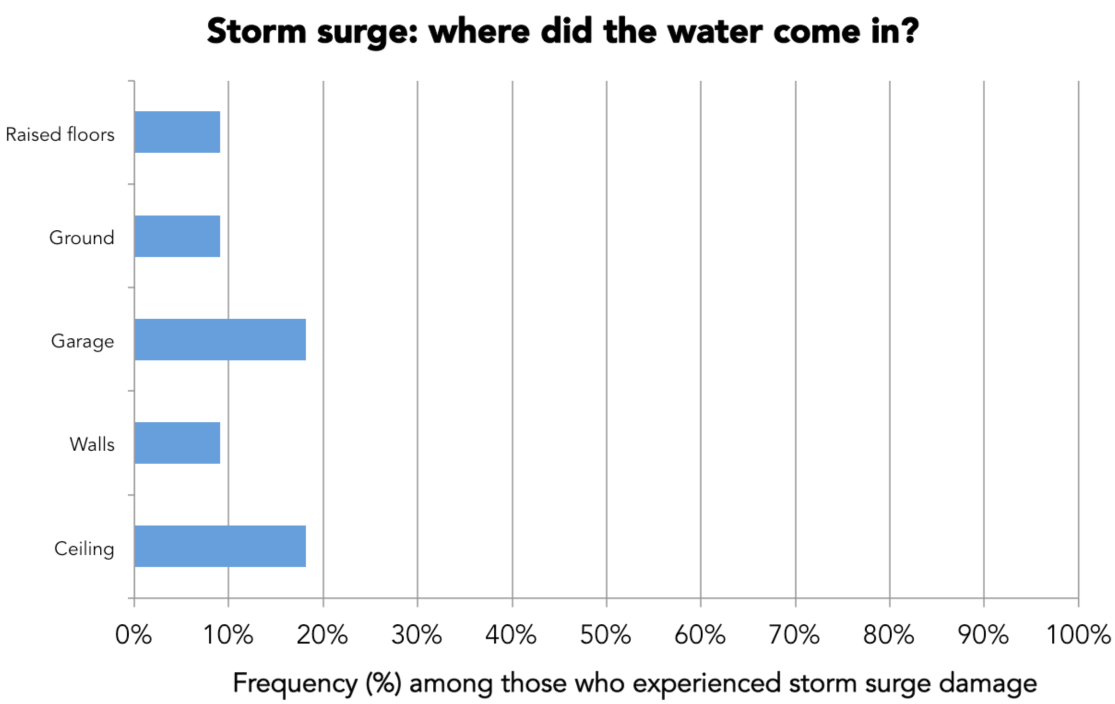


Figure 76. Where the water came in as a result of Hurricane Irma for those reporting storm surge damage

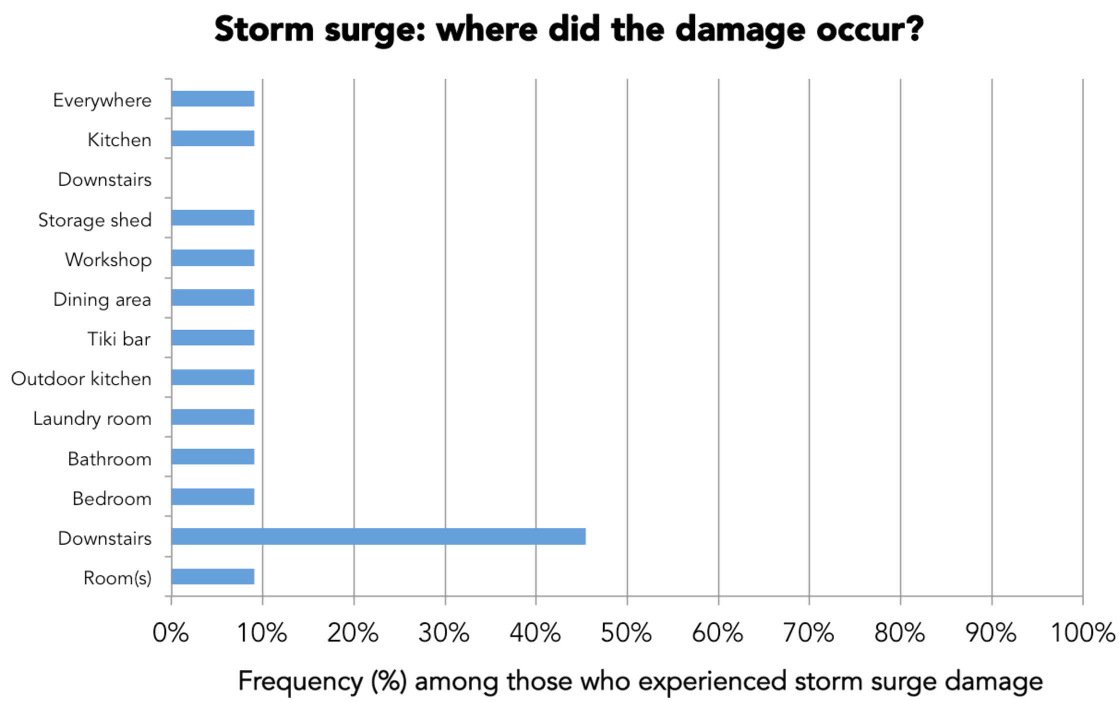


Figure 77. Location in the home where the water damage occurred

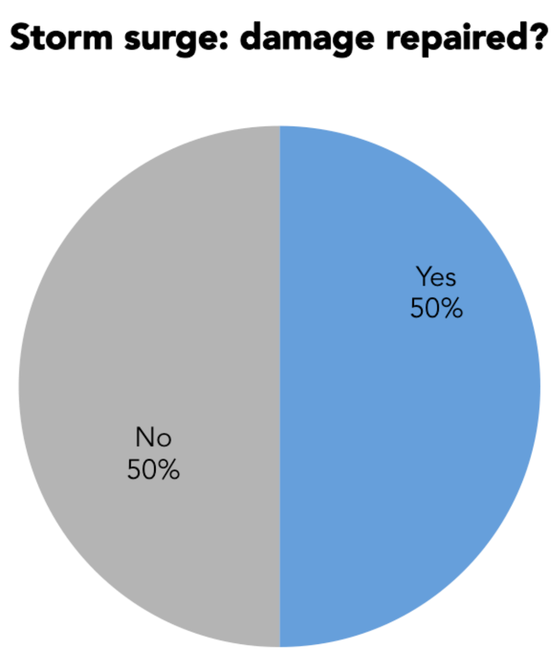


Figure 78. Whether the storm surge damage has been repaired

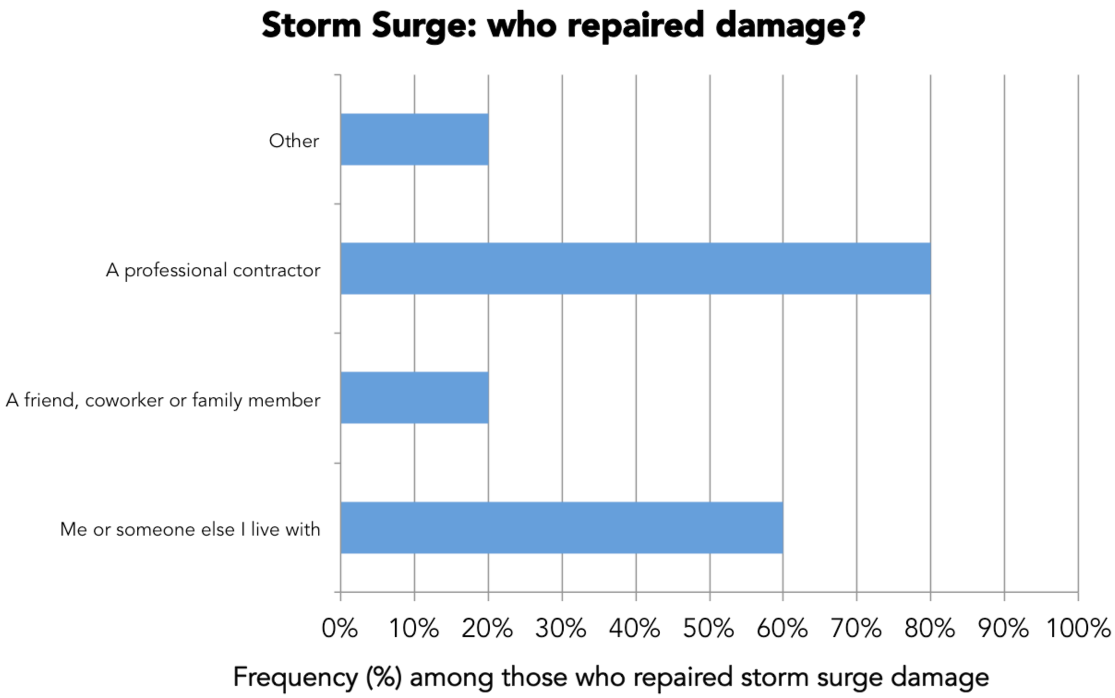


Figure 79. Among those who repaired the storm surge damage, who did the repairs

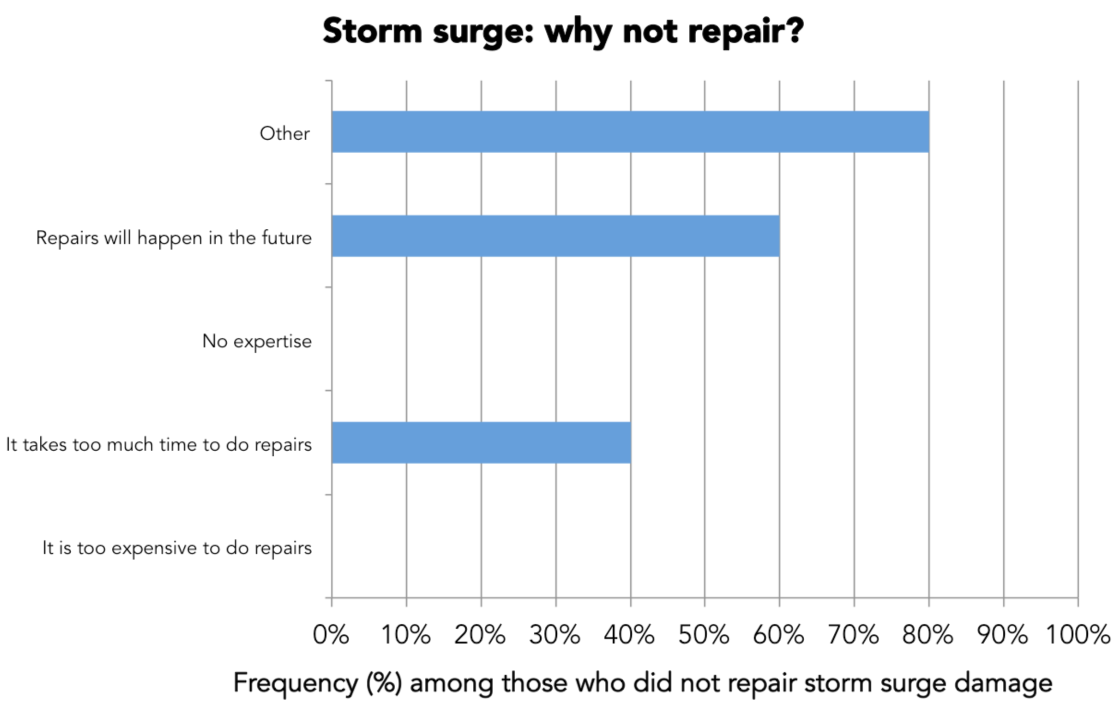


Figure 80. Among those who did not repair the storm surge damage, the reason given

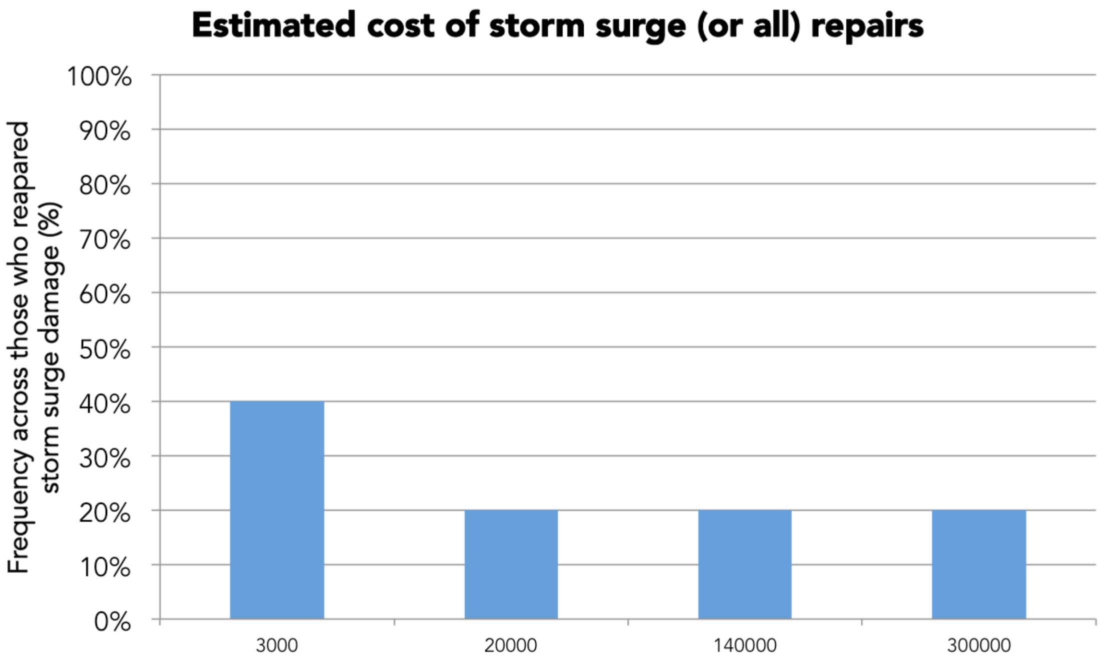


Figure 81. Range of estimated cost of repairing storm surge damage among those who did repairs

5.3.7.3 Wind

Figure 30 shows that wind came in from a variety of places in people's homes, with the dominant location being from the roof (44%). Participants reported that the majority of the damage occurred upstairs (11%), interior in general (11%), and the porch area (11%) (Figure 31).

As shown in Figure 32, 50% of the participants who experienced interior damage from wind reported having repaired that damage with most (78%) hiring a professional contractor for the repairs (Figure 33). Among those who experienced damage but have made repairs, many reported that repairs will happen in the future (50%) however most (83%) reported some other reason for not making repairs now (Figure 34). Reasons given for not making repairs included: being unable to get a building permit, waiting for a permit, waiting to get a roofer, waiting to get a contractor (hard to get), and deciding to sell the home As-Is. Figure 35 shows a wide range of estimated costs for repairs among those who have already made them, ranging from $16,000 to $300,000.

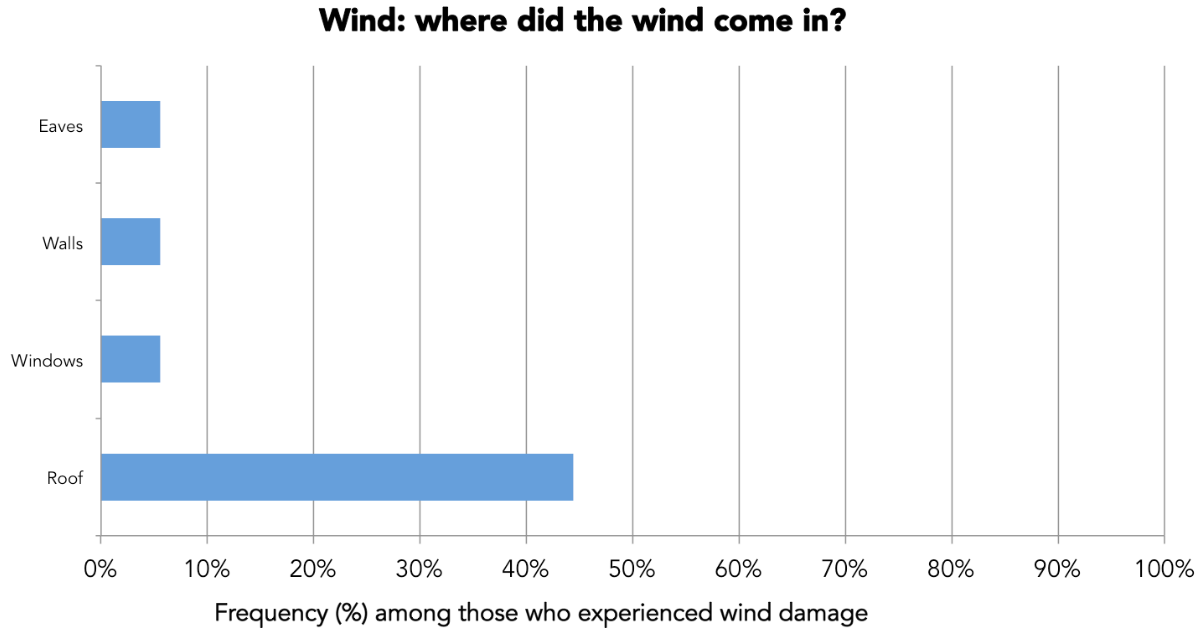


Figure 82. Where the wind came in as a result of Hurricane Irma for those reporting wind damage

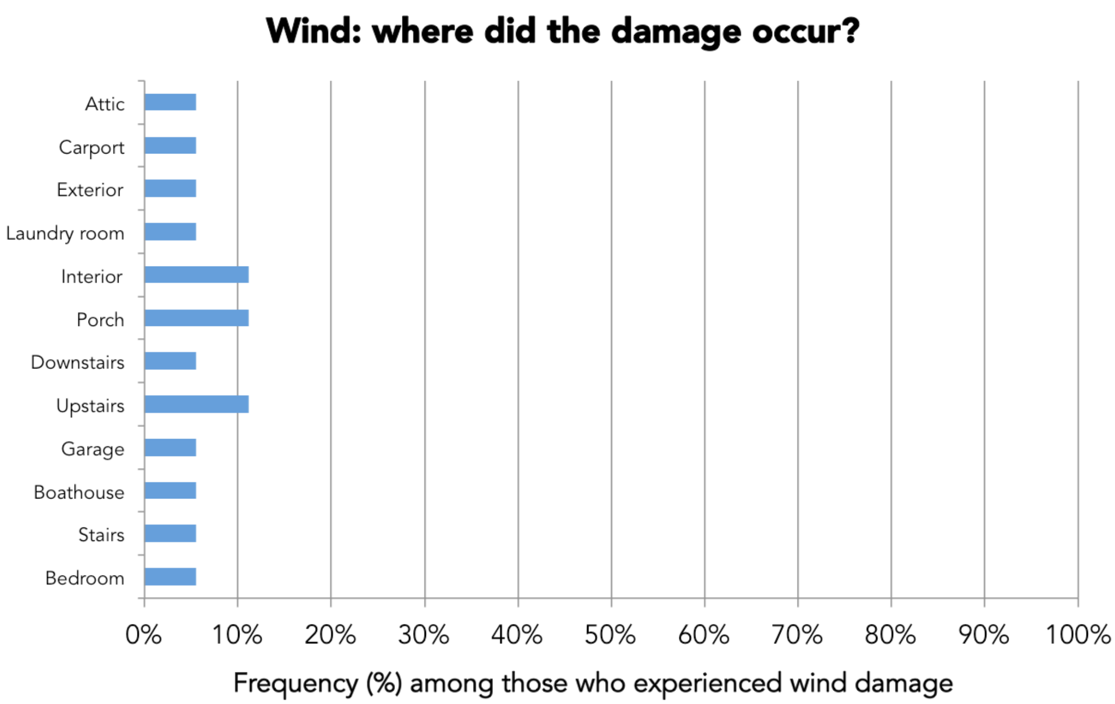


Figure 83. Location in the home where the wind damage occurred

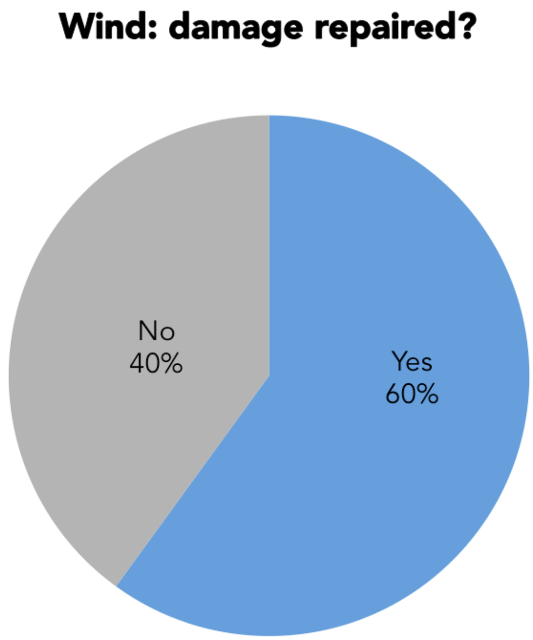


Figure 84. Whether the wind damage has been repaired

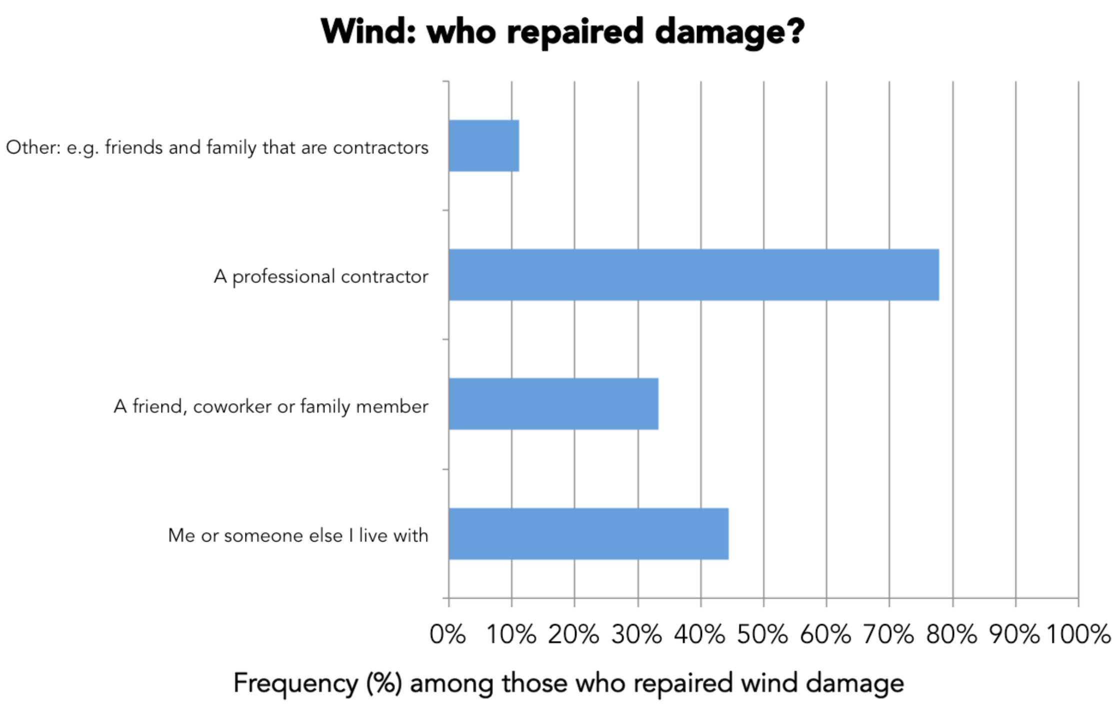


Figure 85. Among those who repaired the wind damage, who did the repairs

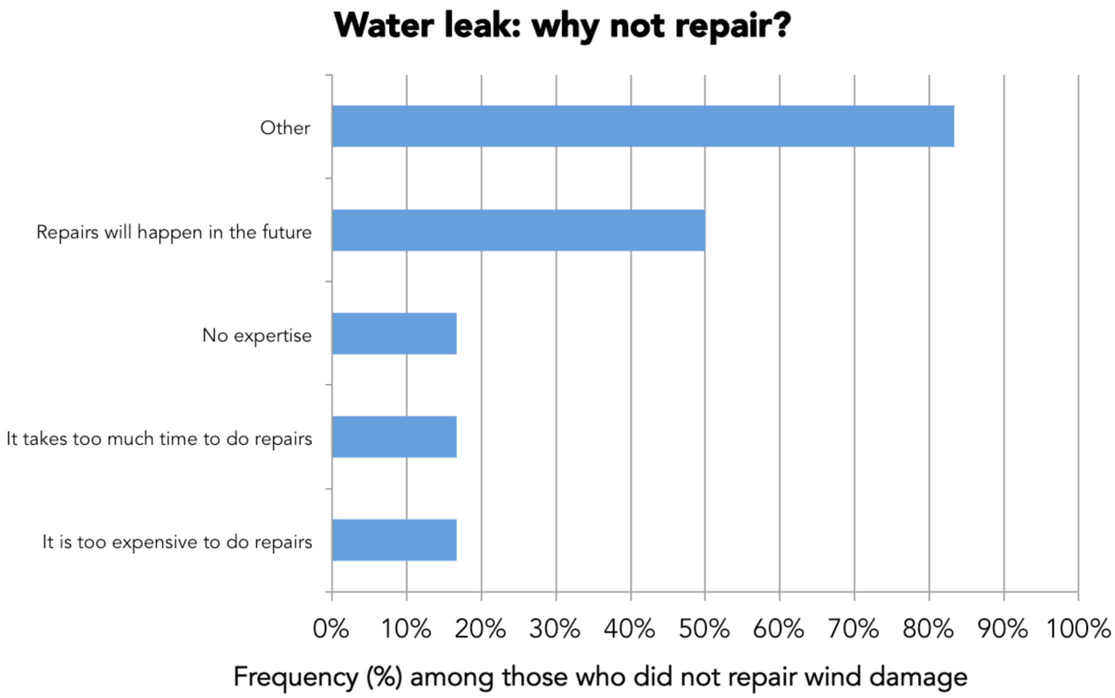


Figure 86. Among those who did not repair the wind damage, the reason given

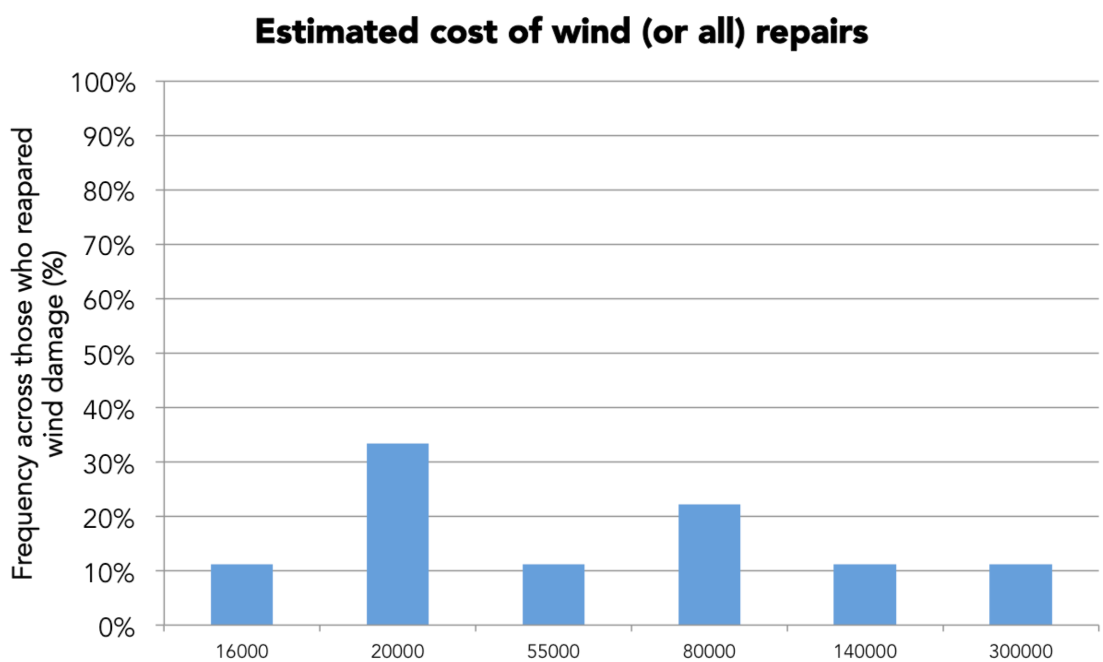


Figure 87. Range of estimated cost of repairing wind damage among those who did repairs

5.3.8 Structural retrofits

As shown in Figure 36, participants reported a range of structural improvements to protect against hurricanes. The most frequent types of structural improvements include installing hurricane shutters (34%), metal roofs (28%), hurricane windows (28%), and hurricane windows (16%). Most of these improvements were permitted. On balance, participants thought that their homes held up well in the face of Hurricane Irma (*M*=3.75, *SD*=1.22) yet still would consider making future improvements to their homes to protect against hurricanes (*M*=3.38, *SD*=1.43) (Figure 37).

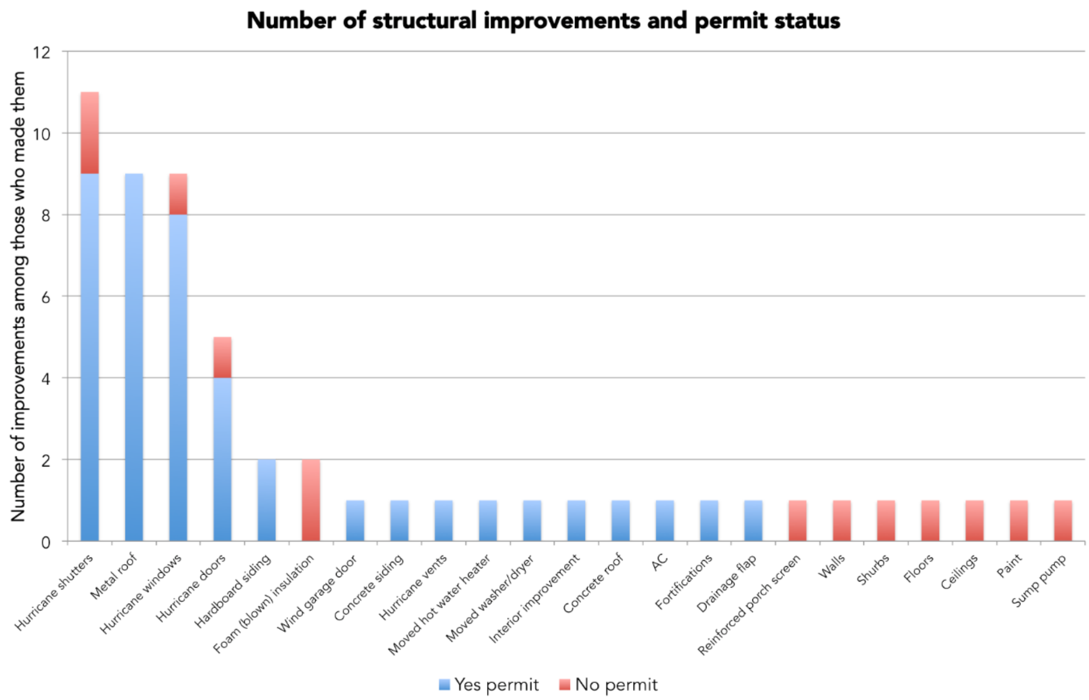


Figure 88. Number of major structural improvements and permit status

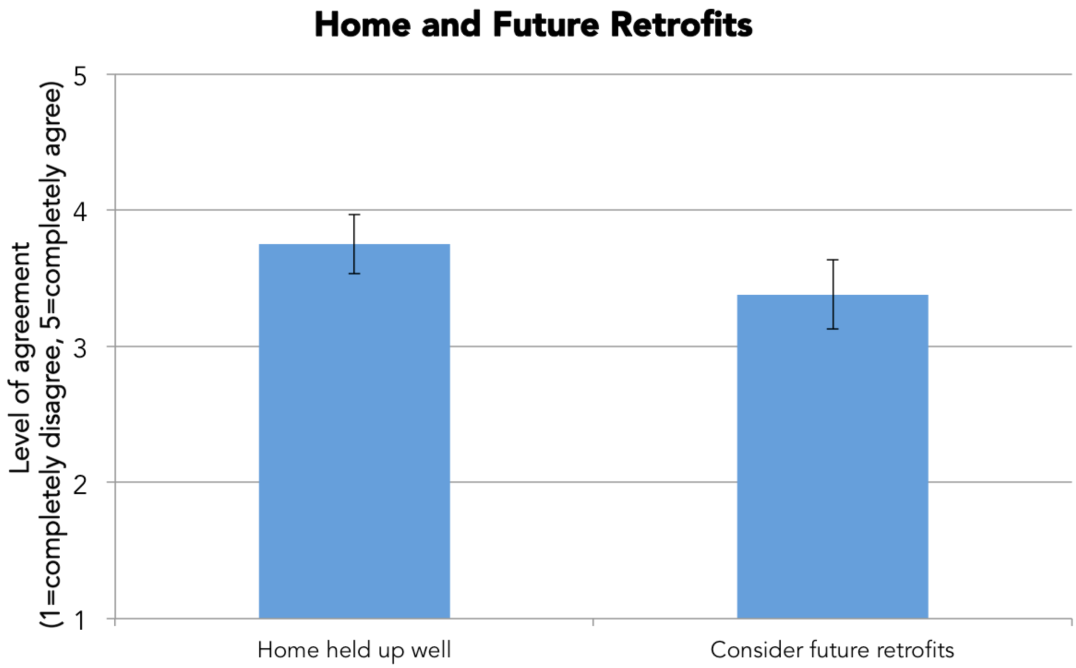


Figure 89. Views on whether the home held up well with respect to Hurricane Irma and whether participants would consider future retrofits

6 RECOMMENDATIONS

The following provides the major recommendations stemming from this report regarding future storm survey efforts:

1. The investigators found that it would help in future events to include more detailed forensic case studies in the assessment workflow to identify more precisely successes or causes of failure. Given the path of Hurricane Irma, many Florida counties of were affected by strong winds resulting in damage to houses over a wide swath of the state. In order to capture reasonable trends, an extensive survey was required to over 800 houses. The breadth of the survey made it difficult to focus much attention on any one structure within the assessed regions given the available financial resources and personnel. Future surveys could investigate utilizing UAV deployments, vehicle-mounted cameras, and other rapid assessment types more extensively to allow more time in the field for detailed forensic case studies.
2. The investigators found there is limited usefulness of publicly-available websites that provide permitting information. Every jurisdiction has its own unique website format, without the ability to extract the necessary data in bulk for matching with damage assessment locations, and the permit information itself is not standardized. More streamlined process is needed for accessing relevant permit information for assessed structures. It was necessary for us to find permit dates to reduce the large uncertainties in results due to age of roof replacement, retrofits, and more, particularly for component and cladding failures. This data is currently difficult to access and standardize for use in our data models but is critical to properly attributing causes of failure and failure rates.
3. The value of the damage survey exercises could be enhanced if the survey teams were able to work collaboratively with a local building official, who could more rapidly identify code compliance issues during the field assessment portion. Of course, this recommendation (which ties in with Recommendation #1) may be very optimistic from researchers, given that building officials would likely be under high demand immediately after a hurricane. A collaborative partnership between field assessment teams and local building code officials is helpful. Where these collaborations did occur (e.g., St. John’s County), they resulted in a wealth of data still to be analyzed.
4. We recommend that soffit failure performance be classified as a separate building component category, rather than classifying it as part of general wall cladding failure as

was done in this survey. Failure of roof soffits results in high volumes of water entering the house that damages interior finishes, building contents.

5. Future assessments would also benefit from separating cladding failures by type in our survey form when multiple wall cladding systems are present in a given building. This would allow us to clearly attribute failures to specific cladding systems in the data analysis, to examine cladding performance by type more precisely.
6. Investigate means of improving the response rate for homeowner interviews. The homeowner interviews have provided useful data necessary to quantify the extent of interior damage to houses. As yet, no other means is available that reliably captures interior damage. However, the response rate to survey requests is low, despite the multiple recruitment strategies used. Other approaches may yield higher participation, potentially by collaborating with well-known stat-wide or national organizations.

The following provides recommendations related to the Florida Building Code stemming from the findings of this study:

1. Wind load requirements for vinyl siding in the code should be investigated. The prevalence of vinyl siding failures in post-2001 homes, in a hurricane event well below design, is concerning. More research should be conducted on these systems to determine the specific causes of failure and possible mitigation strategies.
2. Soffit wind load requirements in the code should also be investigated. Failures were commonly observed, leading to increased volumes of wind-driven rain entering the interior of the building.
3. Aging effects on wind performance of roofing systems should be investigated. Dixon et al. (2014) showed that the vulnerability of asphalt shingle roofing systems can increase within the service life of the shingles due to the unsealing of shingle strips over time. Aging effects on other roof system types (e.g., tile and metal roofs) to our knowledge has not yet been quantified. Analysis of roofing damage by age of roof will more clearly define the need for this recommendation.

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Appendix A. Florida Building Code Changes in Response to Hurricane Andrew

Much of the discussion in this report is centered around the performance of pre- and post-2002 buildings. This demarcation is important because it was in 2002 that the State of Florida developed and enacted the first statewide building code, preempting all local codes.

Prior to 1974, building codes were a local option only in Florida – there was no mandate for county building code adoption or enforcement. That changed in 1974, when Florida law required counties to adopt, amend and enforce a model building code. Most of the state adopted the Standard Building Code, while Miami-Dade and Broward Counties adopted the South Florida Building Code, which contained more stringent high wind velocity requirements. The hurricane protection requirements in these codes were for the most part prescriptive specifications for common construction types with little to no engineering basis.

In 1992, Hurricane Andrew struck the SE coast of Florida and exposed the limitations of the locally managed building code system and the buildings constructed to these codes. The devastation prompted swift action from the state of Florida with the Florida Board of Building Codes and Standards adopting the Minimum Standard for Wind Design throughout the state in 1993. This was in essence the first wind engineering based design requirement for Florida building codes outside Miami-Dade and Broward Counties. The Florida Building Code Study Commission was also created and began developing a single state-controlled building code. This code came to be known as the 2001 Florida Building Code, and took effect in March 1, 2002.

The specific improvements of the 2001 Florida Building Code for wind resistance over previous codes are summarized as follows:

- Higher design wind pressures in South Florida and most coastal areas
- Wind-borne debris protection requirements for windows and glazing in all coastal area
- Improved roof covering system requirements
- Establishment of a product approval system to ensure products comply with wind and impact resistance requirements of the code
- Improved wind performance labeling requirements for more consistent enforcement of the code

Beyond the specific wind resistant improvements to the code, the requirement that it be adopted and enforced throughout the state is also a major factor in expectations of improved wind performance of buildings in Florida built to post-2002 building codes.

The effects of the 2001 Florida Building Code were tested in 2004 and 2005, when hurricanes Charley, Frances, Ivan, Jeanne, Dennis and Wilma all made landfall in Florida with high wind speeds. Studies found a statistically significant improvement in performance for buildings constructed to the 2001 Florida Building Code compared to those built before the code was enacted. Two of the main studies on this topic are listed below.

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Appendix B. Personalized recruitment letter and postcard

Carnegie Mellon University

Department of Engineering and Public Policy
Carnegie Mellon University
Pittsburgh, Pennsylvania 15213-3890
Telephone: 412-268-2670
Fax: 412-268-3757
www.epp.cmu.edu

Dear Homeowner or Current Resident,

I am a researcher from Carnegie Mellon University looking for residents from Brevard, Collier, Miami-Dade, Lee, Monroe, Okeechobee, and St. Johns counties who are age 18 years or older to participate in my research study. You will be asked about your views and decisions regarding Hurricane Irma and its aftermath. You will also be asked some demographic questions. The survey should take about 20-30 minutes, and will conducted online or by phone. We may need to contact you to ask a few brief follow-up questions. You will be compensated $20 for your participation, and you will also be entered into a raffle for a chance to win an Apple® I-Pad Mini.

To participate, please send an email to or call the Principal Investigator, Dr. Gabrielle Wong-Parodi. You must include your participant ID to sign up, which is

Participant ID [XXXXX]

Sign-up instructions are on the next page.

The study is limited to including only 100 participants, so please sign-up now. Survey data collection will end on April 30, 2018.

If you have any questions about this study, you should feel free to ask them by contacting the Principal Investigator, Gabrielle Wong-Parodi, Engineering and Public Policy, 206 Hamburg Hall, 5000 Forbes Avenue, Pittsburgh, PA, 412-589-9037. If you have questions later, desire additional information, or wish to withdraw your participation please contact Dr. Wong-Parodi by mail, phone or e-mail in accordance with the contact information listed above.

If you have questions pertaining to your rights as a research participant; or to report objections to this study, you should contact the Research Regulatory Compliance Office at Carnegie Mellon University. Email: irb-review@andrew.cmu.edu. Phone: 412-268-1901 or 412-268-5460.

Sincerely,

Gabrielle Wong-Parodi
Assistant Research Professor
Department of Engineering and Public Policy
Carnegie Mellon University

1

Email sign-up

If signing up by email, please include **your participant ID in both the subject line and body of the email**. Please send your email to **gwongpar@cmu.edu**.

If you want to participate online, your email should look like this:

> I am interested in participating in the survey. My participant ID is [XXXXX]. I am interested in participating online. Please send me a link. I can be reached at [phone number] for follow-up questions if necessary.

If you want to participate by phone, your email should look like this:

> I am interested in participating in the survey. My participant ID is [XXXXX]. I am interested in participating by phone. Please call me at [phone number] to set up a time to conduct the survey by phone.

This survey is anonymous and confidential. Please DO NOT LEAVE YOUR FULL NAME.

Phone sign-up

If signing up by phone, please include **your participant ID in your voicemail**. Please leave your voicemail at **412-589-9037**.

If you want to participate online, you can leave the following message:

> I am interested in participating in the survey. My participant ID is [XXXXX]. I am interested in participating online. Please send me a link at [your email address]. I can be reached at [phone number] for follow-up questions if necessary.

If you want to participate by phone, your email should look like this:

> I am interested in participating in the survey. My participant ID is [XXXXX]. I am interested in participating by phone. Please call me at [phone number] to set up a time to conduct the survey by phone.

This survey is anonymous and confidential. Please DO NOT LEAVE YOUR FULL NAME.

2

Dear Homeowner or Current Resident,

Please join other Florida residents participating in the Carnegie Mellon University study!

It's easy to participate, go to the following website: **https://goo.gl/k8FuLG** and enter your **Participant ID XXXX**.

Or you can participate by phone by calling **412-589-9037** and provide your **Participant ID 3MK34**.

The survey should take 15-20 minutes on average to complete. You will earn a $20 Amazon Gift Card if you complete all required questions. You will also be entered into a raffle for a chance to win an Apple® I-Pad Mini.

Who can participate: Only one person per household may participate in the study. You must be 18 or older to participate. You can only participate once.

Appendix C. Copy of approval letter

Carnegie Mellon University

APPROVAL OF SUBMISSION

April 3, 2018

Type of Review:	Initial Study
Title of Study:	Homeowner views and decisions regarding Hurricane Irma and its aftermath
Investigator: Study Team Members:	Gabrielle Wong-Parodi
IRB ID:	STUDY2018_00000157: Homeowner views and decisions regarding Hurricane Irma and its aftermath
Funding:	Personal funds from PI Gabrielle Wong-Parodi

The Carnegie Mellon University Institutional Review Board (IRB) has reviewed and granted **APPROVAL under as Exempt on 4/3/2018, in accordance with 45 CFR 46.101(b)(2)**.

This approval does not expire. However, if you wish to make modifications to this protocol, please contact the IRB regarding these changes prior to their implementation to ensure compliance with this designation.

The Investigator(s) listed above in conducting this protocol agree(s) to follow the recommendations of the IRB of any conditions to or changes in procedure subsequent to this review. In undertaking the execution of the protocol, the investigator(s) further agree(s) to abide by all CMU research policies including, but not limited to the policies on responsible conduct research and conflict of interest.

Sincerely,

John Zimmerman
IRB Chair

Appendix D. Copy of survey

Hurricane Irma_FBC

Start of Block: INTRODUCTION

Q3
Carnegie Mellon University

Q70
Thank you for your interest in this important study. Your name and home address were obtained through public records from the Florida Department of Revenue. The purpose of this research is to better understand the impact of recent hurricanes and their aftermath on individuals living in Florida. Your participation is completely voluntary. We do not ask for any identifying information, and no personally identifiable information will be attached to any response. We expect the survey to take 15-20 minutes.

On the next page you will see a brief consent form, which you should read before participating in the survey.

Page Break

Q71
This activity is part of a research study conducted by Gabrielle Wong-Parodi at Carnegie Mellon University. The purpose of this study is to understand your views and experiences with respect to Hurricane Irma and its aftermath.

Procedures
You will be asked about your views and decisions regarding Hurricane Irma and its aftermath. Then, you will be asked some demographic questions. Please do not mention anything during the survey that is both identifiable and private in your responses. This survey should take no more than 20 minutes in total to complete.

Participant Requirements
Participation in this study is limited to individuals age 18 and older and residents of Brevard, Collier, Miami-Dade, Lee, Monroe, and St. Johns counties.

Risks
The primary risk is a breach of confidentiality. Steps will be taken to minimize the risk of breach of confidentiality by assigning each participant with an ID at the beginning of the study. Names and identifiable information will be separated from participants' responses, and kept in a separate and secured location in the PI's office. There is also a chance that participants could become tired or bored during the study, however it should take about 20 minutes and so these risks are minimized.

Benefits
There are no direct or indirect benefits to you for your participation in the study.

Compensation & Costs
You will be compensated $20 for your participation in the survey through receipt of an Amazon gift card. To obtain your gift card, you will need to provide your email address. You will also be automatically entered into a raffle for a chance to win an Apple® I-Pad Mini. The winner will be selected in June 2018, and an Apple® gift card up to the amount of an I-Pad Mini will be sent by email.

There will be no cost to you if you participate in this survey.

Confidentiality
By participating in this research, you understand and agree that Carnegie Mellon may be required to disclose your consent, data and other personally identifiable information as required by law, regulation, subpoena or court order. Otherwise, your confidentiality will be maintained in the following manner: (a) to the fullest extent possible, all identifiable information will be separated from your survey and (b) in publications, if quoted, you will be referred to in general terms such as a "southern Florida resident."

Page 2 of 38

By participating, you understand and agree that the data and information gathered during this study may be used by Carnegie Mellon and published and/or disclosed by Carnegie Mellon to others outside of Carnegie Mellon.

Right to Ask Questions & Contact Information
If you have any questions about this study, you should feel free to ask them by contacting the Principal Investigator, Dr. Gabrielle Wong-Parodi, Engineering and Public Policy, 206 Hamburg Hall, 5000 Forbes Avenue, Pittsburgh, PA, 15213, (510) 316-1631, gwongpar@cmu.edu. If you have questions later, desire additional information, or wish to withdraw your participation please contact the Principal Investigator by mail, phone or e-mail in accordance with the contact information listed above.

If you have questions pertaining to your rights as a research participant; or to report objections to this study, you should contact the Research Regulatory Compliance Office at Carnegie Mellon University. Email: irb-review@andrew.cmu.edu. Phone: 412-268-1901 or 412-268-5460.

Voluntary Participation
Your participation in this research is voluntary. You may discontinue participation at any time during the research activity.

Q72
I am age 18 or older. I have read and understand the information above and I want to participate in this research

- ○ Yes (1)
- ○ No (2)

End of Block: INTRODUCTION

Start of Block: PARTICIPANT ID AND EMAIL

Q73
In order to participate, you need to enter your valid participant ID. It can be found in the letter that you received in the mail, and should look something like this:

Can you please confirm your participant ID?

____

Page Break

Q74 In order to receive your $20 Amazon gift card and to be entered into the raffle for the chance to win an Apple I-Pad Mini, please enter in your email address. You must complete the survey to receive your compensation and to be entered into the raffle.

____

End of Block: PARTICIPANT ID AND EMAIL

Start of Block: STRESS

Q1 With respect to Hurricane Irma and its aftermath, how often have you experienced the following over the past week or so?

	1=never (1)	2=rarely (2)	3=sometimes (3)	4=often (4)	5=all the time (5)
Have you had nightmares about the hurricane or thought about it when you did not want to? (1)	○	○	○	○	○
Have you tried hard not to think about the hurricane or gone out of your way to avoid situations that reminded you of it? (2)	○	○	○	○	○
Were constantly on guard, watchful, or easily startled? (3)	○	○	○	○	○
Have you felt numb or detached from others? (4)	○	○	○	○	○
Have you felt guilty or unable to stop blaming yourself or others for any problems the hurricane may have caused. (5)	○	○	○	○	○

Page 6 of 38

Page Break

Q2 How often have you experienced the following over the past week or so?

	1=never (1)	2=rarely (2)	3=sometimes (3)	4=often (4)	5=all the time (5)
How often have you worried about a natural disaster affecting your community? (1)	○	○	○	○	○
I worry that a natural disaster will personally affect me or someone in my family in the future. (2)	○	○	○	○	○
How often have you worried about exposure to environmental hazards following a natural disaster (e.g., toxic chemicals or mold)? (3)	○	○	○	○	○
I worry that exposure to environmental hazards following a natural disaster will personally affect me or someone in my family in the future. (4)	○	○	○	○	○
How often have you worried about experiencing	○	○	○	○	○

financial stress or strain? (5)					
I worry that I, or someone in my family, will not have enough money to pay for basic needs (e.g., food, shelter, clothing). (6)	○	○	○	○	○

End of Block: STRESS

Start of Block: EVACUATION BEHAVIOR

Q4 Did you evacuate your home at any time before or during Hurricane Irma?

○ Yes (1)

○ No (2)

Display This Question:

If Did you evacuate your home at any time before or during Hurricane Irma? = No

Q6 Why did you not evacuate? (please check all that apply)

- ☐ Because I didn’t live in an evacuation zone (1)
- ☐ Because I didn't have anywhere to go (2)
- ☐ Because I had pets I couldn't take with me (3)
- ☐ Because I wanted to take care of my home (4)
- ☐ Because I - someone else I live with - is disabled (5)
- ☐ Because I couldn't afford to (6)
- ☐ I didn't leave my home for another reason (please specify) (7) ____
- ☐ I didn't evacuate, but I wish I had done so (8)

Display This Question:

If Did you evacuate your home at any time before or during Hurricane Irma? = Yes

Q7 Why did you evacuate? (please check all that apply)

- ☐ Because I live in an evacuation zone (1)
- ☐ Because I had somewhere to go (2)
- ☐ Because I had pets I could take with me (3)
- ☐ Because I could afford to (4)
- ☐ Because I felt at risk (5)
- ☐ I evacuated for another reason (please specify) (6) ____

Display This Question:

If Why did you evacuate? (please check all that apply) , Because I live in an evacuation zone Is Displayed

Q8 How many times did you evacuate?

▼ 1 (1) ... 10 (10)

Display This Question:

If How many times did you evacuate? = 1

Q9 Where did you evacuate to and how long were you there?

○ City (1) ____

○ State (2) ____

○ How long were you there (days) (3) ____

Display This Question:

If How many times did you evacuate? = 2

Or How many times did you evacuate? = 3

Or How many times did you evacuate? = 4

Or How many times did you evacuate? = 5

Or How many times did you evacuate? = 6

Or How many times did you evacuate? = 7

Or How many times did you evacuate? = 8

Or How many times did you evacuate? = 9

Or How many times did you evacuate? = 10

Q11 Where did you **first** evacuate to and how long were you there?

- City (1) ____
- State (2) ____
- Days (3) ____

Display This Question:

If How many times did you evacuate? = 2

Or How many times did you evacuate? = 3

Or How many times did you evacuate? = 4

Or How many times did you evacuate? = 5

Or How many times did you evacuate? = 6

Or How many times did you evacuate? = 7

Or How many times did you evacuate? = 8

Or How many times did you evacuate? = 9

Or How many times did you evacuate? = 10

Q19 Where was the **second** place you evacuated to and how long were you there?

- City (1) ____
- State (2) ____
- Days (3) ____

Display This Question:

If How many times did you evacuate? = 3

Or How many times did you evacuate? = 4

Or How many times did you evacuate? = 5

Or How many times did you evacuate? = 6

Or How many times did you evacuate? = 7

Or How many times did you evacuate? = 8

Or How many times did you evacuate? = 9

Or How many times did you evacuate? = 10

Q20 Where was the **third** place you evacuated to and how long were you there?

○ City (1) ____

○ State (2) ____

○ Days (3) ____

Display This Question:

If How many times did you evacuate? = 4

Or How many times did you evacuate? = 5

Or How many times did you evacuate? = 6

Or How many times did you evacuate? = 7

Or How many times did you evacuate? = 8

Or How many times did you evacuate? = 9

Or How many times did you evacuate? = 10

Q21 Where was the **fourth** place you evacuated to and how long were you there?

○ City (1) ____

○ State (2) ____

○ Days (3) ____

Display This Question:

If How many times did you evacuate? = 5

Or How many times did you evacuate? = 6

Or How many times did you evacuate? = 7

Or How many times did you evacuate? = 8

Or How many times did you evacuate? = 9

Or How many times did you evacuate? = 10

Q22 Where was the **fifth** place you evacuated to and how long were you there?

- City (1) ____
- State (2) ____
- Days (3) ____

Display This Question:

If How many times did you evacuate? = 6

Or How many times did you evacuate? = 7

Or How many times did you evacuate? = 8

Or How many times did you evacuate? = 9

Or How many times did you evacuate? = 10

Q23 Where was the **sixth** place you evacuated to and how long were you there?

- City (1) ____
- State (2) ____
- Days (3) ____

Display This Question:

If How many times did you evacuate? = 7

Or How many times did you evacuate? = 8

Or How many times did you evacuate? = 9

Or How many times did you evacuate? = 10

Q24 Where was the **seventh** place you evacuated to and how long were you there?

- City (1) ____
- State (2) ____
- Days (3) ____

Display This Question:

If How many times did you evacuate? = 8

Or How many times did you evacuate? = 9

Or How many times did you evacuate? = 10

Q25 Where was the **eighth** place you evacuated to and how long were you there?

- City (1) ____
- State (2) ____
- Days (3) ____

Display This Question:

If How many times did you evacuate? = 9

Or How many times did you evacuate? = 10

Q26 Where was the **ninth** place you evacuated to and how long were you there?

- City (1) ____
- State (2) ____
- Days (3) ____

Display This Question:

If How many times did you evacuate? = 10

Q27 Where was the **tenth** place you evacuated to and how long were you there?

- City (1) ____
- State (2) ____
- Days (3) ____

Page Break

Q28 Are you back in your home now?

◯ Yes (1)

◯ No (2)

End of Block: EVACUATION BEHAVIOR

Start of Block: RISK PERCEPTIONS

Q29 The next questions ask you to give the percent chance that something will happen. Use a '0' to indicate the event will not happen and a '100' to indicate it will be certain to happen. Before Hurricane Irma hit, what did you think was the percent chance that:

	0 10 20 30 40 50 60 70 80 90 100
% your home would be severely damaged or destroyed because of the hurricane or its aftermath? ()	
% sure that any damages would be covered by insurance? ()	
% you would never be able to return to your current home as a result of the hurricane or its aftermath? ()	
% you would be seriously injured by the hurricane or its aftermath? ()	
% someone close to you would be seriously injured by the hurricane or its aftermath? ()	

End of Block: RISK PERCEPTIONS

Start of Block: STORM RELATED BELIEFS

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Q30 How much do you agree or disagree with the following?

	1=completely agree (1)	2=agree (2)	3=neither agree nor disagree (3)	4=disagree (4)	5=completely disagree (5)
There is someone I can call on, if I need help during a hurricane or its aftermath (1)	○	○	○	○	○
There is someone who would call on me, if they needed help during a hurricane or its aftermath (2)	○	○	○	○	○
The federal government should provide disaster relief for people whose lives are disrupted by the hurricane or its aftermath (3)	○	○	○	○	○
The federal government should pay to rebuild homes that are destroyed by a hurricane or its aftermath (4)	○	○	○	○	○
I did everything I could to prepare my	○	○	○	○	○

home for the hurricane and its aftermath (5)					
Climate change helped make this season's hurricanes so strong (6)	○	○	○	○	○

End of Block: STORM RELATED BELIEFS

Start of Block: PREPARATION

Q31 There are many things that people might do to prepare for natural disasters, like hurricanes. Please check all those that you were able to do before Hurricane Irma.

☐ Learn about the risks from hurricanes and how to prepare for them (1)

☐ Move vehicles to a safe location (2)

☐ Put together an emergency kit (e.g., food, medical supplies, flashlight) (3)

☐ Develop and practice an emergency plan (4)

☐ Identify shelter locations in the event of an evacuation (5)

☐ Copy important documents (e.g., birth certificates, driver's licenses) (6)

☐ Get a row boat or inflatable raft (7)

☐ Make my home more hurricane proof (e.g., install hurricane shutters, sand bags) (8)

☐ Have flood insurance (9)

☐ Other (please specify) (10) ____

- -

Q32 How much do you think these actions will protect you from future hurricanes and their aftermath?

- ○ Not at all (1)
- ○ Just a little (2)
- ○ Somewhat (3)
- ○ Mostly (4)
- ○ Completely (5)

Q33 Do you think hurricanes during future hurricane seasons will be

- ○ less intense than the ones in the 2017 season (1)
- ○ about the same intensity (2)
- ○ more intense than the ones in the 2017 season (3)

Q34 Do you think hurricanes during future hurricane seasons will

- ○ happen less frequently than the ones in the 2017 season (1)
- ○ happen with about the same frequency (2)
- ○ happen more frequently than the ones in the 2017 season (3)

End of Block: PREPARATION

Start of Block: INTERIOR HOME DAMAGE

Q35 Did your home experience any **interior damage** from the following due to Hurricane Irma and its aftermath? (please check all that apply)

- ☐ Water leak (1)
- ☐ Storm surge or flood (2)
- ☐ Wind (3)
- ☐ Other (please specify) (4) ____

Page Break

Display This Question:

If Did your home experience any interior damage from the following due to Hurricane Irma and its aft... = Water leak

Q37 Consider the **water leak damage** to your home. In your own words, please describe the following:

- Where did the water leak damage occur? (1) ________________
- What was the extent of the damage to your home? (2) ________________
- What was the extent of the damage to your belongings? (3) ________________
- Why do you think the water leak occurred? (4) ________________

Display This Question:

If Did your home experience any interior damage from the following due to Hurricane Irma and its aft... = Water leak

Q38 Has the damage been repaired?

- Yes (1)
- No (2)

Display This Question:

If Has the damage been repaired? = Yes

*

Q40 Approximately, how much did it cost to repair ($USD)?

____

Display This Question:

If Has the damage been repaired? = Yes

Q41 Who did the repairs? (check all that apply)

- ☐ Me or someone else I live with (1)
- ☐ A friend, coworker, neighbor or family member (2)
- ☐ A professional contractor (3)
- ☐ Other (please specify) (4) ____

Display This Question:

If Has the damage been repaired? = No

Q42 What have you not repaired the damage? (check all that apply)

- ☐ Too expensive to do repairs (1)
- ☐ It takes too much time to do repairs (2)
- ☐ I or someone else I live with do not have the expertise to do repairs (3)
- ☐ Repairs will happen in the future (4)
- ☐ Other (please specify) (5) ____

Page Break

Display This Question:

If Did your home experience any interior damage from the following due to Hurricane Irma and its aft... = Storm surge or flood

Q48
Approximately how high did the water reach in your main living area (feet)?

____

Display This Question:

If Did your home experience any interior damage from the following due to Hurricane Irma and its aft... = Storm surge or flood

Q43 Consider the **water damage** to your home. In your own words, please describe the following:

- Where did the water damage occur? (1) ____
- What was the extent of the damage to your home? (2) ____
- What was the extent of the damage to your belongings? (3) ____
- Why do you think the water damage occurred? (4) ____

Display This Question:

If Did your home experience any interior damage from the following due to Hurricane Irma and its aft... = Storm surge or flood

Q44 Has the damage been repaired?

- Yes (1)
- No (2)

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Display This Question:

If Has the damage been repaired? = Yes

*

Q45 Approximately, how much did it cost to repair ($USD)?

____

Display This Question:

If Has the damage been repaired? = Yes

Q46 Who did the repairs? (check all that apply)

- ▢ Me or someone else I live with (1)
- ▢ A friend, coworker, neighbor or family member (2)
- ▢ A professional contractor (3)
- ▢ Other (please specify) (4) ____

Display This Question:

If Has the damage been repaired? = No

Q47 What have you not repaired the damage? (check all that apply)

- ▢ Too expensive to do repairs (1)
- ▢ It takes too much time to do repairs (2)
- ▢ I or someone else I live with do not have the expertise to do repairs (3)
- ▢ Repairs will happen in the future (4)
- ▢ Other (please specify) (5) ____

Page Break

Display This Question:

If Did your home experience any interior damage from the following due to Hurricane Irma and its aft... = Wind

Q49 Consider the **wind damage** to your home. In your own words, please describe the following:

◯ Where did the wind damage occur? (1)

____

◯ What was the extent of the damage to your home? (2)

____

◯ What was the extent of the damage to your belongings? (3)

____

◯ Why do you think the wind damage occurred? (4)

____

Display This Question:

If Did your home experience any interior damage from the following due to Hurricane Irma and its aft... = Wind

Q50 Has the damage been repaired?

◯ Yes (1)

◯ No (2)

Display This Question:

If Has the damage been repaired? = Yes

*

Q51 Approximately, how much did it cost to repair ($USD)?

____

Display This Question:

If Has the damage been repaired? = Yes

Q52 Who did the repairs? (check all that apply)

- ☐ Me or someone else I live with (1)
- ☐ A friend, coworker, neighbor or family member (2)
- ☐ A professional contractor (3)
- ☐ Other (please specify) (4) ____

Display This Question:

If Has the damage been repaired? = No

Q53 What have you not repaired the damage? (check all that apply)

- ☐ Too expensive to do repairs (1)
- ☐ It takes too much time to do repairs (2)
- ☐ I or someone else I live with do not have the expertise to do repairs (3)
- ☐ Repairs will happen in the future (4)
- ☐ Other (please specify) (5) ____

Page Break

Display This Question:

If Did your home experience any interior damage from the following due to Hurricane Irma and its aft... = Other (please specify)

Q54 Consider the **other damage** to your home. In your own words, please describe the following:

◯ Where did the other damage occur? (1) ____

◯ What was the extent of the damage to your home? (2) ____

◯ What was the extent of the damage to your belongings? (3) ____

◯ Why do you think the other damage occurred? (4) ____

Display This Question:

If Did your home experience any interior damage from the following due to Hurricane Irma and its aft... = Other (please specify)

Q55 Has the damage been repaired?

◯ Yes (1)

◯ No (2)

Display This Question:

If Has the damage been repaired? = Yes

*

Q56 Approximately, how much did it cost to repair ($USD)?

____

Display This Question:
If Has the damage been repaired? = Yes

Q57 Who did the repairs? (check all that apply)

- ▢ Me or someone else I live with (1)
- ▢ A friend, coworker, neighbor or family member (2)
- ▢ A professional contractor (3)
- ▢ Other (please specify) (4) ____

Display This Question:
If Has the damage been repaired? = No

Q58 What have you not repaired the damage? (check all that apply)

- ▢ Too expensive to do repairs (1)
- ▢ It takes too much time to do repairs (2)
- ▢ I or someone else I live with do not have the expertise to do repairs (3)
- ▢ Repairs will happen in the future (4)
- ▢ Other (please specify) (5) ____

End of Block: INTERIOR HOME DAMAGE

Start of Block: STRUCTURAL RETROFITS

Q59 Have you made major structural retrofits to your home (e.g., installed hurricane shutters, installed wind-resistant shingles, re-nailed roof decking, installed wind-rated garage door, installed flood vents)?

- ○ Yes (1)
- ○ No (2)

Display This Question:

If Have you made major structural retrofits to your home (e.g., installed hurricane shutters, instal... = Yes

Q61 Please list the improvements you've made since owning the home (or moving in), and indicate whether the work was done through local permitting and inspection.

	B	Was the work done through local permitting and inspection?	
	Improvement (1)	Yes (1)	No (2)
1 (1)		○	○
2 (2)		○	○
3 (3)		○	○
4 (4)		○	○
5 (5)		○	○

Page Break

Q64 How much do you agree or disagree with the following statements?

	Agree or Disagree					In one or two sentences, please explain your answer.
	1=completely disagree (1)	2=disagree (2)	3=neither agree nor disagree (3)	4=agree (4)	5=completely agree (5)	In one or two sentences, please explain your answer. (1)
My home held up very well in the face of Hurricane Irma and its aftermath (1)	o	o	o	o	o	
I would consider doing structural retrofits to protect against future hurricanes (2)	o	o	o	o	o	

End of Block: STRUCTURAL RETROFITS

Start of Block: DEMOGRAPHICS

Q65 In what year were you born?

▼ 1918 (1) ... 2002 (85)

Q66 What is your gender?

- ○ Male (1)
- ○ Female (2)
- ○ Other (3)
- ○ Prefer not to answer (4)

Q67 What is your annual household income?

- ○ Less than $10,000 (1)
- ○ $10,000 - $19,999 (2)
- ○ $20,000 - $29,999 (3)
- ○ $30,000 - $39,999 (4)
- ○ $40,000 - $49,999 (5)
- ○ $50,000 - $59,999 (6)
- ○ $60,000 - $69,999 (7)
- ○ $70,000 - $79,999 (8)
- ○ $80,000 - $89,999 (9)
- ○ $90,000 - $99,999 (10)
- ○ $100,000 - $149,999 (11)
- ○ More than $150,000 (12)
- ○ Prefer not to answer (13)

Q69 In what year did you move into your home?

▼ 1918 (1) ... 2018 (101)

Q70 When was your home built?

▼ 1918 (1) ... 2018 (101)

Q71 Do you own or rent your home?

- ○ Own (1)
- ○ Rent (2)
- ○ Other (please specify) (3) ____
- ○ Prefer not to answer (4)

Q72 How many adults over the age of 65 live in your home?

▼ 1 (1) ... 20 (20)

Q73 How many children under the age of 5 live in your home?

▼ 1 (1) ... 20 (20)

Q74 Have you ever been diagnosed with depression?

- ○ Yes (1)
- ○ No (2)
- ○ Prefer not to answer (3)

Q75 Have you ever been diagnosed with anxiety?

- ○ Yes (1)
- ○ No (2)
- ○ Prefer not to answer (3)

Q76 What is your highest level of education?

- ○ Less than high school (1)
- ○ High school graduate (2)
- ○ Some college (3)
- ○ 2 year degree (4)
- ○ 4 year degree (5)
- ○ Professional degree (6)
- ○ Doctorate (7)
- ○ Prefer not to answer (8)

Q77 What is your current employment status?

- ○ Employed full time (1)
- ○ Employed part time (2)
- ○ Unemployed looking for work (3)
- ○ Unemployed not looking for work (4)
- ○ Retired (5)
- ○ Student (6)
- ○ Disabled (7)
- ○ Prefer not to answer (8)

Q78 Comments?

____

End of Block: DEMOGRAPHICS

Appendix E. Hurricane Damage to Homes of Interview Respondents

Table 6. Comparison of damage assessment data and relevant homeowner interview responses.

Address	Year Built	Re-Roofed	Water Height Above Ground (ft)	Gust Wind Speed (mph)	Damage Rating	Roof Cover	Roof Sheathing	Roof Structure	Wall Cladding	Wall Sheathing	Wall Structure	Windows	Doors	Damage Description	Leak Damage Cost	Water Damage Cost	Wind Damage Cost	Other Damage Cost
600 Vilabella Ave, Coral Gables	1953		0	81	1	0%	0%	0%	0%	0%	0%	0%	0%					$ 1,600.00
489 Blackbeard, Little Torch	1988	2016	4	117	2	0%	0%	0%	40%	10%	0%	0%	0%	Wind-driven rain through walls and windows	$ 125,000.00		$ 80,000.00	
27439 Jamaica Ln, Ramrod Key	1984		6	117	2	30%	0%	0%	30%	0%	0%	0%	0%	Minor wind damage to interior and attic			$ 20,000.00	
30368 Killdeer Ln, Big Pine Key	1979	2012	2	116	1	0%	0%	0%	10%	0%	0%	0%	0%	Leaks in bedroom				
28211 Dorothy Avenue, Little Torch Key	1956		1	117	3	80%	50%	0%	0%	0%	0%	0%	0%	Rain intrusion through patio doors; minor roof leaks caused by wind-borne debris impacts; destroyed screened-in porch and carport				
800 4th St, Big Coppitt Key	2002		0	110	1	10%	0%	0%	10%	0%	0%	0%	0%	Roof, siding, fence, hot tub, deck				
521 W Goodland Drive,	2008		3	110	1	10%	0%	0%	10%	0%	0%	0%	0%					
576 Nassau Road, Marco Island	1993		0	106	0	0%	0%	0%	0%	0%	0%	0%	0%					
1265 Fruitland Avenue, Marco Island	1967		1	106	0	0%	0%	0%	0%	0%	0%	0%	0%					
590 80th St, Marathon	1994	2016	3	123	1	0%	0%	0%	0%	0%	0%	0%	0%	Minimal wind damage to vinyl siding				
32 Palm Dr, Key West	2007		1	112	2	30%	0%	0%	0%	0%	0%	0%	0%	Leaks through asphalt-shingle roof into upstairs living area;	$ 40,000.00		$ 20,000.00	
787 W Shore Dr, Summerland Key	1984		2	114	1	40%	0%	0%	0%	0%	0%	0%	0%	Wind damage to laundry room; portions of roof removed			$ 16,000.00	
425 Mango Ave, Goodland	1983		0	110	1	10%	0%	0%	0%	0%	0%	0%	20%			$ 3,000.00		
23026 Tarpon Lane, Cudjoe Key	1988	2003	3	114	0	0%	0%	0%	0%	0%	0%	0%	0%	Wind-driven rain through wall siding; roof leaks into hallway, ceilings and one bedroom. Downstairs storage area destroyed from storm surge				
42 Bay Dr, Key West	1987	1998	2	112	2	40%	0%	0%	0%	0%	0%	0%	0%	Roof damage caused interior damage from rain	$ 55,000.00		$ 55,000.00	
31133 Avenue E, Big Pine Key	2005		4	117	2	20%	0%	0%	40%	0%	0%	0%	0%	All shingles ripped off; interior water damage to sheetrock on one wall				
31279 Avenue G, Big Pine Key	2000		6	117	2	30%	0%	0%	10%	0%	0%	0%	0%	Soffit damage allowed wind-driven rain to damage interior; surge damage to underside of house	$ 7,000.00			$ 36.00
1290 Orange Ct, Marco Island	2016		0	108	0	0%	0%	0%	0%	0%	0%	0%	0%	Flying tiles damaged roof; ensuing leaks damaged 2nd floor	$ 500,000.00	$140,000.00		
62900 Overseas Hwy, Conch Key	0		1	116	3	40%	20%	20%	30%	30%	30%	0%	0%	Extensive damage; surge damage to lower level bedroom, bathroom, laundry room and more; siding blown loose; roof damage	$ 140,000.00		$140,000.00	$140,000.00
980 Sundrop Ct, Marco Island	1975		0	108	2	10%	0%	0%	0%	0%	0%	10%	20%					
743 Trinidad Lane, Little Torch Key	1958	1999	3	117	4	100%	100%	100%	80%	80%	80%	0%	0%	Wind-driven rain through eaves; wind damage from neighborhood	$ 125,000.00	$300,000.00		
No Data			0											Interior damage throughout due to wind-driven rain through eaves	$ 250,000.00	$ 75,000.00	$300,000.00	
23054 Wahoo Ln, Cudjoe Key	1977		2	114	1	0%	0%	0%	0%	0%	0%	0%	0%	Upstairs and downstairs water damage; 2 ft of water in living area	$ 2,000.00		$ 80,000.00	
821 Magnolia Ct, Marco Island	2015		1	108	0	0%	0%	0%	0%	0%	0%	0%	0%	Roof leaks into guest bedroom from damaged drain pipe on roof	$ 2,000.00			
1124 82nd Street, Marathon	1973		3	123	1	0%	0%	0%	10%	0%	0%	10%	0%	4-6" water in kitchen; 5.5 ft of water in adjacent storage room		$ 20,000.00		
17174 Buttonwood Dr W, Sugarloaf Key	1988	2009	2	112	0	0%	0%	0%	0%	0%	0%	0%	0%	Wind-driven rain caused damage in bedroom; surge damage to lower level	$ 20,000.00		$ 20,000.00	
320 Calusa Dr, Chokoloskee	1990		0	113	0	0%	0%	0%	0%	0%	0%	0%	0%	Wind-driven rain through soffits into bedroom and bathroom				
57642 Overseas Hwy, Grassy	1958		3	118	3	80%	10%	0%	0%	0%	0%	0%	0%	Roof damage; widespread water damage				
406 Buckner Avenue North, Everglade	1967		5	110	1	10%	0%	0%	0%	0%	0%	0%	0%	Wind damage to roof, boathouse and garage; flood debris broke water and sewer lines				
28 Beach Dr, Key West	1988	1999	2	112	1	10%	0%	0%	0%	0%	0%	0%	0%	Electrical pipe oscillated in the wind causing a hole in the roof				
253 Sunset Dr, Islamorada	1963	2005	1	109	1	0%	0%	0%	0%	0%	0%	0%	0%					
19570 Indian Mound Dr., Sugarloaf Key	1999		1	111	1	20%	0%	0%	0%	0%	0%	0%	0%	Leaks through roof; tree-induced damage to roof; bedroom window damaged	$ 12,000.00			