Hazus Hurricane Wind for Puerto Rico and the U.S. Virgin Islands

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Acronyms and Abbreviations

Acronym/ Abbreviation	Definition
3DEP	3D Elevation Program
BUR	Built-up Roof
CDMS	Comprehensive Data Management System
CMU	Concrete Block Masonry Unit
EF	Essential Facility
FEA	Finite Element Analyses
FEMA	Federal Emergency Management Agency
FIA	Forest Inventory Analysis
GBS	General Building Stock
GIS	Geographic Information Systems
GSHHG	Global Self-Consistent, Hierarchical, High-resolution Geography Database
HIFLD	Homeland Infrastructure Foundation-Level Data
HSOAC	Homeland Security Operational Analysis Center
HOT	Humanitarian OpenStreetMap Team
HUD	United States Department of Housing and Urban Development
IA	Individual Assistance
Lidar	Light Detection and Ranging
LULC	Land Use/Land Cover
ML	Machine Learning
MAT	Mitigation Assessment Team
MHCSS	Manufactured Home Construction and Safety Standards
MRLC	Multi-Resolution Land Characteristics
NCEI	NOAA National Centers for Environmental Information
NCLD	National Land Cover Database
NOAA	National Oceanic and Atmospheric Administration
OSB	Oriented Strand Board
OSM	OpenStreetMap
OWSJ	Open-Web Steel Joist
PDA	Preliminary Damage Assessment
PR	Puerto Rico
RPFVL	Real Property FEMA-Verified Loss
SBA	Small Business Administration
SBT	Specific Building Type
SDE	Substantial Damage Estimations
SFHA	Special Flood Hazard Area
SPM	Single-ply Membrane

Acronym/ Abbreviation	Definition
WBC	Wind Building Characteristic
UDF	User-Defined Facilities
USACE	United States Army Corps of Engineers
USFS	United States Forest Service
USGS	United States Geological Survey
USVI	U.S. Virgin Islands
VIERS	Virgin Islands Environmental Resource Station

Section 1. Executive Summary

This document presents the development and implementation of the Hazus Hurricane Wind Model capability for Puerto Rico (PR) and the U.S. Virgin Islands (USVI).

As a model designed for estimating physical damage and economic loss due to earthquake, flood, wind, and tsunami, Hazus provides value across all phases of disaster management. Hazus was initially deployed within FEMA for mitigation planning efforts, with later expansion to state and local government, regional planning authorities, universities, and the private sector, for expanded use in response, recovery, and preparedness.

The Hazus Hurricane Wind Model was originally developed for the mainland United States and Hawaii, incorporating specific topographic and construction characteristics to approximate expected damages from hurricane winds, and later, storm surge. In the immediate aftermath of Hurricanes Irma and Maria in 2017, when Hazus was utilized to assist in response and recovery activities, the existing Wind Model was found to lack the necessary datasets for use in the Caribbean island territories. To remedy this, wind speed profiles, building characteristics, tree cover and debris parameters, and their associated damage functions from the mainland U.S. were updated and incorporated into the Hazus Hurricane Wind Model for the specific conditions found in the Caribbean territories.

Adaptations to Hazus as described in this document fall into four major categories:

- Development of a comprehensive structure inventory for both PR and the USVI, including counts of each building type by location, age, construction style, and distribution
- Identification of unique, territory-specific building characteristics and construction practices and their performance in hurricane-force winds
- Classification of environmental parameters such as surface roughness, topography and terrain, and tree coverage, and their impacts on wind speed profiles and potential for debris generation
- Use of these data development efforts to inform the development of new, territory-specific damage and loss functions

This model expansion effort provided unique opportunities to enhance the Hazus Hurricane Wind Model, learn about damage and loss modeling in a new environment, and move beyond wind mitigation practices driven by assumptions formed by mainland U.S. conditions. Noteworthy examples include the exploration of machine learning techniques for rapid post-disaster damage assessment, the addition of jalousie windows and elastomeric roofing to wind building characteristics, and the need for new tree and landcover classifications specific to the Caribbean territories.

Results generated by the updated Hazus Hurricane Wind Model were validated against post-Irma and post-Maria damage and loss reports, with excellent alignment. Hazus was found to overestimate damage and subsequent loss in some comparisons, however, this is partially attributable to variation in observation and calculation methodology in reporting actual losses. Overall, the new Hazus Hurricane Wind Model for PR and the USVI will provide robust, reliable, and tailored support to all areas of hurricane response in the territories for years to come.

Section 2. Adapting the Hazus Model for Caribbean Territories

2.1 A Need for Hazus following Hurricanes Irma and Maria

Prior to Hazus 5.0, Hazus analysis in the Caribbean territories faced limitations due to the absence of damage functions and built environment attributes specific to local construction practices in Puerto Rico and the U.S. Virgin Islands. The 2017 hurricane season provided significant opportunities to collect the scientific and engineering data required to fully develop the damage curves and building information needed to enhance Hazus modeling capabilities for the Caribbean. This data collection and development process is the focus of this report.

During the Atlantic hurricane season of 2017, two major hurricanes impacted the Caribbean territories: Hurricane Irma and Hurricane Maria. In early September, Irma fluctuated between a Category 4 and 5 storm as it passed north of Puerto Rico and the U.S. Virgin Islands. Only two weeks later, on September 20, Hurricane Maria passed to the north of the U.S. Virgin Islands as a Category 5 storm, then made landfall near Yabucoa, Puerto Rico as a strong Category 4 storm, compounding the damage wrought by Irma. The impacts from Maria and Irma were devastating in both territories. Storm characteristics pertinent to Hazus model development are discussed in Section 7.1. Additional details on the impacts, and FEMA's response and recovery effort, are available in the Mitigation Assessment Team (MAT) reports for both islands (FEMA, 2018a and FEMA, 2018b).

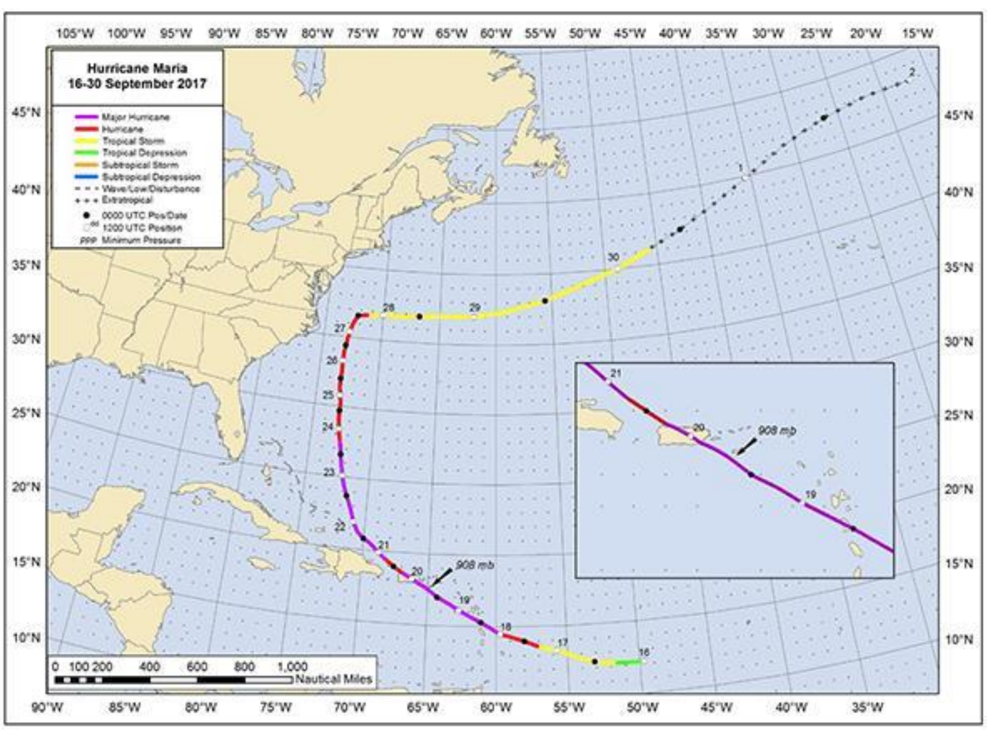

Figure 2-1: Hurricane Maria Measured Storm Track (NOAA, 2017)

The need for Hazus Hurricane in the Caribbean Territories became evident in the immediate aftermath of these storms as various federal, territorial, and local actors attempted to identify and provide response and recovery efforts to the hardest-hit locations. As part of standard post-disaster procedures (44CFR), impacted local jurisdictions frequently conduct Substantial Damage Estimations (SDE) for structures located within Special Flood Hazard Areas (SFHAs) to quickly identify structures with more than 50% physical damage, which are considered substantially damaged. If a structure identified by the SDE as “substantially damaged” will be rebuilt, the new structure must be brought into compliance with local floodplain regulations and adhere to updated building codes to prevent substantial damage in future events. In ideal circumstances, the SDE effort is conducted by the local organization with land-use jurisdiction over the floodplain areas with damage; however, these organizations are typically overwhelmed following a disaster and FEMA assists in conducting the SDE. Often there is a need to quickly identify areas where SDE teams should focus their efforts and a site-specific analysis using Hazus Hurricane is used to provide this information. However, without hurricane building inventory or hazard analysis for the Caribbean Territories, FEMA SDE teams were not able to use Hazus immediately following Irma or Maria. The enhancements to Hazus modeling capability outlined in this report can help to support future SDE missions, as well as mitigation planning, response planning, and a variety of other risk reduction and decision-making efforts.

2.2 Leveraging Damage Inspections and Local Caribbean Conditions Data

Hurricane analyses within Hazus currently use a combination of Hazus wind and flood models, to address the damaging aspects of both hurricane winds and storm surge. Capability was already available in Hazus, including flood, earthquake, and tsunami analysis for Puerto Rico and the U.S. Virgin Islands. The development of the building inventory and damage functions unique to the Caribbean for Puerto Rico and the U.S. Virgin Islands enables analysis of all four hazards for both territories beginning with Hazus 5.0. The effort outlined in this report focused primarily on efforts to develop the wind modeling capability for Puerto Rico and the U.S. Virgin Islands, as well as the building inventory data collection necessary to enable additional hazard analysis.

The wind component of Hazus Hurricane uses a set of mathematical functions to estimate damage to structures, with each structure type having its own curve that represents structural damage as a function of wind speed. The curves are developed using a combination of building characteristics of the structures themselves, such as construction materials or the presence of damage mitigation features, or the surrounding environment that might contribute to faster or slower wind speeds.

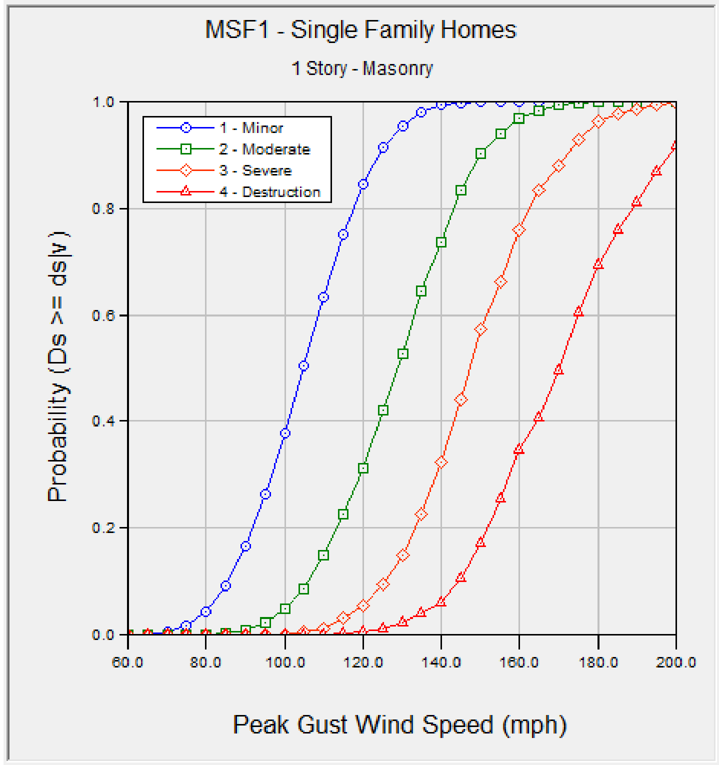

Figure 2-2: Sample Hazus Hurricane Damage Curve

In the Hazus Hurricane Wind Model available for the continental United States and Hawaii, the building characteristics and environmental considerations that form the basis of the damage curves are based on construction styles and environments common to the gulf coast, east coast, Hawaii, and southeast United States, reflecting both the geographic risk of landfalling hurricanes and the availability of wind climatology and damage curves. Details of how these damage curves and building characteristic mapping schemes were created can be found in the *Hazus Hurricane Model Technical Manual* (FEMA, 2021).

None of these preexisting model conditions ideally captured the local conditions unique to Puerto Rico and the U.S. Virgin Islands. The key differences for creating a separate wind model for the Caribbean territories are described below.

2.2.1 Topographic Differences

The coastal areas of the mainland United States where hurricanes make landfall has mostly flat terrain, with some low inland hills, which presents a widespread, relatively uniform area for wind to move across during landfall. The size of the landmass means that, regardless of the size of the storm or where it makes landfall, a hurricane hitting the mainland United States is likely to be weakened across its full diameter when the storm moves from open water to over the United States landmass. The Caribbean territories, however, are smaller islands surrounded by open ocean and with inland mountains, creating smaller, more localized weakening impacts within the full circulation of the storm.

Because of this mainland terrain, modeled wind speeds developed for the mainland United States represent maximum sustained wind speeds and 3-second peak gusts at 10 m above ground in flat, open terrain at each Census tract centroid. In more mountainous areas, such as in Hawaii or the Caribbean Territories, surface-level winds can be accelerated across ridges, channeled along valleys, or blocked across valleys. Vickery et al. (2019) developed an empirical model for such speed-ups and slow-downs as a function of the local topography and wind direction. Mudd et al. (2018) modeled the peak 3-second gusts for Hurricane Maria in Puerto Rico using the methodology developed by Vickery (2019). The resulting winds were then averaged over known building locations within each Census tract for that event. These modified peak 3-second gusts are available in Hazus 5.0 when selecting the Historic storm option for Maria. At this time, no other events or locations in the territories incorporate topographically induced speed changes in their modeled wind speeds. The methodology for this approach is discussed in Section 5.4, with limitations and validation of this approach discussed further in Section 7.6.

Beyond topographic changes in wind speed, surface roughness must also be considered for local speed-up or slow-down of sustained winds. A rough surface, such as a densely populated area with variation in the height of structures, will see localized increases in wind speed as air is forced between buildings or around corners. To determine which surface roughness(es) should be used in the Caribbean damage curves, the post-Maria SDE structure data were grouped by land-use class. A majority of the SDE data points, 84.6%, were in the impervious surface land-use class, and 14.5% were located in the grassland land class. Since no other land-use class accounted for more than 0.3% of the data, all other classes were omitted from the comparisons. Additionally, there was no practical difference between the mean surface roughness for the impervious surface and grassland locations. The mean Hazus roughness values were 0.378 and 0.345 meters, respectively, and the standard deviations were 0.188 and 0.194 meters, respectively. Therefore, the two classes were combined for subsequent analysis.

2.2.2 Differences in the Built Environment

Most of the wind damage curves in Hazus were developed for the coastal areas of the mainland United States, and Hawaii, where construction practices are different from the Caribbean territories.

2.2.2.1 RESIDENTIAL CONSTRUCTION

Just as terrain and topography must be treated differently in Hazus damage curves for the mainland United States and its Caribbean territories, there are also significant differences in building construction styles. Residential occupancies are typically where construction differences are most pronounced, and residential buildings comprise a majority of the building inventory within Hazus. At a high level, the residential buildings in the southeast United States – where the existing Hazus damage curves were developed – are wood frame with shingle roofing. In the Caribbean islands, residential construction is most typically masonry or concrete with metal roofing, requiring new or updated damage curves in Hazus.

For construction with concrete roofs, the closest existing combination of Hazus building parameters are masonry houses with hip roofs, strong roof-to-wall connection (hurricane straps), strong roof deck attachment (8d nails at 6” spacing on the edges and in the field), high wind-rated shingles, and secondary water resistance. For the metal roof construction, the closest existing combination of Hazus building parameters are wood-frame houses with gable roofs, weak roof-to-wall connection (toe-nailed), weak roof deck attachment (6d nails at 6” spacing on the edges and 12” spacing in the field), ordinary shingles, and no secondary water resistance.

Estimated damages using the damage curves currently in Hazus were compared with damage percentages collected from the SDE surveys. For the multi-story cases, the existing Hazus curves were in reasonably good agreement with the SDE data at the uppermost wind speeds (e.g., 120-125 mph), where the SDE data were more likely to be representative of the true population mean. For the one-story cases, however, the SDE and Hazus curves only intersect when the SDE data reach a local minimum at

125 mph. Thus, the existing Hazus curves appear to understate the mean SDE damage for the one-story cases.

It is notable that the number of stories does not appear to be a significant differentiator in the SDE results. This is an unexpected result, as the number of stories has long been known to be a significant risk differentiator for single-family homes (HUD 1993; ARA 2008).

2.2.2.2 INFORMAL CONSTRUCTION AND BUILDING CODES

Differences in construction type impact the damage curves, but also impact individual building characteristics such as roof shape, roof material, window styles, or the presence of wind mitigation measures like hurricane shutters or roof clips. Current users of Hazus Hurricane will be familiar with the mapping schemes available in the models, where users can identify the presence of individual building characteristics and construction types by percentage over a Census tract, county, or multi-county region.

It is difficult to estimate the exact percentages of buildings of different types in Puerto Rico because of longstanding patterns of informal construction. Informal construction is that which was completed outside of the normal design and permitting process and is likely not up to the codes enforced on the island. In an article by the American Bar Association (Garcia, 2020), a 2018 study of the Puerto Rico Builders Association is cited that estimates between 585,000 and 715,000 homes and commercial buildings in Puerto Rico are informal, unpermitted construction. These values suggest 45 to 55% of structures fall in that category. A February 2018 Miami Herald article (Viglucci, 2018) indicates that while current building codes in Puerto Rico are robust and appropriate for the hurricane dangers faced, at least 65% of legally built homes were constructed before 1980 when weaker building codes were in place. Similar challenges can also be found in the U.S. Virgin Islands.

Section 3. Data Development

3.1 Input data/data sources

Creating the Hazus Hurricane Wind Model for Puerto Rico and the U.S. Virgin Islands required the use, manipulation, and combination of a variety of datasets, including spatial imagery, municipal data, and FEMA publications. This section describes the data sources used in developing the necessary components of the Hazus Hurricane Wind Model for Puerto Rico and the U.S. Virgin Islands grouped into the following categories:

- Damage Curves
- Building Footprints
- Machine Learning
- Mapping Schemes
- Surface Roughness and Wind Field Calculations
- Tree Parameters and Debris

The data sources used for this effort were evaluated and selected based on criteria for completeness, relationship to existing data, and temporal relevancy. While all efforts were made to leverage the best available data, some datasets were selected primarily for completeness and accuracy of the data, others in context of what data was already acquired (to prevent duplication), and others by time-based necessities. For example, building footprints for the territories were developed from pre-Hurricane Irma and pre-Hurricane Maria Light Detection and Ranging (Lidar).

When collecting building attributes, it was important to make sure the datasets used to identify building characteristics in Hazus corresponded to the year of the Lidar building footprint. This was necessary to confirm that the building attributes being collected for Hazus matched the buildings they were collected from and were not sampled during construction or after a building sustained damage. This allowed FEMA to generate comprehensive Hazus building attributes that are as reliable and accurate as possible by using contemporary data. This internal validity allowed for greater comparison of Hazus model run outputs and adds to the validity of the updated Hazus products for Puerto Rico and the U.S. Virgin Islands.

The sections below document the specific data inputs used in the creation of the Hazus Hurricane Wind Model for the Caribbean territories and note that, in some cases, input data could have been used for more than one model component.

3.1.1 Damage Curves

There are several types of single-family construction commonly found in Puerto Rico or the U.S. Virgin Islands that are not covered by previous versions of the Hazus Hurricane Wind Model. To fill this gap, new fragility and vulnerability curves were developed for single-family construction with corrugated metal, standing seam metal, concrete, and elastomeric roof coverings. The development of the new fragility and vulnerability curves followed the same approach used to develop the original set of single-family houses with shingle roof cover, which is described in detail in the *Hazus Hurricane Model Technical Manual* (FEMA, 2021).

There were no new third-party data sets used in the development of the new damage curves. Modeling assumptions made regarding the model building configurations and component resistances are documented in Section 6.

3.1.2 Building Footprints

The input data used to create the building footprint products are identified below. These datasets were used to create the specific building footprints, which are necessary components in both Hazus building inventory data and Hazus mapping schemes. The methodologies for using this data are described in Sections 3.3, 3.5, and 3.6.

Table 3-1: Input Data for Creating Building Footprints

Dataset Name	Dataset Date	Source (Provider)	Description of Dataset	Availability	Geography Coverage	Online Link
Esri World Imagery	3-Jun-2018 and 26-Nov-2017	Maxar	High-resolution satellite and aerial imagery	Public	U.S. Virgin Islands	https://www.arcgis.com/home/item.html?id=10df2279f9684e4a9f6a7f08febac2a9
NOAA Topographic Lidar: U.S. Virgin Islands	Nov-2013 through Dec-2013 (Collected)	National Oceanic and Atmospheric Administration (NOAA)	Topographic elevation point data	Public	U.S. Virgin Islands	https://www.fisheries.noaa.gov/inport/item/48219
HOTOSM United States Virgin Islands Buildings	10-Sep-18	OpenStreetMap	Crowd sourced Building footprints	Public	St. Croix, U.S. Virgin Islands	HOTOSM United States Virgin Islands Buildings (OpenStreetMap Export) - Humanitarian Data Exchange (humdata.org).
U.S. Virgin Islands On-line GIS Viewer	2019	U.S. Virgin Islands GIS Division	Property and parcel	Public	U.S. Virgin Islands	https://ltg.gov.vi/departments/gis-program/
NOAA Topographic Lidar: Puerto Rico	Jan-2016 through Mar-2017 (Collected)	National Oceanic and Atmospheric Administration (NOAA)	Topographic elevation point data	Public	Puerto Rico	https://www.fisheries.noaa.gov/inport/item/54852
Puerto Rico Imagery	2015	DigitalGlobe/ Maxar	imagery	License	Puerto Rico	https://www.maxar.com/

3.1.3 Machine Learning

The input data used in the machine learning models are identified below. These datasets were used to train machine learning algorithms to identify building characteristic information only within Puerto Rico for roof cover types and wood versus concrete building type, thus reducing manual effort to count or identify these from building imagery. The machine learning methodology is described in Section 3.2.

Table 3-2: Input Data for Machine Learning Models

Dataset Name	Dataset Date	Source (Provider)	Description of Dataset	Availability	Geography Coverage	Online Link
NOAA Topographic Lidar: Puerto Rico	Jan-2016 through Mar-2017 (Collected)	National Oceanic and Atmospheric Administration (NOAA)	Topographic elevation point data	Public	Puerto Rico	https://www.fisheries.noaa.gov/inport/item/54852
Puerto Rico Orthographic Imagery	Oct- 2009 through Jan-2010	National Oceanic and Atmospheric Administration (NOAA)	Orthophotos with a 0.3-meter (approximately 1 foot) ground sample distance. The orthographic imagery is a 4-band (red, green, blue, and infrared) GeoTIFF	Public	Puerto Rico	https://www.fisheries.noaa.gov/inport/item/49483
DR-4339-PR SDE HSFE06-18-J-0006 Methodology Documentation Federal Emergency Management Agency - Region 2	Jun-2018	STARR II JV (FEMA Contractor)	Substantial Damage Estimation data collection methods, observations, conclusions, and recommendations on the performance of buildings and other structures affected by wind forces, flooding, and other hazards for DR-4339-PR, Hurricane Maria on Puerto Rico.	Restricted	Puerto Rico	N/A

Dataset Name	Dataset Date	Source (Provider)	Description of Dataset	Availability	Geography Coverage	Online Link
Inception_v3	2018	Boosted regression tree model	Convolutional Neural Network (CNN) algorithm architecture with pre-trained weights from ImageNet. ImageNet is a database of millions of labeled images from diverse categories.	Public	N/A	https://github.com/dmlc/xgboost

3.1.4 Mapping Schemes

The input data used to create the territory-specific Hazus Hurricane Wind Model mapping schemes are identified below. The mapping schemes are distribution percentages of building characteristics for specific building types within the region and are based on building inventory data for each territory. The baseline percent distribution mapping schemes within Hazus were modified where possible and a further discussion is provided in Sections 3.5 and 3.6.

Table 3-3: Input Data for Creating Mapping Schemes

Dataset Name	Dataset Date	Source (Provider)	Description of Dataset	Availability	Geography Coverage	Online Link
St. John & St. Thomas, Imagery	2010 (St. Thomas) and 2012 (St. John)	United States Army Corps of Engineers (USACE)	4-Band 8 Bit Imagery	Public	St. John & St. Thomas, U.S. Virgin Islands	https://coast.noaa.gov/htdata/raster2/imagery/StJohnStThomasUSVI_2010_1422/
St. Croix, Imagery	2010 and 2011 St. Croix	United States Army Corps of Engineers (USACE)	4-Band 8 Bit Imagery	Public	St. Croix, U.S. Virgin Islands	https://chs.coast.noaa.gov/htdata/raster2/imagery/StCroixUSVI_2011_1423/
Oblique photos (after Irma and Maria)	2017	Civil Air Patrol	High-resolution photos (after Hurricanes Irma and Maria)	Public	U.S. Virgin Islands	https://gis.cap.gov/datasets/imageevents-aerial-oblique-photo-points/data?geometry=-65.112%2C18.266%2C-64.541%2C18.380
Google Street View	2016	Google	High-resolution photos from street point of view	Public	U.S. Virgin Islands	https://www.google.com/maps

Dataset Name	Dataset Date	Source (Provider)	Description of Dataset	Availability	Geography Coverage	Online Link
U.S. Virgin Islands Parcels Data	10-Dec-2018	U.S. Virgin Islands GIS Division Office	Property boundary extents	Restricted	U.S. Virgin Islands	N/A
U.S. Virgin Islands Tax Assessor Data	10-Dec-2018	U.S. Virgin Islands GIS Division Office	Property value information	Restricted	U.S. Virgin Islands	N/A
Building Footprints (Original)	2018 (Created date by using 2013 Lidar collection)	Compass JV (FEMA Contractor)	Residential and commercial building footprints	By Request	U.S. Virgin Islands	Contact fema-hazus-support@fema.dhs.gov
Mitigation Assessment Team Report Hurricanes Irma and Maria in the U.S. Virgin Islands	Sep-2018	FEMA P-2021	Evaluation of damage, observations, conclusions and recommendations on the performance of buildings and other structures affected by wind forces, flooding, and other hazards due to the hurricanes	Public	U.S. Virgin Islands	https://www.fema.gov/sites/default/files/2020-07/mat-report_hurricane-irma-maria_virgin-islands.pdf
Esri World Imagery	10-Mar-2020, 13-Aug-2019, 3-Jun-2018, 26-Nov-2017	Maxar	High-resolution satellite and aerial imagery	Public	U.S. Virgin Islands	https://www.arcgis.com/home/item.html?id=10df2279f9684e4a9f6a7f08febac2a9
Esri World Imagery	15-Jan-2019	Maxar	High-resolution satellite and aerial imagery	Public	Puerto Rico	https://services.arcgisonline.com/ArcGIS/rest/services/World_Imagery/MapServer
Google Street View	Apr-2016	Google	High-resolution photos from street point of view	Public	Puerto Rico	https://www.google.com/maps

Dataset Name	Dataset Date	Source (Provider)	Description of Dataset	Availability	Geography Coverage	Online Link
Mitigation Assessment Team Hurricanes Irma and Maria in Puerto Rico Islands	Oct-2009 through Jan-2010	FEMA P-2021	Evaluation of damage, observations, conclusions and recommendations on the performance of buildings and other structures affected by wind forces, flooding, and other hazards due to the hurricanes	Public	Puerto Rico	https://www.fema.gov/sites/default/files/2020-07/mat-report_hurricane-irma-maria-puerto-rico_2.pdf
NOAA Post Disaster Imagery	Sep-2017	NOAA	High-resolution photos (after Maria)	Public	Puerto Rico	https://storms.ngs.noaa.gov/storms/maria/index.html#20/17.98728/-66.66388
Google Earth	2020	Google	Imagery/3D views	Public	Puerto Rico	https://www.google.com/earth/
Building Footprints (Original)	2018 (Created date by using 2016-2017 Lidar collection)	Compass JV (FEMA Contractor)	Residential and commercial building footprints	By Request	Puerto Rico	Contact fema-hazus-support@fema.dhs.gov
Uniform Building Code Volume 2	1994	International Conference of Building Officials	Documentation supporting development of better building construction and greater safety of building laws	Public	N/A	https://digitalassets.lib.berkeley.edu/ubc/UBC_1994_v2.pdf
Protecting Manufactured Homes from Floods and Other Hazards	Nov-2009	FEMA P-85	Manufactured Home Construction and Safety Standards	Public	N/A	https://www.fema.gov/sites/default/files/2020-08/fema_p85.pdf
Protecting Manufactured Homes from Floods and Other Hazards	Nov-2009	FEMA P-85	Manufactured Home Construction and Safety Standards	Public	N/A	https://www.fema.gov/sites/default/files/2020-08/fema_p85.pdf

Note: Some Dataset Names are repeated as they have been used for multiple purposes.

3.1.5 Surface Roughness and Wind Field Calculations

The input data used to identify surface roughness and calculate wind fields for the territories are identified below. These datasets were used to determine appropriate values to assign for surface roughness (land cover) in the territories, as well as identify the best methods for calculating wind fields. In earlier studies, as noted previously, wind fields were calculated using the methodology proposed by Vickery et al. (2019). The methodologies for using this data are described in Section 5.1.

Table 3-4: Input Data for Surface Roughness and Wind Field Calculations

Dataset Name	Dataset Date	Source (Provider)	Description of Dataset	Availability	Geography Coverage	Online Link
Land Use Land Cover - PR	NLDC 2001	Multi-Resolution Land Characteristics (MRLC) Consortium	Land use categories and tree canopy percentage	Public	Puerto Rico	https://www.mrlc.gov/data?f%5B0%5D=category%3Aland%20cover
Land Use Land Cover - VI	Unknown	U.S. Virgin Islands	Land use categories	Restricted	U.S. Virgin Islands	N/A
Distance inland	Census 2010	Customer and Data Services (FEMA Contractor)	Census tract and Census block centroids	Restricted	U.S. Virgin Islands and Puerto Rico	N/A

3.1.6 Tree and Debris Parameters

The input data used to identify tree and related debris parameters for the territories are identified below. These parameters are used in Hazus to estimate hurricane-induced tree damage, which can lead to building damage, road blockages, power outages, and a need for debris removal in restoring critical infrastructure. The methodologies for using this data are described in Section 5.2.

Table 3-5: Input Data for Tree and Debris Parameters

Dataset Name	Dataset Date	Source (Provider)	Description of Dataset	Availability	Geography Coverage	Online Link
Forest Inventory and Analysis Database	2019 (U.S. Virgin Islands) 2020 (Puerto Rico)	United States Forest Service	Tree species, height distribution, and density (stems/acre)	Public	U.S. Virgin Islands and Puerto Rico	https://www.fia.fs.fed.us/tools-data/
TIGER/Line Shapefiles	Census 2020	U.S. Census	Street segments	Public	U.S. Virgin Islands and Puerto Rico	https://www.census.gov/geographies/mapping-files/time-series/geo/tiger-line-file.html

3.2 Puerto Rico Machine Learning for SDE Following Irma and Maria

In addition to the input data listed in the previous section, the machine learning (ML) processes described in this document were informed by previous ML efforts conducted in Puerto Rico immediately following Hurricane Irma and Hurricane Maria in 2017. This section provides a summary of the initial machine learning effort from 2017. For more information on those initial efforts, please contact the Hazus Help Desk for the “Near-term Recommendations for Modeling Puerto Rico Hurricane Wind Damage and Loss in Hazus” report.

Following a major disaster involving flooding, local entities with jurisdiction over FEMA-designated flood zones often conduct a SDE survey, as described in Section 2, to identify structures within a flood zone, if any, that sustained more than 50% damage. These structures are considered “substantially damaged” and may not be repaired or rebuilt without being brought up to code or incorporating flood mitigation measures. In large-scale coastal disasters, FEMA is often asked to assist local flood jurisdictions with conducting the SDE survey by providing both survey teams to the impacted areas, and modeling potential damage using Hazus Hurricane. In Hurricanes Irma and Maria, the damage was beyond what typical deployment teams can survey, and at that time, Hazus Hurricane was not available for Puerto Rico. Alternative methods for estimating substantial damage to structures were explored to address these gaps.

In the unique case of the 2017 hurricane season impacting territories where Hazus was not yet available, a ML method was proposed to identify structures for inclusion in the SDE survey. Using a combination of field reconnaissance and remote sensing data, FEMA and its partners were able to develop a boosted regression tree model using only a small sample of damaged structures from Puerto Rico. The patterns of likely substantial damage indicated by the regression model were applied to the remainder of the island, allowing FEMA to identify areas of substantial damage more quickly, and deploy resources accordingly. Additional applications of this ML method used in the development of the wind building inventory are mentioned in Section 3.5.

The success of the model developed in 2017 presented two additional opportunities to expand the machine learning approach for assessing damage:

1. Further training of the model using improved structure data from Puerto Rico to develop a more comprehensive building inventory, and
2. Use of the building inventory to train a new model to develop Hazus damage functions.

After validating both approaches, the first option – using the initial model to train additional ML applications – was viable for developing a comprehensive structure inventory for Puerto Rico. This inventory was modeled after the current Hazus inventories for the mainland United States, with added customizations for Caribbean construction materials, styles, and practices. Hazus-specific building attributes, such as wood versus concrete building types and roof cover types, aided in the collection of building characteristic information, as detailed in Section 3.5 of this document.

The second ML option – training a new model to develop Hazus damage functions – showed promising results based on real-world data, especially for the unique combination of an island wind environment interacting with Caribbean construction practices. ML performed especially well in modeling extreme conditions at either end of a typical Hazus curve; ultimately however, this approach will require additional input data to better train the model, and to develop more complete damage functions for use in Hazus. A physics-based methodology that more closely aligns with existing Hazus Wind damage functions was selected and is described in Section 6.

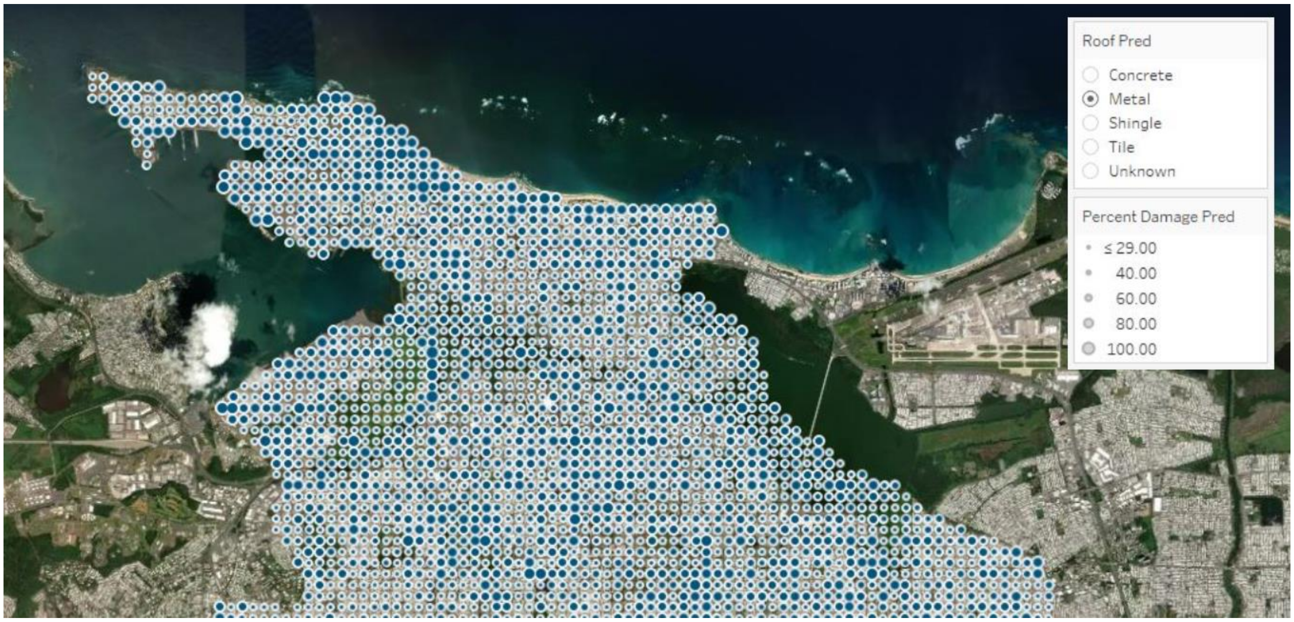

Figure 3-1: Machine Learning Output from Hurricane Maria Speedup Wind Damage

3.3 Description of Lidar-derived Building Footprints

3.3.1 Puerto Rico and the U.S. Virgin Islands Building Footprint Creation

Building footprints derived from Lidar are critical to support decision making in unique environments like Puerto Rico and the U.S. Virgin Islands. Knowing location and structure information can inform stakeholders of their risk before a natural disaster occurs. A dataset that depicts an accurate building footprint is critical in disaster preparedness, mitigation, response, and recovery operations. When disaster strikes, FEMA and their stakeholders require situational awareness supported by an inventory of life and property at risk. Structure data that is attributed with relevant information such as flood hazard and cadastral data is therefore necessary for FEMA to effectively respond to a disaster.

The building footprint dataset for Puerto Rico and the U.S. Virgin Islands was created from 2015 Lidar to be integrated with Hazus to support FEMA in risk-informed decision-making efforts by estimating potential losses during a given event. To create reliable inventory datasets for Puerto Rico and the U.S. Virgin Islands, a robust building footprint layer was created for each territory. Output data was set to a coordinate system of NAD 1983 NSRS2007 State Plane Puerto Rico Virgin Isles FIPS5200 Meters. The following software was used to create the building footprints:

- LP360
- LAS Tools
- TerraScan 018.008
- ArcGIS Pro 2.1.2
- ArcGIS Desktop 10.4.1
- Google Earth Pro
- Microsoft Excel

3.3.2 Puerto Rico and U.S. Virgin Islands Building Footprint Creation Process

For both Puerto Rico and the U.S. Virgin Islands, building footprints were created from Lidar. Lidar is a remote sensing method that uses light in the form of a pulsed laser to measure ranges to the Earth's surface, and the perfect medium for this effort given its accuracy and public availability through the United States Geological Survey (USGS) 3D Elevation Program (3DEP). These light pulses—combined with other data recorded by the airborne system—generate precise, three-dimensional information about the shape of the Earth and its surface characteristics (NOS, 2019). Light pulses return to the airborne system and are recorded to provide a dynamic dataset which can be interpreted by specialized software to provide a variety of insights beyond simple elevation data, including detailed land cover information. With spatial resolutions as fine as 10 cm, Lidar provides excellent data for the classification of detailed building footprints.

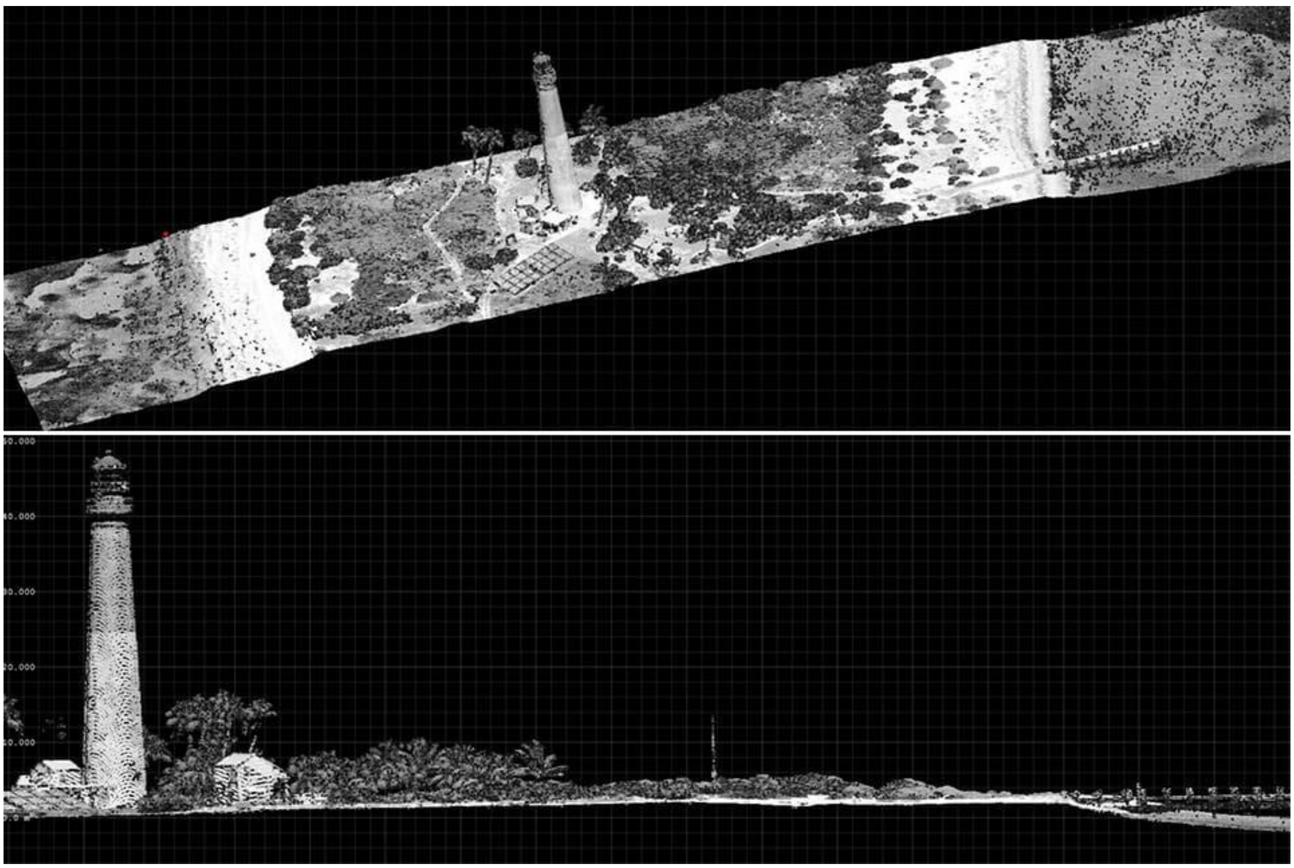

Figure 3-2: Example Lidar data of Loggerhead Key Lighthouse, Dry Tortugas, Florida

The utilized Lidar data were USGS compressed .LAZ files for Puerto Rico from 2015 and U.S. Virgin Islands from 2013, which were downloaded and extracted by employing LAS Tools software. This software decompressed the files to analyze the point cloud data, which would derive building footprints for the areas of interest.

Of the datasets from USGS, Puerto Rico data had been pre-classified, which helped building footprint extraction. The other datasets were not classified and required processing using TerraSolid's "TerraScan" and GeoCue's "LP360" software for classification and extraction.

The Lidar data covering Puerto Rico contained pre-existing ground classification so the Lidar software tools would be able to expedite the remainder of the processing to extract the buildings footprints for Puerto Rico. The U.S. Virgin Island raw Lidar was not classified and required additional processing to extract building footprints. TerraScan was used to scan through the classified and unclassified point cloud and identify regions of points that exhibit planarity akin to roof surfaces. The parameters associated with the planarity and the area/size were then manipulated to extract points as desired. Points defining planar surfaces were classified as Class 6 (building) and the outline of Class 6 building point clusters was later individually vectorized using LP360 into an Esri Shapefile.

Figure 3-3: Example Area of Point Cloud Classified Points

Figure 3-4: Example Area of Building Footprints

Once the extraction was complete, results were reviewed for accuracy with extant ground conditions, which revealed many of the building footprints aligned when viewed with the buildings as seen in ArcGIS Imagery Basemap, minus any temporal difference between the two datasets. A further examination was performed on the automated processes to identify the location of false positives (FP) that would require the need to be reviewed and discarded. Many of the FP point cloud building results were sections of canopy, rock outcrops, or large vessels that resemble planar surfaces that were separated from the ground classified points vertically. A small percentage of FP results represented structures under the canopy that cannot be seen using imagery alone.

The shapefile of the building footprints was then loaded into ArcGIS Pro and run through a process to intersect parcel data where applicable with medium and large building footprint polygons that were irregularly shaped. The process produced a more desirable footprint with "squared-off" footprint boundaries.

3.3.2.1 PUERTO RICO BUILDING FOOTPRINT DENSE CITY FOOTPRINT SPLITTING

Through quality control, it was identified that Puerto Rico had a number of dense urban areas causing many large building footprint polygons; in some cases, an entire square block. To correct this, additional efforts were used to split some of the footprint geometries using reference data, such as parcels, when available in dense cities such as San Juan, PR. In instances where townhome-style or rowhome-style buildings were captured as a single footprint, but were in fact individually owned properties, the parcel polygon was used as the dividing feature to split the single building footprint in multiple footprints. This function divided what appeared as a single structure into the individually owned properties needed for analysis. The following workflow was used to perform this task:

1. Reproject the parcel spatial layer to match the building footprint spatial file coordinate system.
2. Ensure all feature classes resided in an Esri file geodatabase.
3. Perform a Repair Geometry function to inspect each feature in the database for geometry problems.
4. Perform a Simplify function on the building footprints to straighten building edges.
    a. Tolerance of 0.333333 m was used

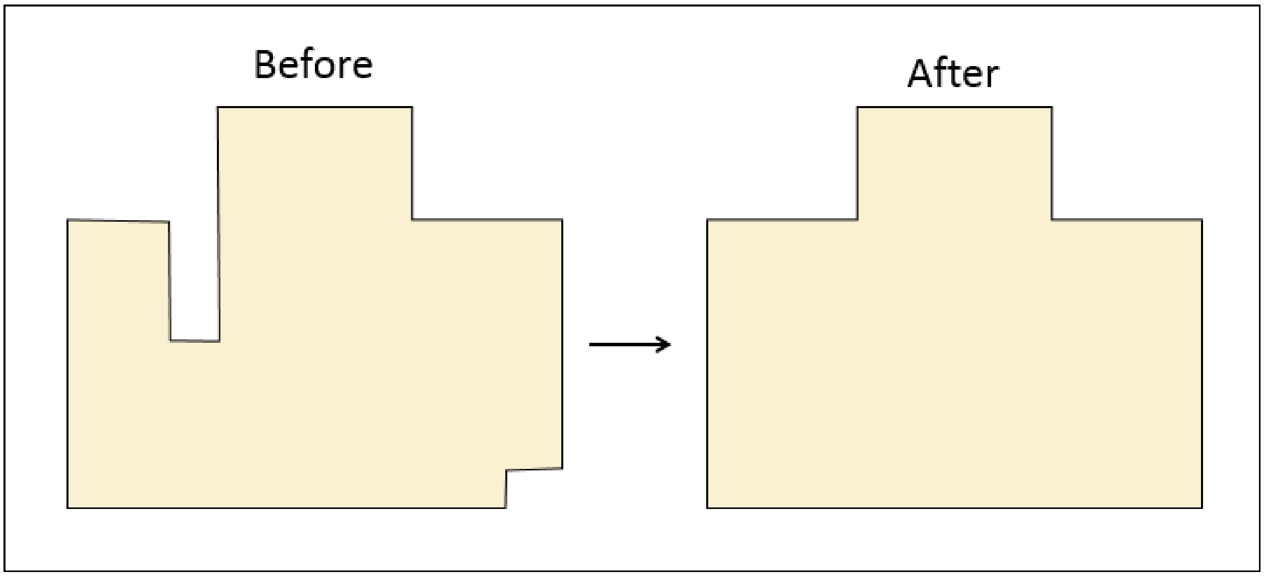

Figure 3-5: Simplify Building Footprint Process

5. Perform a Generalize function on parcel spatial layer.
    a. Tolerance of 0.333333 m was used

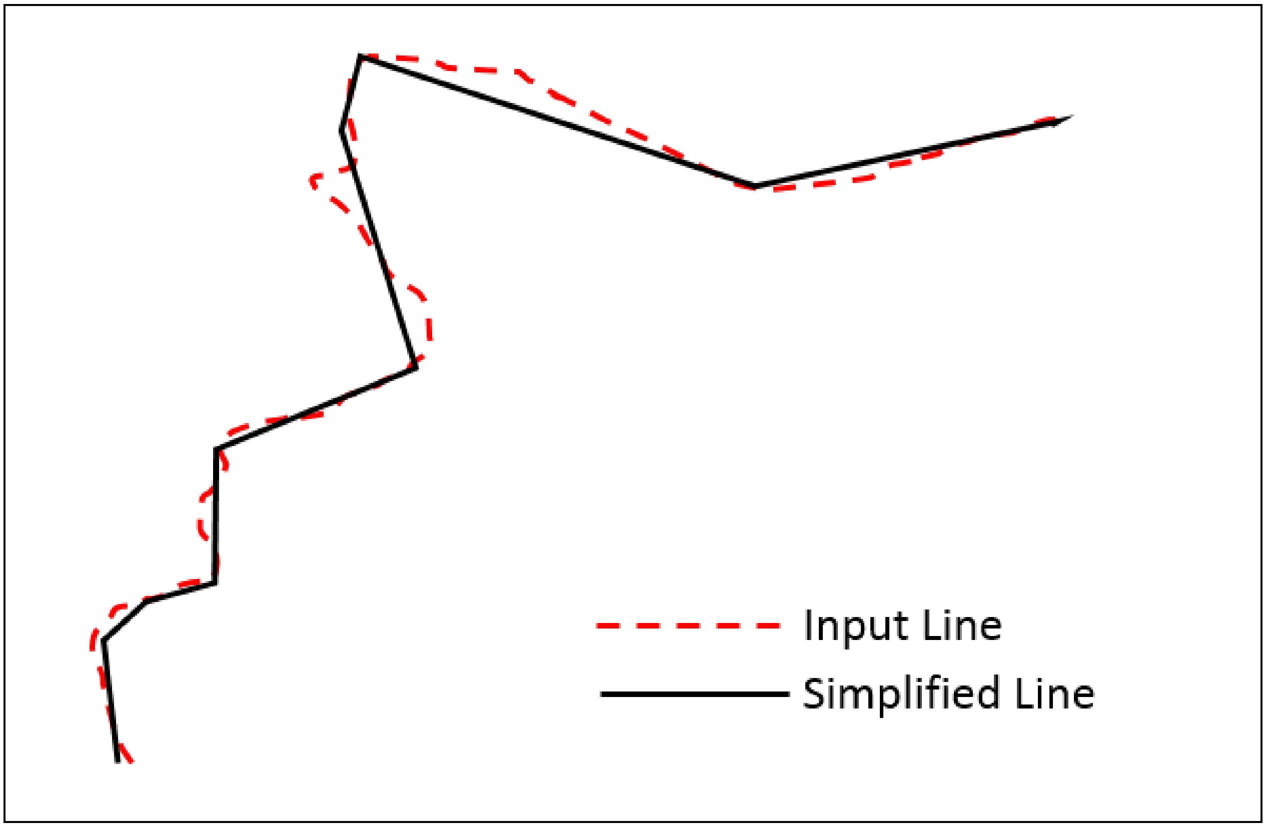

Figure 3-6: Generalize Parcels Process

6. Create a grid index feature for buildings.
    a. 12800 x 12800 m
7. Create a grid index feature for parcels.
    b. 25600 x 25600 m
8. Perform a Spatial Join using buildings/buildings grid as inputs.
    c. "HAVE_THEIR_CENTER_IN" was used as the match option
9. Perform a Spatial Join using parcels/parcels grid as inputs.
    d. "INTERSECT" was used as the match option
10. Use a definition query to select a block of buildings/overlapping parcels.
11. Perform an Identity function to split buildings at parcel boundaries for each grid.

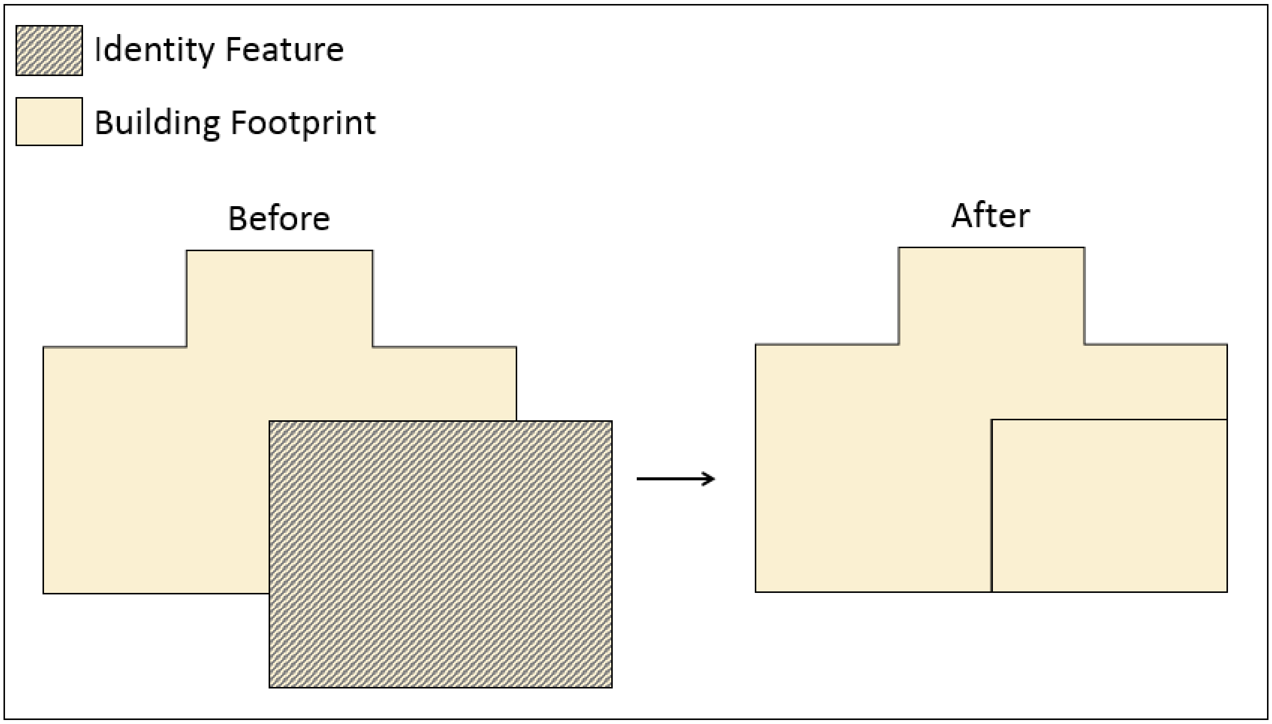

Figure 3-7: Identity Function

12. Perform an Aggregate function with the Step 11 output to remove slivers and small features. This will create a new spatial layer of building outputs.

3.3.2.2 AUTOMATED AND MANUAL QUALITY CONTROL (QC) PROCESS

The resulting structure database included a significant volume of "noise," including false positives, false negatives, and polygons (slivers) left over from splitting and other processing operations. Given the variable nature of structures, a large-scale manual quality control process was performed on the dataset to remove false positives, duplications, overlaps, and slivers.

Due to the size and spatial spread of the dataset, the buildings were divided into sub grids for the initial review to flag the false positives, then broken down to regions, municipalities, and then by density for review. In review, each building footprint dataset subset was visually compared against imagery. In instances where imagery from DigitalGlobe™ was obscured by heavy cloud cover, an ArcGIS add-in was used to mirror the extent of the ArcGIS window in Google Earth Pro, allowing users to view more useable imagery. Alternatively, the NOAA Data Viewer was used on occasion to download the area of interest.

The quality control review process consisted of three tasks:

1. ***Deleting false positives***: Reviewers deleted building footprints that were not the actual location of a corresponding building from DigitalGlobe™. Examples included tree canopies, cars, ships in harbors, livestock, etc.
2. ***Identifying false negatives***: Reviewers identified locations where imagery showed a building while the classification process did not identify a structure. For these locations, reviewers placed a point on the building's location according to imagery, building a separate point shapefile for missing footprints. Across the territory, 86,376 such points were identified.
3. ***Splitting unsplit rowhome buildings***: Reviewers used the split polygon function to manually split single-structure, multiple-owner homes that were not split apart by the parcel-split process.

Figure 3-8: Rowhome Buildings Unsplit

Figure 3-9: Rowhome Buildings Split Using Manual Process

3.3.3 Hazus Hurricane Mapping Scheme Data Collection Review

The Puerto Rico and the U.S. Virgin Islands building footprints were further reviewed before and during the creation of the Hazus Hurricane Wind Model mapping schemes to ensure data validity. Before review, Puerto Rico contained 1.5 million building footprints and the U.S. Virgin Islands contained 41,000. The sections below document the review process for the territories' building footprints.

3.3.3.1 PUERTO RICO BUILDING FOOTPRINT DATA REVIEW

A combination of automated processing and manual reviews was used to review the 1.5 million building footprints in Puerto Rico. Automated processes were used to remove non-structure building footprints and clean remaining data, then was followed by a manual review to correct any errors.

<u>Automated Process:</u>

The dataset was first processed to ensure a one-to-one congruency between building counts and table records, meaning two building footprints could not be represented by one table record. After establishing this congruency, a minimum square footage for building footprints was set to remove non-building footprints, such as baseball dugouts or sheds, that had been captured from the Lidar data. In consultation with subject matter experts from FEMA Building Sciences, it was determined that all buildings in Puerto Rico under 150 square feet that did not touch or share a segment with another building polygon should be removed.

Due to Puerto Rico having several very dense urban areas such as San Juan and Ponce, special consideration was given to footprints that shared or touched a segment with another building polygon. In these cases, an elimination process was performed to merge neighboring footprints that have the largest area or the longest shared border to another.

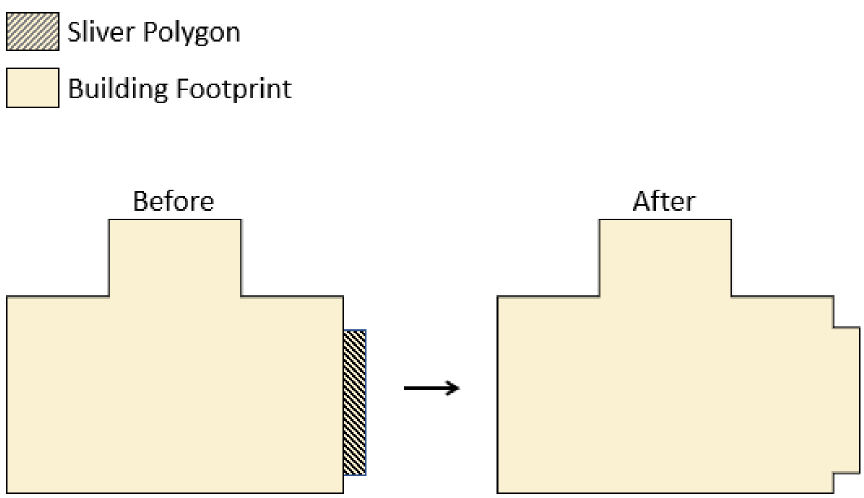

Figure 3-10: Eliminating and Merging Sliver Footprints

This process was run through multiple iterations for footprints under 150 square feet in areas where footprints intersected or overlapped. This would cause footprints to grow only if the neighboring polygon was under 150 square feet.

Next, footprints were deleted that had identical geometries in an identical spatial location to ensure no duplicates. Lastly, for any features that touched one another that were still under 150 square feet, the same rule applied, and these were deleted.

<u>Manual Process:</u>

After the automated processing was completed, Puerto Rico was divided into six sections for a manual review.

Figure 3-11: Puerto Rico Divided into Six Sections for Manual Review

All buildings (over 150 square feet) with a Near Distance = 0 were reviewed to ensure that they were supposed to be sharing a segment with another building, providing possible locations to merge building polygons. Topology that had been created for the automated process was used to review buildings that were over 150 square feet and resulted in overlaps and duplicates. These structures were either merged, deleted, or clipped based on the following rules:

- **Non-Existing Buildings**: polygons that were not over a structure. These buildings were deleted based on imagery.

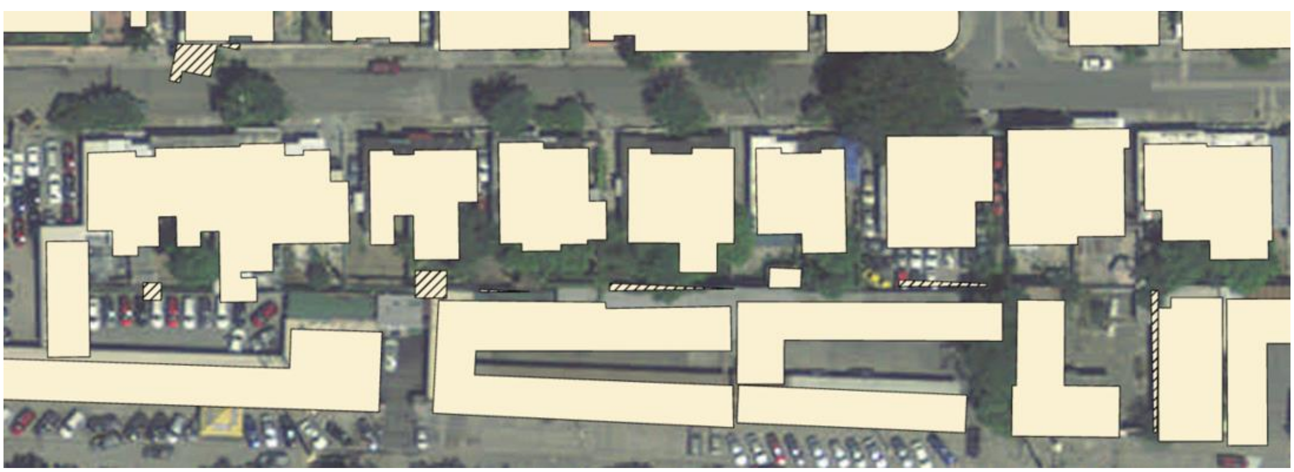

Figure 3-12: Example of Non-Existing Building Polygons Identified

- **Overlapping Buildings or Segments of Buildings**: Structures that are in the same spatial location, but not exact duplicates. These were merged using Esri topology tools, when possible.
  - Other examples of this issue were separate polygons that did not overlap but comprised a single structure and these were merged.

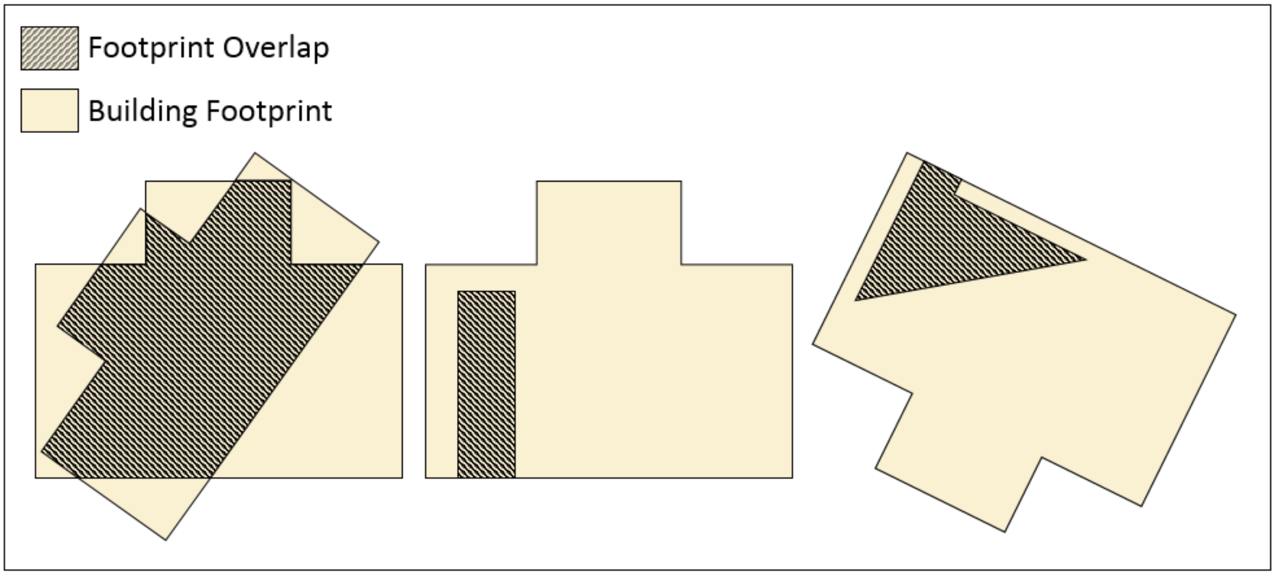

Figure 3-13: Example of Overlapping Building Polygons or Segments of Buildings

- **Overlapping Buildings with Differing Extents:** These structures needed to be augmented for an accurate building footprint representation. The original building footprint was edited to remove overlap.

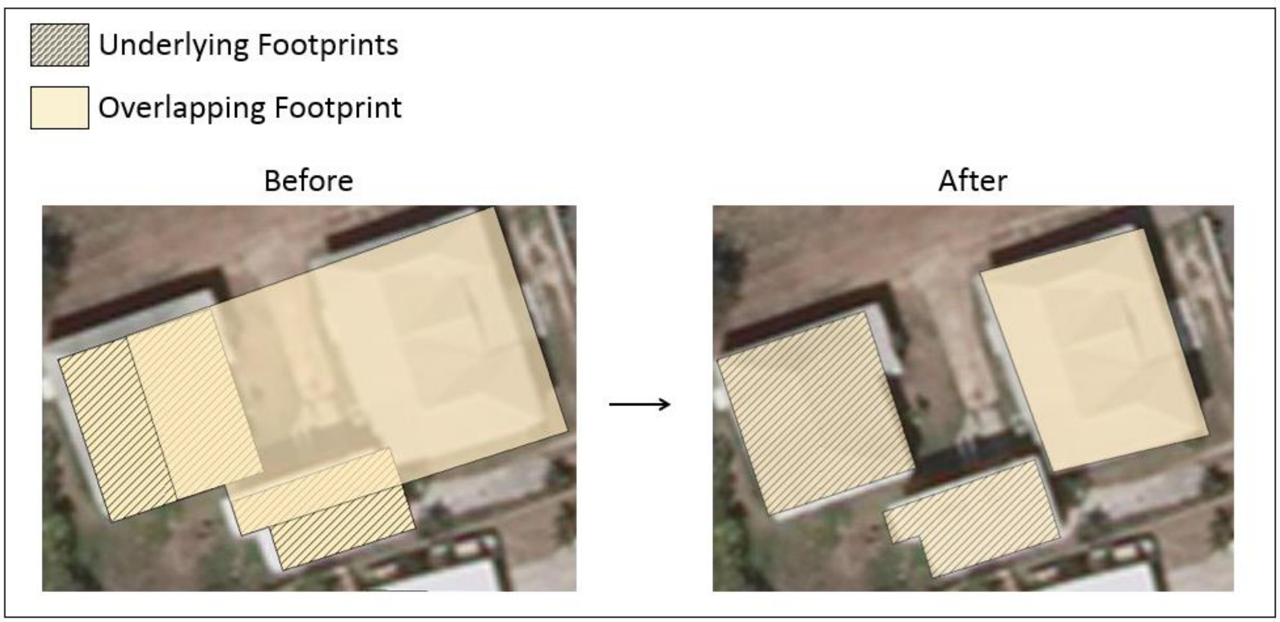

Figure 3-14: Example of Overlapping Building Polygons with Differing Extents

Once all areas were completed in the visual quality check, the data were merged into a single file, one section at a time, verifying that there were no overlaps/duplicates, no slivers under 150 square feet, and no stand along building polygons under 150 square feet.

3.3.3.2 U.S. VIRGIN ISLANDS BUILDING FOOTPRINT DATA REVIEW

The U.S. Virgin Islands' Lidar-derived building footprints were compared against OpenStreetMap (OSM) produced by the Humanitarian OpenStreetMap Team (HOT). A comparison between the two datasets was performed to look for discrepancies and abnormalities with the potential for assessing how OSM could be leveraged to confirm or enhance the building footprints derived from Lidar data.

Building Footprint Assessment:

The initial evaluation of Lidar and OSM building footprint layers revealed:

1. Both datasets were territory-wide.
2. Given the relative different dates or timestamps associated with the source data, some differences existed as would be expected of data from differing dates.
3. The Lidar footprints, having been created through automated methods included certain areas where closely clustered buildings existed as a single polygon, whereas the OSM building footprints offered distinctions.
4. Both building footprint layers, while territory-wide in geographic coverage, did not include footprints for relatively recent development (approximate 5-year time span).
5. A companion review and cross-reference of the parcel & tax assessor data also revealed that not all buildings included a corresponding tax assessment record. It is understood that public, non-taxable properties could potentially account for many of the buildings lacking tax assessment information, it was observed via post-Irma imagery (NOAA Remote Sensing Division September 15 & 16, 2017) that certain buildings demonstrated a reasonable appearance of being a valid structure based on all information available; for example, the existence of automobiles at the structure thus indicating an occupied or non-vacant structure.

Table 3-6 indicates the comparison of building counts between the two primary building footprint data layers leveraged. The table exemplifies those situations where a single footprint from the 2013 Lidar-derived building footprints were more favorably divided into distinct buildings identified from the OSM data. This analysis led to locations, commonly in dense urbanized areas, where the more refined OSM building footprints were leveraged.

Table 3-6: Comparative Building Counts - 2013 Lidar-based vs. OSM Building Footprints

<table>
<tr><th>Count of 2013 Lidar-based Building Footprints</th><th>Count of OSM Centroids Intersecting</th><th>Indication</th></tr>
<tr><td>8,099</td><td>None</td><td>2013 Lidar data indicates building. OSM does not (or) centroid location offset from spatial differences.</td></tr>
<tr><td>30,847</td><td>1</td><td>Both 2013 Lidar & OSM indicate a building; 1 To 1.</td></tr>
<tr><td>1,784</td><td>2</td><td rowspan="8">Both 2013 Lidar & OSM indicate a building; 1 To Many.</td></tr>
<tr><td>318</td><td>3</td></tr>
<tr><td>106</td><td>4</td></tr>
<tr><td>51</td><td>5</td></tr>
<tr><td>31</td><td>6</td></tr>
<tr><td>12</td><td>7</td></tr>
<tr><td>13</td><td>8</td></tr>
</table>

Count of 2013 Lidar-based Building Footprints	Count of OSM Centroids Intersecting	Indication
10	9	Both 2013 Lidar & OSM indicate a building; 1 To Many.
5	10	
1	11	
3	12	
4	13	
2	14	
1	15	
1	18	

Based on this comparative analysis between these two building footprint layers, it was recommended to create a blended master building footprint polygon layer that seeks to correct or compensate for those locations where an automated footprint encompassing multiple buildings is resolved. In addition, certain OSM buildings were added to the master building footprints in locations where the automated process did not capture certain structures; an example area includes Maho Bay Campground. Finally, footprints in certain areas were added via manual digitization considering a “best-fit” given all available resources to capture new structures, redeveloped neighborhoods or other buildings that would assist in creating a valuable dataset that could be managed into the future.

The following figures provide examples of the various Indicator-types defined in Table 3-6; 2013 Lidar-based features represented in yellow and OSM features indicated in purple. Figure 3-15 demonstrates an instance where the Lidar-based building footprint layer indicated the presence of a building and the OSM footprints did not. In these instances, the Lidar-based footprint was retained.

Figure 3-15: Example of a Lidar-Based Footprint Not Identified by OSM

Figure 3-16 demonstrates an instance where the Lidar-based building footprint does not contain the centroid of the OSM building footprint because of a spatial difference. While both building footprint resources captured the structure, the difference in shape and extents of the spatial feature result in this anomaly. In these instances, the Lidar-based building footprints were retained.

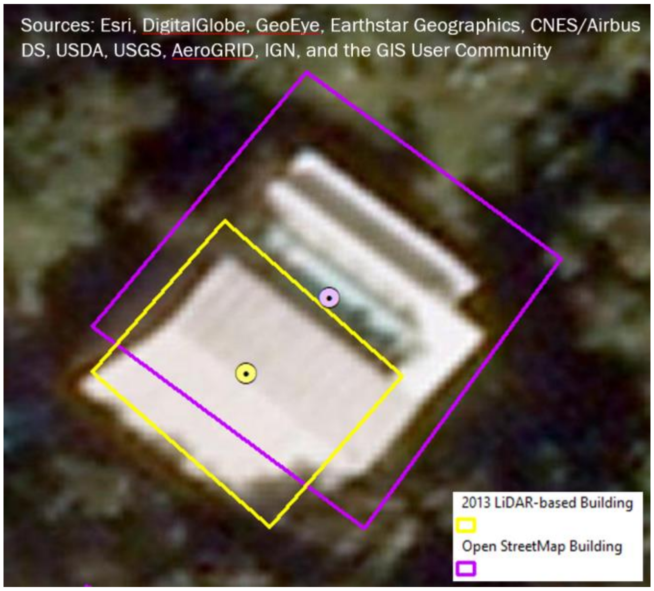

Figure 3-16: Example of a Lidar-Based Footprint Mis-Aligned with OSM Footprint due to Spatial Differences

Figure 3-17 demonstrates instances where the Lidar-based footprint largely coincides with the OSM footprint and intersects with the OSM centroid. In these instances, the Lidar-based footprints were retained.

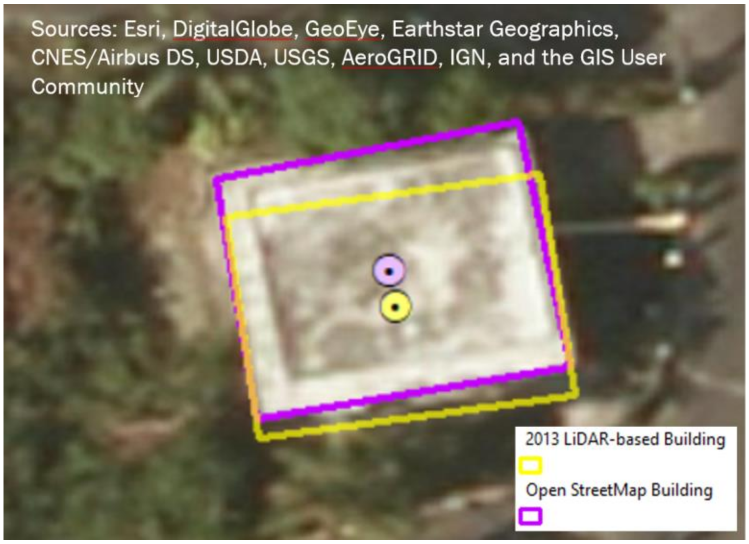

Figure 3-17: Example of Lidar-Based Footprint Corresponding to OSM Footprint and Centroid

Figure 3-18 demonstrates an instance where there is only one Lidar-based footprint, but multiple OSM footprints for the same location. In these instances, the OSM building footprints were retained.

Figure 3-18: Example of One Lidar-Based Building Footprint to Many OSM Building Footprints

Figure 3-19 demonstrates an instance where Lidar-based building footprints did not capture buildings, but the OSM dataset did contain footprints and a review of the NOAA post-Irma orthophotography identified additional buildings in the area. In these instances, the OSM building footprints were retained and the additional building footprints were added to the U.S. Virgin Islands dataset.

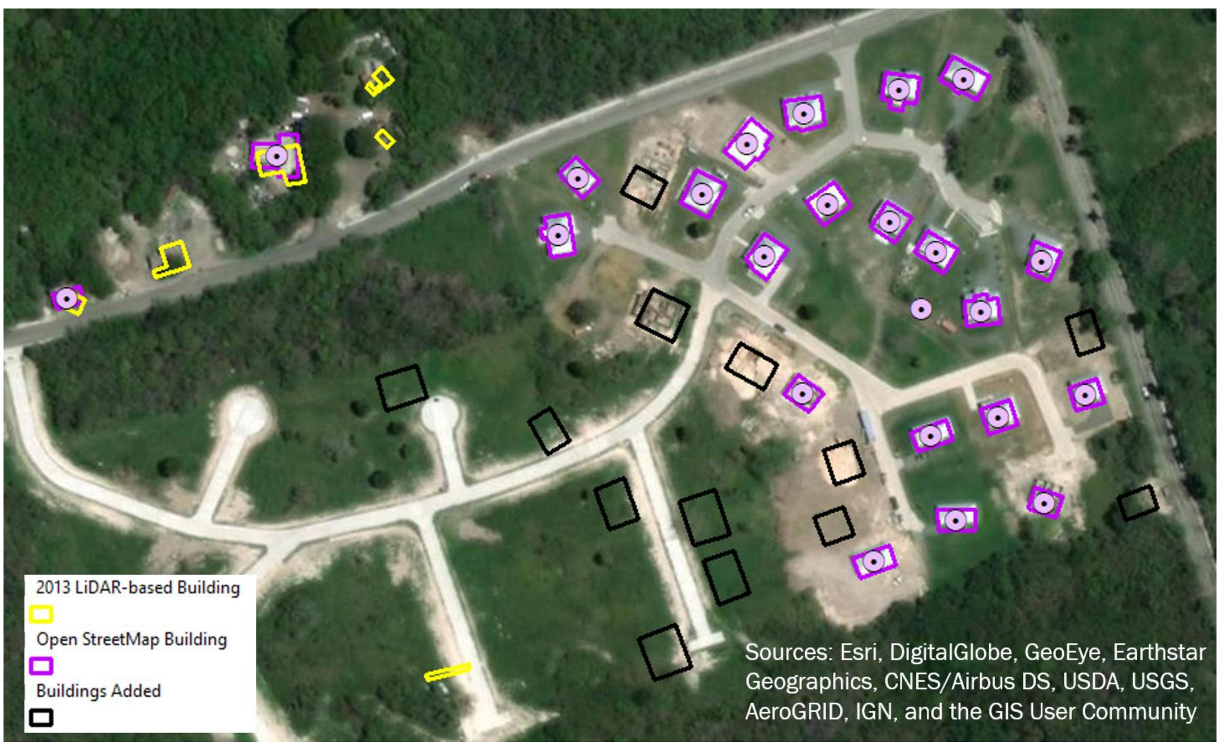

Figure 3-19: Example Area of Insufficient Lidar-Based Building Footprints and Supplemental OSM and NOAA Data

Given the demonstrated differences between the two building footprint data layers available for use, the building footprints from OSM were utilized where a one-to-many situation existed: specifically, one building footprint from the Lidar-based building footprints to “many” OSM building footprints. This effort corrected approximately 6% of the original count of building footprints coming from the Lidar-based building footprint layer. The percentages are demonstrated below in Table 3-7.

Table 3-7: Building Footprints by Source with Counts and Percent of Total

2013 Lidar-based Building Footprints	Count of OSM Centroids Intersecting	Action	Percent Total
8,099	<Null>	Use Lidar-based Building Footprint	19.616%
30,847	1	Use Lidar-based Building Footprint	74.712%
1,784	2	Use OSM Footprint	4.321%
318	3	Use OSM Footprint	0.770%
106	4	Use OSM Footprint	0.257%
51	5	Use OSM Footprint	0.124%
31	6	Use OSM Footprint	0.075%
12	7	Use OSM Footprint	0.029%
13	8	Use OSM Footprint	0.031%
10	9	Use OSM Footprint	0.024%
5	10	Use OSM Footprint	0.012%
1	11	Use OSM Footprint	0.002%
3	12	Use OSM Footprint	0.007%
4	13	Use OSM Footprint	0.010%
2	14	Use OSM Footprint	0.005%
1	15	Use OSM Footprint	0.002%
1	18	Use OSM Footprint	0.002%
TOTALS 41,288			*100%*

The resultant master spatial data layer of building footprints contained the best information from Lidar, OSM, and supplementary sources of buildings not yet present circa 2013 when the NOAA Lidar data were collected or were not captured as part of any OpenStreetMap data collection efforts. The data sources leveraged to add building footprints included open source orthophotos and maps or renderings available from public websites. The primary resource leveraged included orthoimagery available from the U.S. Virgin Islands Geographic Information System (GIS) Division served through the public-facing mapping application available from the GIS Division website.

The U.S. Virgin Islands GIS Division includes Aerial Photo orthoimagery from years 2010 and 2017 as well as NOAA Hurricane Irma and Hurricane Maria (post-storm) orthoimagery with dates throughout September 2017. Another primary orthoimagery resource included the use of Esri World Imagery.

A key secondary resource for the capture of building footprints included maps or renderings from public websites that were used as a cross-reference:

- Virgin Islands Environmental Resource Station (VIERS) site map
- University of the Virgin Islands campus maps (St. Thomas & St. Croix)
- Tutu Mall Map
- National Park Service, Cruz Bay Visitor Center Parking & Site Map
- The Preserve at BOTANY BAY lot layout rendering
- Queens Quarter Villas Site Map
- Maho Bay Camps Site Map
- Cottages By The Sea Site Rendering
- Coral World Site Rendering
- Coakley Bay Condominium Units Layout Drawing

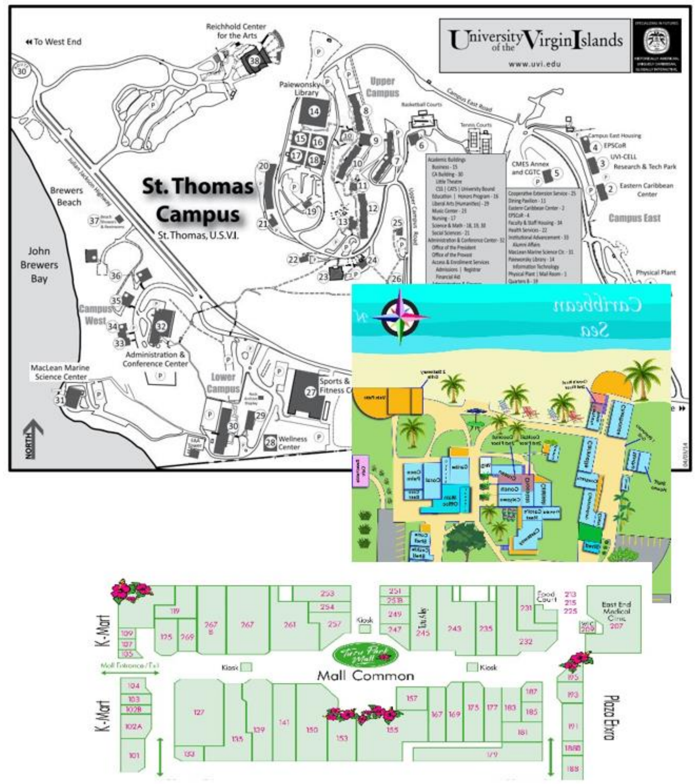

Figure 3-20: Examples of Site Maps and Renderings Leveraged to Cross-Reference for the Creation of Building Footprint

Additional geometry checks were performed on the U.S. Virgin Islands building footprints for multipart features to create a one-to-one count of buildings to table records. Duplicate features were also removed so no two footprints had the same geometry and spatial reference. The U.S. Virgin Islands dataset contains none of these errors. This ensures an accurate building count for the territory and is critical for users to perform analysis or to enhance from for any future efforts.

3.3.3.3 BUILDING FOOTPRINT DEVELOPMENT EXPERT GUIDANCE

The following are considerations for users seeking to use the current Puerto Rico and/or U.S. Virgin Islands datasets in future or enhanced Hazus analysis.

- *Missing Buildings* – The use of newer Lidar data to replace or supplement the Hazus-provided baseline data with new buildings drawn or verified from other sources.
- *False Building Identification* – Review to ensure elements such as tennis courts, bridges, dugouts, and pools are not falsely captured as buildings.
- *Dividing Large Building Polygons* – Large polygons should be reviewed to determine if they represent multi-building construction.

- *Inaccurate Polygons* – Adjustments to building polygons that do not correspond to the physical structure.
- *Building Shifts* – Building polygons may not align with imagery and should be reviewed against contemporary data.

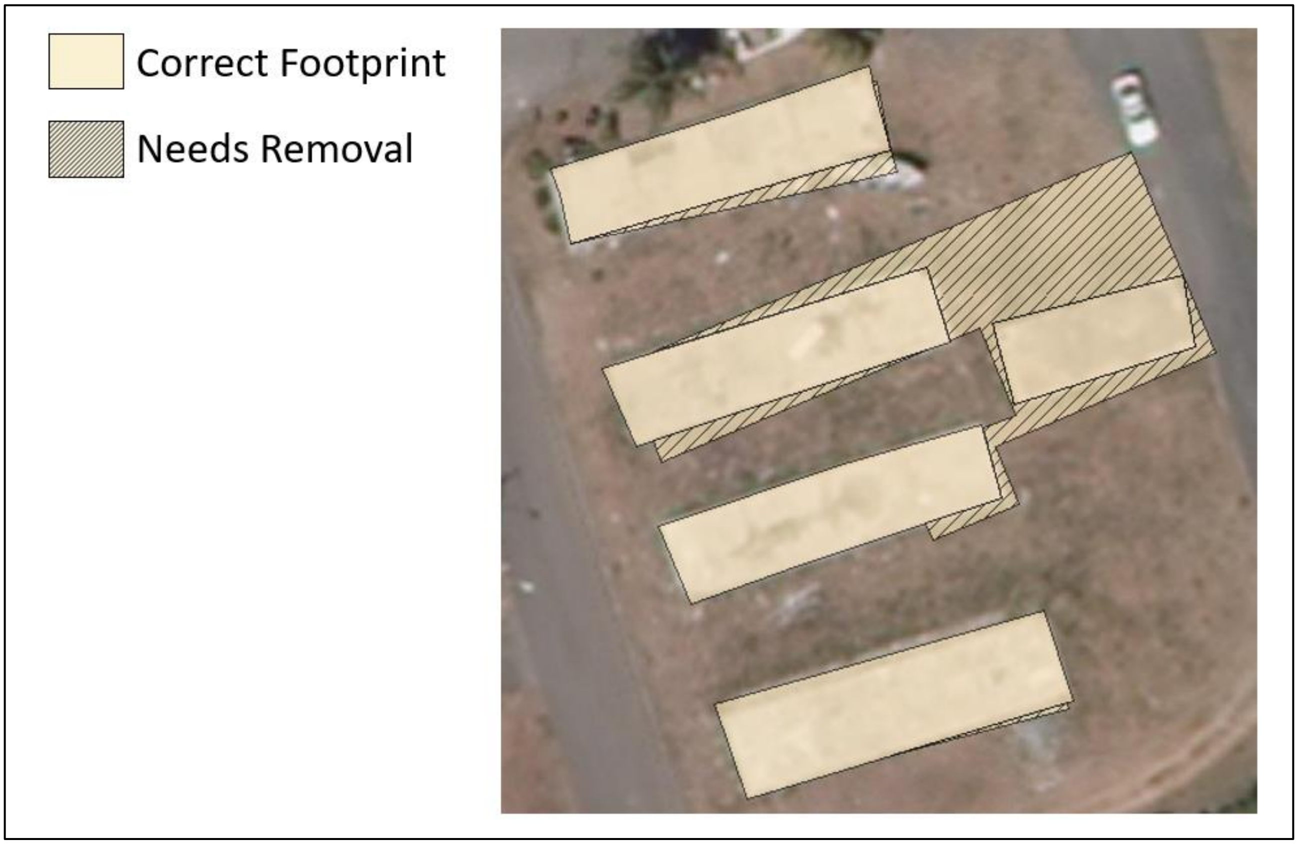

Figure 3-21: Example of Building Footprint Issues

3.4 Hazus Wind Building Characteristics

Brief descriptions of the Wind Building Characteristics (WBCs) used in the Hazus Hurricane Wind Model are provided below. These descriptions include both the new characteristics added specifically for Puerto Rico and the USVI and all of the existing building characteristics except those that are specific to Hawaii. The new WBC are listed in 3.4.1.2, 3.4.1.3, and 3.4.3.2. The primary sources of these WBC descriptions are the *Hazus Hurricane Model Technical Manual* (FEMA, 2021) and the *2008 Florida Residential Wind Loss Mitigation Study* (Applied Research Associates, 2008). The characteristics are presented in groups starting at the top of buildings (e.g., roof cover type) and then working down to the foundation and the surrounding environment (e.g., windborne debris environment). The 5-character code in parentheses following each WBC is the code used for that feature within the Hazus database. WBCs can be viewed in the Hazus user interface within the wind mapping schemes.

3.4.1 Roofing

3.4.1.1 ROOF COVER TYPE

All single-family homes and multi-family homes with hip or gable roofs in the continental U.S. are modeled as having ordinary shingle roofs. For single-family houses with the highest level of roof deck attachment capacity (8d @ 6”/6”), the roof cover is automatically upgraded to a hurricane-rated roof shingle.

Flat roofs are modeled with either built-up roof (BUR) covers or single-ply membrane (SPM) roof covers.

- *Built-up Roof Covers (rcbur):* BUR covers are composed of multiple plies of roofing felts adhered to each other and to the insulation substrate with a full mop of hot asphalt, coal tar or cold adhesive. The number of plies of roofing felt ranges from three to five. Roofing felts are commonly made of polyester, organic or glass-based materials. The surfacing on BUR covers is most often gravel or slag.
- *Single-Ply Membrane Covers (rcspm)*: SPM covers are normally attached to the insulation substrate by adhesives (hot asphalt or cold applied materials) or by mechanical fasteners. Adhered SPM covers can be fully adhered or partially adhered. The adhesive in partially adhered SPM covers will typically have 50% coverage in the central portions of the roof and greater coverage at or near the edges and corners of the roof. Common membranes are thermoplastic membranes, thermoset membranes, modified bitumen membranes and liquid applied membranes.

3.4.1.2 ROOF COVER TYPE (PUERTO RICO & THE USVI)

For Puerto Rico and the USVI, four additional roof cover types are modeled:

- *Concrete (rccnt):* Reinforced concrete roofs are used on some residential buildings. For single-family homes, concrete roofs have been included for masonry houses (MSF1 or MSF2).
- *Corrugated Steel (rccor):* A corrugated steel roof consists of metal sheets that has ridges in a u-shape pattern. Panels are usually 2-3 feet wide and overlap on their outside curved edges, where fasteners are used.
- *Elastomeric Paint – USVI (rcpnt):* Elastomeric roof paint is a liquid coating that is applied to plywood decks. It is applied to the roof as regular paint would be but adds a layer over the roof that protects against ultraviolet rays, pollutants, saline air, and water infiltration.
- *Standing Seam Metal (rcssm):* A standing seam metal roof is a roofing system that consists of interlocking metal panels that run from the ridge of the roof to the eave. It features vertical or trapezoidal legs with a flat space in between them. Fasteners connecting the panels together and to the roof are often concealed clips.

3.4.1.3 METAL ROOF COVER FASTENING (PUERTO RICO & THE USVI)

In Hazus, two types of fasteners are modeled for corrugated steel or standing seam roofs.

- *Strong Corrugated Steel/Standing Seam Roof Fasteners (rcagd):* Exposed fasteners are used to fasten roof cover to roof deck.
- *Weak Corrugated Steel/Standing Seam Roof Fasteners (rcapr):* Clips are used to fasten roof cover to roof deck.

3.4.1.4 ROOF COVER QUALITY

There are two roof cover quality levels modeled for multi-family homes and strip malls.

- *Average/Good (rqgod):* Roof cover installation and condition is of average or good quality. There are no obvious areas where installation is of poor quality or where it has deteriorated such that the roof cover will provide reduced protection in a high wind event.
- *Poor (rqpor):* Roof cover installation and condition is of poor quality. There are areas of roof cover that have been installed poorly or deteriorated due to exposure to weather cycles over time. The roof cover is not expected to perform well in a high wind event.

3.4.1.5 SECONDARY WATER RESISTANCE

Secondary water resistance is provided by applying a waterproof seal, or cover, over the spaces between the roof sheathing panels that prevent water from entering the building through the roof if the roof cover fails in a storm. Methods of applying secondary water resistance include hot-mopping the entire roof deck with tar prior to the application of the roof cover, or covering the spaces between sheathing panels with bitumous strips, usually manufactured for use as ice guards. In Hazus, secondary water resistance is either applied (swrys) or it is not applied (swrno).

3.4.1.6 ROOF DECK ATTACHMENT

There are four roof deck attachment configurations modeled in Hazus:

- *8d @ 6”/6” (rda8s):* Plywood or Oriented Strand Board (OSB), with a minimum thickness of 7/16”, nailed with 8-penny (8d) common nails at 6” spacing on the edge and 6” in the field on 24” truss spacing. Within 4’ of a gable end the nail spacing is 4”. This provides for a mean uplift resistance of 182 lbs per square foot for non-gable end locations and 219 lbs per square foot for gable end locations. The average number of missed or side-splitting nails over a 48” length must be three or less.
- *8d @ 6”/12” (rda8d):* Plywood/OSB (minimum thickness of 7/16”) nailed with 8d common nails at 6” spacing on the edge and 12” in the field on 24” truss spacing. This provides for a mean uplift resistance of 103 lbs per square foot. The average number of missed or side-splitting nails over a 48” length must be three or less.
- *6d/8d @ 6”/6” (rda6s):* This configuration is used to model retrofitting an existing roof deck attachment. The 6d @ 6”/12” roof deck attachment described below is strengthened by the application of 8d common nails at 12” spacing in the field on 24” inch truss spacing (opposite to the 12” spacing of the 6d nails). The result is a plywood/OSB (minimum thickness of 7/16”) nailed with 6d common nails on the edge and alternating 6d and 8d nails at 6” spacing in the field on 24” truss spacing.
- *6d @ 6”/12” (rda6d):* Plywood/OSB (minimum thickness of 7/16”) nailed with 6d common nails at 6” spacing on the edge and 12” in the field on 24” truss spacing. This provides for a mean uplift resistance of 55 lbs per square foot. The average number of missed or side-splitting nails over a 48” length must be three or less.

3.4.1.7 METAL ROOF DECK ATTACHMENT

Metal roof decks are used on masonry and steel engineered buildings, industrial buildings, strip malls, and pre-engineered buildings. Two metal roof deck designs are modeled in Hazus.

- ***Superior (rd110):*** Metal roof deck designed according to 1990's-era editions of the Standard Building Code using a 110 mph fastest mile wind speed.
- ***Standard (rd100):*** Metal roof deck designed according to 1990's-era editions of the Standard Building Code using a 100 mph fastest mile wind speed.

3.4.1.8 ROOF DECK AGE

Two roof deck ages or quality-levels are modeled for metal roof decks on strip malls or pre-engineered buildings to account for the effects of age and fatigue.

- ***New or Average (dqgod):*** A new or average roof with uplift capacity based on the minimum requirements for connection fastening, and short distance between open web steel joists (e.g., 4 feet).
- ***Old (dqpor):*** A metal roof deck with a 50% reduction in uplift capacity of the screwed and welded connections to accounts for effects of age and fatigue (i.e., degradation).

3.4.1.9 ROOF FRAME TYPE

For strip malls (MLRM1 and MLRM2), there are two types of roof frames modeled in Hazus:

- ***Open Steel Web Joist (rfows):*** Light weight Open-Web Steel Joist (OWSJ) roof systems consist of steel members that make up the top chord, bottom chord, and the web. The top and bottom chords are usually a set of two equal or unequal angle members. The web may either be angle or bar members, depending on the span and depth of the steel joist.
- ***Wood Truss (rftrs):*** Wood trusses are constructed of 2x4's and are spaced at 24" on center with plywood roof sheathing and either toenailed or strapped roof-to-wall connections.

3.4.1.10 JOIST SPACING

For strip malls taller than 15 feet (MLRM2), two options are modeled for OWSJ spacing: 4 feet (jspa4); and 6 feet (jspa6).

3.4.1.11 ROOF SHAPE

For practical reasons, only two basic roof shapes for single-family homes have been modeled for Hazus: hip and gable (see Figure 3-22). Since flat roofs have not been explicitly modeled as a separate roof shape for single-family homes, it is recommended that flat roofs be modeled using the gable roof option for these cases. For multi-family buildings, three basic roof shapes are used: hip, gable, and flat.

- ***Hip roof (rship):*** A pure hip roof has sloping ends and sloping sides and horizontal eaves around the full perimeter of the building. The roof slope assumed in Hazus is 4:12.
- ***Gable roof (rsgab):*** Gable roofs have vertical walls that extend all the way to the top of the inverted V. The roof slope assumed in Hazus is 4:12.
- ***Flat Roof (rsflt):*** In Hazus, a roof is classified as flat if it has a slope of less than 2:12.

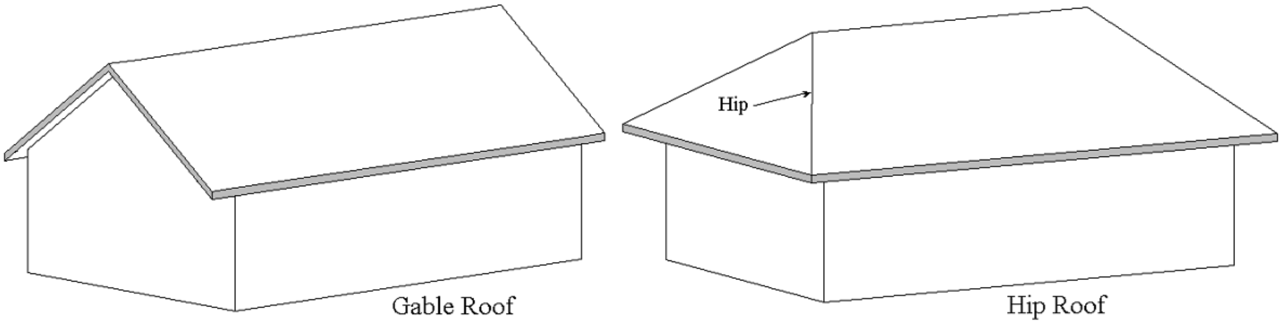

Figure 3-22. Gable and Hip Roof Geometry.

3.4.1.12 ROOF-WALL CONNECTION

The roof-to-wall connection keeps the roof on the building by transferring uplift loads on the roof into the supporting walls. Two roof-to-wall connections are modeled in Hazus:

- ***Straps (strap):*** Metal straps attached to the side and/or bottom of the top plate and nailed to the rafter/truss. At least three fasteners are needed to transfer the loads at each end of the strap and the fasteners must always be loaded in shear (perpendicular to the nail direction). The strap may be embedded into the bond beam of a masonry wall. In this case, the point of embedment must be within 1.5 inches of the rafter/truss.
- ***Toenails (tnail):*** Typically, three nails driven at an oblique angle through the rafter and into the top plate.

3.4.2 Walls

3.4.2.1 MASONRY REINFORCING

There are two options for reinforcement of masonry construction:

- ***Yes (rmfys):*** Reinforced masonry construction has at least two-thirds of the exterior wall area constructed of masonry materials that are reinforced with both vertical and horizontal steel reinforcement and are relied upon for structural stability. It is important that the vertical reinforcement is fully grouted in the hollow cells of Concrete Block Masonry Units (CMUs), and that the horizontal reinforcement be fully grouted in specially formed units. The walls may be unfinished, stuccoed, or have a veneer system hung from the walls.
- ***No (rmfno):*** Unreinforced masonry wall construction has at least two-thirds of the exterior wall area constructed of masonry materials that do not meet the reinforcing requirements of reinforced masonry construction. The walls may be unfinished, stuccoed, or have a veneer system hung from the walls.

3.4.3 Fenestrations and Doors

3.4.3.1 WINDOW AREA

For engineered commercial and residential buildings, the amount of glazing (windows) is characterized in Hazus as a percentage of the wall envelop. This is important for steel and concrete buildings because windows are often the most vulnerable buildings components to wind damage.

- ***Low (walow):*** Nominal glazing coverage is 20% of building wall envelope.
- ***Medium (wamed):*** Nominal glazing coverage is 33% of building wall envelope.
- ***High (wahig):*** Nominal glazing coverage is 50% of building wall envelope.

3.4.3.2 WINDOW TYPE (PUERTO RICO & THE USVI)

Two types of windows are used for single-family homes (WSF1, WSF2, MSF1, MSF2):

- ***Jalousie (wtjal):*** A Jalousie window consists of angled glass louvers. These are widely used in Puerto Rico and other tropical climates. The louvers can be tilted open and closed by turning a crank to control airflow.
- ***Regular (wtnor):*** A typical single pane glass window.

3.4.3.3 GARAGE DOORS AND SHUTTERS – SINGLE-FAMILY HOMES

For single-family homes in Hazus, the garage door and shutters are combined such that the following pairings are modeled together:

3.4.3.3.1 Houses Without Shutters or Impact Resistant Glazing

- ***No Garage Door (gdnodshtno):*** This house does not have an attached garage.
- ***Standard Garage Door (gdstdshtno):*** This house has an attached garage, and the garage door has a mean resistance of 20 psf.
- ***Weak Garage Door (gdwkdshtno):*** This house has an attached garage, and the garage door has a mean resistance of 10 psf (half that of the standard garage door).

3.4.3.3.2 Houses With Shutters or Impact Resistant Glazing Protecting All Glazed Openings

- ***No Garage Door (gdno2shtys):*** This house does not have an attached garage.
- ***Superior Garage Door (gdsupshtys):*** This house has an attached garage, and the garage door has a mean resistance of 40 psf (double that of the standard garage door). Shutters are applied to all glazed openings (windows, doors, and sliders), providing enhanced opening protection from windborne debris impacts.

The first building code to adopt opening protection requirements in the United States was the South Florida Building Code in 1994. The testing protocol in this code requires the protection device or impact resistant glazing to withstand impacts by a 9 lb. wood 2 x 4 impacting the shutter at a speed of 50 fps followed by a pressure cycle loading test. The Standard Building Code's SSTD-12 has similar requirements. In 1999, the ASTM also came out with a debris impact standard (E 1996) and test (E 1886). These standards include requirements for both wind pressure and debris impact. In Hazus, the use of shutters indicates that all glazed openings are protected with an impact resistant covering meeting the requirements of Standard Building Code's SSTD-12, ASTM E 1886 and ASTM E 1996, or other similar standards. The same impact resistance is used for shutters in Puerto Rico and the USVI as in the continental United States.

3.4.3.4 SHUTTERS – OTHER THAN SINGLE-FAMILY HOMES

For all buildings that are not single-family homes, the following shutter (or impact resistant glazing) options are available:

- ***Yes (shtys):*** Shutters protect glazed openings from windborne debris impacts with an energy of up to 350 lb-ft (i.e., a 9 lb. wood 2 x 4 impacting the shutter at a speed of 50 fps as required by SFBC).
- ***No (shtno):*** Glazed openings are unprotected. These openings are far more likely to be damaged by windborne debris, resulting in increased water infiltration and internal pressures.

3.4.4 Number of Units

All building models in Hazus are divided into compartments. For most Specific Building Types (SBTs), only one option is specified. For example, commercial engineered buildings contain a single compartment or unit per floor, whereas residential engineered buildings contain multiple units per floor. For one SBT (MLRM2 – masonry, low-rise strip mall, more than 15 feet), either single or multiple-units can be specified in Hazus.

- ***Multiple Units (numlt):*** Small office and retail buildings are often constructed with units separated by firewalls, each having separate roof structures but a common roof cover. Because the units are separated by firewalls and have separate roof systems, window or door breaches in one unit do not impact either the internal pressure or the water infiltration in the adjacent units.
- ***Single Units (nusgl):*** Single units are constructed such that they do not have firewalls or other barriers that would constrain internal pressures or water infiltration in other parts of the building. Hence if a window or door is breached, internal pressure and water infiltration would impact the entire building.

3.4.5 Tie Downs (Manufactured Housing)

The design and fabrication processes are governed by U.S. Department of Housing and Urban Development (HUD) regulations known at the “Manufactured Home Construction and Safety Standards MHCSS)” 24 CFR, Part 3280. These went into effect in 1976. In 1994, the wind loading requirements were increased in response to years of excessive damage, particularly Hurricane Andrew in 1992. HUD regulates manufactured home construction, but not installation. State and local governments, some of which have no tie-down requirements, regulate installation. The manufacturers’ responsibility is to provide a homeowner’s manual with installation details for the specific model. The American National Standards Institute’s Standard A225.1, “Manufactured Home Installations” is a consensus standard for the installation of manufactured homes and minimum construction requirements for manufactured home communities. Model building codes also address the issue of tie-down of manufactured homes.

- ***Yes (mtdys):*** Tie-downs that meet the requirements of MHCSS, ANSI A225.1, or another equivalent standard is used to secure the manufactured home.
- ***No (mtdno):*** No tie-downs or tie-downs that do not meet MHCSS, ANSI A225.1, or another equivalent standard is used to secure the manufactured home.

In locations where manufactured home tie-down enforcement is known to be poor, “No” should be set to 100%.

3.4.6 Windborne Debris

For engineered buildings, four different windborne debris missile environments are considered in Hazus. The missile environments include combinations of residential-type missiles (e.g., roof shingles, roof tiles, and roof sheathing) and commercial-type missiles (e.g., roof gravel), as shown in Table 3-8.

- ***Missile Environment A (widdA):*** An equal mix of commercial and residential-type missiles are used for each 45° directional sector.
- ***Missile Environment B (widdB):*** Residential-type missiles are used for all but two of the 45° directional sectors. Commercial-type missiles are used for the other two directions.
- ***Missile Environment C (widdC):*** Residential-type missiles are used for each 45° directional sector.
- ***Missile Environment D (widdD):*** No missiles are used for any of the directional sectors.

Table 3-8: Description of Missile Environments

Missile Environment Designation	Wind Direction							
	N	NE	E	SE	S	SW	W	NW
A	M	M	M	M	M	M	M	M
B	R	C	R	R	C	R	R	R
C	R	R	R	R	R	R	R	R
D	N	N	N	N	N	N	N	N

Note: C = Commercial-type missiles; R = Residential-type missiles; M = Equal mix of commercial and residential-type missiles; N = No missiles.

3.5 Puerto Rico Methodology for Building Inventory Development

3.5.1 New Roofing Material

For the Hazus Hurricane Wind Model project, there were new roof cover type materials added to the baseline of the Hazus Southeast Coastal Mapping Scheme. This was due to common construction practices in the Caribbean. The new roofing materials were elastomeric, corrugated steel, standing seam metal, and concrete. Damage curves were modeled for these four new roofing materials on:

- Single-Family Homes, 1 Story - Wood (WSF1)
- Single-Family Homes, 2 or More Stories – Wood (WSF2)
- Single-Family Homes, 1 Story - Masonry (MSF1)
- Single-Family Homes, 2 or More Stories - Masonry (MSF2)

The elastomeric covering is a roof coating thicker than paint and becomes waterproof once dried but is not widely used in Puerto Rico. Using a combination of machine learning and visual inspection of orthophotography and Street View photos, most of the roof cover types in Puerto Rico were determined to be concrete and corrugated steel.

3.5.2 Puerto Rico-Specific Building Characteristics

3.5.2.1 COLLECTION METHODS

The building characteristic collection methods used a combination of datasets noted in Section 3.1. The underlying data was building footprint polygons for Puerto Rico developed by Compass. Puerto Rico had 1,406,245 structures that the project team needed to consider in its collection of building characteristic attributes. The basis of needed building characteristic attributes included eighteen categories from the Hazus Southeast Coastal Mapping Scheme, with an additional three new categories added to align with new damage functions. Both the original and new categories are identified in Table 3-9.

Table 3-9: Puerto Rico Building Characteristics

Building Characteristics	Collection Method
Roof Shape [2]	Confirmed: orthophotography and street view photos
Secondary Water Resistance	Estimated: weakest characteristic
Roof Deck Attachment	Estimated: weakest characteristic
Roof-Wall Connection [2]	Supplemental: used Census year built
Shutters	Supplemental: street view photos
Garage without Shutters [2]	Confirmed: street view photos
Garage with Shutters [2]	Confirmed: street view photos
Roof Cover Type [2]	Confirmed: machine learning and street view photos
Roof Cover Quality [2] [3]	No data available
Masonry Reinforcing [2] [3]	No data available
Roof Deck Age [2] [3]	No data available
Roof Frame Type [2] [3]	No data available
Windborne Debris [2]	Confirmed: spatial analysis
Metal Roof Deck Attachment [3]	No data available
Joist Spacing [2] [3]	No data available
Number of Units [2] [3]	No data available
Window Area [2]	Confirmed: street view photos
Tie Downs	Supplemental: weakest characteristic
Roof slope [1] [4]	N/A
Metal Roof Cover Fastening [1] [2] [3]	No data available
Window Type [1] [2]	Confirmed: street view photos

[1] New Building Characteristic
[2] Collection Method was applied to a subset of the structures within an SBT, not for 100% of the structures
[3] Used Southeast Coastal Mapping Scheme
[4] Hazus model used 3/12 slope. Model can be enhanced in the future for additional roof pitches as appropriate
Definitions: Confirmed – gathered at an individual structure level
Supplemental – derived from 3rd party data and assigned to many structures
Estimated – subject matter expert decisions not based on supplemental data

Within these categories, there are specific building types that align with certain building characteristic categories. Therefore, collecting data on all 1,406,245 structures for every specific building type is not needed. The Hazus Southeast Coastal Mapping Scheme contains thirty-nine specific hurricane building types that were used in the development of the Puerto Rico mapping scheme shown in Table 3-10.

Table 3-10: Specific Building Type

Subtype (Specific Building Type)	Subtype Description
WSF1	Single-Family Homes, 1 Story - Wood
WSF2	Single-Family Homes, 2 or More Stories - Wood
WMUH1	Wood Multi-Unit/Hotel/Motel, 1 Story
WMUH2	Wood Multi-Unit/Hotel/Motel, 2 Stories
WMUH3	Wood Multi-Unit/Hotel/Motel, 3 or More
MSF1	Single-Family Homes, 1 Story - Masonry
MSF2	Single-Family Homes, 2 or More Stories - Masonry
MMUH1	Masonry Multi-Unit/Hotel/Motel, 1 Story
MMUH2	Masonry Multi-Unit/Hotel/Motel, 2 Stories
MMUH3	Masonry Multi-Unit/Hotel/Motel, 3 or More
MLRM1	Low-Rise Masonry Strip Mall, Up to 15ft high
MLRM2	Low-Rise Masonry Strip Mall, More than 15ft high
MLRI	Low-Rise Masonry Warehouse/Factory, 20ft high
MERBL	Masonry Engineered Residential Buildings, 1-2 Stories
MERBM	Masonry Engineered Residential Buildings, 3-5 Stories
MERBH	Masonry Engineered Residential Buildings, 6 or More Stories
MECBL	Masonry Engineered Commercial Buildings, 1-2 Stories
MECBM	Masonry Engineered Commercial Buildings, 3-5 Stories
MECBH	Masonry Engineered Commercial Buildings, 6 or More Stories
CERBL	Concrete Engineered Residential Buildings, 1-2 Stories
CERBM	Concrete Engineered Residential Buildings, 3-5 Stories
CERBH	Concrete Engineered Residential Buildings, 6 or More Stories
CECBL	Concrete Engineered Commercial Buildings, 1-2 Stories
CECBM	Concrete Engineered Commercial Buildings, 3-5 Stories
CECBH	Concrete Engineered Commercial Buildings, 6 or More Stories
SPMBS	Pre-Engineered Metal Building, Small - Steel
SPMBM	Pre-Engineered Metal Building, Med - Steel
SPMBL	Pre-Engineered Metal Building, Large - Steel
SERBL	Steel Engineered Residential Buildings, 1-2 Stories

Subtype (Specific Building Type)	Subtype Description
SERBM	Steel Engineered Residential Buildings, 3-5 Stories
SERBH	Steel Engineered Residential Buildings, 6 or More Stories
SECBL	Steel Engineered Commercial Buildings, 1-2 Stories
SECBM	Steel Engineered Commercial Buildings, 3-5 Stories
SECBH	Steel Engineered Commercial Buildings, 6 or More Stories
MHPHUD	Manufactured Home, Before 1976
MH76HUD	Manufactured Home, 1976-1994
MH94HUDI	Manufactured Home, After 1994 Zone 1
MH94HUDII	Manufactured Home, After 1994 Zone 2
MH94HUDIII	Manufactured Home, After 1994 Zone 3

3.5.2.2 BUILDING SAMPLING METHOD

For each category, out of the 1,406,425 structures that were identified as applicable building footprints, a subset was created for each building characteristic category per SBT. For example, collecting "Roof Shape" information, included ten SBT which encompassed 1,215,941 structures as potential attribution candidates. The total SBT count, per building characteristic, is shown in Table 3-11. These are the applicable structures for which it was decided that a random sample size would suffice. The sample was based upon using a 95% confidence level with a 5% margin of error using the SurveyMonkey sample size calculator. The sample sizes in this document are specific to the Puerto Rico model and for each building characteristic. This created a sample size depending on the building characteristic category ranging from 346 to 385 structures needed for attribution. The total sample size per category is listed in Table 3-11.

Table 3-11: Puerto Rico Building Characteristic Sample Size

Building Characteristic	Specific Building Type Structure Count	Confidence Level = 95% and Margin of Error 5% Count
Roof Shape	1,215,972	385
Secondary Water Resistance	1,215,972	385
Roof Deck Attachment	1,215,972	385
Roof-Wall Connection	1,215,972	385
Shutters	1,406,245	385
Garage without Shutters	1,211,772	385
Garage with Shutters	1,211,772	385
Roof Cover Type	191,076 (Existing) & 1,211,772 (New)	384 & 385
Roof Cover Quality	4,200	353

Building Characteristic	Specific Building Type Structure Count	Confidence Level = 95% and Margin of Error 5% Count
Masonry Reinforcing	951,776	385
Roof Deck Age	N/A	N/A
Roof Frame Type	N/A	N/A
Windborne Debris	186,876	384
Metal Roof Deck Attachment	90,279	383
Joist Spacing	N/A	N/A
Number of Units	N/A	N/A
Window Area	186,876	384
Tie Downs	3,397	346
Roof Slope	N/A	N/A
Metal Roof Cover Fastening	1,211,772	385
Window Type	1,211,772	385

3.5.2.3 BUILDING CHARACTERISTIC DEVELOPMENT

3.5.2.3.1 Roof Shape

Roof shape determinations used actual visual inspections from multiple orthophotography sources, primarily Google Street View and Google Earth. For areas that had no or poor image quality, NOAA post-disaster imagery was used to try to establish the roof shape. A total of 311 roof shapes were collected for Puerto Rico to determine and assign “Hip”, “Gable”, or “Flat” for roof shapes. No machine learning was used for Puerto Rico roof shape determinations.

3.5.2.3.2 Secondary Water Resistance

No data could be obtained for this building characteristic. A total of 1,215,972 applicable SBT structures were set to “No”.

3.5.2.3.3 Roof Deck Attachment

No data could be obtained, nor could the building characteristic be visually inspected. It was assumed all 1,215,972 applicable SBT structures were set to 6d @ 6"/12". Please see section 3.4.1.3 for a description of nail-spacing and the assumptions used.

3.5.2.3.4 Roof-Wall Connection

The roof-wall connection was inferred using Census year-built. If the structure was built in 1995 or after, the attribute was set to "Strap" only. If the structure was built before 1995, the attribute was set to "Toe-Nail". A total of 1,215,972 applicable SBT structures were used for setting a determination.

3.5.2.3.5 Shutters

Shutters were collected using visual inspection from Google Street View images. Shutters are applicable to all SBT structures. Determining if a structure met the shutter requirement, shutters and/or shutter hardware needed to be seen from street view using multiple angles of the building. This included the front and two sides from the street. From the 378 SBT structures none had any shutters. Using estimation, it was determined that all 1,406,245 SBT buildings had no shutters. The random sample of 378 SBTs focused only on areas that had Google Street View availability.

3.5.2.3.6 Garage without Shutters

The collection of buildings without shutters which had garages was performed using actual visual inspection from Google Street View. Garages were defined as having a roof, garage door and enclosed on three sides. Carports were not considered as a garage. A random sample looked at 287 SBT structures.

3.5.2.3.7 Garage with Shutters

The collection of homes with shutters which had garages was performed using actual visual inspection using Google Street View images. Garages were defined as having a roof, garage door and enclosed on three sides. A carport was not considered as a garage. A random sample looked at 285 SBT structures.

3.5.2.3.8 Roof Cover Type

Roof cover type determinations were performed using machine learning and visual inspection. This was performed using multiple orthophotography data sources. There were 382 visual inspections performed to assign SBT attributes. The machine learning efforts only collected attribution for corrugated steel and concrete roof cover types. Roof cover type was attributed for a total of 1,211,772 SBT structures.

3.5.2.3.9 Roof Cover Quality

No data could be obtained for this building characteristic. The mapping scheme used a distribution from the Hazus Southeast Coastal Mapping Scheme.

3.5.2.3.10 Masonry Reinforcing

Masonry reinforcing was assumed using the Census year-built attribute applied to the building footprints. This methodology was determined as practical through the expert opinion of work done by engineers from the FEMA MAT studies performed after Hurricane Maria. Building footprints were intersected with the 2010 Census Urban Area shapefile for the RES1 general occupancy data type. For structures with a year built of 1987 and greater and located in an urban area, masonry reinforcing was applied. For structures with a year-built pre-1987 and located in a rural area (including the Census Urban Cluster designation), masonry reinforcing was not applied. Initial results from the above methodology indicated 15 SBTs for this category built after 1987, which were incongruous with the informal construction observed on the island. Further investigation discovered that masonry buildings in the urban areas accounted for 114,439 buildings, but these were for masonry engineered and not applicable to the SBTs needed for masonry reinforcing. Due to limitations, the Hazus Southeast Coastal Mapping Scheme was used for final SBT attributes.

3.5.2.3.11 Roof Deck Age

No data could be obtained for this building characteristic and no attributions were made for any SBT structures. The mapping scheme used a distribution from the Hazus Southeast Coastal Mapping Scheme.

3.5.2.3.12 Roof Frame Type

No data could be obtained for this building characteristic. The mapping scheme used a distribution from the Hazus Southeast Coastal Mapping Scheme.

3.5.2.3.13 Windborne Debris

For windborne debris, spatial analysis was used to assign mapping scheme attributes. A 500 feet buffer was created for all structures and then analyzed to identify a subset of buildings that were within 500 feet of only other residential structures. The buildings in this subset were set to "Residential" within the mapping scheme. If a structure was within 500 feet of residential and commercial structures, it was set to "RES/COM". If a structure had no other structures within 500 feet, it was set to "None". No use of "Varies by direction" was used. There was no visual review of commercial structures to determine if the roof had gravel. Windborne debris was attributed for 71,108 SBT structures.

3.5.2.3.14 Metal Roof Deck Attachment

Metal roof deck attachment could not be determined with available data. The mapping scheme used a distribution from the Hazus Southeast Coastal Mapping Scheme.

3.5.2.3.15 Joist Spacing

Joist spacing could not be determined with available data. The mapping scheme used a distribution from the Hazus Southeast Coastal Mapping Scheme.

3.5.2.3.16 Number of Units

Number of units relates to only one SBT, a low-rise strip mall. No low-rise strip mall SBT was determined in Puerto Rico to make any determination for this attribute. Number of units was not attributed for any SBT structures. The mapping scheme used a distribution from the Hazus Southeast Coastal Mapping Scheme.

3.5.2.3.17 Window Area

Window area determinations used actual visual inspection from Google Street View images. The capturing of window area used three thresholds:

- High - Greater Than >40% Window Area
- Medium - Between 25-40% Window Area
- Low - Less Than <25% Window Area

The random sampling focused only on areas having Google Street View availability. Window area was assessed by viewing the structure from the best angle possible. Window area was attributed for 63 SBT structures.

3.5.2.3.18 Tie Downs

No data could be obtained for this building characteristic, so a default of “No” was attributed. Tie downs were attributed for 3,397 SBT structures.

3.5.2.3.19 Roof Slope

Roof slope was added to the Hazus Model but with only one model variable at a 3/12 slope. No additional roof slope data was collected for this building characteristic. Roof slope is a significant factor in the Hazus Model, but in Puerto Rico there was not a substantial variety to warrant modeling numerous roof slopes.

3.5.2.3.20 Metal Roof Cover Fastening

Metal roof cover fastening could not be determined with available data. The mapping scheme used a distribution from the Hazus Southeast Coastal Mapping Scheme.

3.5.2.3.21 Window Type

Window type determinations used actual visual inspection from Google Street View images. The random sampling focused only on areas having Google Street View availability. Window type was assessed using the best possible angle. Window type was collected based on 279 SBT structures.

3.6 U.S. Virgin Islands Methodology for Building Inventory Development

3.6.1 New Roofing Material

For the Hazus Hurricane Wind Model project, there were new roof cover type materials added to the baseline of the Hazus Southeast Coastal Mapping Scheme. This was due to common construction practices in the U.S. Virgin Islands. The new roofing materials were elastomeric, corrugated steel, standing seam metal, and concrete. Damage curves were modeled for these four new roofing materials on:

- Single-Family Homes, 1 Story - Wood (WSF1)
- Single-Family Homes, 2 or More Stories – Wood (WSF2)
- Single-Family Homes, 1 Story - Masonry (MSF1)
- Single-Family Homes, 2 or More Stories - Masonry (MSF2)

The elastomeric covering is widely used around the Islands as a roof coating thicker than paint and becomes waterproof once dried. Before the elastomeric covering was modeled for all wind conditions, a pilot study was performed. This determined that elastomeric would have an impact on building losses between wind speeds of approximately 50-125 MPH when compared to shingle roofs. It was determined that 17% (WSF1) to 29% (WSF2) of the wood frame single-family building stock in the U.S. Virgin Islands is estimated to have elastomeric roof coverings. The corresponding numbers for MSF1 and MSF2 are 20% and 25%, respectively. Details of the modeling will be discussed in Section 6.

3.6.2 U.S. Virgin Islands-Specific Building Characteristics

3.6.2.1 COLLECTION METHODS

The building characteristic collection methods used a combination of datasets noted in Section 3.1. The underlying data was the U.S. Virgin Islands building footprints from 2018 that had received continuous updates up until July 2019. The July 2019 dataset was the foundational dataset used for collecting building characteristic data. The number of U.S. Virgin Islands building footprints that the project team needed to consider for attribution was around 45,154. Attribution consisted of eighteen building characteristics from the existing Hazus Southeast Coastal mapping scheme. With an additional three new categories added to align with new damage functions. Both the original and new categories are identified below in Table 3-12.

Table 3-12: U.S. Virgin Islands Building Characteristics

Building Characteristics	Collection Method
Roof Shape [2]	Confirmed: orthophotography
Secondary Water Resistance	Estimated: weakest characteristic
Roof Deck Attachment	Estimated: weakest characteristic
Roof-Wall Connection [2]	Supplemental: tax assessor data
Shutters [2]	Confirmed: street view photos
Garage without Shutters [2]	Confirmed: street view photos
Garage with Shutters [2]	Confirmed: street view photos
Roof Cover Type [2]	Confirmed: orthophotography
Roof Cover Quality [2]	Supplemental: used tax assessor data
Masonry Reinforcing [2]	Supplemental: Hazus earthquake data
Roof Deck Age [2]	Estimated: tax assessor data
Roof Frame Type [3]	No available data
Windborne Debris	Confirmed: spatial analysis
Metal Roof Deck Attachment [2]	Estimated: building code research
Joist Spacing [2]	Estimated: building code research
Number of Units	Supplemental: occupancy notes
Window Area [2]	Confirmed: street view photos
Tie Downs [2]	Supplemental: building code research
Roof slope [1] [4]	N/A
Metal Roof Cover Fastening [1] [2]	Estimated: roof cover type material
Window Type [1] [2]	Confirmed: street view photos

[1] New Building Characteristic
[2] Collection Method was applied to a subset of the structures within an SBT, not for 100% of the structures
[3] Used Southeast Coastal Mapping Scheme
[4] Hazus model used 3/12 slope. Model can be enhanced in the future for additional roof pitches as appropriate
Definitions: Confirmed – gathered at an individual structure level
Supplemental – derived from 3rd party data and assigned to many structures
Estimated – subject matter expert decisions not based on supplemental data

Within the categories, there were specific building types that aligned with certain building characteristic categories. Therefore, collecting data on all 45,154 structures for every specific building type is not needed. Thirty-nine specific building types were evaluated using the Southeast Coastal Mapping scheme identified below in Table 3-13.

Table 3-13: Specific Building Type

Subtype (Specific Building Type)	Subtype Description
WSF1	Single-Family Homes, 1 Story - Wood
WSF2	Single-Family Homes, 2 or More Stories - Wood
WMUH1	Wood Multi-Unit/Hotel/Motel, 1 Story
WMUH2	Wood Multi-Unit/Hotel/Motel, 2 Stories
WMUH3	Wood Multi-Unit/Hotel/Motel, 3 or More
MSF1	Single-Family Homes, 1 Story - Masonry
MSF2	Single-Family Homes, 2 or More Stories - Masonry
MMUH1	Masonry Multi-Unit/Hotel/Motel, 1 Story
MMUH2	Masonry Multi-Unit/Hotel/Motel, 2 Stories
MMUH3	Masonry Multi-Unit/Hotel/Motel, 3 or More
MLRM1	Low-Rise Masonry Strip Mall, Up to 15ft high
MLRM2	Low-Rise Masonry Strip Mall, More than 15ft high
MLRI	Low-Rise Masonry Warehouse/Factory, 20ft high
MERBL	Masonry Engineered Residential Buildings, 1-2 Stories
MERBM	Masonry Engineered Residential Buildings, 3-5 Stories
MERBH	Masonry Engineered Residential Buildings, 6 or More Stories
MECBL	Masonry Engineered Commercial Buildings, 1-2 Stories
MECBM	Masonry Engineered Commercial Buildings, 3-5 Stories
MECBH	Masonry Engineered Commercial Buildings, 6 or More Stories
CERBL	Concrete Engineered Residential Buildings, 1-2 Stories
CERBM	Concrete Engineered Residential Buildings, 3-5 Stories
CERBH	Concrete Engineered Residential Buildings, 6 or More Stories
CECBL	Concrete Engineered Commercial Buildings, 1-2 Stories
CECBM	Concrete Engineered Commercial Buildings, 3-5 Stories
CECBH	Concrete Engineered Commercial Buildings, 6 or More Stories
SPMBS	Pre-Engineered Metal Building, Small - Steel
SPMBM	Pre-Engineered Metal Building, Med - Steel
SPMBL	Pre-Engineered Metal Building, Large - Steel
SERBL	Steel Engineered Residential Buildings, 1-2 Stories
SERBM	Steel Engineered Residential Buildings, 3-5 Stories
SERBH	Steel Engineered Residential Buildings, 6 or More Stories
SECBL	Steel Engineered Commercial Buildings, 1-2 Stories
SECBM	Steel Engineered Commercial Buildings, 3-5 Stories
SECBH	Steel Engineered Commercial Buildings, 6 or More Stories

Subtype (Specific Building Type)	Subtype Description
MHPHUD	Manufactured Home, Before 1976
MH76HUD	Manufactured Home, 1976-1994
MH94HUDI	Manufactured Home, After 1994 Zone 1
MH94HUDII	Manufactured Home, After 1994 Zone 2
MH94HUDIII	Manufactured Home, After 1994 Zone 3

3.6.2.2 RANDOM SAMPLING METHOD

For each category, out of the 45,154 structures that were identified as applicable building footprints, a subset was created for each building characteristic category per SBT. For example, collecting “Roof Shape” information included ten SBTs, which encompassed 34,327 structures as potential attribution candidates. The total SBT count per building characteristic is shown below in Table 3-14. These are the applicable structures for which it was decided that a random sample size would suffice. The sample was based upon using a 95% confidence level with a 5% margin of error using the SurveyMonkey sample size calculator. This created a sample size depending on the building characteristic category ranging from 218 to 381 structures needed for attribution. The total sample size per category is listed below in Table 3-14Table 3-14.

Table 3-14: U.S. Virgin Islands Building Characteristic Sample Size

Building Characteristic	Specific Building Type Structure Count	Confidence Level = 95% and Margin of Error 5% Count
Roof Shape	34,319	380
Secondary Water Resistance	34,319	380
Roof Deck Attachment	36,984	381
Roof-Wall Connection	36,984	381
Shutters	45,144	381
Garage without Shutters	29,569	380
Garage with Shutters	29,569	380
Roof Cover Type	14,711(Existing) & 29,569 (New)	375 & 380
Roof Cover Quality	4,750	356
Masonry Reinforcing	27,257	379
Roof Deck Age	3,027	341
Roof Frame Type	2,665	336
Windborne Debris	9,961	370
Metal Roof Deck Attachment	3,821	350
Joist Spacing	2,108	326
Number of Units	2,108	326
Window Area	7,296	365

Building Characteristic	Specific Building Type Structure Count	Confidence Level = 95% and Margin of Error 5% Count
Tie Downs	502	218
Roof Slope	N/A	N/A
Metal Roof Cover Fastening	29,569	380
Window Type	29,569	380

The random sampling was performed on structures using a combination of a grid system and the availability of Google Street View imagery/photos. A 5,000 feet grid system was created to cover all three islands. Building footprints that intersected the grid system was a baseline for sampling. This ensured some sort of building footprint sampling across all Island geographies. Figure 3-23 provides an example of a group of buildings where the hashed polygons are buildings that were selected for random sampling analysis.

Figure 3-23: Grid Sample

Further refinement of the random sampling came from where there was availability of Google Street View. Since many of the building characteristics (e.g., Shutters and Window Area) needed a street view or oblique imagery for a determination, sampling was weighted to areas having this type of data availability. Additional structures may have been added or removed from the initial grid intersection to obtain the needed sample size. Once footprints were identified for data collection, this guided users on where to collect needed attribution. Additional structures were added to the needed sampling to make sure if street view imagery had any visual obstructions when determining a building characteristic, it could be skipped. In many cases, the minimum sample size of collected data was exceeded for the U.S. Virgin Islands.

3.6.2.3 BUILDING CHARACTERISTIC DEVELOPMENT

3.6.2.3.1 Roof Shape

Roof shape determinations were confirmed from visual inspection using multiple orthophotography sources. Through previous work, roof shape was also a construction characteristic that was included within the U.S. Virgin Islands Tax Parcel data, however, not all records were populated in the tax assessor source dataset. Furthermore, the source dataset includes values that are ultimately not leveraged by the Hazus model, such as “Mansard”, “Shed”, “Gambrel”, “Other” or “Unknown”. The current Hazus wind model is enabled only to analyze “Hip”, “Gable” and “Flat” roof shapes. Data collection efforts for roof shape were to primarily populate values that were void of tax assessor attribution. The actual visual inspection of roof shape attributes was collected on 3,838 buildings which were sampled on the three primary islands of St. Thomas, St. John, and St. Croix – as well as Water Island. NOAA and Esri imagery were used as the primary orthophotography sources. For locations with poor image resolution, Civil Air Patrol oblique photos and Google Street view were utilized to supplement roof shape determinations. Using a combination of visual inspection and the tax assessor information, 27,603 roof shape attributes were collected as “Hip”, “Gable”, or “Flat”. No machine learning was used for the U.S. Virgin Islands roof shapes.

3.6.2.3.2 Secondary Water Resistance

For secondary water resistance, there was no source data that could be obtained for this building characteristic. This was estimated for a total of 34,319 applicable SBT structures and set to “No” because this is the weakest characteristic type.

3.6.2.3.3 Roof Deck Attachment

For roof deck attachment, there was no data that could be obtained or way to visually inspect structures for this building characteristic. It was estimated all 36,984 applicable SBT structures were set to 6d @ 6"/12" because this is the weakest characteristic type.

3.6.2.3.4 Roof-Wall Connection

The roof-wall connection was supplemented using construction class information. Both construction quality and condition information existed within the assessor data (i.e., fields named “QUALITY” and “CONDITION”). Assessor data was joined with the building footprints. Previous data development work included translation of the assessor quality and condition information to Hazus RES1 (Single-Family) construction classes; namely, Economy, Average, Custom, and Luxury. Roof-wall connection determinations were then made based on the RES1 construction class; where “Economy” or “Average” structures were set to "Toe-Nail", and “Custom” or “Luxury” structures were set to "Strap" if the construction date was after 1995, "Toe-Nail" if before 1995. A total of 24,532 applicable SBT structures were used for setting a determination.

3.6.2.3.5 Shutters

Shutter information was confirmed through visual inspection from Google Street View. Shutters are applicable to all SBT structures. Determining if a structure met the shutter requirement, shutters and/or shutter hardware needed to be seen from Google Street View using multiple angles of the building. Multiple angles meant the front and two sides from the street. In special cases, determinations were made from the internet using real-estate websites on rental properties to view photos when a determination could not be made from Google Street View. For a building to be designated as having shutters (Yes), 100% of the visible windows needed to be covered by shutters or shutter hardware. If a building had shutters only on 75% of the visible windows, the structure was classified as not having shutters (No). Shutter eligibility was assessed visually to make sure that the design factor was intended for hurricane winds. Collecting shutter information required a random sample of 774 SBT structures on St. Thomas, St. John, and St. Croix. The random sample focused only on areas that had Google Street View availability. No machine learning was used for U.S. Virgin Islands shutter attribution.

3.6.2.3.6 Garage without Shutters

The collection of buildings without shutters which had garages was confirmed through visual inspection from Google Street View. Garages were defined as having a roof, garage door and enclosed on three sides. A carport was not considered as a garage. A random sample looked at 412 SBT structures. From the random sample on St. Thomas, St. John, and St. Croix, only thirteen buildings had a garage and no shutters. It was randomly assumed, seven were classified as “Weak” and six as “Standard”.

3.6.2.3.7 Garage with Shutters

The collection of buildings with shutters which had garages was confirmed through visual inspection from Google Street View. Garages were defined as having a roof, garage door and enclosed on three sides. A carport was not considered as a garage. A random sample looked at 412 SBT structures. From the random sample on St. Thomas, St. John, and St. Croix, only three buildings had a garage with shutters. It was assumed they met “SFBC 1994”.

3.6.2.3.8 Roof Cover Type

Roof cover type determinations were confirmed through visual inspection from multiple orthophotography sources on 8,214 applicable SBT structures on St. Thomas, St. John, and St. Croix. The total number of roof cover types collected for the U.S. Virgin Islands were split among existing and new roof cover types. The existing roof cover types were BUR and SPM. The new roof cover types were “Elastomeric”, “Corrugated Steel”, “Standing Seam”, and “Concrete”. For the existing roof cover types, data was collected for 1,682 SBT structures. For new cover types, data were collected for 6,450 SBT structures.

3.6.2.3.9 Roof Cover Quality

Roof cover quality was supplemented using assessor data joined with building footprints. The assessor data had a data field called “Quality”. Buildings were attributed with “Good” and “Poor” using the assessor data. Roof cover quality was attributed for 2,736 SBT structures. It was not reviewed to see if the roof cover types for SPM and BUR looked to be maintained.

3.6.2.3.10 Masonry Reinforcing

Masonry reinforcing was supplemented from previous data development efforts that established the earthquake building types for each valid building footprint. The predominant indication from previous work indicating unreinforced masonry included the year built attribute. Inference was made based on building code adoption dates and the assumption that prior to 1940, reinforcement does not exist. Therefore, using these earthquake building types from previous Hazus input data, buildings were attributed with “Yes” and “No” using the Hazus data. Masonry reinforcing was attributed for 20,785 SBT structures.

3.6.2.3.11 Roof Deck Age

Roof deck age was estimated using assessor data joined with building footprints. If a structure’s construction date was 1996 or newer, the mapping scheme was set to "New or Average" assuming improvements were made after Hurricane Marilyn. Construction dates before 1996 were set to "Old". Roof deck age was attributed for 61 SBT structures. Due to limited data, the random sample size could not be met.

3.6.2.3.12 Roof Frame Type

No data could be obtained for this building characteristic. This data was estimated and carried over from the Hazus Southeast Coastal Mapping Scheme distribution.

3.6.2.3.13 Windborne Debris

For windborne debris, spatial analysis was used to assign attributes. A 500 feet radius buffer was created for each appropriate SBT within the model to evaluate debris damage (Masonry, Concrete, and Steel) and then analyzed to see what building(s) were within the radius. If only residential buildings were within the buffer radius of the main subject building, then the attribute was set to "Residential". If residential and commercial buildings were identified, then the attribute was set to "Res/Comm". If the building had no other buildings within 500 feet, it was set to "None". The attribute of "Varies by direction" was not used. There was no visual review of commercial buildings to determine if the roof had gravel ballast. Through the Mitigation Assessment Team Report (Hurricanes Irma and Maria in the U.S. Virgin Islands), gravel ballast was assumed to not exist and therefore highly unlikely. Windborne debris was attributed for 9,961 SBT structures.

3.6.2.3.14 Metal Roof Deck Attachment

Metal roof deck attachment was estimated based upon references found in the 1994 Uniform Building Code (Public & Non-Public Buildings) report. For construction dates after 1995, attribution was set to “Superior”. For construction dates of 1995 or earlier, attribution was set to “Standard”. A metal roof deck attachment characteristic was attributed for 536 SBT structures.

3.6.2.3.15 Joist Spacing

Joist spacing was estimated based upon references found in the 1994 Uniform Building Code (Public & Non-Public Buildings). For construction dates after 1995, the attribution was set to "6 feet". For construction dates of 1995 or earlier, attribution was set "8 feet". Joist spacing was attributed for 44 SBT structures. Due to limited data, the random sample size could not be met.

3.6.2.3.16 Number of Units

Number of units was supplemented using occupancy notes collected from past U.S. Virgin Islands’ activities which may have indicated, for example, that a strip mall or multiple occupancies exist for a given structure. The occupancy notes identified 8% of the structures as being “Multi”-unit buildings. The remaining 92% were defined being “Single-use occupancy”. The occupancy notes were confirmed using imagery and photos. When confirming strip malls and the number of units using imagery/photos, the analysis started with the largest strip mall building footprints and reviewed down to smaller units until it was repetitive of only seeing single units. Number of units was attributed for 2,108 SBT structures, of which approximately 50% were verified from multiple source data gathered and processed during past U.S. Virgin Islands activities.

3.6.2.3.17 Window Area

Window area determinations were confirmed from visual inspection using Google Street View. The capturing of window area used three thresholds:

- “High” - Greater Than >40% Window Area
- “Medium” - Between 25-40% Window Area
- “Low” - Less Than <25% Window Area

The random sampling focused only on areas having Google Street View availability. Window area was assessed using multiple structure angles. Window area was attributed for 565 SBT structures.

3.6.2.3.18 Tie Downs

Tie downs were supplemented using building code information. The MHCSS were strengthened on July 13, 1994, which remains in effect today. All HUD manufactured homes and park model homes constructed after July 13, 1994, that are in Exposure “D”, Wind Zone II or Wind Zone III, shall have a data plate affixed in the home by the manufacturer as proof that the home meets the design standards. Using assessor data, if the manufactured home had a construction date of 1995 or later, the mapping scheme was set to "Yes". If the construction date was before 1995, the mapping scheme is set to "No". Tie downs were attributed for 79 SBT structures. Due to limited data, the random sample size could not be met.

3.6.2.3.19 Roof Slope

Roof slope was added to the Hazus model but with only one model variable at a 3/12 slope. No additional roof slope data was collected for this building characteristic. Roof slope is a significant factor in the Hazus model, but in the U.S. Virgin Islands there was not a substantial variety to warrant modeling numerous roof slopes.

3.6.2.3.20 Metal Roof Cover Fastening

Metal roof cover fastening was estimated using the information collected for roof cover type. It was assumed if the roof cover was corrugated steel, the mapping scheme was set to "Weak", if the roof cover was a standing seam, the mapping scheme was set to "Strong". Metal roof cover fastening was attributed for 549 SBT structures.

3.6.2.3.21 Window Type

Window type determinations were confirmed from visual inspection using Google Street View. The random sampling focused only on areas having Google Street View availability. Window type was assessed using multiple building angles. Buildings that used a combination of window types, whichever was 50% greater for “Jalousie” or “Regular” was used as the final determination. Window type was attributed for 593 SBT structures.

3.7 Integration with Existing Hazus Data

3.7.1 Comparison with Previous Data Updates for the Caribbean Territories

The Hazus state databases for Puerto Rico and the U.S. Virgin Islands have undergone multiple recent updates but it is important to note that all PR and the USVI inventory and hazard data, as well as analysis parameters and results, are provided in, and follow the same format as all other Hazus datasets. In 2019, inventory data for these territories, including building counts, values, and square footage were aggregated for every Census block and Census tract in PR and the USVI. Risk-related building attributes were also estimated, and the final datasets enabled flood and earthquake - in addition to the pre-existing tsunami risk assessments - to be performed using Hazus for PR and the USVI. This document describes the process for updating the hurricane and wind-specific building data to enable Hazus hurricane risk assessment in these same territories.

The methodology for the development of the wind-specific building data included several components from the 2019 development effort for building data in other hazards. As in 2019, building counts, values, and square footages were aggregated for every Census block and Census tract in PR and the USVI using the best Lidar-based building footprints obtained shortly after Hurricanes Maria and Irma in 2017. The footprint data were processed to remove overlapping polygons and slivers and joined with height data to estimate the number of stories. Local data and expert methods were used to estimate risk-related building attributes. As a result, the General Building Stock (GBS) and facility inventories for PR and the USVI are enhanced compared to most other national baseline datasets provided in Hazus. These include the essential facility data, as well as transportation and utility facilities. The Hurricane Model, however, only provides losses for the essential facilities (EFs) of schools, hospitals, fire and police stations, and emergency operation centers. This includes both economic losses and loss of use. The essential facility updates for the USVI were part of the November 2019 data updates described above and in the Release Notes for that effort. In PR, the essential facilities were updated using the Homeland Infrastructure Foundation-Level Data (HIFLD) open datasets.

While customized hurricane wind mapping schemes, including new wind building types, were developed for PR and USVI GBS, the schemes for EFs are duplicated from the Southeast Coastal scheme from the mainland U.S. and are therefore identical. Users can further modify the Wind Building Distribution for both the GBS and EFs in their Hazus Study Regions by using the Inventory→General Building Stock (or Essential Facilities)→Wind Building Characteristics Distribution feature. This is also where a user can evaluate the potential reduction of losses for wind mitigation strategies.

The General Building Stock for the Tsunami model was not updated at this time. The 2017 tsunami inventory was developed from the USACE National Structure Inventory as described in the *Hazus Inventory Technical Manual* (FEMA, 2021).

3.7.2 Using CDMS and Other Input or Results Tables

Hazus' Comprehensive Data Management System (CDMS) supports the ability to bring in site-specific user-defined facilities (UDF) for any hurricane region in the U.S., including PR and the USVI. However, it is important to note that the loss analysis for these site-specific UDF is based on the Census tract level peak gust and state-wide mapping schemes.

CDMS can be used in the same way as other state databases to update and enhance PR and USVI data. All PR and USVI inventory and hazard data, analysis parameters, and results, are provided in and follow the same format as all other state datasets. However, there are some notable differences in how the PR and USVI baseline datasets were developed as compared to other states. One example is that the GBS data for PR and USVI are based on detailed site-specific datasets developed from Lidar building footprints and aggregated to the Census block and Census tract levels; a considerable improvement over the existing GBS baseline datasets for other states, which are based on aggregated datasets from the U.S. Census and a commercial provider. Additional information describing the development of the inventory data for PR and the USVI is provided in the November 2019 data release notes.

Section 4. Mapping Scheme Development

4.1 How Hazus Uses Mapping Schemes

Mapping schemes within the Hazus Hurricane Wind Model allow users to quickly classify the types of structures in a geographic area. The schemes are built by determining the distribution of types of structures within a geographic area; in the case of the Hurricane Model, this is done at the Census tract level. Hazus defines the type of structure in terms of "General Building Types" and users will recall the General Building Types in Hazus are:

- Wood
- Masonry
- Concrete
- Steel
- Manufactured Housing

Each General Building Type has subtypes, called Specific Building Types (SBT), that represent different types of general construction. For example, in the Southeast Coastal mapping scheme in Hazus, wood building types can be subdivided into two types of single-family homes, and three types of multi-unit buildings depending on the number of stories or number of units in the structure. To see the full list of SBTs, you can review Table 3-10.

In addition to general building types to describe construction, Hazus can also classify buildings by their General Occupancy Type, which include:

- Residential
- Commercial
- Industrial
- Agriculture
- Religious
- Government
- Education

Occupancy types, like building types, have subtypes called Specific Occupancy, that describe different ways the general building type can be used. Commercial structures, for example, have a variety of occupancies, ranging from small, standalone retail businesses, to large retail warehouse facilities, to non-retail commercial occupancy with minimal inventory, such as a movie theater.

Classifying structures this way and counting them at geographic aggregations like Census tracts allows Hazus to account for regional construction practices, building codes, and localized hazard mitigation efforts when estimating damage to structures in a Study Region. Building characteristics pertinent to hurricanes and the Caribbean Territories – such as hurricane shutters, window area, or tie downs – are defined in Section 3.4.

Once the general and specific building types and building characteristics are known for a geographic area, mapping schemes can be developed for use in Hazus analysis within that area. For each SBT, building characteristics that could reasonably be a part of construction for that SBT are identified and counted. For example, residential roof shape is included for the SBTs of single-family homes but is not included for flat-roofed structures, such as masonry strip malls or concrete high-rises. The number of structures with pertinent roof shapes are counted and assigned a percentage of the total structures within the SBT. Once this is complete for all building characteristic subtypes within the SBT, the results are combined into the Hazus mapping scheme for all SBTs. An example of the Hazus Southeast Coastal Mapping Scheme is provided in Table 4-1:

Table 4-1: Example Mapping Scheme for Single-Family Home, One-Story, Wood Frame (SBT SWF1)

Categories	Building Characteristic	Percent Distribution
Roof Shape	Hip	19
	Gable	81
	Total	100
Secondary Water Resistance	Yes	0
	No	100
	Total	100
Roof Deck Attachment	6d @ 6”/12”	37
	8d @ 6”/12”	33
	6d/8d Mix @ 6”/6”	0
	8D @ 6”/6”	30
	Total	100
Roof-Wall Connection	Toe-nail	23
	Strap	77
	Total	100

Hazus applies the building characteristic distributions to all structures in the area labeled with the mapping scheme. In this way, Hazus can estimate damage caused by hurricanes by applying the appropriate mapping scheme for the area(s) impacted by the hurricane. Regardless of how many of each type of structure are in the impacted area, Hazus will be able to estimate damage based on the percentages in the mapping scheme. In the example above, this would mean that whether Hazus is looking at damage to residential wood frame construction in coastal South Carolina or coastal Mississippi, the model can assume 81% of these structures have gable roofs, or 77% have strap connections between roof and walls, and apply the appropriate damage functions regardless of how many houses are being analyzed in the model.

Currently in Hazus, there are 8 default hurricane wind mapping schemes for the United States:

- Northeast U.S. Inland
- Northeast U.S. Coastal
- Southeast U.S. Inland
- Southeast U.S. Coastal
- Florida North
- Florida Central
- Florida South
- Florida Southeast

As noted in previous sections of this document, much of the existing Hazus Southeast Coastal Mapping Scheme is appropriate for use in Puerto Rico and the U.S. Virgin Islands. However, new building types, building characteristics, and building characteristic distribution were also developed for these island territories; therefore, justifying the development of a new mapping scheme specifically for Puerto Rico and one for the U.S. Virgin Islands. The process for developing this mapping scheme is described in the following section(s).

4.2 Methodology for Caribbean Mapping Scheme Development

Using a combination of the new building inventory developed for Puerto Rico and the U.S. Virgin Islands, the existing Hazus Southeast Coastal Mapping Scheme, and the new building characteristic subtypes identified for the territories, the following steps were performed for creating a new Caribbean mapping scheme.

4.2.1 Step 1: hzGenBldgScheme in syHazus

- The BldgType column was grouped by Specific Occupancy and summed, to yield a total number of each building type within each occupancy
- The summed building types within each occupancy were then used as the denominator to calculate the percentage distribution of building type across specific occupancy

Example result: RES1 = 60% wood + 30% masonry + 10% concrete

4.2.2 Step 2: huBldgMapping

- Note that each building characteristic subtype is assigned a unique value. Values are available in the BldgCharID column in the huListofBldgChar table.

Example: Roof Shape Hip = 1, Roof Shape Gable = 2, Roof Shape Flat = 3

- Each building characteristic subtype was counted and summed.
- Using totals for each building characteristic as the denominator, the percentage composition of each building characteristic by subtype was calculated.

Example: Roof Shape = 10% hip + 30% gable + 60% flat

The methodology for creating the Caribbean building inventory, as described in Sections 3.5 and 3.6, informs the counts and totals of building characteristic subtypes and does not allow for all building characteristic subtypes to be counted. Some characteristics – such as roofing components that sit inside the building between exterior roofing and interior ceiling or walls – cannot be determined through visual inspection of the building or imagery. In areas where wind-specific building codes exist, it is possible to estimate counts for these characteristics across different construction types based on building code requirements. For Puerto Rico and the U.S. Virgin Islands, availability of visible inspection and access to building codes were limited for the purposes of developing a building inventory. For this reason, for building characteristics where the denominator of the percentage was fewer than 30 structures, the corresponding percentage from the Hazus Southeast Coastal Mapping Scheme was used.

4.2.3 Step 3: huListOfBldgChar

The unique values for each building characteristic subtype were added to the reference table "huListofBldgChar." Most subtypes already have unique IDs; however, new IDs were created for territory-specific building characteristics, such as jalousie windows.

Table 4-2: Hurricane Model Building Characteristic Subtypes

BldgCharID	CharType	BldgChar	bcName	bcDescription
1	Roof Shape	rship	Hip	Roof Shape Hip
2	Roof Shape	rsgab	Gable	Roof Shape Gable
3	Roof Shape	rsflt	Flat	Roof Shape Flat
4	Roof Cover Type	rcbur	BUR	Roof Cover BUR
5	Roof Cover Type	rcspm	SPM	Roof Cover SPM
6	Roof Cover Quality	rqgod	Good	Roof Cover Quality Good
7	Roof Cover Quality	rqpor	Poor	Roof Cover Quality Poor
8	Secondary Water Resistance	swrys	Yes	Second Water Resistance Yes
9	Secondary Water Resistance	swrno	No	Second Water Resistance No
10	Roof Deck Attachment	rda6d	6d @ 6"/12"	Roof Deck Attachment 6d @ 6"/12"
11	Roof Deck Attachment	rda8d	8d @ 6"/12"	Roof Deck Attachment 8d @ 6"/12"
12	Roof Deck Attachment	rda6s	6d/8d Mix @ 6"/6"	Roof Deck Attachment 6d/8d Mix @ 6"/6"
13	Roof Deck Attachment	rda8s	8D @ 6"/6"	Roof Deck Attachment 8d @ 6"/6"
14	Roof Deck Age	dqgod	New or Average	Roof Deck Age New or Average
15	Roof Deck Age	dqpor	Old	Roof Deck Age Old
16	Roof Frame Type	rftrs	Wood Truss	Roof Framing Wood Truss
17	Roof Frame Type	rfows	OWSJ	Roof Framing OWSJ
18	Joist Spacing	jspa4	4 feet	Joist Spacing 4 feet
19	Joist Spacing	jspa6	6 feet	Joist Spacing 6 feet
20	Roof-Wall Connection	tnail	Toe-nail	Roof-Wall Connection Toe-nail
21	Roof-Wall Connection	strap	Strap	Roof-Wall Connection Strap
22	Window Area	walow	Low	Window Area Low
23	Window Area	wamed	Medium	Window Area Medium
24	Window Area	wahig	High	Window Area High
25	Garage, Houses w/out Shutters	gdnod	None	Garage Door No

BldgCharID	CharType	BldgChar	bcName	bcDescription
26	Garage, Houses w/out Shutters	gdwkd	Weak	Garage Door Weak
27	Garage, Houses w/out Shutters	gdstd	Standard	Garage Door Standard
28	Garage, Houses with Shutters	gdno2	None	Garage Door No
29	Garage, Houses with Shutters	gdsup	SFBC 1994	Garage Door SFBC 94
30	Shutters	shtys	Yes	Shutters Yes
31	Shutters	shtno	No	Shutters No
32	Windborne Debris	widdA	Res./Comm.	Residential\Commercial Missile Environment
33	Windborne Debris	widdB	Varies by direction	Residential\Commercial Missile Environment - Varies By Direction
34	Windborne Debris	widdC	Residential	Residential Missile Environment
35	Windborne Debris	widdD	None	No Missiles
36	Number of Units	nusgl	Single	Number of Units Single
37	Number of Units	numlt	Multi	Number of Units Multi
38	Masonry Reinforcing	rmfys	Yes	Reinforced Masonry Yes
39	Masonry Reinforcing	rmfno	No	Reinforced Masonry No
40	Tie Downs	mtdys	Yes	Mobile Home Tie Downs Yes
41	Tie Downs	mtdno	No	Mobil Home Tie Downs No
42	Roof Cover Type Hawaii	rcshl	Shingle	Roof Cover Shingle
43	Roof Cover Type Hawaii	rsmtl	Metal	Roof Cover Metal
44	Roof Deck Attachment Hawaii	rdast	Standard	Roof Deck Attachment Standard
45	Roof Deck Attachment Hawaii	rdasu	Superior	Roof Deck Attachment Superior
46	Truss Spacing	tspa2	2 feet	Truss Spacing 2 feet
47	Truss Spacing	tspa4	4 feet	Truss Spacing 4 feet
48	Wall Construction	wcdbl	Double Wall	Wall Construction Double Wall
49	Wall Construction	wcsgl	Single Wall	Wall Construction Single Wall
50	Uplift Restraint	uprys	Yes	Uplift Resistance Yes
51	Uplift Restraint	uprno	No	Uplift Resistance No
52	Metal Roof Deck Attachment	rd100	Standard	Metal Roof Deck Attachment Standard

BldgCharID	CharType	BldgChar	bcName	bcDescription
53	Metal Roof Deck Attachment	rd110	Superior	Metal Roof Deck Attachment Superior
54	Window Type	wtjal	Jalousie	Jalousie Window Type
55	Window Type	wtnor	Regular	Regular Window Type
56	Roof Cover Attachment	rcapr	Weak	Weak Roof Cover Attach - Corrugated steel/Standing seam roof fasteners
57	Roof Cover Attachment	rcagd	Strong	Strong Roof Cover Attach - Corrugated steel/Standing seam roof fasteners
58	Roof Cover Type	rccnt	Concrete	Concrete (MSF1 or MSF2 Only)
59	Roof Cover Type	rccor	Corrugated Steel	Corrugated Steel
60	Roof Cover Type	rcssm	Standing Seam Metal	Standing Seam Metal
61	Roof Cover Type	rcpnt	Elastomeric	Elastomeric Paint - Virgin Islands
62	Roof Cover Type	rcshg	Shingle	Shingle

4.2.4 Final Mapping Scheme Distribution

The distribution of attributes for PR and the USVI can be found within Hazus by opening the Hazus Study Region, and accessing the Inventory→General Building Stock (or Essential Facilities)→Wind Building Characteristics Distribution feature.

Section 5. Methods and Results for Secondary Environmental Factors

Several new hazard-related data sets were required to extend the applicability of the Hazus Hurricane Wind Model to Puerto Rico and the U.S. Virgin Islands. These include aerodynamic surface roughness, tree inventory models for tree debris estimation and tree blowdown damage to single-family homes, and distance inland data required to model wind fields based on NOAA forecast/advisories or user-defined storm tracks. The development of these new data sets is documented in this section.

5.1 Surface Roughness

Aerodynamic surface roughness reduces the speed of the wind near the surface of the earth. All else being equal, buildings located in rougher terrain experience lower wind pressures and less energetic windborne debris environments than buildings located in smoother, more open terrain. In Hazus, each Census tract or Census block is assigned a characteristic roughness length denoted by z_0. The fragility and vulnerability curves in the model are a function of the local surface roughness and the peak gust wind speed in open terrain.

5.1.1 Methodology

The aerodynamic surface roughness for Puerto Rico and the U.S. Virgin Islands is modeled using a similar methodology to that used for the continental United States, which is described in detail in Section 4.4 of the *Hazus Hurricane Model Technical Manual* (FEMA, 2021). However, a few improvements have been made to the surface roughness methodology for PR and the USVI, as described below.

5.1.1.1 APPLICATION OF TREE CANOPY

As with previous versions of Hazus, tree canopy percentage is incorporated into computation of the surface roughness for two land use/land covers (LULCs): Developed, Open Space; and Developed, Low Intensity. The National Land Cover Database (NLCD) LULC and tree canopy percentage data are provided as separate raster data layers. For the continental United States, the average tree canopy percentage within each of these two LULCs was used in each county. However, for Puerto Rico and the USVI, the methodology has been improved such that tree canopy percentages are applied at the pixel level to modify the surface roughness for these two LULCs. The effect of this improvement is that rather than having the same surface roughness value (z_0) for every pixel of these two LULCs within a county, each pixel will have its own aerodynamic roughness length, z_0. This is shown in the updated equations shown below. For each pixel of Developed, Open Space, the increased roughness due to the presence of trees is estimated as:

Equation 5-1:

$$z_{0dosT} = \sqrt{z_{0dos}^2 + \left(z_{0ef}^2 - z_{0dos}^2\right) * \left(\frac{P_{Tdos}}{P_{Tef}}\right)^2}$$

Where:

z_{0dosT}	is an increased z_0 for Developed, Open Space due to presence of trees
z_{0dos}	is a baseline z_0 for Developed, Open Space in areas with few or no trees
z_{0ef}	is the z_0 for Evergreen Forest
P_{Tdos}	is the percent tree canopy in Developed, Open Space (value of individual pixel)
P_{Tef}	is the percent tree canopy in Evergreen Forest (computed separately for each county)

For each pixel of Developed, Low Intensity, the increased roughness due to the presence of trees is estimated as:

Equation 5-2:

$$z_{0dliT} = \sqrt{z_{0dli}^2 + \left(z_{0ef}^2 - z_{0dli}^2\right) * \left(\frac{P_{Tdli}}{P_{Tef}}\right)^2}$$

Where:

z_{0dliT}	is an increased z_0 for Developed, Low Intensity due to presence of trees
z_{0dli}	is an initial z_0 for Developed, Low Intensity in areas with few or no trees
z_{0ef}	is the z_0 for Evergreen Forest
P_{Tdli}	is the percent tree canopy in Developed, Low Intensity (value of individual pixel)
P_{Tef}	is the percent tree canopy in Evergreen Forest (computed separately for each county)

The county average of tree canopy for Developed, Open Space and Developed, Low Intensity was only for pixels where NLCD tree canopy percentage values were not available (see Section 5.1.2).

5.1.1.2 CENSUS BLOCKS

As described in Section 4.4.4 of the *Hazus Hurricane Model Technical Manual* (FEMA, 2021), surface roughness was computed by taking the average z_0 value derived from the LULC and tree canopy data within each Census block. As was done for the continental United States, the average z_0 value for the 2010 Census blocks (US Census Bureau, 2020) with an area less than 1 square kilometer were computed based on a circular area with a diameter of approximately one kilometer, using the Census block centroid as the center of the circle. This was done to ensure that a minimum fetch of approximately 500 meters was obtained for small Census blocks. The fetch is the distance over which the wind has blown before reaching the point of interest.

For 2010 Census blocks (US Census Bureau, 2020) larger than 1 square kilometer, the average z_0 was computed from all the pixels within the Census blocks. However, for PR and the USVI, the Census blocks larger than 1 square kilometer in area were buffered out by 500 meters to include the same oncoming fetch as is done for a smaller Census block.

5.1.1.3 CENSUS TRACTS

As shown for Census blocks with areas greater than one square kilometer, the 2010 Census tracts (US Census Bureau, 2020) were buffered out by 500 meters to include the same oncoming fetch as Census blocks less than 1 square kilometer in area.

5.1.2 Puerto Rico

Though the general methodology used to model the surface roughness for PR and the USVI are the same, there are differences in the underlying data that resulted in adjustments to how the methodology is applied.

For Puerto Rico, raster data layers from the most recently available NLCD were used to determine the surface roughness (z_0):

- NLCD 2001 Land Cover (Puerto Rico) (MRLC, 2003)
- NLCD 2020 USFS Tree Canopy Cover (Puerto Rico) (MRLC, 2019)

The LULCs in NLCD's Puerto Rico are the same as those for the continental U.S., listed in Table 4-13 of the *Hazus Hurricane Model Technical Manual* (FEMA, 2021), which is reproduced as in

Table 5-1 below.

Table 5-1: LULCs for NLCDs Puerto Rico (MRLC, 2003)

Class No.	Class Name
11	Open Water
12	Perennial Ice/Snow
21	Developed, Open Space
22	Developed, Low Intensity
23	Developed Medium Intensity
24	Developed, High Intensity
31	Barren
41	Deciduous Forest
42	Evergreen Forest
43	Mixed Forest
52	Shrub/Scrub
71	Grassland
81	Pasture/Hay
82	Cultivated Crops
90	Woody Wetlands
95	Emergent Herbaceous Wetlands

The tree canopy layer contains values that range from 0-100% tree canopy. For Puerto Rico, additional values of 110 and 127 are also included to designate areas where tree canopy coverage could not be determined due to obstructions in satellite images, such as shadows or clouds (MRLC, 2019). The areas with undetermined tree coverage are black in Figure 5-1.

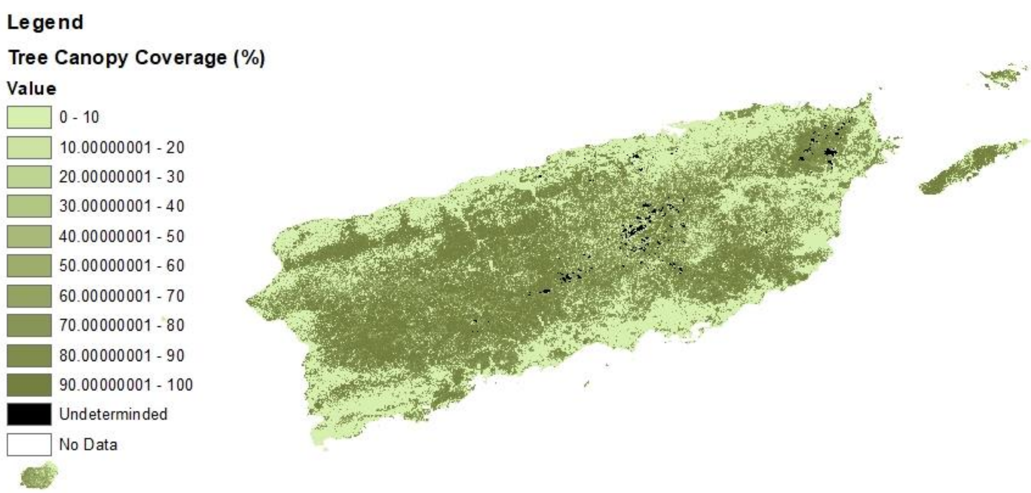

Figure 5-1: Tree Cover Canopy for PR

As discussed in Section 5.1.1, the surface roughness (z_0) values for Developed, Open Space and Developed, Low Intensity are based on the tree canopy percentages for each individual pixel. For the case where the tree canopy coverage for a pixel of these LULCs was not available, the municipality (county-equivalent) average tree canopy value for the appropriate LULC was used to align with the methodology used for the continental U.S.

5.1.3 U.S. Virgin Islands

Unlike the continental U.S. and Puerto Rico, the LULC data used for the USVI is not from the NLCD. The LULC raster data layer for the USVI was provided by the University of the Virgin Islands. The NLCD 2020 USFS Tree Canopy Cover (Puerto Rico) (MRLC, 2019) raster data layer was used since it included the USVI.

The LULC classification scheme used in the USVI raster data layer differs from the NLCD scheme. The mapping of the USVI LULCs to those of Puerto Rico and the continental U.S. in Table 5-2 shows that though the LULCs are similar, they are not identical. As shown in this table, only three LULCs for the USVI did not map directly to those of Puerto Rico and the continental U.S.: Airports, Rangeland, and Seaside. Airports are typically included in Developed, Open Space for the NLCD, but Developed, Open Space includes a lot more than just airports (e.g., golf courses, rural highways, and roads). Therefore, the Airport LULC for the USVI is treated slightly differently than Developed, Open Space in NLCD. Rangeland is broader than pastures or grasslands, and NLCD does not provide a seaside/beach category.

Table 5-2: Mapping of the USVI LULCs to those of Puerto Rico and Continental U.S.

U.S. and Puerto Rico LULCs (LULC #)	Corresponding USVI LULCs (LULC #)
Open Water (11)	Water (13)
Perennial Ice/Snow (12)	N/A
Developed, Open Space (21)	Developed Open Space (7)
Developed, Low Intensity (22)	Developed Low Intensity (5)

U.S. and Puerto Rico LULCs (LULC #)	Corresponding USVI LULCs (LULC #)
Developed, Medium Intensity (23)	Developed Medium Intensity (6)
Developed, High Intensity (24)	Developed High Intensity (4)
Barren Land (31)	Barren (2)
Deciduous Forest (41)	N/A
Evergreen Forest (42)	Forest (8)[1]
Mixed Forest (43)	N/A
Shrub/Scrub (52)	Shrub (12)
Grasslands/Herbaceous (71)	N/A
Pasture/Hay (81)	N/A
Cultivated Crops (82)	Cultivated (3)
Woody Wetlands (90)	Wetland (14)[2]
Emergent Herbaceous Wetlands (95)	N/A
N/A	Airport (1)
N/A	Rangeland (10)
N/A	Seaside (11)

[1] It was assumed that the Forest LULC for the USVI mapped to Evergreen Forest rather than Deciduous or Mixed Forest in Puerto Rico because the NLCD land cover data for Puerto Rico only included Evergreen Forest.

[2] Wetlands for the USVI were mapped to Woody Wetlands for Puerto Rico. However, Wetlands included a mix of woody and emergent herbaceous wetlands.

Both the LULC and tree canopy cover data are at a 30-meter resolution. The pixels were not perfectly aligned with one another, unlike Puerto Rico and the continental United States. However, the difference in pixel alignment was small, and the nearest tree canopy pixel is used for computation of the z_0 for the appropriate LULC pixel (i.e., Developed Open Space and Developed Low Intensity).

5.1.4 Special Cases for Census Blocks and Tracts

The methodology described in Section 5.1.1 could not be used in some cases, as described below.

5.1.4.1 PUERTO RICO CENSUS BLOCKS

There are 15 Census blocks in Puerto Rico that are not covered by the NLCD LULC data. Fourteen of these Census blocks are located on Mona Island, which is managed by the Mona Island Nature Reserve. There are no native inhabitants, and only rangers and biologists live on the island. The fifteenth Census blocks not covered by the NLCD LULC data is the Desecheo National Wildlife Refuge, which is uninhabited.

Based on a review of Google Earth images of these Census blocks, the land of these islands is heavily treed. Therefore, Census block surface roughness values (z_0) were computed as a weighted average of Census block area and the buffered block area. The unbuffered Census block area was assigned a z_0 of 900 millimeters and the buffered area was assigned a z_0 of 3 millimeters.

5.1.4.2 USVI CENSUS BLOCKS

A grid of approximately equal small squares was used as a substitute for actual Census blocks in the USVI to be consistent with those used for the Hazus Tsunami model. LULC data was not available for 32 of these Census blocks. As shown by the green dots (Census block centroids without LULC data) in Figure 5-2 and Figure 5-3, most of these Census blocks are for the smaller islands off the coast of St. Thomas. As was done for Puerto Rico, Google Earth images were reviewed for each island and it was observed that these islands were heavily treed. Therefore, as with Puerto Rico, the Census block surface roughness values (z_0) were computed as a weighted average of the unbuffered Census block area and the buffered Census block area, for which the unbuffered Census block area was assigned a z_0 of 900 millimeters and the buffered area was assigned a z_0 of 3 millimeters.

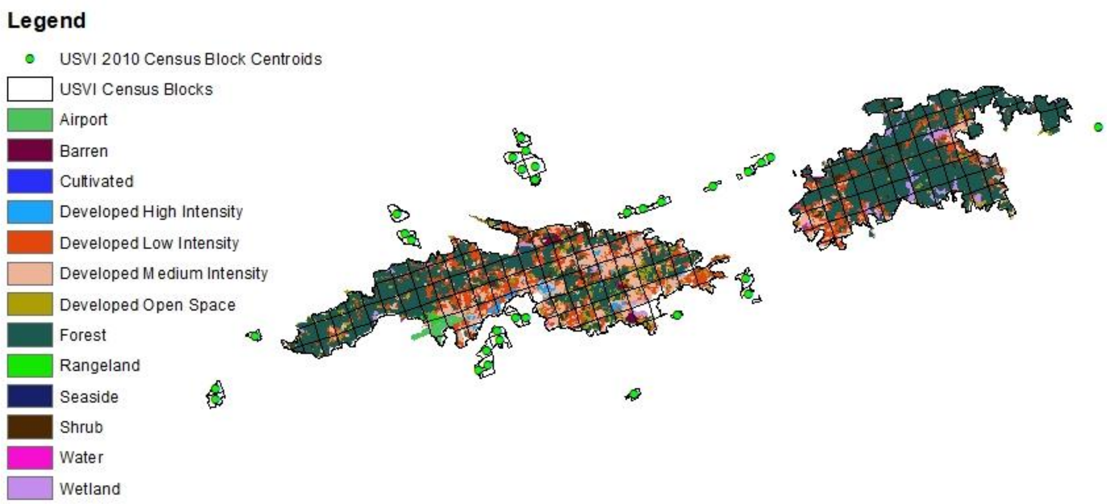

Figure 5-2: LULC Data for St. Thomas and St. John, USVI

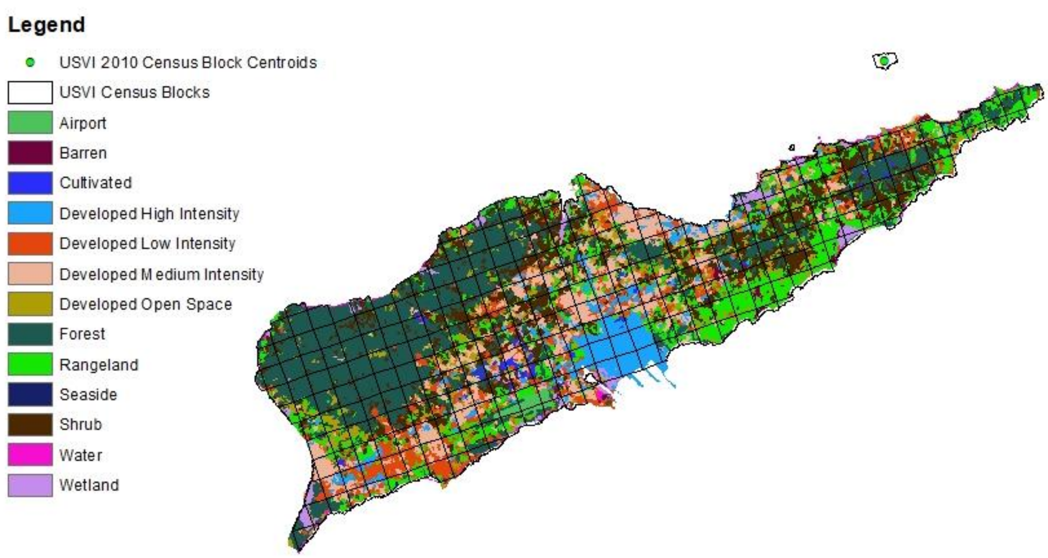

Figure 5-3: LULC Data for St. Croix, USVI

5.1.4.3 PUERTO RICO CENSUS TRACTS

One Census tract (72109990000) for Puerto Rico is located in an area not covered by the NLCD LULC data. As shown in Figure 5-4, this Census tract (highlighted in blue) is in an area of no data (black). Google Earth images were reviewed to verify that there was no land in the area associated with this Census tract. As a result, a surface roughness of 3 millimeters is assigned to this Census tract to indicate open water.

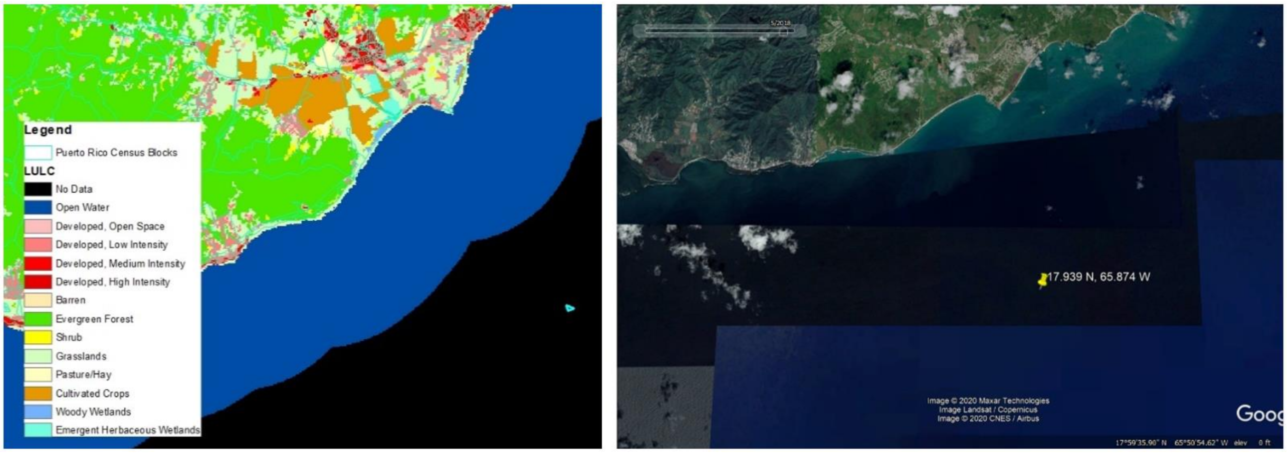

Figure 5-4: GIS Map and Google Map Image of PR Census Tract 72109990000

5.1.4.4 USVI CENSUS TRACTS

LULC data was only available for the major islands of the USVI (St. Croix, St. Thomas, and St. John). The smaller surrounding islands were associated with Census tracts on the main islands and thus used their z_0 values, with one exception. St. Thomas includes one Census tract (78030082000) for which no LULC data was available, as highlighted in Figure 5-5. For this Census tract, the average value of the Census blocks within that Census tract was used. The z_0 values of Census blocks for the areas where no LULC data was available are discussed in the subsections above.

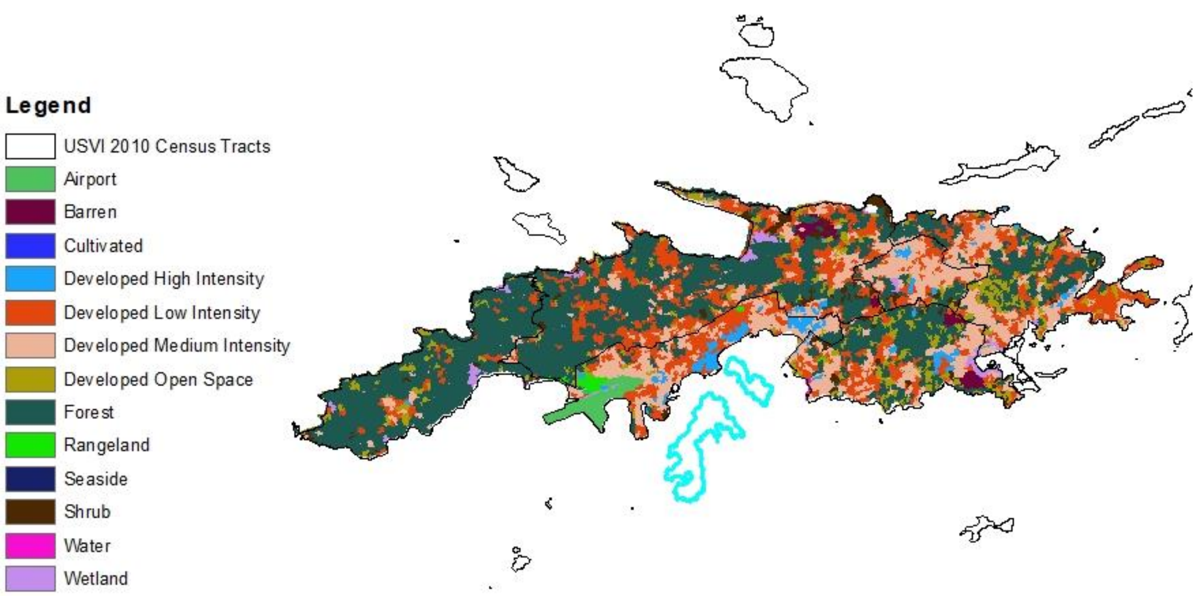

Figure 5-5: Census Tract in St. Thomas Without LULC Data

5.2 Tree Coverage Database

The Hazus Hurricane Wind Model includes methodologies for estimating the expected volume of tree debris generated by hurricanes and the added damage to single-family homes and manufactured housing due to tree fall. To model tree debris volume and tree fall damage, Hazus requires a predominant tree type (coniferous, deciduous, or mixed), a tree density (stems per acre), a tree height distribution, and a tree debris collection factor for each Census tract or Census block. These parameters are defined in Section 4.5.5 of the *Hazus Hurricane Model Technical Manual* (FEMA, 2021). The steps taken to extend the Hazus tree coverage database to include Puerto Rico and the USVI are summarized in the following subsections.

5.2.1 Tree Inventory Data by County

The predominant tree type and tree height distributions are assigned by county. Throughout both PR and the USVI, evergreen softwood trees are most common. In fact, all the forested areas in Puerto Rico are classified as Evergreen Forest in the 2001 NLCD. In Hazus, evergreen forests are currently modeled using typical strength and drag characteristics of pine trees and are designated as coniferous. Thus, the predominant tree type for all Census tracts and Census blocks in Puerto Rico and the USVI has been set to coniferous as this is the best available alternative for tropical evergreens. Using drag characteristics of pine trees to represent all evergreen trees is a limitation of the current implementation of the Hazus Hurricane Wind Model.

The tree height distributions for each county have been derived from the USFS Forest Inventory Analysis (FIA) database (USFS, 2018a and 2018b). In Hazus, only trees greater than 30 feet in height are considered, as impacts from trees less than 30 feet in height are unlikely to significantly damage homes, and trees less than 30 feet in height do not typically constitute a substantial portion of the overall tree debris weight, or volume after chipping, in most hurricane-prone areas.

The FIA provides tree heights for all trees located within a stratified sampling of plots or subplots in forest land within each county or county-equivalent area. The species, diameter, height, and other characteristics are recorded for each tree that is greater than 1 inch in diameter.

- Tree heights were grouped into four groups:
  - Neglected: ACTUALHT < 30 feet
  - Short: 30 ≤ ACTUALHT < 40 feet
  - Medium: 40 ≤ ACTUALHT < 60 feet
  - Tall: 60 ≤ ACTUALHT
- The number of trees per acre represented by each sampled tree is TPA_UNADJ*EXPNS*ADJ_FACTOR_SUBP, where:
  - TPA_UNADJ is the unadjusted tree height from the XX_TREE table, where XX=PR or VI
  - EXPNS is the expansion factor associated with each plot is obtained from the XX_POP_PLOT_STRATUM_ASSGN table, where XX=PR or VI
  - ADJ_FACTOR_SUBP is the subplot adjustment factor from the XX_POP_STRATUM table, where XX=PR or VI

FIA survey data for both live and dead trees were included in the computations. For Puerto Rico, 2019 inventory data were used, and for the USVI, 2014 inventory data are used. These were the most recently available inventory years for each territory. The results for the USVI are provided in Table 5-3:

Table 5-3: USVI County-Level Tree Inventory Data for Forested Land

FIPS	Island	Tree Type	Stems≥30ft	Stems/Acre	Short	Medium	Tall
78010	St. Croix	Coniferous	1,888,991	64	89%	11%	0%
78020	St. John	Coniferous	1,401,558	143	77%	22%	1%
78030	St. Thomas	Coniferous	653,641	87	94%	6%	0%

An equivalent set of results was developed for Puerto Rico using the same approach. However, FIA data were not available for 10 of the 78 municipalities (county-equivalents) in Puerto Rico. For each of these 10 municipalities, the averages of the values from two adjacent municipalities were used as substitutes.

5.2.2 Tree Density at Census Block Level

As described in Section 4.5.5.2 of the *Hazus Hurricane Model Technical Manual* (FEMA, 2021), there are four steps to determine the average tree density at the Census block level.

Step 1. Compute the Average Tree Density for Forested Land in Each County

See Section 5.2.1.

Step 2. Compute Average Tree Canopy Percentage for Forested Land in Each County

As described in Section 4.5.5.2 of the *Hazus Hurricane Model Technical Manual* (FEMA, 2021), the NLCD tree canopy percentage layer was used to compute the average tree canopy coverage of forested land in each county. For Puerto Rico, the average tree canopy was computed from pixels classified as evergreen forest and woody wetlands. As previously mentioned, there are no LULC pixels classified as deciduous or mixed forest for Puerto Rico and Hazus only has two categories of tree models: hardwood (deciduous) and softwood (coniferous). The USFS categorizes the vast majority of tropical trees as softwoods, so that categorization was applied for PR and the USVI.

Although some of the categories in the USVI LULC layer differ from those used in the NLCD, the forested LULCs are similar: Forest and Wetlands. Google Earth images of areas classified as wetlands in the USVI were reviewed and it was determined that they included areas that would most likely be classified as either woody wetlands or emergent herbaceous wetlands under the NLCD LULC classification system. The data from Puerto Rico were also reviewed, and it was found that the number of pixels classified as woody wetlands (about 116,000 pixels) was similar to the number of pixels classified as emergent herbaceous wetlands (about 156,000 pixels). The mean tree canopy coverage for forested land was computed for the USVI counties both including and excluding wetlands for each county. As shown in Table 5-4, the difference in mean tree canopy for forested land including vs. excluding wetlands is very small, which was expected since there are approximately 8,500 pixels classified as wetland versus approximately 143,500 pixels classified as forest in the USVI. Ultimately, it was decided to include Wetlands to ensure that forested wetlands were included with Forested land in the calculation.

Table 5-4: Mean tree canopy coverage for forested land in the USVI including vs. excluding wetlands

County	Mean Tree Canopy including Wetlands (%)	Mean Tree Canopy excluding Wetlands (%)	Difference (%)
St. Croix	66.85	68.86	2.01
St. John	79.20	80.23	1.03
St. Thomas	75.02	75.70	0.68

Step 3. Compute Stems per Acre for 100 Percent Tree Canopy in County

Next, the number of stems per acre corresponding to a tree canopy percentage of 100% was estimated for each county by assuming that the tree density and average canopy over forested areas are proportional. For example, if a county has 75 stems per acre and an average tree canopy percentage of 50% in its forested land, the stems per acre at 100% canopy was assumed to be 150 stems per acre. As stated in the *Hazus Hurricane Model Technical Manual* (FEMA, 2021), the maximum stems per acre is capped at 400 to reflect real-world limits on tree density.

Step 4. Compute Stems per Acre for Census Blocks

Finally, the average tree canopy percentage over forested land of each Census block was multiplied by its county's corresponding stems per acre for 100% tree canopy. The average tree canopy percentage for forested areas in each Census block was computed using the approach described for counties under Step 2.

As discussed in Section 5.1, Puerto Rico included areas where tree canopy cover data was not available due to obstructions in satellite images such as shadows or clouds. In some cases, these areas cover an entire Census block. For such Census blocks, the county average tree canopy percentage was used for the Census block. The USVI did not include any areas where the tree canopy coverage was undefined.

5.2.3 Tree Debris Collection Factor

As described in Section 6.3 of the *Hazus Hurricane Model Technical Manual* (FEMA, 2021), the methodology for estimating tree debris collection quantities is based on the premise that downed trees lying near streets, buildings, and other developed areas will most likely be cut into pieces and moved to the roadside for collection and disposal. In moderately or densely built areas, virtually all downed trees are likely to be collected. In sparsely built or undeveloped areas, only a fraction of trees downed are likely to be collected.

The parameters required for the tree debris collection model are the Census block area, the Census block perimeter, the number of buildings per acre in the Census block, and the total length of any roadways that lie within a Census block. The areas, perimeters, and building densities for each Census block in Puerto Rico and the USVI come directly from the Census block shapefiles and the Hazus building inventory.

To compute the total length of interior roadways, 2019 roadway shapefiles were downloaded from the U.S. Census Bureau for each county in Puerto Rico and the USVI (US Census Bureau, 2019).

For Puerto Rico, a negative buffer of 25 feet was applied to the 2010 Census blocks. The purpose of the negative buffer is to avoid the inclusion of roads that define the Census block boundary (see Figure 5-6). The use of 25 feet as a buffer is consistent with the assumed perimeter collection area described in Section 6.3 of the *Hazus Hurricane Model Technical Manual* (FEMA, 2021). That is, downed tree debris within 25 feet of bounding roads would most likely be cleared from the right-of-way and collected for disposal.

Figure 5-6. Roads and Block Boundaries With Negative Buffer of 25 Feet

For the USVI, Hazus uses a regular grid of rectangles in place of actual Census block boundaries. Unlike Puerto Rico, where it was clear that the Census blocks followed the path of roads and highways, the Census blocks for the USVI were small squares with approximately equal areas (see Figure 5-7). Because these Census blocks did not follow any known roads and highways, any length of road within their boundaries was included, meaning no negative buffer was applied to the Census blocks for the USVI.

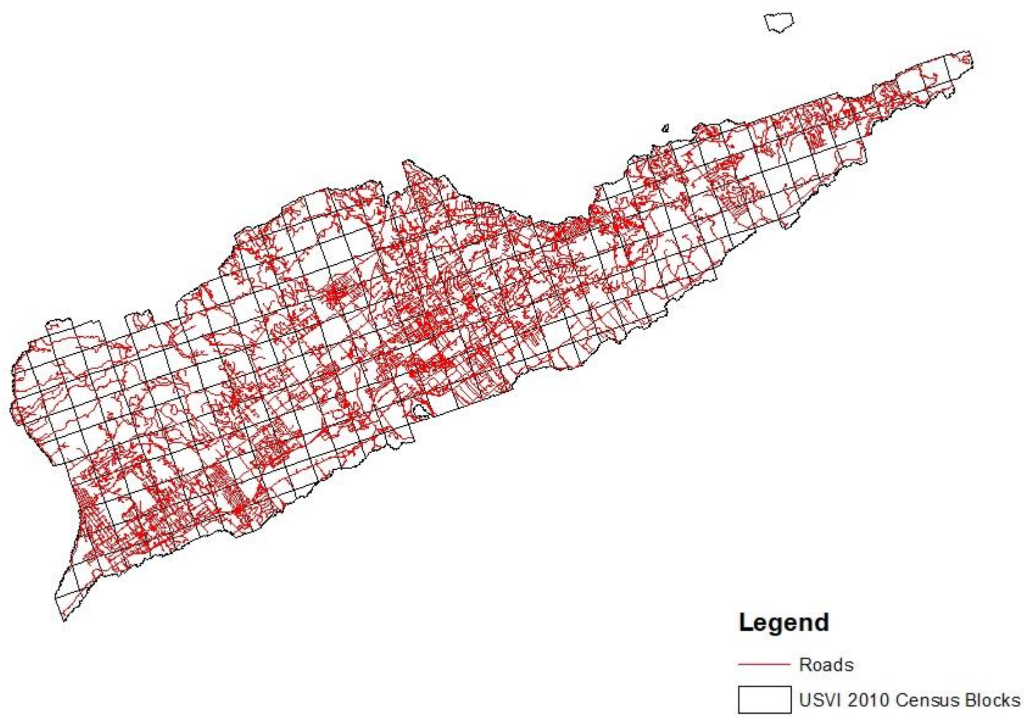

Figure 5-7: Roads and Regular Grid Used by Hazus to Approximate Census Blocks for St. Croix

5.2.4 Final Results

In the Hazus Hurricane Module, a default tree database combines the results of the analysis outlined in Section 5.2.1 through 5.2.3. An example of the default Hazus tree database for the first 16 Census tracts in Puerto Rico is shown in Figure 5-8. As shown in Figure 5-8, each Census tract includes the following parameters:

- Predominant tree type
- Stems per acre
- Percentage of trees 30-40 feet tall
- Percentage of trees 40-60 feet tall
- Percentage of trees greater than 60 feet tall
- Tree debris collection factor

For Study Regions that include both hurricane and flood hazards, the Hurricane Model operates at the Census block level of resolution. For such Study Regions, the rows in the tree parameters table are Census blocks instead of Census tracts. All of the other column headings remain the same.

Tree Parameters

Table:

	Census Tract	Predominate Tree Type	Stems per Acre	Tree Height Less 40 ft	Tree Height 40 ft To 60 ft	Tree Height Greater than 60 ft	Tree Collection Factor
1	72001956300	Coniferous	228	61	34	5	0.23
2	72001956400	Coniferous	228	61	34	5	0.20
3	72001956500	Coniferous	228	61	34	5	0.20
4	72001956600	Coniferous	228	61	34	5	0.60
5	72001956700	Coniferous	228	61	34	5	0.70
6	72001956800	Coniferous	228	61	34	5	0.23
7	72003430100	Coniferous	52	44	48	8	0.40
8	72003430200	Coniferous	52	44	48	8	0.39
9	72003430300	Coniferous	52	44	48	8	0.70
10	72003430401	Coniferous	52	44	48	8	0.53
11	72003430402	Coniferous	52	44	48	8	0.40
12	72003430501	Coniferous	52	44	48	8	0.46
13	72003430502	Coniferous	52	44	48	8	0.44
14	72003430601	Coniferous	52	44	48	8	0.45
15	72003430602	Coniferous	52	44	48	8	0.37
16	72005400100	Coniferous	68	59	34	7	0.53

Print Map OK Cancel

Figure 5-8: Example Tree Parameters for Census Tracts in Puerto Rico

5.3 Distance Inland to Census Tract Centroids

The Hazus Hurricane Wind Model includes a capability to estimate wind speeds at each Census tract centroid within a Study Region given a storm track. In addition to the storm track parameters, the Hazus Hurricane Wind Model requires the distance inland from the coastline to each Census tract centroid to model the transition of the hurricane boundary layer wind field from marine to overland conditions.

To enable use of the Hazus Hurricane Wind Model for user-defined storm scenarios or NOAA forecast/advisory scenarios affecting Puerto Rico or the USVI, distance inland values were computed for each 2010 Census tract centroid for each of 36 compass directions in 10 degree increments (e.g., 0, 10, 20, ..., 350). These distances were computed using a coastline from the NOAA Global Self-consistent, Hierarchical, High-resolution Geography Database (GSHHG) (NOAA, 2019). The distances were computed using a custom Fortran program that projects a two-dimensional ray from a point in a specified direction. The point and a polygon representing the coastline are projected to Cartesian coordinates using an Albers projection. The distance to the coast is the Cartesian length of the ray from its point of origin to the point where the ray intersects the polygon. Results were tabulated for each of 36 directions. The minimum and maximum distances to the coast from each centroid were also tabulated for quality assurance checks.

An initial calculation was completed to determine if any of the Census tract centroids had negative values, such as if the centroid was located in the water outside the coastline. Of the 924 Census tract centroids for Puerto Rico and the USVI, 29 were located outside the coastline. These centroids were moved on land but kept close to their original offshore locations. Once all Census tract centroids were confirmed to be over land, the distance inland was calculated again.

The minimum and maximum distances inland are tabulated for each island (Puerto Rico, St. Croix, St. John, St. Thomas) in Table 5-5. As expected, the minimum distance inland on each island is positive and the maximum distance inland on each island is less than the length of the island. A distance of 0.0 km indicates that the Census tract centroid is closer to the coast than 0.05 km. The minimum distance inland for each Census tract in Puerto Rico and the USVI is shown in Figure 5-9 through Figure 5-11.

Table 5-5: Minimum and Maximum Distance Inland for PR and USVI

Island	Min. Distance Inland (km)	Max. Distance Inland (km)	Approximate Length of Island (km)
Puerto Rico	0.0	171.0	175
St. Croix	0.3	33.1	36
St. John	0.2	9.1	12
St. Thomas	0.1	18.3	22

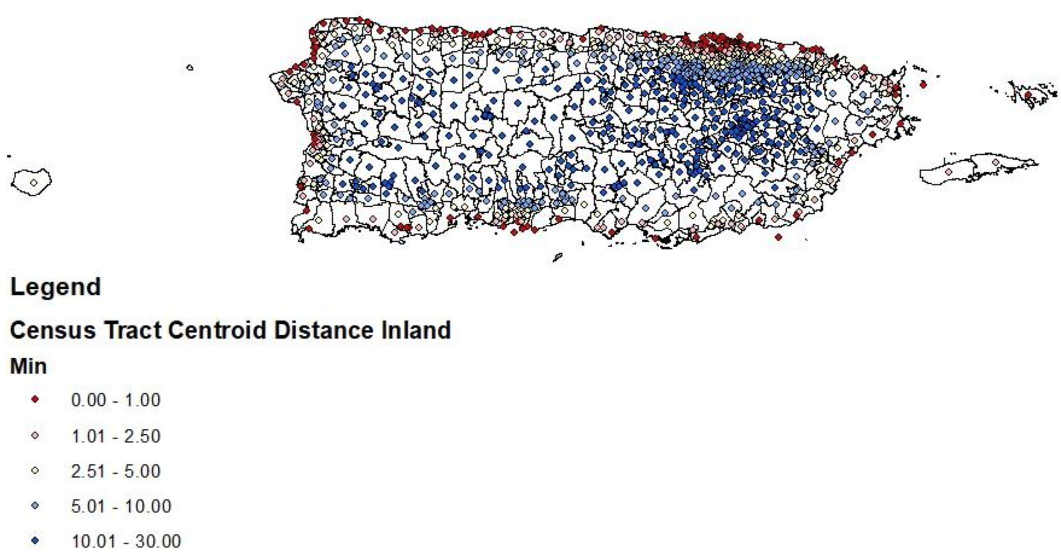

Figure 5-9: Minimum Distance Inland (km) for Census Tract Centroids in Puerto Rico

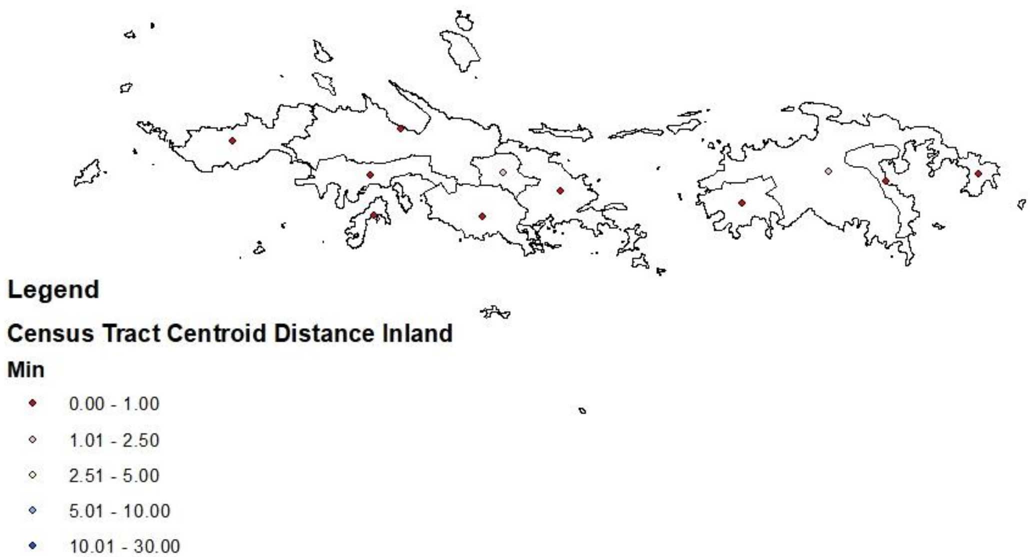

Figure 5-10: Minimum Distance Inland (km) for Census Tracts in St. Thomas and St. John

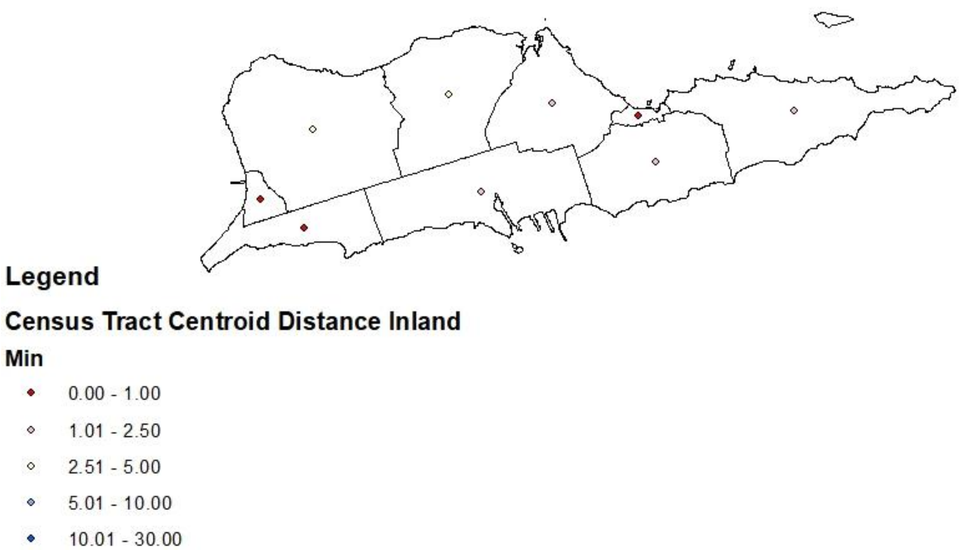

Figure 5-11: Minimum Distance Inland (km) for Census Tracts in St. Croix

5.4 Topographic Wind Speed Changes

Topography can create speed-up or slow-down effects on wind speed, depending on local conditions and the shape and altitude of the terrain. Hazus Hurricane Wind accounts for this in Hawaii, which has mountainous terrain similar to that found in Puerto Rico and U.S. Virgin Islands. At the time of publication for this report, the wind speed data required to fully incorporate all topographic speed-up and slow-down effects, across all types of hurricane modeling in Hazus, is not yet available. However, one study was done to analyze and develop topographically-induced wind speed changes for Hurricane Maria in Puerto Rico. The methodology for this study was developed for multiple hurricanes in Vickery (2019) and applied to Hurricane Maria for Puerto Rico in Mudd et al. (2018).

The results of these reports for Hurricane Maria in Puerto Rico were applied to the Hazus Hurricane Wind speed profile data included in Hazus. This was achieved by adapting the methodology proposed in Vickery (2019) and Mudd et al. (2018), where the topographically adjusted wind speeds were averaged over each building footprint location within a Census tract, producing a single updated average wind speed value for each Census tract.

It is important to note that this was done only for Hurricane Maria in Puerto Rico. Users wishing to update wind speed data for Maria in the U.S. Virgin Islands, or additional storms in both territories, will need to follow these steps:

1. Calculate wind speeds for the desired storm/location over an appropriate area for flat, open terrain. Hazus Hurricane Wind has some capability for this now.
2. Apply the methodology outlined in Vickery (2019) to the calculated wind speeds. Vickery (2019) provides the necessary methods for applying topographic speed-up or slow-down as appropriate, and also contains completed data for Hurricanes Harvey, Irma, and Nate, in addition to Maria.
3. To apply the topographic wind speeds to Hazus General Building Stock, the method described above must be used where a single average wind speed is calculated across each Census tract in the desired Study Region.

5.5 Probabilistic Modeling

Probabilistic hurricane event analyses can be performed for Puerto Rico and the U.S. Virgin Islands, but with the following differences from the mainland US probabilistic model:

1. The wind model for PR and USVI – including probabilistic events – does not include topographic speed-up or slow-down factors. Users should exercise caution when interpreting results generated by these windfield models without topographic adjustments.

2. The probabilistic event sets for PR and USVI do not align with the US Mainland event set, with the exception of the 100,000-year event which is the same for PR and USVI, US Mainland, and Hawaii. Users should avoid creating study regions for probabilistic scenarios that include areas from both PR/USVI and US Mainland.

The methodology for running a probabilistic wind scenario in PR and USVI is otherwise the same as doing so for the US Mainland in previous versions of Hazus. Users should refer to the Hazus Hurricane User Guidance and all relevant Release Notes for more information.

Section 6. Development of Damage and Loss Functions for USVI and PR

6.1 Introduction

The unique characteristics of the building stock in PR and the USVI could not be modeled using the existing Hazus damage functions, which were developed for use in the contiguous United States and Hawaii. Examples of building stock characteristics present in PR and the USVI, which are not accounted for in existing Hazus damage functions, include:

- Informal construction in Puerto Rico typically comprising of a masonry lower story with a wood frame second story, and a corrugated metal roof nailed to wood rafters with spacing of four feet
- The prevalence of jalousie windows
- Single-family residences with concrete roofs
- Single-family residences with standing seam metal roofs mounted on a plywood or OSB roof deck
- Single-family residences with an elastomeric waterproof coating over the plywood or OSB roof deck

In order to model the new building types and characteristics, new damage curves had to be developed for corrugated metal roof panels, standing seem metal roof panels, and jalousie windows. Various attachment methods were examined for both types of metal roof panels and the failure pressures were computed using finite element models. The use of finite element modeling to estimate the uplift capacities of metal panels is the same methodology used to develop the uplift capacity of steel roof deck panels in the original version of the Hazus Hurricane Wind Model. The capacity of the jalousie windows was obtained through a literature search of experimental studies examining the pressure resistance of jalousie windows.

6.2 Development of Fragilities for Metal Roof Panels

The version of Hazus developed for the U.S. mainland does not have the capability to model metal roofs. Since metal roofs are common in both PR and the USVI, it was necessary to add the ability to model them. Three types of metal roofs were considered, namely:

- Corrugated metal nailed or screwed to wood purlins
- Standing seam metal attached to metal purlins using clips
- Standing seam metal attached to plywood or OSB decking using screws

In all cases, the metal roof serves as the water resistant barrier. Since there is limited public domain information on the uplift capacities of metal roofing systems, finite element analyses (FEA) were performed to develop the uplift capacities of the metal roof systems examined.

The corrugated metal roofs are commonly used in informal construction where a second story comprising a wood frame structure is added above an existing one-story masonry or concrete structure. The corrugated metal panels are usually nailed to purlins which may be spaced up to four feet apart, resulting in a relatively weak roofing system. The analysis of the corrugated metal panel uplift capacity considered a range of metal panel thicknesses, purlin spacings, and two methods of attachment (nails and screws). Sensitivity studies varying the gauge (thickness) of the metal, fastener spacing, and purlin spacings were performed.

The uplift capacities of the metal panels were all computed using FEA, specifically using the ANSYS software package. This same approach was used to develop the uplift resistances of the engineered metal deck currently used in Hazus for commercial buildings having metal decks fastened to open web steel joists using mechanical fasteners or welds. The metal panels used in commercial structures are much different than the metal panels used for light frame residential construction.

6.2.1 Finite Element Analyses

6.2.1.1 UPLIFT RESISTANCE OF CORRUGATED METAL ROOFING

Detailed finite element models of corrugated metal roof were developed to evaluate their wind uplift resistances where the metal panels are connected to the supporting battens using 8d common nails.

6.2.1.1.1 ANSYS Model Components

The finite element models of metal roofs were developed using the general purpose finite element software ANSYS 16.0 using the techniques presented in Mahendran (1990, 1992, 1994). The metal panels were modeled using elastic orthotropic 3D shell elements (SHELL181), which is defined by four nodes having six degrees of freedom at each node (i.e., translations in the x, y, and z directions and rotations about the x, y, and z directions). The shell element has shear, bending, and membrane stiffness, and is also well-suited for linear, large rotation, and large strain nonlinear applications. The battens and trusses are modeled using isotropic 3D beam elements (BEAM188), which are defined using two nodes having six degrees of freedom at each node. The beam element has axial and bending stiffness and is well-suited for linear, large rotation, and large strain nonlinear applications. The connections between metal panels and the supporting battens are modeled by using a zero-mass nonlinear spring element (COMBIN39) that connects a pair of nodes with nonlinear generalized force-displacement capability. This element is unidirectional and hence, each 8d nail connection is modeled with three independent nonlinear spring elements to account for one axial and two lateral stiffnesses representing the load-displacement relationships in the x, y, and z directions. This type of element has been successfully used for numerical simulation of timber structures by Kumar et al. (2012) and Pan et al. (2013).

Figure 6-1 shows a typical finite element mesh for the corrugated metal panel roof system used in this study. Note that the metal roof panel elements were placed at an offset from the framing elements to account for the difference in the location of the centroid of the framing members to the centroid of the metal roof panel, as shown in Figure 6-1. The offset of the framing and metal panel planes is true to the physical system; however, it has no bearing on the behavior of the model because of the manner in which the fasteners are modeled.

This metal panel roof system was analyzed by applying uniform wind uplift pressure with boundary conditions applied only to the fastener locations.

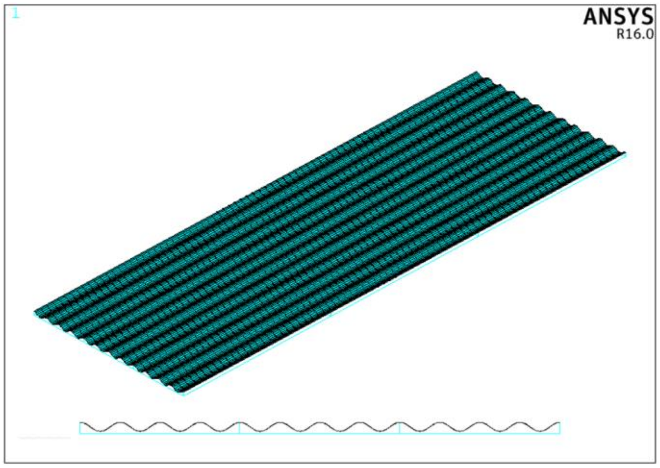

Figure 6-1: Typical Finite Element Mesh of Corrugated Metal Roof

6.2.1.1.2 Material Properties

The finite element model accounts for the anisotropic and nonlinear material properties of the cladding as reported in the study by Lovisa et al. (2013) for a G550 corrugated metal sheet. The material properties of the G550 corrugated metal sheet, including the strain hardening characteristics, were incorporated into the numerical model through a multilinear kinematic hardening model developed by fitting an experimental stress-strain curve (Xu and Teng 1994, Lovisa et al. 2013), as shown in Figure 6-2. The isotropic elastic modulus and Poisson's ratio for wood battens are obtained from Doudak (2005) and Martin et al. (2010), respectively. The force-displacement responses used in the modeling of nonlinear springs representing 8d nail connections are presented in Figure 6-3 and were obtained from test results reported by Thampi (2010), where the connection was tested under withdrawal load, lateral slip, and moment to characterize the nail behavior. The nonlinear force-displacement data obtained from these tests were used as input material properties for the 8d nails by approximating the nonlinear experimental responses with a multilinear model.

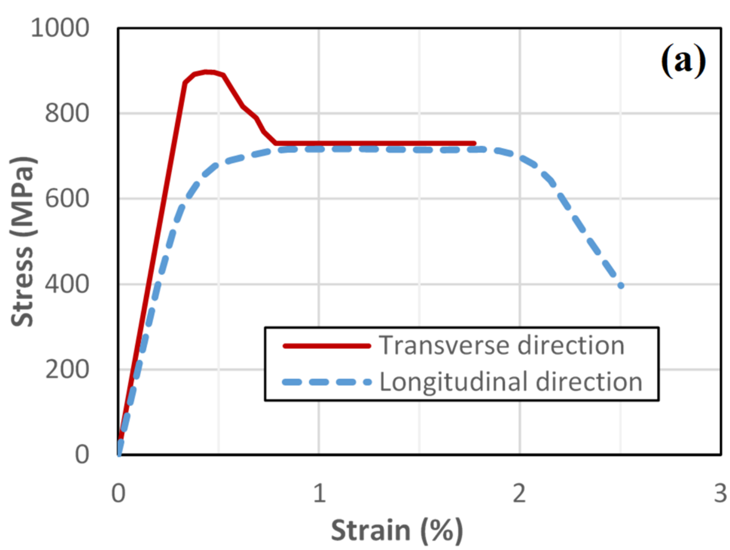

Figure 6-2: Uniaxial Stress-Strain Response of G550 Corrugated Metal Sheet from Xu and Teng (1994) and Lovisa et al. (2013)

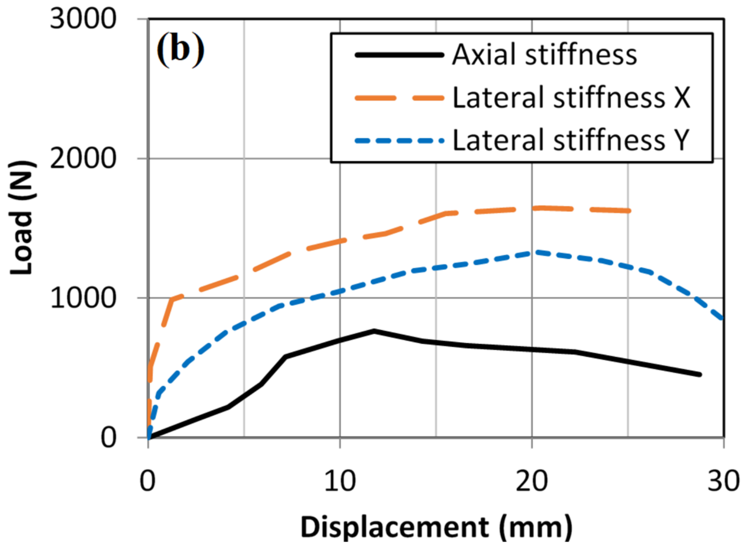

Figure 6-3: Force-Displacement Relationships Used for Nonlinear Springs Representing 8d Nails Connecting Metal Cladding to Wood Battens (Thampi, 2010)

Table 6-1 shows the material properties used for the wood battens and metal panels of the corrugated metal roof system. In this study, nonlinear springs representing connections between metal cladding and battens were used to define the stiffnesses in the axial and two lateral directions.

Table 6-1: Material Properties of Different Components of the Corrugated Metal Roof System

Component	Young's modulus (GPa)	Yield stress (MPa)	Poisson's ratio
Batten	9.6	-	0.4
Metal cladding	219-longitudinal 252-transverse	716-longitudinal 886-transverse	0.3

6.2.1.1.3 Model Validation

The finite element models of a corrugated metal roof with nail connections between metal claddings and battens could not be validated due to the unavailability of experimental responses on such roof systems. However, the finite element models were validated against experimental responses of a corrugated metal roof system where the metal claddings were connected to battens using sheet metal screws. These experimental data were taken from the studies of Xu and Reardon (1993) and Lovisa et al. (2013), where a 26-gauge corrugated metal roof of 900 millimeters span was tested under static uplift loads. The finite element models were developed according to the experimental setup and material properties specified in Xu and Reardon (1993) and Lovisa et al. (2013). The simulated uplift pressures versus vertical deflections of the metal panels are compared to the measured responses in Figure 6-4, where it is observed that the finite element models predict the experimental uplift responses reasonably well.

Simulated von-Mises stress contours of the corrugated metal roof system indicate that the stresses around the connections were close to the ultimate strength of sheet metal, suggesting a pull-through failure of the connection. This is consistent with the failure modes observed in the experiments. Given that the numerical technique developed herein can accurately calculate the uplift resistance of a corrugated metal roof with screw connections to battens, the same model was used to investigate the uplift resistance of a corrugated metal roof with nail connections to battens.

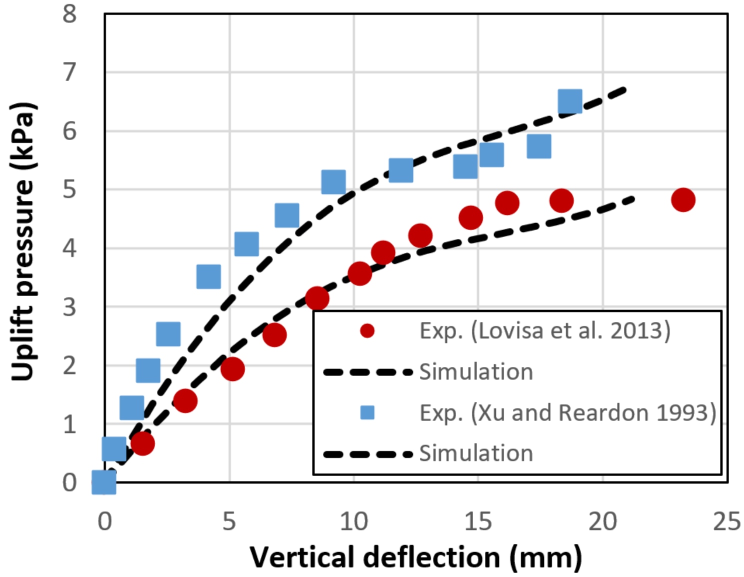

Figure 6-4: Comparison of Uplift Pressure-Vertical Displacement Responses Between Experiment (Lovisa et al. 2013) and Simulation

6.2.1.1.4 Sensitivity Analysis

The developed finite element models were used to investigate the effect of batten spacing, panel width, nail spacing, and sheet metal gauge on the uplift resistance of a corrugated metal roof with nail connections to battens. In the analysis, the depth and the pitch distance of corrugations are taken as 16 millimeters and 76.2 millimeters, respectively. The nail spacing in the direction of the corrugation (x-direction) was taken as 300 millimeters, while the nail spacing in the direction perpendicular to corrugation (z-direction) was varied between 600-1,250 millimeters. The gauge of the metal was varied between 24-35 and the panel width and batten spacing were varied between 600-1,250 millimeters.

The uplift resistances of the metal roof obtained from the analysis are presented in Figure 6-5 for different nail spacings and gauges of metal cladding. With an increase in the gauge of the cladding, the uplift resistance increases. With an increase in the spacing between the nails in the direction perpendicular to corrugations, there is a noticeable decrease in the uplift resistance of the panels.

Figure 6-6 shows the vertical reactions in the nails as a function of nail spacing, which are less than the nail pullout capacity during loading. This indicates that the governing failure mode of the corrugated metal roof where the metal claddings are connected to wood battens with nails was pull-through failure of the sheet metal panel and further explains the increase in the uplift capacity of the roof panels with increasing thickness of the base metal. The failure mode was also confirmed by the stress contours, where it was found that the von-Mises stresses were close to the ultimate strength of the base metal around the fastener locations.

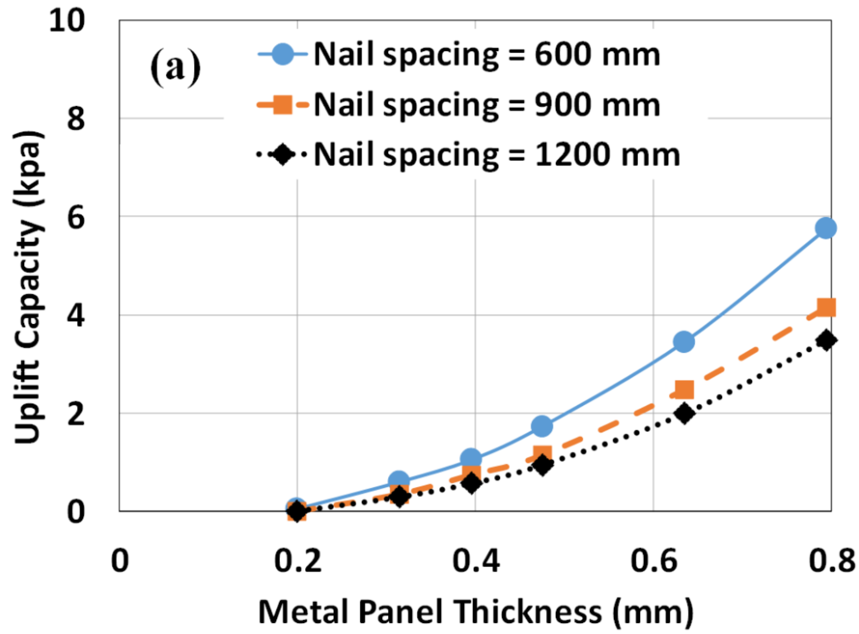

Figure 6-5: Modeled Uplift Resistances of Corrugated Metal Roof with Nail Connections to Battens

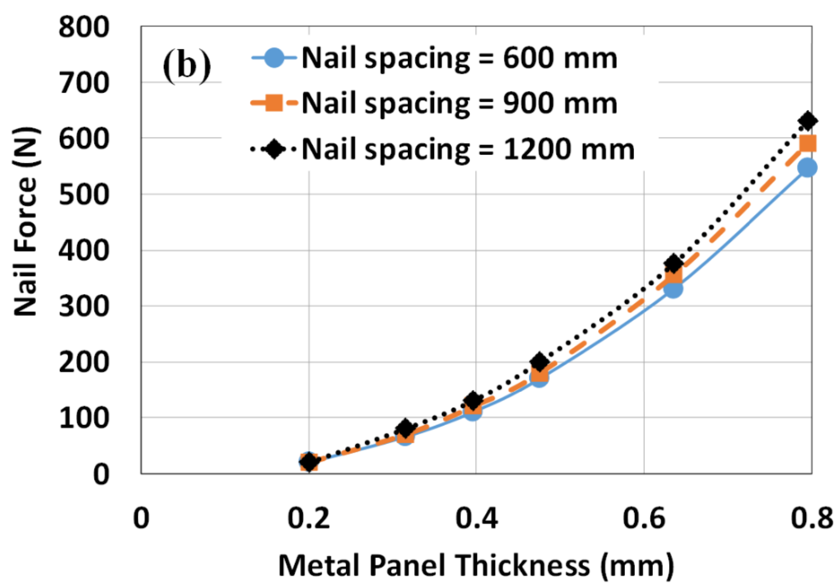

Figure 6-6: Modeled Nail Vertical Reactions Plotted Against Metal Panel Thickness

6.2.1.2 UPLIFT RESISTANCE OF STANDING SEAM METAL ROOFS CONNECTED TO ROOF DECK USING THROUGH FASTENERS

Detailed finite element models of standing seam metal roofs connected to a plywood roof deck with sheet metal screws were developed to evaluate their wind uplift resistances. The finite element model was utilized to study the influence of several design variables on the uplift resistances such as seam height, metal thickness, fastener spacing, and width of the panel. Based on FEA responses, parametric equations were developed to calculate wind uplift resistances of these standing seam metal roofs connected to plywood roof decks subjected to uniform uplift pressure.

6.2.1.2.1 ANSYS Model Components

The finite element models of metal roofs were developed using the general purpose finite element software ANSYS following the techniques presented in Damatty et al. (2003). The metal panels and roof deck were modeled using elastic orthotropic 3D shell element (SHELL181), defined earlier. The trusses and battens are modeled using isotropic 3D beam element (BEAM188), also defined earlier. For standing seam metal roofs, seams and fasteners are modeled using nonlinear spring elements (COMBIN39), which are unidirectional elements with nonlinear generalized force-displacement capability. The seam was simulated as a continuous spring system having a horizontal component simulating the stiffness provided by the seam in the transverse in-plane direction of the panel, and a rotational component simulating the rotational stiffness provided by the seam about the longitudinal axis of the panel. The screws were simulated as discrete vertical springs.

Figure 6-7 shows typical finite element mesh of the standing seam metal roof panels used in this study. This metal panel roof system was analyzed by applying uniform wind uplift pressure with boundary conditions applied only to the fastener locations. The corresponding simulated von-Mises stress contours (in MPa) under wind uplift loads are shown in the right image.

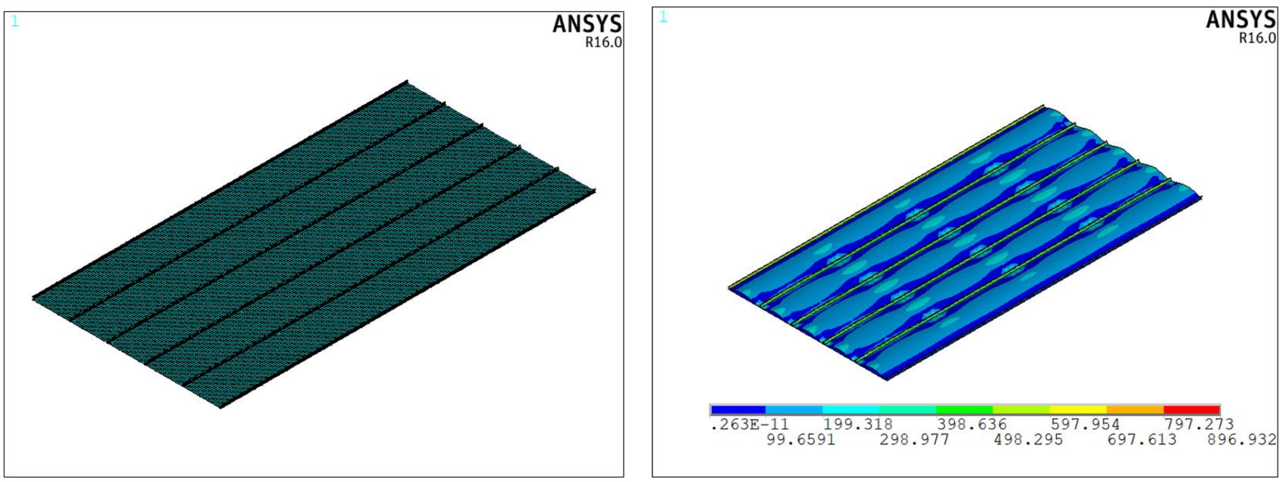

Figure 6-7: Finite Element Mesh of Standing Seam Metal Roof and Corresponding von-Mises Stress Contours

6.2.1.2.2 Material Properties

The material properties of the metal panels were taken from studies by Ali and Senseny (2003) and Damatty et al. (2003) using ASTM A792, Grade 50 steel. The force-displacement responses of the nonlinear springs representing the seam were obtained from test results reported by Damatty et al. (2003) and Damatty and Rahman (2004). The force-displacement responses of the nonlinear springs representing fasteners between the metal panel and roof deck were obtained from test results reported by Sivapathasundaram and Mahendran (2018).

6.2.1.2.3 Sensitivity Analysis

The uplift resistance of the standing seam metal roof was evaluated by changing the seam height, metal panel thickness, fastener spacing, and width of the panel so that the influence of each of these parameters could be investigated and a relationship developed to calculate static uplift resistances. The width of the panel was varied between 304.8-914.4 millimeters, with seam height varying between 12.7-50.8 millimeters. The thickness of the metal panel was varied between 0.7957-0.3175 millimeters and the fastener spacing was varied between 300-1,550 millimeters.

The uplift resistances of the metal roof obtained from one set of sensitivity analyses are presented in Figure 6-8 for different gauges of metal cladding, seam heights, panel widths, and fastener spacing. It was observed that with increasing panel thickness and seam height, the uplift resistance of the roof increased, as shown in parts a and b of the image, respectively. With an increase in panel width and fastener spacing, the uplift resistance decreases, as shown in parts c and d of the image, respectively.

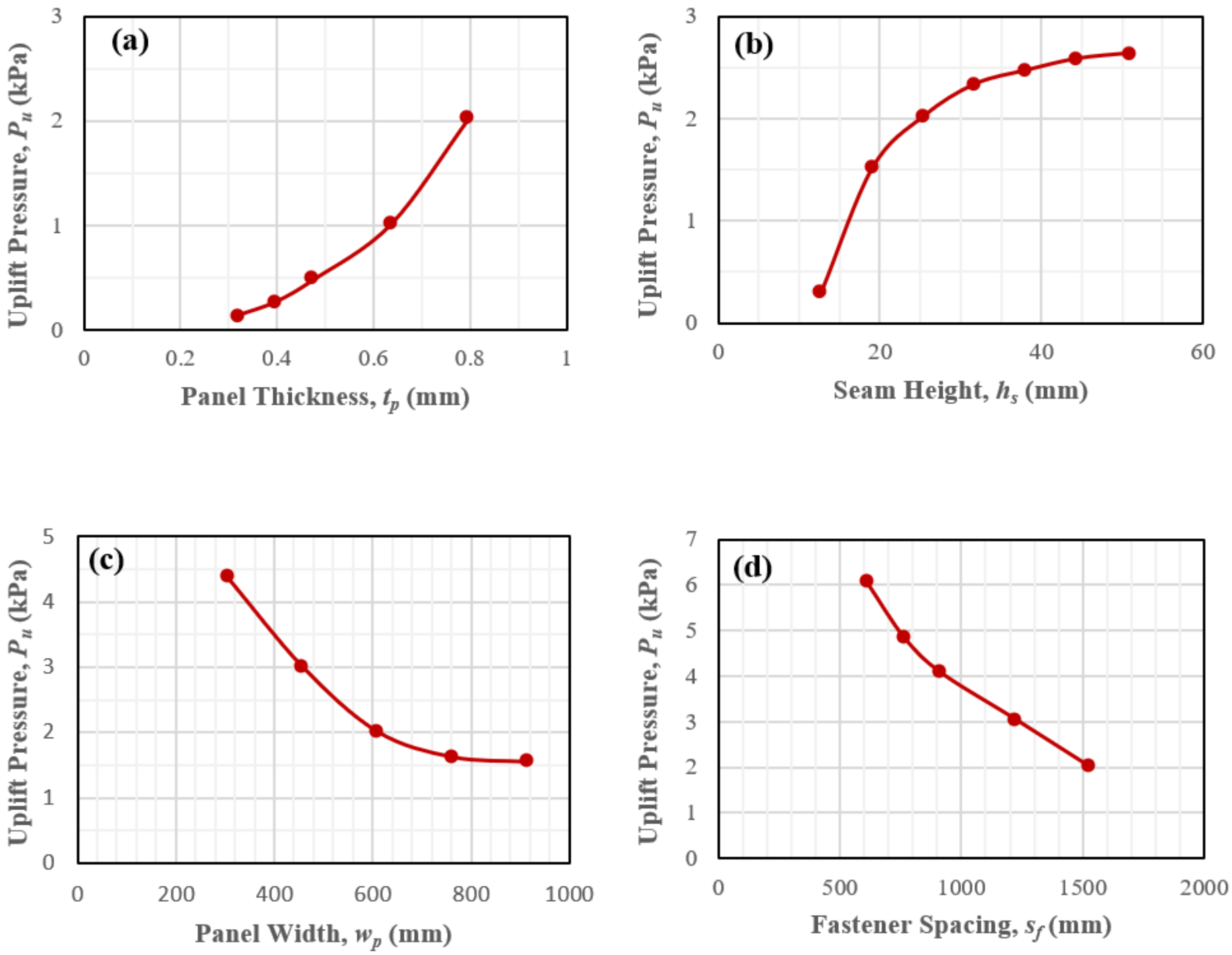

Figure 6-8: Simulated Uplift Resistance of Standing Seam Metal Roof Showing Effect of (a) Panel Thickness, (b) Seam Height, (c) Panel Width, and (d) Fastener Spacing

Based on the responses from the analysis, it was evident that the parameters considered in this study influence the uplift resistance of standing seam metal roofs connected to roof decking. A relationship between these parameters and the uplift resistance of standing seam metal roofs connected to roof decking was developed from a broad set of data generated by varying these parameters.

6.2.1.2.4 Parametric Model for Uplift Resistance

Figure 6-9 shows the uplift resistance of the base case example of a 609.6 millimeters wide standing seam metal roof with 25.4 millimeters seam height plotted against the fastener spacing normalized by panel thickness (s_f/t_p). It was found that the uplift resistance decreases nonlinearly with an increase in the ratio s_f/t_p. Hence, the uplift resistance is expressed as a nonlinear function of the dimensionless quantity s_f/t_p given as:

Equation 6-1

$$P_u = 11.48\left(1 - \frac{s_f}{5995t_p}\right)^{4.347}$$

Where:

P_u	is uplift resistance in kPa
t_p	is panel thickness in millimeters (mm)
s_f	is fastener spacing in millimeters (mm)

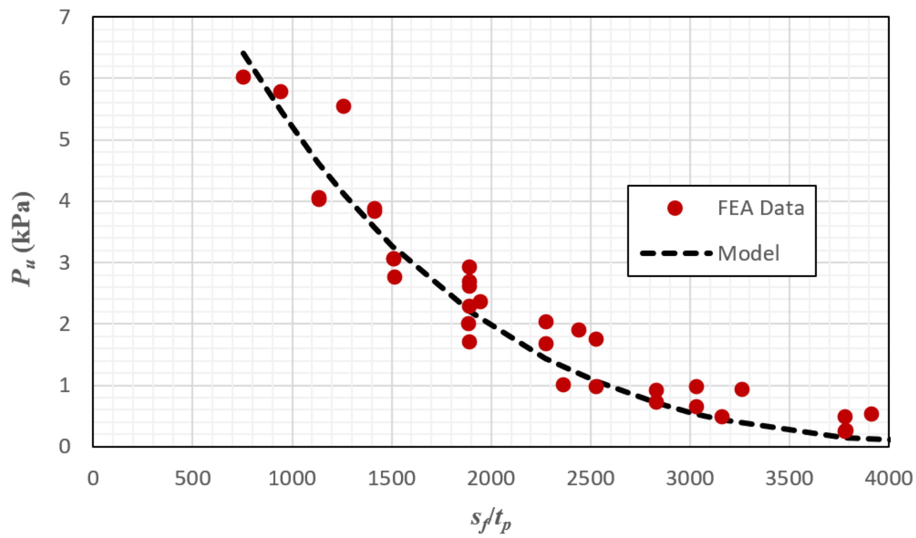

Figure 6-9: Simulated Uplift Resistance of 609.6 Millimeters Wide Standing Seam Metal Roof with 25.4 Millimeters Seam Height

To calculate uplift resistances for different panel widths and seam heights, uplift resistances normalized to the base case (609.6 millimeters wide standing seam metal roof with 25.4 millimeters seam height) were plotted against panel width and seam heights as shown in Figure 6-10. The normalized uplift resistance was found to decrease nonlinearly with an increase in panel width and increase nonlinearly with an increase in seam height. By varying panel width and seam height in the finite element modeling, two adjustment factors were developed to allow the model to be used for a range of panel widths and seam heights without the need for a new finite element model analysis. The expressions for these two adjustment factors are given in Equation 6-2 and Equation 6-3, respectively.

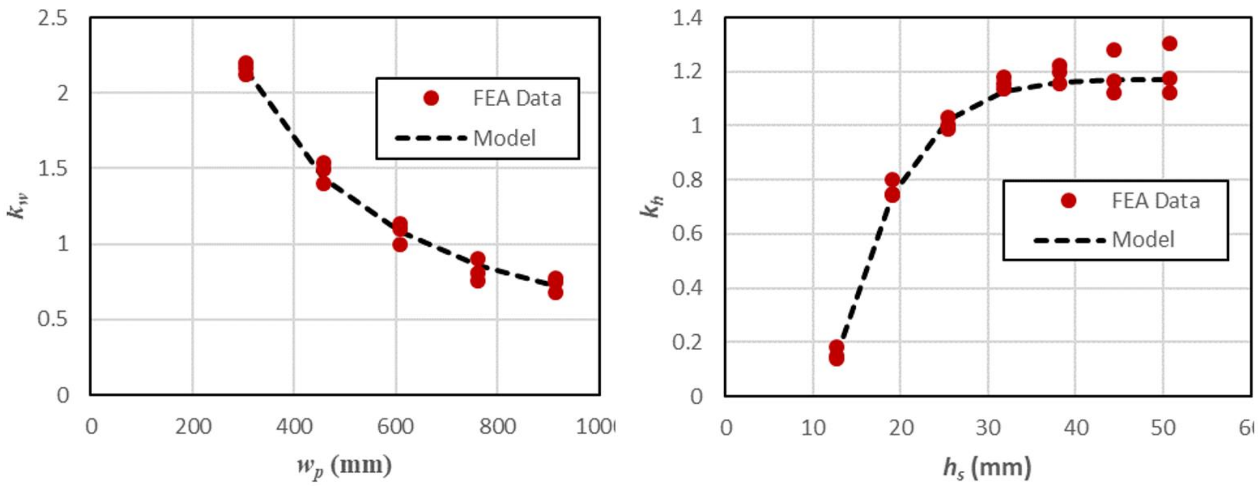

Figure 6-10: Normalized Uplift Resistance of Standing Seam Metal Roof for Different Panel Widths (w_p) and Seam Heights (h_s)

Equation 6-2

$$k_w = \frac{620.18}{1 + 0.941 w_p}$$

Equation 6-3

$$k_h = 1.17 - 2.56 e^{-0.0143 {h_s}^{1.638}}$$

Where:

k_w	is a factor that takes into account various panel widths
k_h	is a factor that takes into account various seam heights
w_p	is panel width in millimeters (mm)
h_s	is seam height in millimeters (mm)

By combining Equation 6-1, Equation 6-2, and Equation 6-3, the uplift resistance of a standing seam metal roof can be calculated using Equation 6-4 for different panel thicknesses, seam heights, panel widths, and fastener spacing.

Equation 6-4

$$P_u = 11.48 k_w k_h \left(1 - \frac{s_f}{5995 t_p}\right)^{4.347}$$

Figure 6-11 shows an equity line plot where the finite element model-simulated responses are plotted against the parametric model (Equation 6-4) predicted values. Note that the finite element model simulated responses are obtained by changing the design variables one at a time while the remaining variables are held constant. Figure 6-11 demonstrates that the predicted values are in good agreement with the finite element model-simulated responses as indicated by the R^2 value of 0.967.

For use in the damage modeling, the standing seam metal roofs attached to a plywood roof deck were modeled using 29 gauge metal, with a rib height of 15.9 millimeters and a fastener spacing of 610 millimeters, yielding a mean uplift resistance of 3.8 kPa.

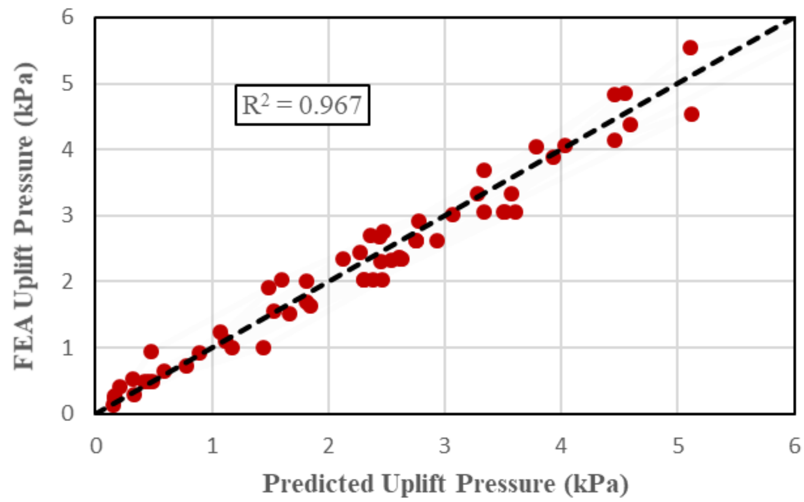

Figure 6-11: Equity Line Plot Showing Uplift Resistance Comparison Between Finite Element Model Simulation Results and Predicted Responses from Equation 6-4

6.2.1.3 UPLIFT RESISTANCE OF STANDING SEAM METAL ROOFS CONNECTED TO PURLINS USING CLIPS

Detailed finite element models of standing seam metals roofs connected to purlins with clips were developed to evaluate their wind uplift resistances. The finite element model was utilized to study the influence of several design variables on the uplift resistances such as seam height, metal thickness, fastener spacing and width of the panel. Based on FEA responses, parametric equations were developed to calculate wind uplift resistances of these standing seam metal roofs connected to purlins subjected to uniform uplift pressure.

6.2.1.3.1 Ansys Model Components

The finite element models of metal roofs were developed using the general purpose finite element software ANSYS following the techniques presented in Damatty et al. (2003) and Lovisa et al. (2013). The metal panels were modeled using an elastic orthotropic 3D shell element (SHELL181) defined earlier. The purlins are modeled using an isotropic 3D beam element (BEAM188) defined earlier. For standing seam metal roofs, seams and supporting clips were modeled using nonlinear spring elements (COMBIN39), which are unidirectional elements with nonlinear generalized force-displacement capability. The seam was simulated as a continuous spring system having a horizontal component simulating the stiffness provided by the seam in the transverse in-plane direction of the panel, and a rotational component simulating the rotational stiffness provided by the seam about the longitudinal axis of the panel. The clips were simulated as discrete vertical springs.

Figure 6-12 shows a typical finite element mesh of standing seam and through fastened metal roofs used in this study.

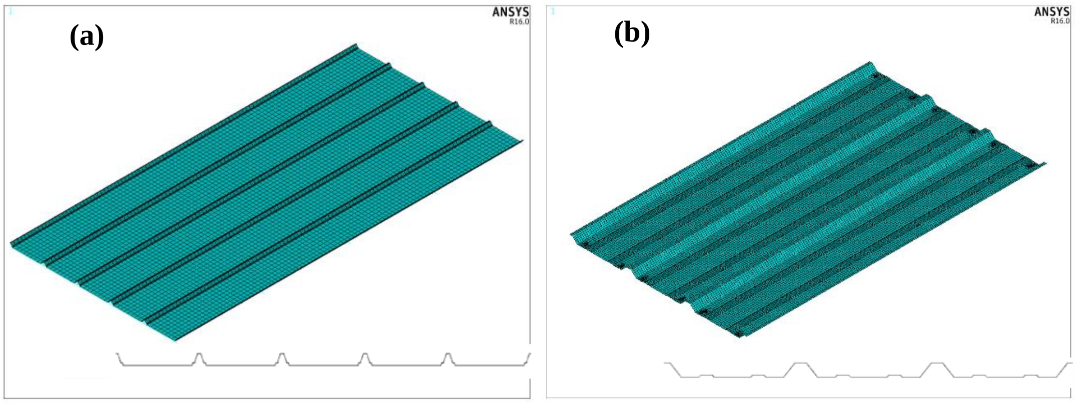

Figure 6-12: Typical Finite Element Mesh of a Standing Seam and Through Fastened Metal Roof

6.2.1.3.2 Material Properties

The material properties of metal panels were taken from studies by Ali and Senseny (2003) and Damatty et al. (2003) for ASTM A792, Grade 50 steel. The force-displacement responses of the nonlinear springs representing seam and supporting clips were obtained from test results reported by Damatty et al. (2003) and Damatty and Rahman (2004). The boundary conditions applied in the simulation of the metal roof were the same as those used by Damatty et al. (2003) in their studies on standing seam metal roofs.

6.2.1.3.3 Model Validation

To validate the finite element model, a test conducted at Mississippi State University (Sinno et al. 2004) on the static uplift resistance of a standing seam metal roof was taken into consideration. The test involved attaching a full-scale standing seam roof to a pressure chamber and applying an uplift static load. The test was conducted using a 6.43 m long standing seam metal panel system. The metal deck had a thickness, a Modulus of Elasticity and a Poisson’s ratio equal to 0.76 millimeters, 2.34×10^5 MPa, and 0.3, respectively.

Five full width panels were seamed together to constitute the full-scale test specimen. The roof was supported by a row of clips aligned along the seam line and spaced at 1,550 millimeters. The clips were, in-turn, supported by a number of purlins aligned in the direction perpendicular to the seams. The purlins were made of aluminum tubes having a rectangular cross section (76.2 × 44.5 millimeters) and a length of 3.962 meters. The Modulus of Elasticity and Poisson’s ratio of the aluminum tubes were equal to 6.97×10^4 MPa and 0.33, respectively. The purlins, spaced at 1,550 millimeters, were supported at their ends to the sides of the test chamber. The load was applied to the roof in the form of an uplift pressure.

In the finite element model, the standing seam metal panel dimensions and experimental setup were imitated and uniform uplift pressure was applied to evaluate the metal panel’s uplift resistance and the clip reactions. Figure 6-13 shows simulated von-Mises stress contours of the standing seam metal panel under static uplift pressure. The simulated clip reactions were compared to experimental responses for six clip locations (see Figure 6-13), as shown in Figure 6-14.

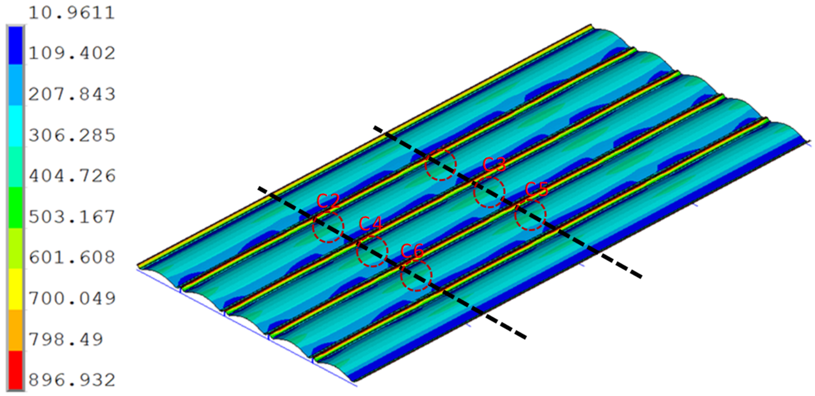

Figure 6-13: von-Mises Stress Contours (MPa) of Standing Seam Metal Roof Under Uniform Uplift Pressure

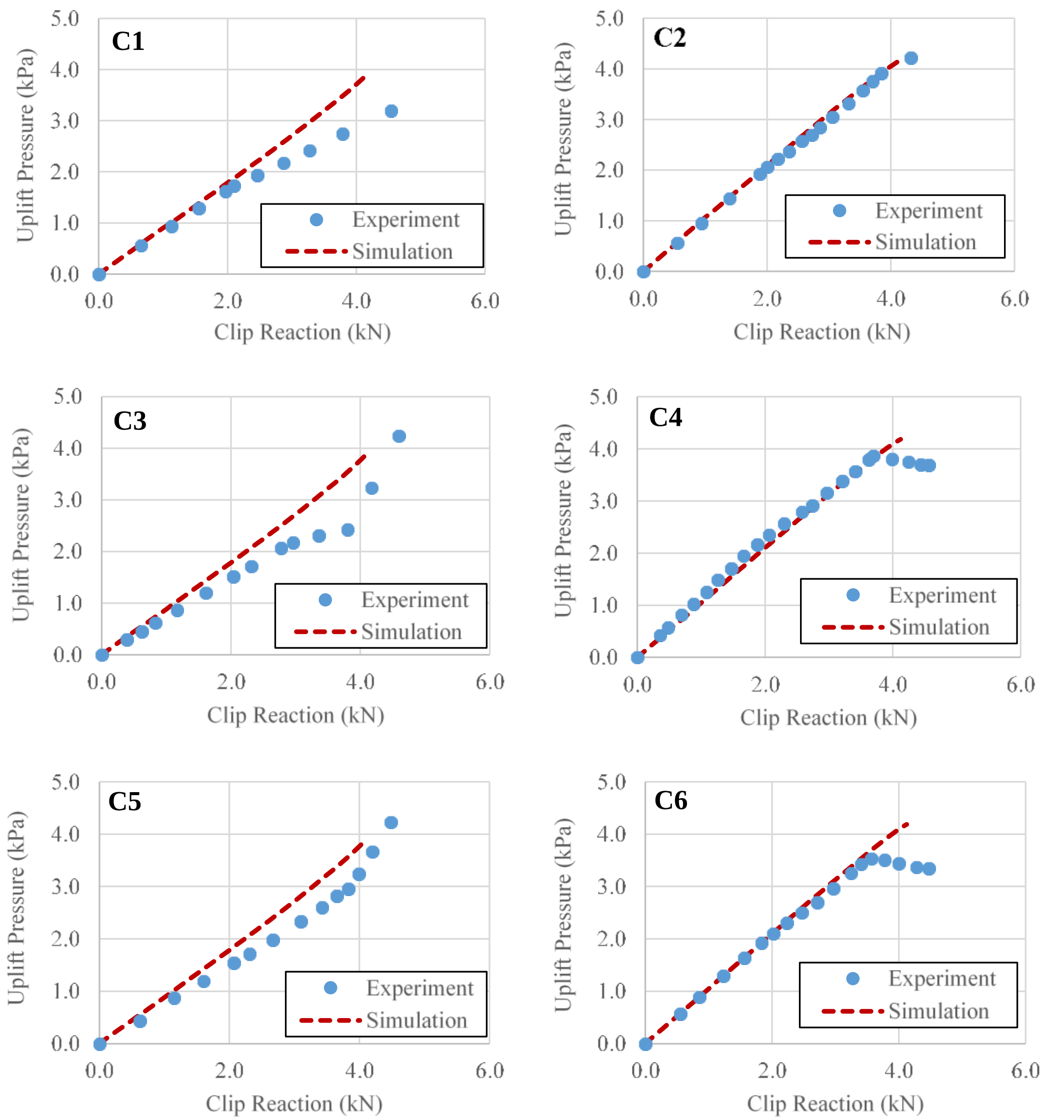

Figure 6-14: Comparison of Measured and Simulated Clip Reaction Versus Uplift Pressure

The finite element model predicts the experimental uplift resistance and clip reactions reasonably well. The failure in the finite element model occurred due to seam disengagement, which is the same failure mode observed in the full-scale experiment. This was taken as validation of the finite element model of the standing seam metal roof, and the model was further utilized to study the influence of different variables on the static uplift resistances of standing seam metal roofs.

6.2.1.3.4 Sensitivity Analysis

Uplift resistance of a standing seam metal roof panel was evaluated by changing the seam height, metal panel thickness, purlin spacing, and width of the panel so that the influence of each of these parameters could be investigated and a relationship developed to calculate static uplift resistances. The width of the panel was varied between 300-762 millimeters with two major corrugations 50-75 millimeters high along each edge. The thickness of the metal was varied between 0.76-0.46 millimeters and the purlin spacing was varied between 0.76-1.55 meters.

Figure 6-15 shows one set of simulated uplift resistances of a standing seam metal roof as a function of these parameters. It was observed that with an increase in panel thickness and seam height, the uplift resistance of the roof increased, as shown in images a and b of Figure 6-15. For example, a 609.6 millimeter wide 22 gauge standing seam metal roof with 50.8 millimeters seam height and 1,550 millimeters purlin spacing possesses 71% more uplift resistance than that of a 24 gauge metal roof. Similarly, a 609.6 millimeter wide 22 gauge standing seam metal roof with 76.2 millimeters seam height and 1,500 millimeters purlin spacing possesses 21% more uplift resistance than the same metal roof with 50.8 millimeters seam height. With an increase in panel width and purlin spacing, the uplift resistance decrease, as shown in images c and d of Figure 6-15. For example, a 762 millimeter wide 22 gauge standing seam metal roof with 50.8 millimeters seam height and 1,550 millimeters purlin spacing possesses 23% less uplift resistance than that of a 609.6 millimeters wide metal roof panel. Similarly, a 609.6 millimeter wide 22 gauge standing seam metal roof with 50.8 millimeters seam height and 1,550 millimeters purlin spacing provides 33% less uplift resistance than that of a metal roof panel with 760 millimeters purlin spacing.

Based on the responses from the analysis, it is evident that the parameters considered in this study influence the uplift resistance of standing seam metal roofs connected to purlins. A relationship between these parameters and the uplift resistance of standing seam metal roofs connected to purlins was developed from a broad set of data generated by varying these parameters.

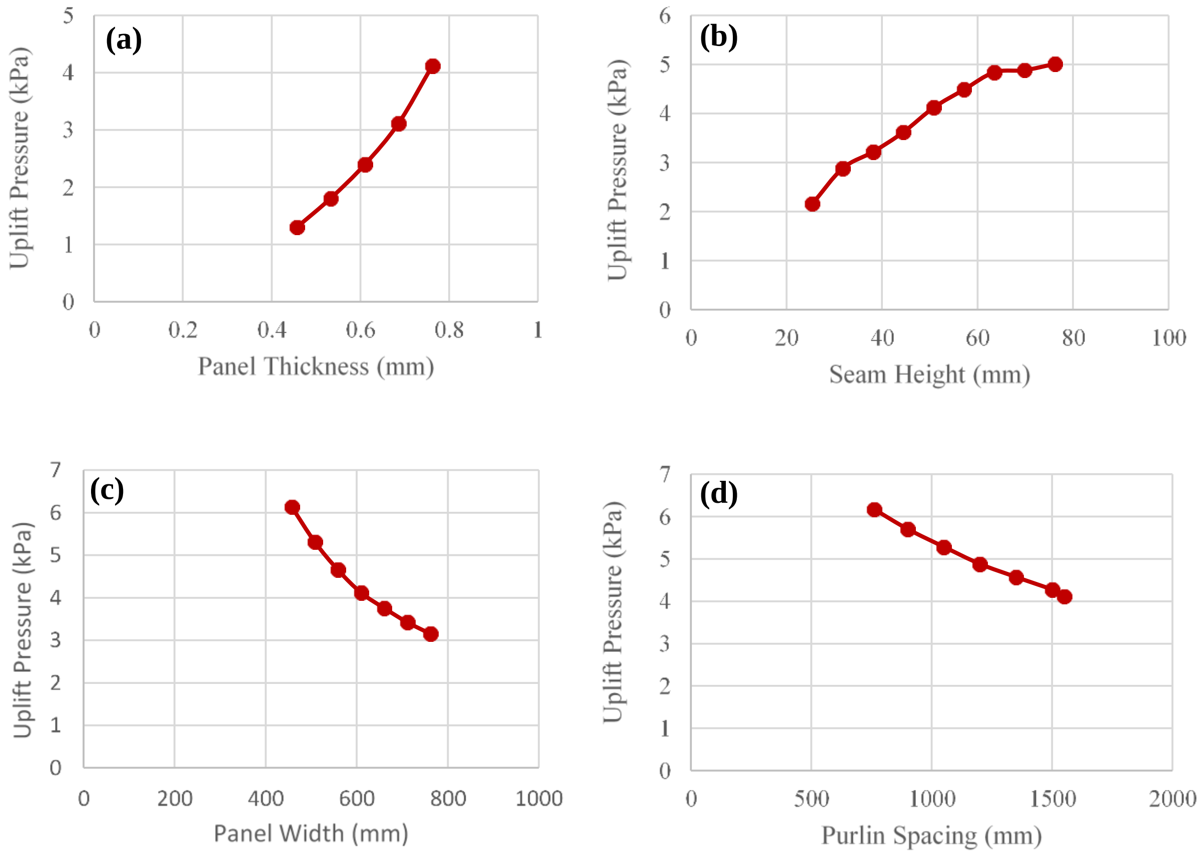

Figure 6-15: Simulated uplift resistance of a standing seam metal roof showing the effect of (a) panel thickness, (b) seam height, (c) panel width, and (d) purlin spacing.

6.2.1.3.5 Parametric Model for Uplift Resistance

Figure 6-16 shows the uplift resistance of a 609.6 millimeters wide standing seam metal roof with 1,550 millimeters purlin spacing plotted against panel thickness for different seam heights. It was observed that the uplift resistance varies nonlinearly with panel thickness for each of the seam heights. Hence, the uplift resistance was expressed as a nonlinear function of panel thickness and seam height given as:

Equation 6-5

$$P_u = 10.15e^{-e^{(1.056-0.0412h_s)}} t^{2.194*0.475^{\frac{1}{h_s}}*h_s^{0.00836}}$$

Where:

P_u	is uplift resistance in kPa
T	is panel thickness in millimeters (mm)
h_s	is seam height in millimeters (mm)

This expression was developed for a 609.6 millimeters panel width with 1,550 millimeters purlin spacing.

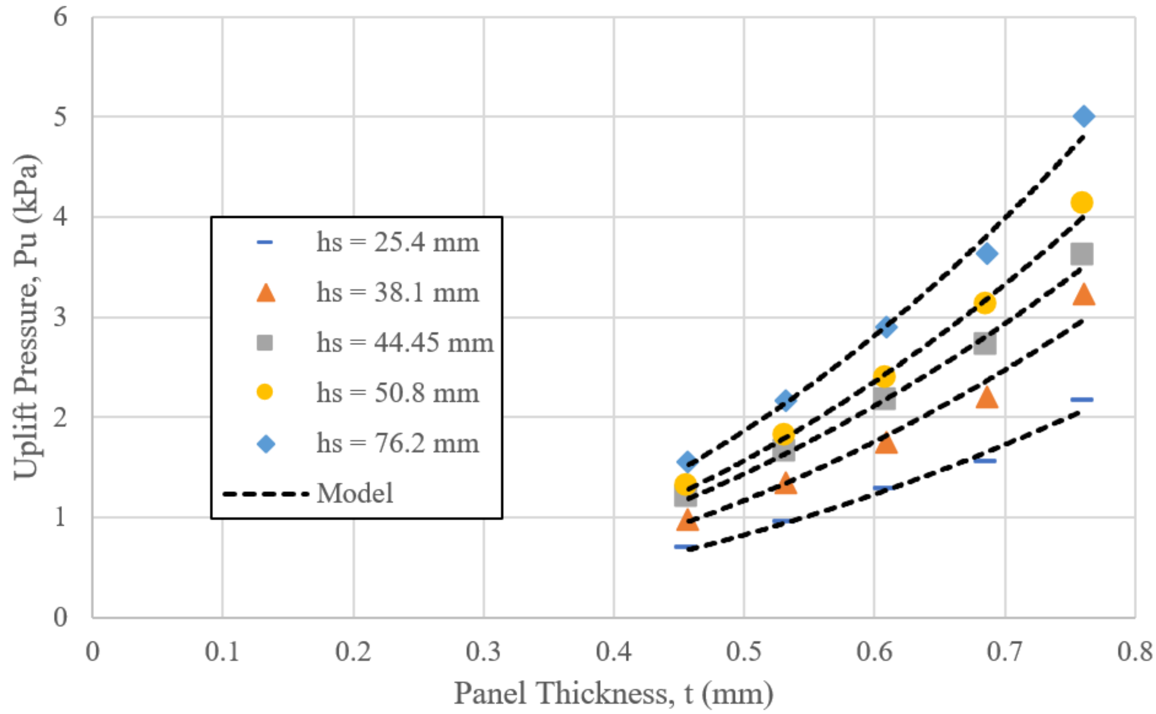

Figure 6-16: Simulated Uplift Resistance of a 609.6 Millimeters Wide Standing Seam Metal Roof with 1,550 Millimeters Purlin Spacing for Different Panel Thicknesses and Seam Heights

In order to calculate uplift resistances for different panel widths and purlin spacing, uplift resistances normalized to the base case (e.g., 609.6 millimeters wide standing seam metal roof with 1,550 millimeters purlin spacing) were plotted against panel width and purlin spacing as shown in Figure 6-17 and Figure 6-18, respectively. The normalized uplift resistance decreases nonlinearly with an increase in panel width and purlin spacing and hence, two adjustment factors were proposed to take into account the effect of panel width and purlin spacing. The expressions for these two adjustment factors are given in Equation 6-6 and Equation 6-7, respectively.

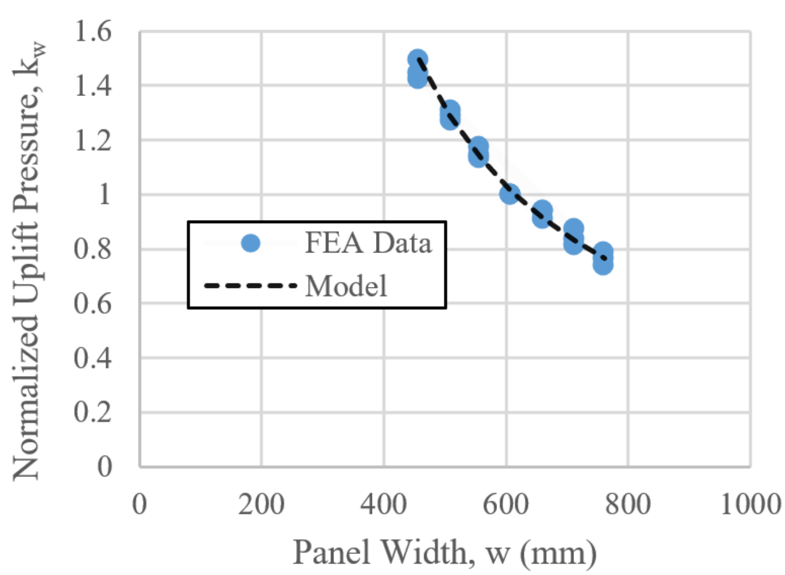

Figure 6-17: Normalized Uplift Resistance of Standing Seam Metal Roof for Different Panel Widths

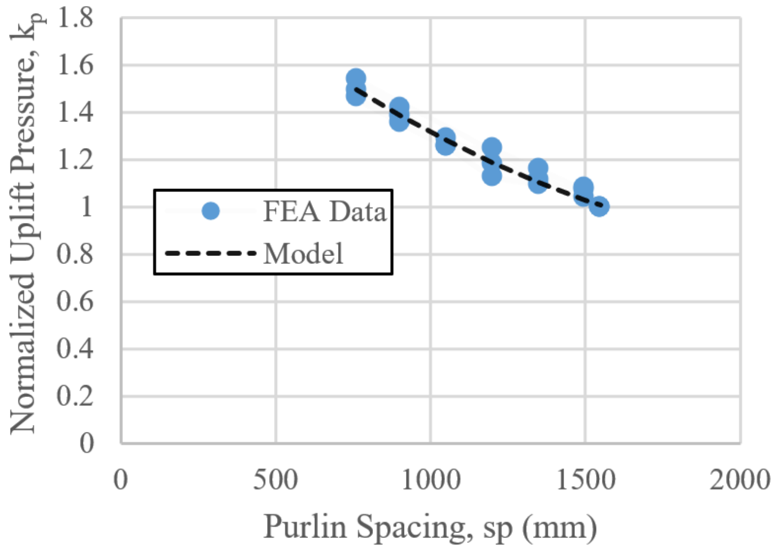

Figure 6-18: Normalized Uplift Resistance of Standing Seam Metal Roof for Different Panel Widths

Equation 6-6

$$k_w = e^{\left(4.55+\frac{305.2}{w}-0.786 \ln w\right)}$$

Equation 6-7

$$k_p = \frac{2.26}{1+\left(\frac{s_p}{1301.8}\right)^{1.25}}$$

Where:

k_w	is an adjustment factor for panel width
k_p	is an adjustment factor for purlin spacing
w	is panel width in millimeters (mm)
s_p	is purlin spacing in millimeters (mm)

By combining Equation 6-5 through Equation 6-7, uplift resistance of a standing seam metal roof can be calculated using Equation 6-8 for different panel thicknesses, seam heights, panel widths, and purlin spacings.

Equation 6-8

$$P_u = \left(10.15e^{-e^{(1.056-0.0412h_s)}} t^{2.194*0.475^{\frac{1}{h_s}}*h_s^{0.00836}}\right) * e^{\left(4.55+\frac{305.2}{w}-0.786 \ln w\right)} * \frac{2.26}{1+\left(\frac{s_p}{1301.8}\right)^{1.25}}$$

Figure 6-19 shows an equity line plot where the finite element model-simulated responses have been plotted against the parametric model (Equation 6-8 predicted values). Note that the finite element model-simulated responses are obtained by changing the design variables one at a time (i.e., when one variable is changed, the other parameters are kept constant). It is seen from Figure 6-19 that the predicted values are in good agreement with the finite element model-simulated responses as indicated by the R^2 value of 0.966.

For use in the damage modeling, the standing seam metal roofs attached using clips were modeled using 26 gauge metal, with a rib height of 38 millimeters and a clip spacing of 610 millimeters, yielding a mean uplift resistance of 3.1 kPa.

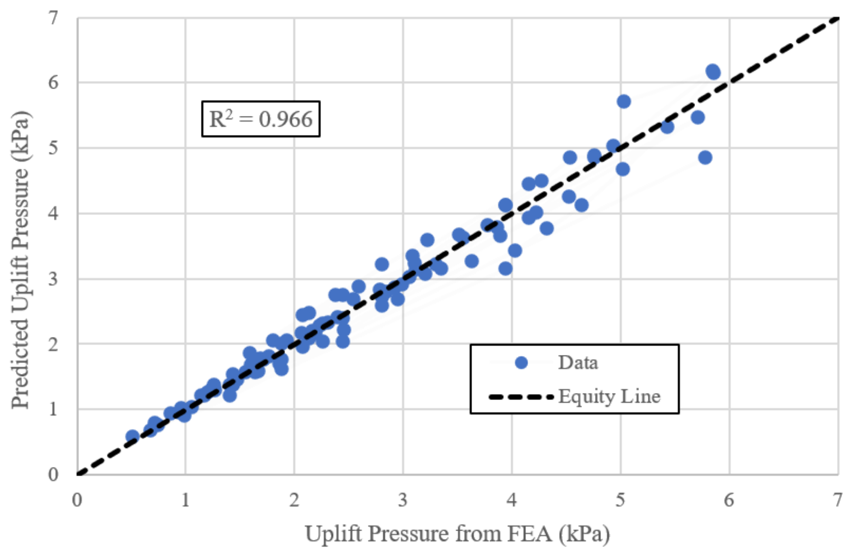

Figure 6-19: Equity Line Plot Showing Uplift Resistance Comparison Between Finite Element Model Simulation Results and Predicted Responses from Equation 6-8

6.3 Elastomeric Roof Covers

The elastomeric roof covering model developed for use for residential construction in the USVI comprises a water resistant paint applied directly onto the wood roof sheathing. The model does not allow for the possible effects of external battens installed between the roof decking below and the elastomeric top coat. The elastomeric top coat is treated as being 100% waterproof until a roof sheathing panel fails. Since there are no data on the possible progressive failure of elastomeric roof covers due to the failure of a roof panel, it is assumed that the elastomeric roof covering on panels adjacent to a failed roof panel is not affected by the failure.

6.4 Concrete Roofs

Concrete roofs on residential buildings are modeled as being impervious, and do not consider the costs or consequences associated with the failure of a roof membrane (if one exists) covering the concrete roof deck. Since no detailed analyses were performed to assess the damage susceptibility of concrete roofs to wind loads, the concrete roof deck/structure is assumed to not fail at any of the considered wind speeds. The walls of all buildings with concrete roofs are modeled as masonry and are able to fail.

6.5 Model Buildings Used to Develop Damage Functions

The new model buildings used to develop the damage functions for the USVI are presented in Figure 6-20 and the new buildings used to develop the damage functions for Puerto Rico are given in Figure 6-21. Clearly, the buildings depicted in Figure 6-20 and Figure 6-21 can be used in any location where building characteristics consistent with those modeled here are relevant.

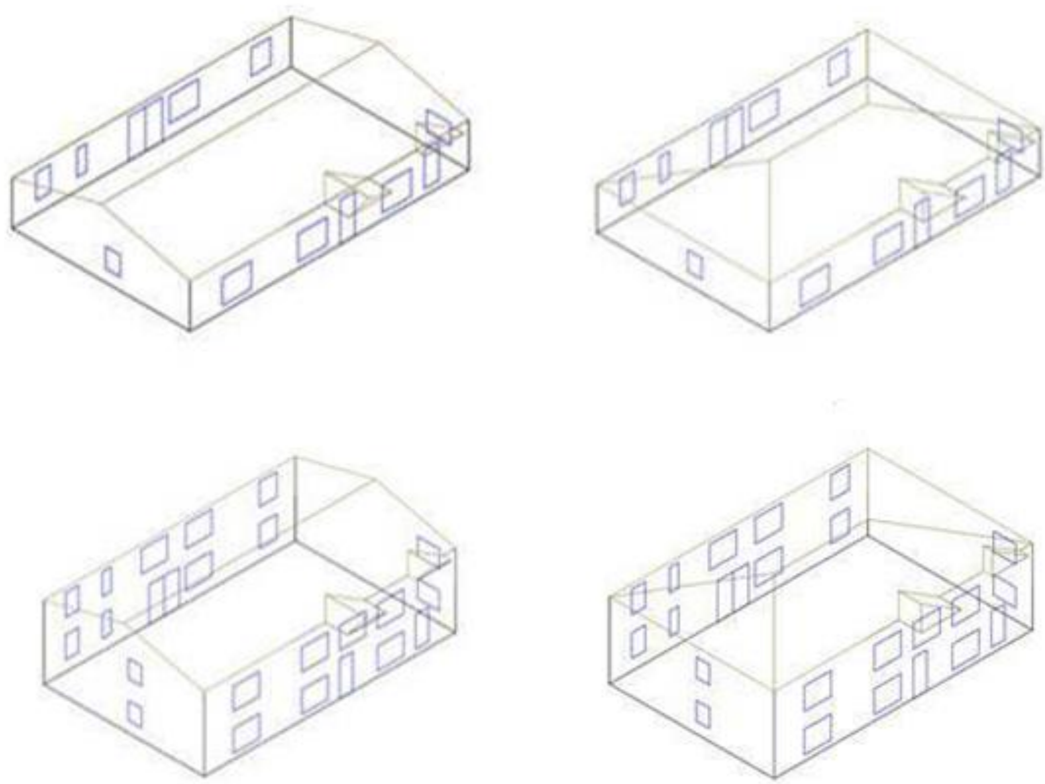

Figure 6-20: Model Buildings Used for the USVI

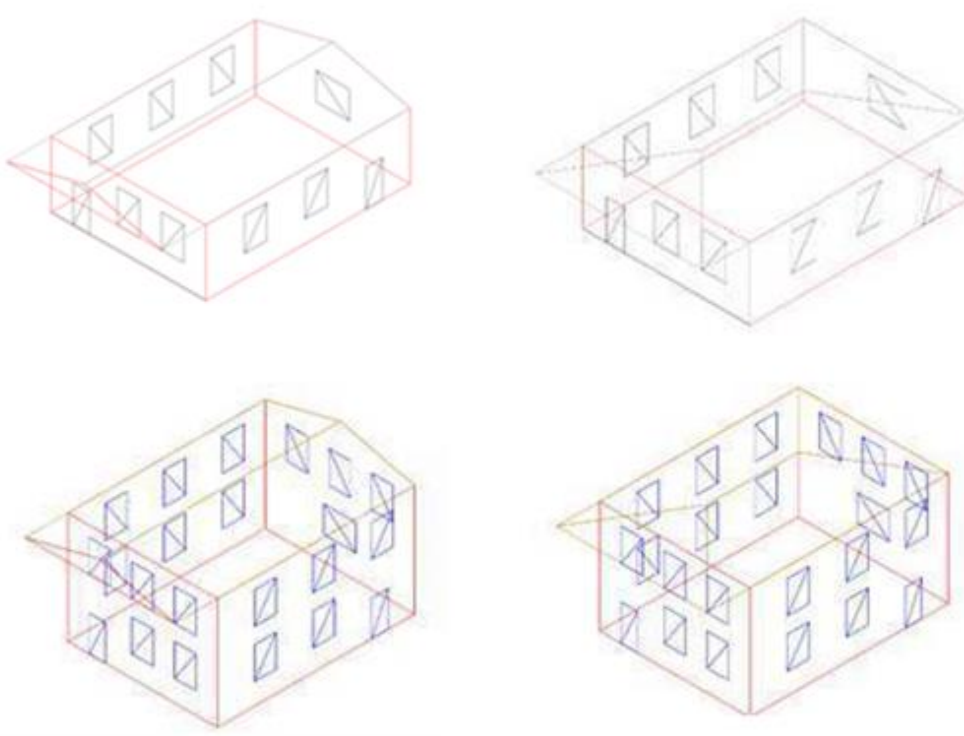

Figure 6-21: Model buildings used for PR

The methodology used herein to develop the building and content loss estimates, building damage estimates, and estimates of building debris are essentially the same as those described in the *Hazus Hurricane Model Technical Manual* (FEMA, 2021), with differences described below.

One of the major differences between the methodology used in the development of the damage, debris, and loss functions is the change in the modeling of the roof pressure coefficients. The roof pressure coefficients used in the development of the original damage/loss functions were adjusted to match those given in ASCE 7-02. The roof pressure coefficients used to develop the damage/loss functions described herein use roof pressure coefficients that are closer to those given in ASCE 7-16 and ASCE 7-22, which are higher than those given in ASCE 7-02. Consequently, with all else held constant it would be expected that damage functions developed herein would yield higher damage and loss for the same wind speed compared to those developed around 2002.

To develop the damage and loss functions, a 100,000-year simulation of hurricane wind speeds and directions was used to generate building damage and loss data on a storm-by-storm basis. The development of the Hazus loss functions given in the original version of Hazus used a 20,000-year simulation. Both loss functions were developed using simulations performed for a location in Miami. Note Miami has a higher wind hazard than the USVI and consequently has more high wind speed storms than would be experienced in the USVI, resulting in improved damage and loss estimates for high wind speed events. To reduce computational time, a reduced set of weighted events was selected by assigning each event to a wind speed bin based on its maximum overland wind speed. Only 500 storms in each 5 mph bin are saved and used for the prediction of damage. This approach ensures computational effort is not wasted on events that produce very low losses. A total of 7,700 storms were retained for use in the damage calculations.

For each storm, 30 replications of building damage were produced. At the start of each replication, resistance values were sampled for each component on the building (roof deck, roof cover, window resistance, roof-wall connection, etc.). Once all the resistances were assigned, errors in the estimated pressure coefficients and the local wind load sheltering factor were sampled. The error term is an estimate of the differences between full scale and wind tunnel derived exterior pressure coefficients. The error term is discussed in more detail in the *Hazus Hurricane Model Technical Manual* (FEMA, 2021). The wind load sheltering factor, takes into account the reduction in wind loads due to the effects of sheltering brought about by near-by buildings. The factor was developed using the results of wind tunnel tests where low-rise buildings were tested in open and suburban terrain conditions with and without surrounding buildings in place. These factors were treated as fully correlated over the exterior of the building. After the wind load error terms were sampled, the wind speeds and directions associated with each simulated hurricane were computed every fifteen minutes. Using the wind speed and direction data coupled with the wind loading coefficients, wind loads were computed on each component, and the loads were compared to the computed resistances. In addition to the wind loads, windborne debris impacts were computed and the sampled impact energy was checked against the sampled impacted resistance to determine if a component had failed. The windborne debris model is discussed in detail in the *Hazus Hurricane Model Technical Manual* and 2008 Florida Residential Wind Loss Mitigation Study, prepared for the Florida Office of Insurance Regulation (ARA, 2008). Upon completion of the failure check for every component, if any components had failed, the internal pressure was recomputed and each component was checked again to determine if any additional failures had occurred. This process was repeated until there were no more additional failures. A total of 231,000 simulations were performed for each building examined. The resistances used for each component are presented in Table 6-2.

Damage results from each individual simulation were stored and subsequently used in the calculations for content loss, number of days for reconstruction, and debris. The final results, in terms of wind speed dependent averages, are stored in 5-mph wind speed bins.

Table 6-2: Modeled Component Resistances

Component	Resistance	Source
Regular Windows	Mean = 50 psf, CoV=15%	Hazus Hurricane Model Technical Manual
Jalousie Windows (old)	Mean = 32 psf, CoV = 23%	Finite Element Modeling
Jalousie Windows (new)	Mean =85 psf, CoV = 23%	Finite Element Modeling
Corrugated Metal Roof (nailed)	Mean = 33.3 psf, CoV = 20%	Finite Element Modeling
Corrugated Metal Roof (screwed)	Mean = 46.8 psf, CoV = 20%	Finite Element Modeling
Standing Seam Metal Roof (through fastened on plywood)	Mean = 86.5 psf, CoV = 15%	Finite Element Modeling
Standing Seam Metal Roof (clips on plywood)	Mean = 70.3 psf, CoV = 15%	Finite Element Modeling
Plywood Roof Deck (6d with 6/12 spacing)	Mean = 54.6 psf, CoV=11.4%	Hazus Hurricane Model Technical Manual
Plywood Roof Deck (8d with 6/12 spacing)	Mean = 103.3 psf, CoV=11.4%	Hazus Hurricane Model Technical Manual
Plywood Roof Deck (8d with 6/6 spacing)	Mean = 226.5 psf, CoV=11.4%	Hazus Hurricane Model Technical Manual
Concrete Roof Deck		Expert Judgement
Roof-Wall Connection (toe-nail)	Mean = 415 lb, CoV = 25%	Hazus Hurricane Model Technical Manual
Roof-Wall Connection (strap/one side wrap)	Mean = 1,200 lb, CoV = 25%	Hazus Hurricane Model Technical Manual
Roof-Wall Connection (concrete)	Mean = 20,000 lb, CoV = 25%	Expert Judgement

Damage results, including the total volume of water entering the building, from each individual simulation are stored and subsequently used in the calculations for building loss, content loss, number of days for reconstruction, and debris. The final results, in terms of wind speed dependent averages are stored in 5-mph wind speed bins.

The loss model, which converts the physical damage to a financial loss, is similar to that described in the *Hazus Hurricane Model Technical Manual* (FEMA, 2021), including the impact on non-modeled losses (such as damage to exterior lighting, damaged gutters, exterior painting, etc. (ARA, 2008)) at low wind speeds. No changes to the loss model in terms of the relative values of the interior vs. exterior of the building were made, nor were there been any updates to the assumed vulnerability of the interior of the building due to water intrusion.

Figure 6-22 through Figure 6-26 present comparisons of the modeled building loss vs. wind speed for various roof types on a one-story, wood-frame building. In all cases, the modeled building loss is applied to a similar building with the current Hazus-standard roof type for reference: a shingled roof where roof sheathing (if applicable) is secured using 8d nails at 6” (edge) and 12” (field) spacing. Recall that the damage and losses associated with the shingle roofed house were computed using different wind loads than those for the new buildings presented herein. The wind speeds presented in Figure 6-22 through Figure 6-26 are peak (3-second) gust wind speeds at a height of 10 m in open terrain. The buildings presented in Figure 6-22 through Figure 6-26 are situated in suburban terrain modeled with a surface roughness of 0.35 m.

The loss curves are presented in two different formats, with the data presented in the left plots providing the loss plotted in logarithmically, while the data given in the right plots present the loss plotted arithmetically. The plots given with the loss data plotted logarithmically are presented to show the differences in the loss functions at low wind speeds (less than 100 mph). In all figures, for low wind speeds, the losses for the shingle-roof house approach zero faster than those for the newly modeled houses, which include the effects of non-modeled losses.

Figure 6-22 presents the losses associated with one-story, wood-frame houses roofed with corrugated metal. The whole roof is attached using toe-nailed connections. The model buildings having corrugated roofs are designed to be representative of informal constriction. The corrugated metal acts as both the roof membrane and the roof sheathing, thus if one corrugated metal panel fails, significant water damage will occur. The results show the buildings having corrugated metal roofs are significantly more vulnerable than those with the shingles attached to a plywood roof deck. Note the plywood roof deck is modeled as having been attached to the roof trusses using 8d nails.

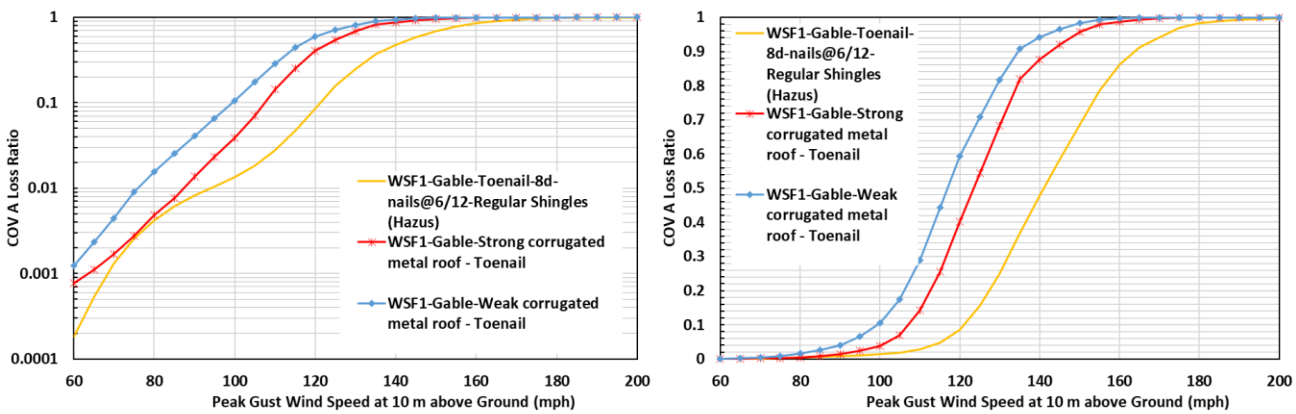

Figure 6-22: Comparisons of Building Loss Functions for Different Corrugated Metal Roof Attachments

Figure 6-23 and Figure 6-24 present the loss functions for the standing seam metal roof cases. Figure 6-23 presents the results for the roof-wall connections modeled as toe-nailed, whereas Figure 6-24 presents the loss functions for the strapped roof-wall connection case. In the toe-nail case, no difference is seen in the performance of the weak (clipped) or strong (through fastened) standing seam metal roof connections because the entire roof fails before the roof cover itself fails. For the toe-nailed roof-wall connection case (Figure 6-23), at low wind speeds (70 mph to 100 mph) it is seen that the shingle roof house produces higher losses than the standing seam metal roof cases. These higher losses are attributed to the cost required to replace the scattered shingles that fail. For wind speeds greater than approximately 100 mph, whole-roof failures for standing seam metal roofs occur at lower wind speeds than in the case of the shingle roof house currently in Hazus. This difference is due to a combination of the smaller deadweight for the roofs with standing seam metal versus those with shingles, as well as differences in the wind loads as noted earlier. In the strapped roof-wall connection case, the same behavior at low wind speeds (70 mph to 100 mph) in the toe-nail roof case is seen here. In the intermediate wind speed range, the standing seam metal roofs yield larger losses than the shingle roofs, likely due to differences in the wind loads. For wind speeds greater than 140 mph, the standing-seam metal roofs perform better than the shingle roofs owing to the higher wind resistance compared to shingles.

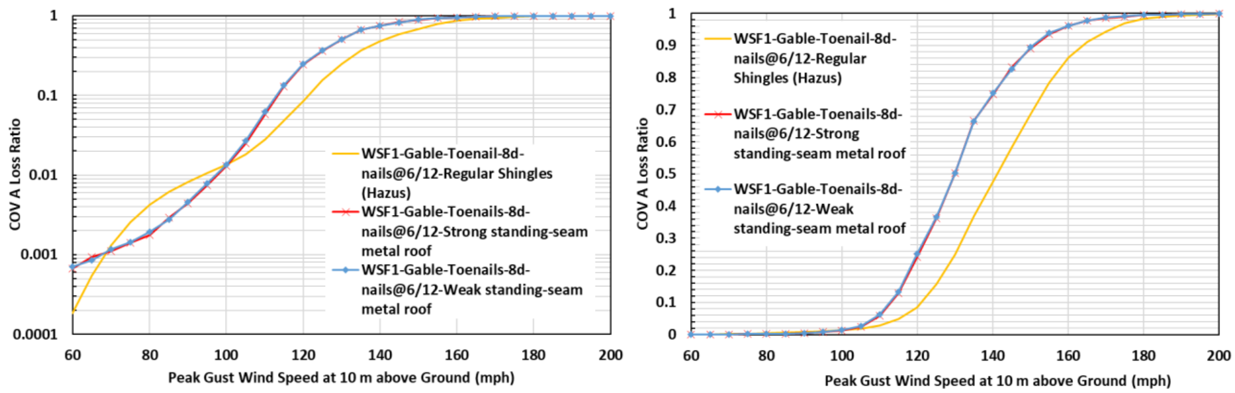

Figure 6-23: Comparison of Building Loss Functions for Different Standing Seam Metal Roof Attachments

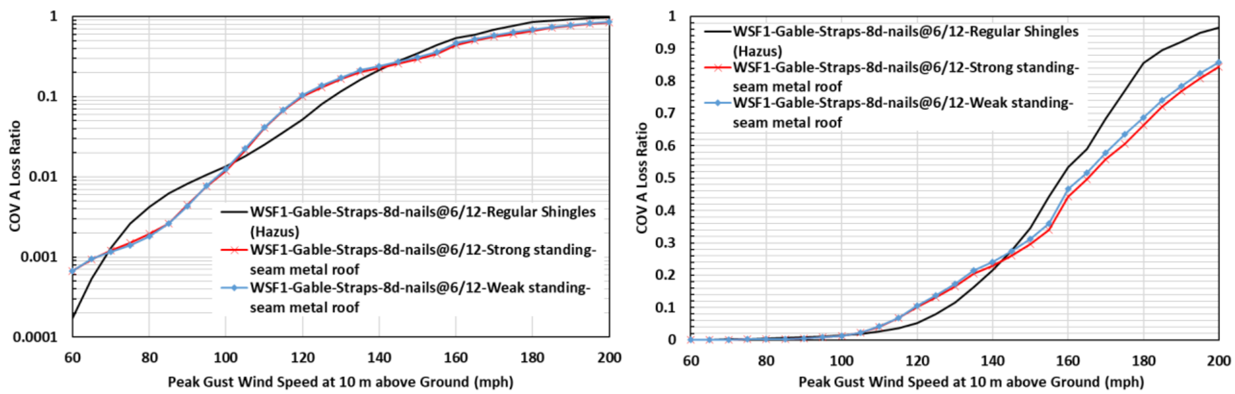

Figure 6-24: Comparison of Building Loss Functions for Different Standing Seam Metal Roof Attachments

Figure 6-25 and Figure 6-26 presents comparisons of the performance of the shingle roof buildings and those with an elastomeric roof cover. The roof deck for both buildings is plywood connected to trusses using 8-d nails using a 6”/12” nail pattern. Figure 6-25 presents the comparisons for the toe-nailed roof-wall connection case, whereas Figure 6-26 presents the strapped roof-wall connection case. In both cases, for wind speeds less than approximately 100 mph the shingled roof building yields higher losses owing to the cost of repairing or replacing scattered shingle damage. For higher wind speeds, the performance of the entire roof system appears to be the dominant cause of the difference in the performance of the buildings with the different roof cover. The modeled shingle roof buildings perform better, owing to the additional total roof deadweight brought about by the additional weight of the shingles combined with differences in the modeled whole roof loads.

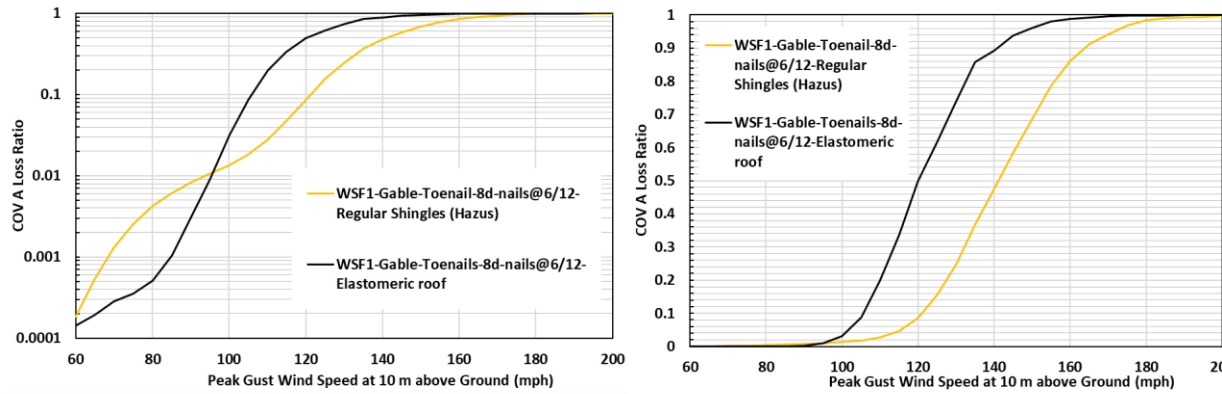

Figure 6-25: Comparison of Building Loss Functions for Plywood Roofed Building with an Elastomeric Roof Membrane

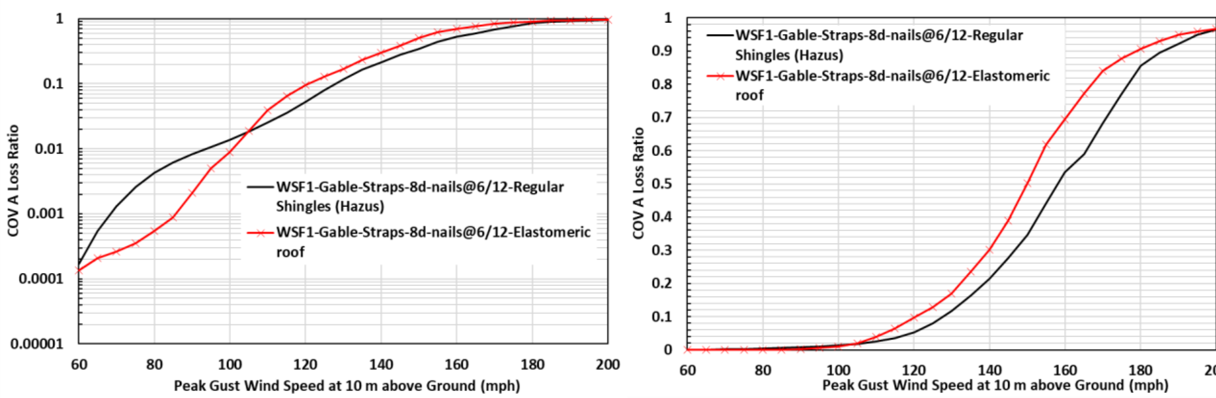

Figure 6-26: Comparison of Building Loss Functions for Plywood Roofed Building with an Elastomeric Roof Membrane

In order to provide a quick comparison of the relative performance (or strength) of the buildings having various attributes, the normalized average annual losses of all buildings with the various combinations of building characteristics (roof covers, window protection, roof-wall connections, etc.) are given in Table 6-3 through Table 6-28. The normalized average annual losses were computed using the Miami climatology applied to the Caribbean building stock to calculate average annual losses, which were then normalized by the building replacement values. The Miami climatology was used because probabilistic climatology for Puerto Rico and the U.S. Virgin Islands was still under development at the time of this validation. These comparisons are presented to assess the relative performance of the various model buildings.

Table 6-25 through Table 6-28 present the normalized (unitless) average annual losses for buildings having shingle roof covers. These data were developed using the loss function for shingle roof buildings in Hazus and currently used in the mainland U.S., normalized to a range between 0 and 1 to allow for comparison of unitless ratios rather than varying scales of annualized loss. While these loss functions can be used in the Caribbean region as well, they are given primarily for comparison purposes and to show good agreement in the annualized loss methodology between the different building types and geographies, so the performance of the various Caribbean building types can be compared to typical U.S. mainland residential buildings.

Table 6-3: Normalized Average Annual Losses for Buildings with Corrugated Metal Gable Roofs and Unreinforced Masonry Walls

No. of Stories	Secondary Water Resistance	Shutter	Window Type	Metal Fastener	Terrain Surface Roughness (m)				
					0.03	0.15	0.35	0.7	1
One	No	Yes	Jalousie	Weak	0.0436	0.0407	0.0318	0.0236	0.0198
	No	Yes	Jalousie	Strong	0.0308	0.0318	0.0226	0.0148	0.0112
	No	Yes	Regular	Weak	0.0434	0.0407	0.0317	0.0235	0.0197
	No	Yes	Regular	Strong	0.0308	0.0321	0.0227	0.0148	0.0112
	No	No	Jalousie	Weak	0.0465	0.0441	0.0341	0.0251	0.0208
	No	No	Jalousie	Strong	0.0356	0.0364	0.0260	0.0169	0.0127
	No	No	Regular	Weak	0.0454	0.0443	0.0343	0.0253	0.0208
	No	No	Regular	Strong	0.0343	0.0374	0.0266	0.0173	0.0128
Two	No	Yes	Jalousie	Weak	0.0559	0.0516	0.0437	0.0363	0.0325
	No	Yes	Jalousie	Strong	0.0418	0.0406	0.0319	0.0241	0.0202
	No	Yes	Regular	Weak	0.0549	0.0514	0.0433	0.0358	0.0321
	No	Yes	Regular	Strong	0.0409	0.0414	0.0322	0.0240	0.0199
	No	No	Jalousie	Weak	0.0596	0.0552	0.0464	0.0381	0.0338
	No	No	Jalousie	Strong	0.0489	0.0461	0.0363	0.0272	0.0224
	No	No	Regular	Weak	0.0574	0.0555	0.0466	0.0382	0.0336
	No	No	Regular	Strong	0.0458	0.0480	0.0379	0.0281	0.0229

Table 6-4: Normalized Average Annual Losses for Buildings with Corrugated Metal Hip Roofs and Unreinforced Masonry Walls

No. of Stories	Secondary Water Resistance	Shutter	Window Type	Metal Fastener	Terrain Surface Roughness (m)				
					0.03	0.15	0.35	0.7	1
One	No	Yes	Jalousie	Weak	0.0309	0.0309	0.0218	0.0144	0.0109
	No	Yes	Jalousie	Strong	0.0191	0.0211	0.0134	0.0077	0.0054
	No	Yes	Regular	Weak	0.0308	0.0311	0.0219	0.0142	0.0109
	No	Yes	Regular	Strong	0.0198	0.0219	0.0137	0.0077	0.0054
	No	No	Jalousie	Weak	0.0355	0.0357	0.0254	0.0164	0.0123
	No	No	Jalousie	Strong	0.0259	0.0256	0.0164	0.0093	0.0065
	No	No	Regular	Weak	0.0343	0.0365	0.0257	0.0166	0.0124
	No	No	Regular	Strong	0.0244	0.0274	0.0173	0.0097	0.0067
Two	No	Yes	Jalousie	Weak	0.0464	0.0439	0.0357	0.0281	0.0243
	No	Yes	Jalousie	Strong	0.0322	0.0320	0.0235	0.0163	0.0128
	No	Yes	Regular	Weak	0.0457	0.0439	0.0355	0.0280	0.0240
	No	Yes	Regular	Strong	0.0317	0.0332	0.0241	0.0165	0.0127
	No	No	Jalousie	Weak	0.0524	0.0490	0.0398	0.0308	0.0263
	No	No	Jalousie	Strong	0.0426	0.0390	0.0291	0.0201	0.0157
	No	No	Regular	Weak	0.0495	0.0498	0.0402	0.0311	0.0263
	No	No	Regular	Strong	0.0381	0.0408	0.0304	0.0207	0.0158

Table 6-5: Normalized Average Annualized Losses for Buildings with Corrugated Metal Gable Roofs and Wood Frame Walls

No. of Stories	Secondary Water Resistance	Shutter	Window Type	Metal Fastener	Terrain Surface Roughness (m)				
					0.03	0.15	0.35	0.7	1
One	No	Yes	Jalousie	Weak	0.0443	0.0414	0.0324	0.0241	0.0203
	No	Yes	Jalousie	Strong	0.0315	0.0324	0.0231	0.0152	0.0116
	No	Yes	Regular	Weak	0.0439	0.0413	0.0322	0.0240	0.0201
	No	Yes	Regular	Strong	0.0313	0.0326	0.0232	0.0152	0.0115
	No	No	Jalousie	Weak	0.0471	0.0447	0.0347	0.0256	0.0213
	No	No	Jalousie	Strong	0.0363	0.0370	0.0265	0.0173	0.0131
	No	No	Regular	Weak	0.0459	0.0448	0.0348	0.0258	0.0213
	No	No	Regular	Strong	0.0348	0.0378	0.0270	0.0176	0.0132
Two	No	Yes	Jalousie	Weak	0.0569	0.0525	0.0445	0.0370	0.0332
	No	Yes	Jalousie	Strong	0.0428	0.0415	0.0327	0.0247	0.0207
	No	Yes	Regular	Weak	0.0557	0.0521	0.0440	0.0365	0.0326
	No	Yes	Regular	Strong	0.0416	0.0420	0.0327	0.0245	0.0204
	No	No	Jalousie	Weak	0.0605	0.0561	0.0473	0.0389	0.0345
	No	No	Jalousie	Strong	0.0498	0.0471	0.0372	0.0280	0.0230
	No	No	Regular	Weak	0.0581	0.0561	0.0471	0.0388	0.0342
	No	No	Regular	Strong	0.0464	0.0484	0.0384	0.0286	0.0233

Table 6-6: Normalized Average Annualized Losses for Buildings with Corrugated Metal Hip Roofs and Wood Frame Walls

No. of Stories	Secondary Water Resistance	Shutter	Window Type	Metal Fastener	Terrain Surface Roughness (m)				
					0.03	0.15	0.35	0.7	1
One	No	Yes	Jalousie	Weak	0.0316	0.0317	0.0224	0.0148	0.0113
	No	Yes	Jalousie	Strong	0.0200	0.0220	0.0140	0.0081	0.0057
	No	Yes	Regular	Weak	0.0313	0.0317	0.0224	0.0147	0.0112
	No	Yes	Regular	Strong	0.0203	0.0226	0.0142	0.0081	0.0056
	No	No	Jalousie	Weak	0.0362	0.0365	0.0261	0.0169	0.0127
	No	No	Jalousie	Strong	0.0268	0.0269	0.0173	0.0099	0.0069
	No	No	Regular	Weak	0.0348	0.0371	0.0262	0.0170	0.0128
	No	No	Regular	Strong	0.0249	0.0282	0.0180	0.0101	0.0070
Two	No	Yes	Jalousie	Weak	0.0473	0.0448	0.0364	0.0287	0.0248
	No	Yes	Jalousie	Strong	0.0332	0.0333	0.0245	0.0170	0.0134
	No	Yes	Regular	Weak	0.0464	0.0445	0.0361	0.0285	0.0245
	No	Yes	Regular	Strong	0.0324	0.0339	0.0247	0.0169	0.0132
	No	No	Jalousie	Weak	0.0531	0.0500	0.0406	0.0315	0.0270
	No	No	Jalousie	Strong	0.0436	0.0406	0.0305	0.0211	0.0165
	No	No	Regular	Weak	0.0500	0.0503	0.0407	0.0316	0.0267
	No	No	Regular	Strong	0.0387	0.0416	0.0311	0.0212	0.0162

Table 6-7: Normalized Average Annual Losses for One-Story Buildings with Standing Seam Metal Gable Roofs and Unreinforced Masonry Walls

Secondary Water Resistance	Shutter	Window Type	Sheathing Nails	Roof/Wall Connection	Metal Fastener	Terrain Surface Roughness (m)				
						0.03	0.15	0.35	0.7	1
Yes	Yes	Jalousie	6d@6/12	Toe-nails	Weak	0.0215	0.0246	0.0163	0.0097	0.0069
Yes	Yes	Jalousie	6d@6/12	Toe-nails	Strong	0.0211	0.0244	0.0162	0.0096	0.0067
Yes	Yes	Jalousie	6d@6/12	Straps	Weak	0.0149	0.0145	0.0093	0.0057	0.0043
Yes	Yes	Jalousie	6d@6/12	Straps	Strong	0.0146	0.0143	0.0091	0.0056	0.0042
Yes	Yes	Jalousie	8d@6/12	Toe-nails	Weak	0.0193	0.0234	0.0153	0.0089	0.0062
Yes	Yes	Jalousie	8d@6/12	Toe-nails	Strong	0.0189	0.0232	0.0152	0.0087	0.0060
Yes	Yes	Jalousie	8d@6/12	Straps	Weak	0.0089	0.0098	0.0063	0.0040	0.0031
Yes	Yes	Jalousie	8d@6/12	Straps	Strong	0.0082	0.0093	0.0059	0.0037	0.0028
Yes	Yes	Jalousie	8d@6/6	Toe-nails	Weak	0.0194	0.0233	0.0154	0.0090	0.0062
Yes	Yes	Jalousie	8d@6/6	Toe-nails	Strong	0.0189	0.0231	0.0152	0.0087	0.0061
Yes	Yes	Jalousie	8d@6/6	Straps	Weak	0.0085	0.0094	0.0062	0.0039	0.0030
Yes	Yes	Jalousie	8d@6/6	Straps	Strong	0.0078	0.0090	0.0058	0.0037	0.0028
Yes	Yes	Regular	6d@6/12	Toe-nails	Weak	0.0226	0.0259	0.0169	0.0098	0.0070
Yes	Yes	Regular	6d@6/12	Toe-nails	Strong	0.0224	0.0258	0.0167	0.0097	0.0068
Yes	Yes	Regular	6d@6/12	Straps	Weak	0.0152	0.0146	0.0092	0.0056	0.0043
Yes	Yes	Regular	6d@6/12	Straps	Strong	0.0149	0.0144	0.0091	0.0055	0.0041
Yes	Yes	Regular	8d@6/12	Toe-nails	Weak	0.0209	0.0250	0.0161	0.0091	0.0062
Yes	Yes	Regular	8d@6/12	Toe-nails	Strong	0.0206	0.0248	0.0159	0.0089	0.0061
Yes	Yes	Regular	8d@6/12	Straps	Weak	0.0084	0.0091	0.0059	0.0038	0.0030
Yes	Yes	Regular	8d@6/12	Straps	Strong	0.0078	0.0086	0.0056	0.0036	0.0027
Yes	Yes	Regular	8d@6/6	Toe-nails	Weak	0.0208	0.0250	0.0160	0.0092	0.0063
Yes	Yes	Regular	8d@6/6	Toe-nails	Strong	0.0205	0.0248	0.0157	0.0089	0.0062
Yes	Yes	Regular	8d@6/6	Straps	Weak	0.0081	0.0088	0.0058	0.0038	0.0030
Yes	Yes	Regular	8d@6/6	Straps	Strong	0.0074	0.0084	0.0055	0.0035	0.0027
Yes	No	Jalousie	6d@6/12	Toe-nails	Weak	0.0275	0.0286	0.0193	0.0115	0.0081
Yes	No	Jalousie	6d@6/12	Toe-nails	Strong	0.0274	0.0286	0.0191	0.0114	0.0079
Yes	No	Jalousie	6d@6/12	Straps	Weak	0.0193	0.0177	0.0115	0.0069	0.0050
Yes	No	Jalousie	6d@6/12	Straps	Strong	0.0190	0.0175	0.0113	0.0068	0.0049
Yes	No	Jalousie	8d@6/12	Toe-nails	Weak	0.0260	0.0277	0.0183	0.0107	0.0074
Yes	No	Jalousie	8d@6/12	Toe-nails	Strong	0.0257	0.0274	0.0181	0.0105	0.0073
Yes	No	Jalousie	8d@6/12	Straps	Weak	0.0123	0.0123	0.0080	0.0049	0.0036
Yes	No	Jalousie	8d@6/12	Straps	Strong	0.0116	0.0118	0.0077	0.0047	0.0034
Yes	No	Jalousie	8d@6/6	Toe-nails	Weak	0.0260	0.0277	0.0182	0.0107	0.0074
Yes	No	Jalousie	8d@6/6	Toe-nails	Strong	0.0256	0.0275	0.0182	0.0105	0.0072
Yes	No	Jalousie	8d@6/6	Straps	Weak	0.0117	0.0118	0.0078	0.0048	0.0036
Yes	No	Jalousie	8d@6/6	Straps	Strong	0.0111	0.0114	0.0074	0.0046	0.0033
Yes	No	Regular	6d@6/12	Toe-nails	Weak	0.0273	0.0315	0.0209	0.0121	0.0084
Yes	No	Regular	6d@6/12	Toe-nails	Strong	0.0271	0.0315	0.0208	0.0122	0.0083
Yes	No	Regular	6d@6/12	Straps	Weak	0.0179	0.0182	0.0115	0.0068	0.0050
Yes	No	Regular	6d@6/12	Straps	Strong	0.0176	0.0181	0.0114	0.0067	0.0048
Yes	No	Regular	8d@6/12	Toe-nails	Weak	0.0260	0.0310	0.0203	0.0116	0.0078
Yes	No	Regular	8d@6/12	Toe-nails	Strong	0.0255	0.0309	0.0201	0.0114	0.0077
Yes	No	Regular	8d@6/12	Straps	Weak	0.0102	0.0115	0.0074	0.0046	0.0034
Yes	No	Regular	8d@6/12	Straps	Strong	0.0096	0.0110	0.0070	0.0043	0.0032
Yes	No	Regular	8d@6/6	Toe-nails	Weak	0.0259	0.0310	0.0202	0.0115	0.0078
Yes	No	Regular	8d@6/6	Toe-nails	Strong	0.0256	0.0308	0.0201	0.0114	0.0077
Yes	No	Regular	8d@6/6	Straps	Weak	0.0098	0.0110	0.0072	0.0045	0.0034
Yes	No	Regular	8d@6/6	Straps	Strong	0.0091	0.0106	0.0068	0.0043	0.0032
No	Yes	Jalousie	6d@6/12	Toe-nails	Weak	0.0215	0.0246	0.0163	0.0097	0.0069
No	Yes	Jalousie	6d@6/12	Toe-nails	Strong	0.0211	0.0244	0.0162	0.0096	0.0067

Secondary Water Resistance	Shutter	Window Type	Sheathing Nails	Roof/Wall Connection	Metal Fastener	Terrain Surface Roughness (m)				
						0.03	0.15	0.35	0.7	1
No	Yes	Jalousie	6d@6/12	Straps	Weak	0.0149	0.0145	0.0093	0.0057	0.0043
No	Yes	Jalousie	6d@6/12	Straps	Strong	0.0146	0.0143	0.0091	0.0056	0.0042
No	Yes	Jalousie	8d@6/12	Toe-nails	Weak	0.0193	0.0234	0.0153	0.0089	0.0062
No	Yes	Jalousie	8d@6/12	Toe-nails	Strong	0.0189	0.0232	0.0152	0.0088	0.0060
No	Yes	Jalousie	8d@6/12	Straps	Weak	0.0089	0.0098	0.0063	0.0040	0.0031
No	Yes	Jalousie	8d@6/12	Straps	Strong	0.0083	0.0093	0.0059	0.0037	0.0028
No	Yes	Jalousie	8d@6/6	Toe-nails	Weak	0.0194	0.0233	0.0154	0.0090	0.0062
No	Yes	Jalousie	8d@6/6	Toe-nails	Strong	0.0189	0.0231	0.0152	0.0087	0.0061
No	Yes	Jalousie	8d@6/6	Straps	Weak	0.0085	0.0094	0.0062	0.0039	0.0030
No	Yes	Jalousie	8d@6/6	Straps	Strong	0.0078	0.0090	0.0058	0.0037	0.0028
No	Yes	Regular	6d@6/12	Toe-nails	Weak	0.0226	0.0259	0.0169	0.0098	0.0070
No	Yes	Regular	6d@6/12	Toe-nails	Strong	0.0224	0.0258	0.0167	0.0097	0.0068
No	Yes	Regular	6d@6/12	Straps	Weak	0.0152	0.0146	0.0092	0.0056	0.0043
No	Yes	Regular	6d@6/12	Straps	Strong	0.0150	0.0144	0.0090	0.0055	0.0041
No	Yes	Regular	8d@6/12	Toe-nails	Weak	0.0209	0.0250	0.0161	0.0091	0.0062
No	Yes	Regular	8d@6/12	Toe-nails	Strong	0.0206	0.0248	0.0159	0.0089	0.0061
No	Yes	Regular	8d@6/12	Straps	Weak	0.0084	0.0091	0.0059	0.0038	0.0030
No	Yes	Regular	8d@6/12	Straps	Strong	0.0078	0.0086	0.0056	0.0036	0.0027
No	Yes	Regular	8d@6/6	Toe-nails	Weak	0.0208	0.0250	0.0160	0.0092	0.0063
No	Yes	Regular	8d@6/6	Toe-nails	Strong	0.0205	0.0248	0.0157	0.0089	0.0062
No	Yes	Regular	8d@6/6	Straps	Weak	0.0081	0.0088	0.0058	0.0038	0.0030
No	Yes	Regular	8d@6/6	Straps	Strong	0.0074	0.0084	0.0054	0.0035	0.0027
No	No	Jalousie	6d@6/12	Toe-nails	Weak	0.0275	0.0287	0.0193	0.0115	0.0081
No	No	Jalousie	6d@6/12	Toe-nails	Strong	0.0274	0.0286	0.0191	0.0115	0.0079
No	No	Jalousie	6d@6/12	Straps	Weak	0.0193	0.0177	0.0115	0.0069	0.0051
No	No	Jalousie	6d@6/12	Straps	Strong	0.0191	0.0175	0.0113	0.0068	0.0049
No	No	Jalousie	8d@6/12	Toe-nails	Weak	0.0260	0.0277	0.0183	0.0107	0.0074
No	No	Jalousie	8d@6/12	Toe-nails	Strong	0.0257	0.0274	0.0181	0.0105	0.0073
No	No	Jalousie	8d@6/12	Straps	Weak	0.0123	0.0123	0.0080	0.0049	0.0036
No	No	Jalousie	8d@6/12	Straps	Strong	0.0116	0.0118	0.0077	0.0047	0.0034
No	No	Jalousie	8d@6/6	Toe-nails	Weak	0.0260	0.0277	0.0182	0.0107	0.0074
No	No	Jalousie	8d@6/6	Toe-nails	Strong	0.0256	0.0275	0.0182	0.0105	0.0072
No	No	Jalousie	8d@6/6	Straps	Weak	0.0117	0.0118	0.0078	0.0048	0.0036
No	No	Jalousie	8d@6/6	Straps	Strong	0.0111	0.0114	0.0074	0.0046	0.0033
No	No	Regular	6d@6/12	Toe-nails	Weak	0.0273	0.0315	0.0209	0.0122	0.0084
No	No	Regular	6d@6/12	Toe-nails	Strong	0.0271	0.0315	0.0208	0.0122	0.0083
No	No	Regular	6d@6/12	Straps	Weak	0.0179	0.0182	0.0115	0.0068	0.0050
No	No	Regular	6d@6/12	Straps	Strong	0.0177	0.0181	0.0114	0.0067	0.0048
No	No	Regular	8d@6/12	Toe-nails	Weak	0.0260	0.0310	0.0203	0.0116	0.0078
No	No	Regular	8d@6/12	Toe-nails	Strong	0.0255	0.0309	0.0202	0.0114	0.0076
No	No	Regular	8d@6/12	Straps	Weak	0.0102	0.0115	0.0074	0.0046	0.0034
No	No	Regular	8d@6/12	Straps	Strong	0.0096	0.0110	0.0070	0.0043	0.0032
No	No	Regular	8d@6/6	Toe-nails	Weak	0.0259	0.0310	0.0202	0.0116	0.0078
No	No	Regular	8d@6/6	Toe-nails	Strong	0.0256	0.0308	0.0201	0.0114	0.0077
No	No	Regular	8d@6/6	Straps	Weak	0.0098	0.0110	0.0072	0.0045	0.0034
No	No	Regular	8d@6/6	Straps	Strong	0.0091	0.0106	0.0068	0.0043	0.0032

Table 6-8: Normalized Average Annual Losses for Two-Story Buildings with Standing Seam Metal Gable Roofs and Unreinforced Masonry Walls

Secondary Water Resistance	Shutter	Window Type	Sheathing Nails	Roof/Wall Connection	Metal Fastener	Terrain Surface Roughness (m)				
						0.03	0.15	0.35	0.7	1
Yes	Yes	Jalousie	6d@6/12	Toe-nails	Weak	0.0306	0.0317	0.0235	0.0162	0.0127
Yes	Yes	Jalousie	6d@6/12	Toe-nails	Strong	0.0301	0.0315	0.0233	0.0160	0.0126
Yes	Yes	Jalousie	6d@6/12	Straps	Weak	0.0195	0.0194	0.0133	0.0085	0.0064
Yes	Yes	Jalousie	6d@6/12	Straps	Strong	0.0190	0.0190	0.0129	0.0081	0.0061

Secondary Water Resistance	Shutter	Window Type	Sheathing Nails	Roof/Wall Connection	Metal Fastener	Terrain Surface Roughness (m)				
						0.03	0.15	0.35	0.7	1
Yes	Yes	Jalousie	8d@6/12	Toe-nails	Weak	0.0295	0.0312	0.0229	0.0159	0.0123
Yes	Yes	Jalousie	8d@6/12	Toe-nails	Strong	0.0293	0.0308	0.0227	0.0156	0.0121
Yes	Yes	Jalousie	8d@6/12	Straps	Weak	0.0151	0.0156	0.0107	0.0069	0.0052
Yes	Yes	Jalousie	8d@6/12	Straps	Strong	0.0145	0.0153	0.0104	0.0066	0.0049
Yes	Yes	Jalousie	8d@6/6	Toe-nails	Weak	0.0295	0.0312	0.0229	0.0159	0.0123
Yes	Yes	Jalousie	8d@6/6	Toe-nails	Strong	0.0293	0.0308	0.0227	0.0156	0.0121
Yes	Yes	Jalousie	8d@6/6	Straps	Weak	0.0147	0.0153	0.0105	0.0068	0.0052
Yes	Yes	Jalousie	8d@6/6	Straps	Strong	0.0141	0.0149	0.0102	0.0064	0.0048
Yes	Yes	Regular	6d@6/12	Toe-nails	Weak	0.0311	0.0346	0.0253	0.0170	0.0130
Yes	Yes	Regular	6d@6/12	Toe-nails	Strong	0.0309	0.0344	0.0251	0.0168	0.0129
Yes	Yes	Regular	6d@6/12	Straps	Weak	0.0179	0.0182	0.0121	0.0076	0.0057
Yes	Yes	Regular	6d@6/12	Straps	Strong	0.0173	0.0179	0.0117	0.0073	0.0054
Yes	Yes	Regular	8d@6/12	Toe-nails	Weak	0.0305	0.0343	0.0249	0.0166	0.0127
Yes	Yes	Regular	8d@6/12	Toe-nails	Strong	0.0302	0.0343	0.0247	0.0164	0.0124
Yes	Yes	Regular	8d@6/12	Straps	Weak	0.0136	0.0144	0.0095	0.0060	0.0045
Yes	Yes	Regular	8d@6/12	Straps	Strong	0.0131	0.0139	0.0090	0.0056	0.0042
Yes	Yes	Regular	8d@6/6	Toe-nails	Weak	0.0305	0.0344	0.0249	0.0166	0.0127
Yes	Yes	Regular	8d@6/6	Toe-nails	Strong	0.0302	0.0342	0.0247	0.0165	0.0125
Yes	Yes	Regular	8d@6/6	Straps	Weak	0.0132	0.0141	0.0093	0.0059	0.0045
Yes	Yes	Regular	8d@6/6	Straps	Strong	0.0127	0.0137	0.0089	0.0055	0.0041
Yes	No	Jalousie	6d@6/12	Toe-nails	Weak	0.0409	0.0385	0.0288	0.0198	0.0153
Yes	No	Jalousie	6d@6/12	Toe-nails	Strong	0.0407	0.0383	0.0286	0.0197	0.0152
Yes	No	Jalousie	6d@6/12	Straps	Weak	0.0271	0.0245	0.0175	0.0115	0.0087
Yes	No	Jalousie	6d@6/12	Straps	Strong	0.0266	0.0240	0.0171	0.0112	0.0084
Yes	No	Jalousie	8d@6/12	Toe-nails	Weak	0.0403	0.0380	0.0281	0.0194	0.0149
Yes	No	Jalousie	8d@6/12	Toe-nails	Strong	0.0402	0.0380	0.0280	0.0192	0.0146
Yes	No	Jalousie	8d@6/12	Straps	Weak	0.0210	0.0199	0.0143	0.0095	0.0071
Yes	No	Jalousie	8d@6/12	Straps	Strong	0.0204	0.0194	0.0139	0.0091	0.0068
Yes	No	Jalousie	8d@6/6	Toe-nails	Weak	0.0404	0.0381	0.0283	0.0192	0.0149
Yes	No	Jalousie	8d@6/6	Toe-nails	Strong	0.0402	0.0379	0.0280	0.0191	0.0147
Yes	No	Jalousie	8d@6/6	Straps	Weak	0.0205	0.0194	0.0140	0.0093	0.0070
Yes	No	Jalousie	8d@6/6	Straps	Strong	0.0199	0.0190	0.0136	0.0090	0.0067
Yes	No	Regular	6d@6/12	Toe-nails	Weak	0.0381	0.0435	0.0329	0.0225	0.0170
Yes	No	Regular	6d@6/12	Toe-nails	Strong	0.0381	0.0437	0.0327	0.0224	0.0169
Yes	No	Regular	6d@6/12	Straps	Weak	0.0230	0.0235	0.0159	0.0099	0.0072
Yes	No	Regular	6d@6/12	Straps	Strong	0.0226	0.0230	0.0155	0.0096	0.0070
Yes	No	Regular	8d@6/12	Toe-nails	Weak	0.0377	0.0434	0.0327	0.0222	0.0167
Yes	No	Regular	8d@6/12	Toe-nails	Strong	0.0374	0.0434	0.0326	0.0221	0.0167
Yes	No	Regular	8d@6/12	Straps	Weak	0.0182	0.0181	0.0122	0.0077	0.0056
Yes	No	Regular	8d@6/12	Straps	Strong	0.0176	0.0176	0.0118	0.0073	0.0053
Yes	No	Regular	8d@6/6	Toe-nails	Weak	0.0376	0.0435	0.0326	0.0222	0.0168
Yes	No	Regular	8d@6/6	Toe-nails	Strong	0.0373	0.0434	0.0325	0.0221	0.0166
Yes	No	Regular	8d@6/6	Straps	Weak	0.0177	0.0177	0.0120	0.0075	0.0055
Yes	No	Regular	8d@6/6	Straps	Strong	0.0173	0.0172	0.0116	0.0071	0.0052
No	Yes	Jalousie	6d@6/12	Toe-nails	Weak	0.0306	0.0317	0.0235	0.0162	0.0127
No	Yes	Jalousie	6d@6/12	Toe-nails	Strong	0.0301	0.0315	0.0233	0.0160	0.0126
No	Yes	Jalousie	6d@6/12	Straps	Weak	0.0196	0.0194	0.0133	0.0085	0.0065
No	Yes	Jalousie	6d@6/12	Straps	Strong	0.0190	0.0190	0.0129	0.0081	0.0061
No	Yes	Jalousie	8d@6/12	Toe-nails	Weak	0.0295	0.0312	0.0229	0.0159	0.0123
No	Yes	Jalousie	8d@6/12	Toe-nails	Strong	0.0293	0.0308	0.0227	0.0156	0.0121
No	Yes	Jalousie	8d@6/12	Straps	Weak	0.0152	0.0157	0.0108	0.0069	0.0052
No	Yes	Jalousie	8d@6/12	Straps	Strong	0.0145	0.0152	0.0103	0.0066	0.0049
No	Yes	Jalousie	8d@6/6	Toe-nails	Weak	0.0295	0.0312	0.0229	0.0159	0.0123

Secondary Water Resistance	Shutter	Window Type	Sheathing Nails	Roof/Wall Connection	Metal Fastener	Terrain Surface Roughness (m)				
						0.03	0.15	0.35	0.7	1
No	Yes	Jalousie	8d@6/6	Toe-nails	Strong	0.0293	0.0308	0.0227	0.0156	0.0121
No	Yes	Jalousie	8d@6/6	Straps	Weak	0.0148	0.0154	0.0105	0.0068	0.0052
No	Yes	Jalousie	8d@6/6	Straps	Strong	0.0141	0.0148	0.0102	0.0065	0.0048
No	Yes	Regular	6d@6/12	Toe-nails	Weak	0.0311	0.0346	0.0253	0.0170	0.0130
No	Yes	Regular	6d@6/12	Toe-nails	Strong	0.0309	0.0344	0.0251	0.0168	0.0129
No	Yes	Regular	6d@6/12	Straps	Weak	0.0180	0.0182	0.0121	0.0076	0.0057
No	Yes	Regular	6d@6/12	Straps	Strong	0.0174	0.0179	0.0117	0.0073	0.0054
No	Yes	Regular	8d@6/12	Toe-nails	Weak	0.0306	0.0343	0.0249	0.0166	0.0127
No	Yes	Regular	8d@6/12	Toe-nails	Strong	0.0302	0.0343	0.0247	0.0164	0.0124
No	Yes	Regular	8d@6/12	Straps	Weak	0.0137	0.0144	0.0095	0.0060	0.0045
No	Yes	Regular	8d@6/12	Straps	Strong	0.0131	0.0139	0.0090	0.0056	0.0042
No	Yes	Regular	8d@6/6	Toe-nails	Weak	0.0305	0.0344	0.0249	0.0166	0.0127
No	Yes	Regular	8d@6/6	Toe-nails	Strong	0.0302	0.0342	0.0248	0.0165	0.0125
No	Yes	Regular	8d@6/6	Straps	Weak	0.0133	0.0141	0.0093	0.0059	0.0045
No	Yes	Regular	8d@6/6	Straps	Strong	0.0127	0.0137	0.0089	0.0056	0.0041
No	No	Jalousie	6d@6/12	Toe-nails	Weak	0.0409	0.0385	0.0288	0.0198	0.0153
No	No	Jalousie	6d@6/12	Toe-nails	Strong	0.0408	0.0383	0.0286	0.0197	0.0152
No	No	Jalousie	6d@6/12	Straps	Weak	0.0271	0.0246	0.0175	0.0116	0.0088
No	No	Jalousie	6d@6/12	Straps	Strong	0.0266	0.0240	0.0171	0.0112	0.0084
No	No	Jalousie	8d@6/12	Toe-nails	Weak	0.0403	0.0380	0.0281	0.0194	0.0149
No	No	Jalousie	8d@6/12	Toe-nails	Strong	0.0402	0.0380	0.0280	0.0192	0.0146
No	No	Jalousie	8d@6/12	Straps	Weak	0.0211	0.0199	0.0144	0.0095	0.0072
No	No	Jalousie	8d@6/12	Straps	Strong	0.0204	0.0194	0.0139	0.0091	0.0068
No	No	Jalousie	8d@6/6	Toe-nails	Weak	0.0404	0.0381	0.0283	0.0192	0.0150
No	No	Jalousie	8d@6/6	Toe-nails	Strong	0.0402	0.0378	0.0280	0.0191	0.0147
No	No	Jalousie	8d@6/6	Straps	Weak	0.0205	0.0195	0.0141	0.0093	0.0070
No	No	Jalousie	8d@6/6	Straps	Strong	0.0200	0.0190	0.0136	0.0090	0.0067
No	No	Regular	6d@6/12	Toe-nails	Weak	0.0381	0.0435	0.0329	0.0225	0.0170
No	No	Regular	6d@6/12	Toe-nails	Strong	0.0381	0.0437	0.0327	0.0224	0.0169
No	No	Regular	6d@6/12	Straps	Weak	0.0230	0.0235	0.0159	0.0099	0.0073
No	No	Regular	6d@6/12	Straps	Strong	0.0227	0.0231	0.0155	0.0096	0.0070
No	No	Regular	8d@6/12	Toe-nails	Weak	0.0377	0.0433	0.0327	0.0222	0.0167
No	No	Regular	8d@6/12	Toe-nails	Strong	0.0374	0.0434	0.0326	0.0221	0.0167
No	No	Regular	8d@6/12	Straps	Weak	0.0183	0.0181	0.0123	0.0077	0.0056
No	No	Regular	8d@6/12	Straps	Strong	0.0176	0.0176	0.0118	0.0073	0.0053
No	No	Regular	8d@6/6	Toe-nails	Weak	0.0376	0.0435	0.0326	0.0222	0.0168
No	No	Regular	8d@6/6	Toe-nails	Strong	0.0373	0.0434	0.0325	0.0221	0.0166
No	No	Regular	8d@6/6	Straps	Weak	0.0178	0.0177	0.0120	0.0075	0.0055
No	No	Regular	8d@6/6	Straps	Strong	0.0173	0.0172	0.0116	0.0071	0.0052

Table 6-9: Normalized Average Annual Losses for One-Story Buildings with Standing Seam Metal Hip Roofs and Unreinforced Masonry Walls

Secondary Water Resistance	Shutter	Window Type	Sheathing Nails	Roof/Wall Connection	Metal Fastener	Terrain Surface Roughness (m)				
						0.03	0.15	0.35	0.7	1
Yes	Yes	Jalousie	6d@6/12	Toe-nails	Weak	0.0115	0.0145	0.0089	0.0049	0.0034
Yes	Yes	Jalousie	6d@6/12	Toe-nails	Strong	0.0114	0.0145	0.0089	0.0049	0.0034
Yes	Yes	Jalousie	6d@6/12	Straps	Weak	0.0073	0.0086	0.0055	0.0035	0.0026
Yes	Yes	Jalousie	6d@6/12	Straps	Strong	0.0071	0.0085	0.0055	0.0034	0.0026
Yes	Yes	Jalousie	8d@6/12	Toe-nails	Weak	0.0113	0.0145	0.0088	0.0049	0.0034
Yes	Yes	Jalousie	8d@6/12	Toe-nails	Strong	0.0113	0.0144	0.0088	0.0049	0.0034
Yes	Yes	Jalousie	8d@6/12	Straps	Weak	0.0067	0.0083	0.0054	0.0034	0.0026
Yes	Yes	Jalousie	8d@6/12	Straps	Strong	0.0064	0.0081	0.0053	0.0034	0.0025
Yes	Yes	Jalousie	8d@6/6	Toe-nails	Weak	0.0114	0.0145	0.0089	0.0049	0.0034
Yes	Yes	Jalousie	8d@6/6	Toe-nails	Strong	0.0113	0.0144	0.0089	0.0049	0.0034
Yes	Yes	Jalousie	8d@6/6	Straps	Weak	0.0067	0.0083	0.0054	0.0034	0.0026

Secondary Water Resistance	Shutter	Window Type	Sheathing Nails	Roof/Wall Connection	Metal Fastener	Terrain Surface Roughness (m)				
						0.03	0.15	0.35	0.7	1
Yes	Yes	Jalousie	8d@6/6	Straps	Strong	0.0064	0.0081	0.0053	0.0034	0.0026
Yes	Yes	Regular	6d@6/12	Toe-nails	Weak	0.0141	0.0171	0.0099	0.0052	0.0035
Yes	Yes	Regular	6d@6/12	Toe-nails	Strong	0.0141	0.0170	0.0098	0.0051	0.0035
Yes	Yes	Regular	6d@6/12	Straps	Weak	0.0064	0.0079	0.0052	0.0033	0.0025
Yes	Yes	Regular	6d@6/12	Straps	Strong	0.0062	0.0078	0.0051	0.0033	0.0025
Yes	Yes	Regular	8d@6/12	Toe-nails	Weak	0.0141	0.0171	0.0099	0.0052	0.0035
Yes	Yes	Regular	8d@6/12	Toe-nails	Strong	0.0140	0.0171	0.0098	0.0051	0.0035
Yes	Yes	Regular	8d@6/12	Straps	Weak	0.0053	0.0072	0.0049	0.0032	0.0025
Yes	Yes	Regular	8d@6/12	Straps	Strong	0.0051	0.0071	0.0048	0.0032	0.0025
Yes	Yes	Regular	8d@6/6	Toe-nails	Weak	0.0142	0.0171	0.0099	0.0052	0.0035
Yes	Yes	Regular	8d@6/6	Toe-nails	Strong	0.0140	0.0170	0.0098	0.0052	0.0034
Yes	Yes	Regular	8d@6/6	Straps	Weak	0.0053	0.0072	0.0049	0.0032	0.0025
Yes	Yes	Regular	8d@6/6	Straps	Strong	0.0050	0.0071	0.0048	0.0032	0.0025
Yes	No	Jalousie	6d@6/12	Toe-nails	Weak	0.0184	0.0171	0.0103	0.0057	0.0039
Yes	No	Jalousie	6d@6/12	Toe-nails	Strong	0.0181	0.0169	0.0103	0.0057	0.0039
Yes	No	Jalousie	6d@6/12	Straps	Weak	0.0104	0.0109	0.0071	0.0043	0.0031
Yes	No	Jalousie	6d@6/12	Straps	Strong	0.0102	0.0108	0.0070	0.0042	0.0031
Yes	No	Jalousie	8d@6/12	Toe-nails	Weak	0.0183	0.0169	0.0103	0.0057	0.0039
Yes	No	Jalousie	8d@6/12	Toe-nails	Strong	0.0182	0.0169	0.0103	0.0057	0.0039
Yes	No	Jalousie	8d@6/12	Straps	Weak	0.0093	0.0105	0.0069	0.0042	0.0031
Yes	No	Jalousie	8d@6/12	Straps	Strong	0.0090	0.0103	0.0068	0.0042	0.0031
Yes	No	Jalousie	8d@6/6	Toe-nails	Weak	0.0183	0.0169	0.0103	0.0057	0.0039
Yes	No	Jalousie	8d@6/6	Toe-nails	Strong	0.0182	0.0169	0.0103	0.0057	0.0039
Yes	No	Jalousie	8d@6/6	Straps	Weak	0.0094	0.0105	0.0068	0.0042	0.0031
Yes	No	Jalousie	8d@6/6	Straps	Strong	0.0091	0.0103	0.0068	0.0042	0.0031
Yes	No	Regular	6d@6/12	Toe-nails	Weak	0.0190	0.0210	0.0123	0.0065	0.0043
Yes	No	Regular	6d@6/12	Toe-nails	Strong	0.0189	0.0209	0.0124	0.0064	0.0042
Yes	No	Regular	6d@6/12	Straps	Weak	0.0083	0.0103	0.0066	0.0041	0.0030
Yes	No	Regular	6d@6/12	Straps	Strong	0.0081	0.0102	0.0065	0.0040	0.0030
Yes	No	Regular	8d@6/12	Toe-nails	Weak	0.0190	0.0210	0.0124	0.0064	0.0043
Yes	No	Regular	8d@6/12	Toe-nails	Strong	0.0189	0.0210	0.0123	0.0064	0.0043
Yes	No	Regular	8d@6/12	Straps	Weak	0.0069	0.0095	0.0063	0.0039	0.0030
Yes	No	Regular	8d@6/12	Straps	Strong	0.0066	0.0093	0.0062	0.0039	0.0029
Yes	No	Regular	8d@6/6	Toe-nails	Weak	0.0190	0.0210	0.0124	0.0064	0.0043
Yes	No	Regular	8d@6/6	Toe-nails	Strong	0.0189	0.0210	0.0123	0.0064	0.0043
Yes	No	Regular	8d@6/6	Straps	Weak	0.0068	0.0095	0.0063	0.0039	0.0029
Yes	No	Regular	8d@6/6	Straps	Strong	0.0066	0.0094	0.0062	0.0039	0.0029
No	Yes	Jalousie	6d@6/12	Toe-nails	Weak	0.0115	0.0145	0.0089	0.0049	0.0034
No	Yes	Jalousie	6d@6/12	Toe-nails	Strong	0.0114	0.0145	0.0089	0.0050	0.0034
No	Yes	Jalousie	6d@6/12	Straps	Weak	0.0073	0.0086	0.0055	0.0034	0.0026
No	Yes	Jalousie	6d@6/12	Straps	Strong	0.0071	0.0085	0.0055	0.0034	0.0026
No	Yes	Jalousie	8d@6/12	Toe-nails	Weak	0.0114	0.0146	0.0089	0.0050	0.0034
No	Yes	Jalousie	8d@6/12	Toe-nails	Strong	0.0113	0.0143	0.0088	0.0049	0.0034
No	Yes	Jalousie	8d@6/12	Straps	Weak	0.0067	0.0083	0.0054	0.0034	0.0026
No	Yes	Jalousie	8d@6/12	Straps	Strong	0.0064	0.0081	0.0053	0.0034	0.0026
No	Yes	Jalousie	8d@6/6	Toe-nails	Weak	0.0114	0.0145	0.0089	0.0049	0.0034
No	Yes	Jalousie	8d@6/6	Toe-nails	Strong	0.0113	0.0144	0.0089	0.0049	0.0034
No	Yes	Jalousie	8d@6/6	Straps	Weak	0.0067	0.0083	0.0054	0.0034	0.0026
No	Yes	Jalousie	8d@6/6	Straps	Strong	0.0064	0.0081	0.0053	0.0034	0.0026
No	Yes	Regular	6d@6/12	Toe-nails	Weak	0.0141	0.0171	0.0099	0.0052	0.0035
No	Yes	Regular	6d@6/12	Toe-nails	Strong	0.0141	0.0170	0.0098	0.0051	0.0035
No	Yes	Regular	6d@6/12	Straps	Weak	0.0064	0.0079	0.0052	0.0033	0.0025

Secondary Water Resistance	Shutter	Window Type	Sheathing Nails	Roof/Wall Connection	Metal Fastener	Terrain Surface Roughness (m)				
						0.03	0.15	0.35	0.7	1
No	Yes	Regular	6d@6/12	Straps	Strong	0.0062	0.0078	0.0051	0.0033	0.0025
No	Yes	Regular	8d@6/12	Toe-nails	Weak	0.0141	0.0171	0.0099	0.0052	0.0035
No	Yes	Regular	8d@6/12	Toe-nails	Strong	0.0140	0.0171	0.0098	0.0051	0.0034
No	Yes	Regular	8d@6/12	Straps	Weak	0.0053	0.0072	0.0049	0.0032	0.0025
No	Yes	Regular	8d@6/12	Straps	Strong	0.0051	0.0071	0.0048	0.0032	0.0025
No	Yes	Regular	8d@6/6	Toe-nails	Weak	0.0142	0.0171	0.0099	0.0052	0.0035
No	Yes	Regular	8d@6/6	Toe-nails	Strong	0.0140	0.0170	0.0098	0.0052	0.0034
No	Yes	Regular	8d@6/6	Straps	Weak	0.0053	0.0072	0.0049	0.0032	0.0025
No	Yes	Regular	8d@6/6	Straps	Strong	0.0050	0.0071	0.0048	0.0032	0.0025
No	No	Jalousie	6d@6/12	Toe-nails	Weak	0.0184	0.0170	0.0103	0.0057	0.0039
No	No	Jalousie	6d@6/12	Toe-nails	Strong	0.0181	0.0169	0.0103	0.0057	0.0040
No	No	Jalousie	6d@6/12	Straps	Weak	0.0104	0.0109	0.0071	0.0043	0.0031
No	No	Jalousie	6d@6/12	Straps	Strong	0.0102	0.0108	0.0070	0.0043	0.0031
No	No	Jalousie	8d@6/12	Toe-nails	Weak	0.0183	0.0169	0.0103	0.0057	0.0039
No	No	Jalousie	8d@6/12	Toe-nails	Strong	0.0182	0.0169	0.0104	0.0057	0.0039
No	No	Jalousie	8d@6/12	Straps	Weak	0.0093	0.0105	0.0068	0.0042	0.0031
No	No	Jalousie	8d@6/12	Straps	Strong	0.0091	0.0103	0.0068	0.0042	0.0031
No	No	Jalousie	8d@6/6	Toe-nails	Weak	0.0183	0.0169	0.0103	0.0057	0.0039
No	No	Jalousie	8d@6/6	Toe-nails	Strong	0.0182	0.0169	0.0104	0.0057	0.0039
No	No	Jalousie	8d@6/6	Straps	Weak	0.0093	0.0105	0.0068	0.0042	0.0031
No	No	Jalousie	8d@6/6	Straps	Strong	0.0090	0.0103	0.0068	0.0042	0.0031
No	No	Regular	6d@6/12	Toe-nails	Weak	0.0190	0.0210	0.0123	0.0065	0.0043
No	No	Regular	6d@6/12	Toe-nails	Strong	0.0189	0.0209	0.0124	0.0064	0.0042
No	No	Regular	6d@6/12	Straps	Weak	0.0083	0.0103	0.0066	0.0041	0.0030
No	No	Regular	6d@6/12	Straps	Strong	0.0081	0.0102	0.0065	0.0040	0.0030
No	No	Regular	8d@6/12	Toe-nails	Weak	0.0190	0.0210	0.0124	0.0064	0.0043
No	No	Regular	8d@6/12	Toe-nails	Strong	0.0189	0.0210	0.0124	0.0064	0.0043
No	No	Regular	8d@6/12	Straps	Weak	0.0069	0.0095	0.0062	0.0039	0.0030
No	No	Regular	8d@6/12	Straps	Strong	0.0066	0.0093	0.0062	0.0039	0.0029
No	No	Regular	8d@6/6	Toe-nails	Weak	0.0190	0.0210	0.0124	0.0064	0.0042
No	No	Regular	8d@6/6	Toe-nails	Strong	0.0189	0.0210	0.0124	0.0064	0.0043
No	No	Regular	8d@6/6	Straps	Weak	0.0069	0.0095	0.0062	0.0039	0.0029
No	No	Regular	8d@6/6	Straps	Strong	0.0066	0.0093	0.0062	0.0039	0.0029

Table 6-10: Normalized Average Annual Losses for Two-Story Buildings with Standing Seam Metal Hip Roofs and Unreinforced Masonry Walls

Secondary Water Resistance	Shutter	Window Type	Sheathing Nails	Roof/Wall Connection	Metal Fastener	Terrain Surface Roughness (m)				
						0.03	0.15	0.35	0.7	1
Yes	Yes	Jalousie	6d@6/12	Toe-nails	Weak	0.0188	0.0203	0.0138	0.0087	0.0064
Yes	Yes	Jalousie	6d@6/12	Toe-nails	Strong	0.0184	0.0202	0.0137	0.0086	0.0063
Yes	Yes	Jalousie	6d@6/12	Straps	Weak	0.0148	0.0154	0.0104	0.0065	0.0048
Yes	Yes	Jalousie	6d@6/12	Straps	Strong	0.0145	0.0152	0.0102	0.0064	0.0047
Yes	Yes	Jalousie	8d@6/12	Toe-nails	Weak	0.0184	0.0201	0.0136	0.0085	0.0063
Yes	Yes	Jalousie	8d@6/12	Toe-nails	Strong	0.0182	0.0200	0.0135	0.0085	0.0062
Yes	Yes	Jalousie	8d@6/12	Straps	Weak	0.0124	0.0141	0.0096	0.0061	0.0045
Yes	Yes	Jalousie	8d@6/12	Straps	Strong	0.0120	0.0138	0.0094	0.0060	0.0044

Secondary Water Resistance	Shutter	Window Type	Sheathing Nails	Roof/Wall Connection	Metal Fastener	Terrain Surface Roughness (m)				
						0.03	0.15	0.35	0.7	1
Yes	Yes	Jalousie	8d@6/6	Toe-nails	Weak	0.0184	0.0201	0.0136	0.0086	0.0063
Yes	Yes	Jalousie	8d@6/6	Toe-nails	Strong	0.0182	0.0200	0.0135	0.0085	0.0062
Yes	Yes	Jalousie	8d@6/6	Straps	Weak	0.0123	0.0140	0.0096	0.0061	0.0045
Yes	Yes	Jalousie	8d@6/6	Straps	Strong	0.0119	0.0137	0.0094	0.0060	0.0044
Yes	Yes	Regular	6d@6/12	Toe-nails	Weak	0.0212	0.0261	0.0173	0.0103	0.0072
Yes	Yes	Regular	6d@6/12	Toe-nails	Strong	0.0209	0.0260	0.0172	0.0103	0.0071
Yes	Yes	Regular	6d@6/12	Straps	Weak	0.0131	0.0143	0.0092	0.0056	0.0042
Yes	Yes	Regular	6d@6/12	Straps	Strong	0.0128	0.0141	0.0091	0.0055	0.0041
Yes	Yes	Regular	8d@6/12	Toe-nails	Weak	0.0209	0.0260	0.0172	0.0103	0.0071
Yes	Yes	Regular	8d@6/12	Toe-nails	Strong	0.0207	0.0259	0.0172	0.0102	0.0071
Yes	Yes	Regular	8d@6/12	Straps	Weak	0.0098	0.0113	0.0076	0.0049	0.0037
Yes	Yes	Regular	8d@6/12	Straps	Strong	0.0093	0.0110	0.0074	0.0047	0.0036
Yes	Yes	Regular	8d@6/6	Toe-nails	Weak	0.0209	0.0260	0.0172	0.0103	0.0070
Yes	Yes	Regular	8d@6/6	Toe-nails	Strong	0.0207	0.0259	0.0172	0.0102	0.0072
Yes	Yes	Regular	8d@6/6	Straps	Weak	0.0097	0.0112	0.0076	0.0049	0.0037
Yes	Yes	Regular	8d@6/6	Straps	Strong	0.0093	0.0110	0.0074	0.0047	0.0036
Yes	No	Jalousie	6d@6/12	Toe-nails	Weak	0.0314	0.0263	0.0182	0.0115	0.0085
Yes	No	Jalousie	6d@6/12	Toe-nails	Strong	0.0313	0.0262	0.0181	0.0115	0.0084
Yes	No	Jalousie	6d@6/12	Straps	Weak	0.0212	0.0197	0.0139	0.0091	0.0067
Yes	No	Jalousie	6d@6/12	Straps	Strong	0.0208	0.0193	0.0137	0.0089	0.0066
Yes	No	Jalousie	8d@6/12	Toe-nails	Weak	0.0312	0.0262	0.0181	0.0114	0.0083
Yes	No	Jalousie	8d@6/12	Toe-nails	Strong	0.0311	0.0261	0.0181	0.0114	0.0082
Yes	No	Jalousie	8d@6/12	Straps	Weak	0.0179	0.0178	0.0129	0.0084	0.0063
Yes	No	Jalousie	8d@6/12	Straps	Strong	0.0174	0.0176	0.0126	0.0083	0.0062
Yes	No	Jalousie	8d@6/6	Toe-nails	Weak	0.0312	0.0263	0.0181	0.0114	0.0083
Yes	No	Jalousie	8d@6/6	Toe-nails	Strong	0.0311	0.0261	0.0181	0.0114	0.0082
Yes	No	Jalousie	8d@6/6	Straps	Weak	0.0178	0.0178	0.0128	0.0085	0.0063
Yes	No	Jalousie	8d@6/6	Straps	Strong	0.0173	0.0175	0.0127	0.0083	0.0062
Yes	No	Regular	6d@6/12	Toe-nails	Weak	0.0292	0.0329	0.0229	0.0142	0.0100
Yes	No	Regular	6d@6/12	Toe-nails	Strong	0.0290	0.0328	0.0229	0.0141	0.0100
Yes	No	Regular	6d@6/12	Straps	Weak	0.0178	0.0185	0.0123	0.0075	0.0054
Yes	No	Regular	6d@6/12	Straps	Strong	0.0175	0.0182	0.0121	0.0074	0.0053
Yes	No	Regular	8d@6/12	Toe-nails	Weak	0.0290	0.0329	0.0229	0.0141	0.0100
Yes	No	Regular	8d@6/12	Toe-nails	Strong	0.0290	0.0328	0.0228	0.0141	0.0100
Yes	No	Regular	8d@6/12	Straps	Weak	0.0135	0.0154	0.0105	0.0065	0.0048
Yes	No	Regular	8d@6/12	Straps	Strong	0.0131	0.0151	0.0103	0.0064	0.0047
Yes	No	Regular	8d@6/6	Toe-nails	Weak	0.0289	0.0329	0.0229	0.0141	0.0100
Yes	No	Regular	8d@6/6	Toe-nails	Strong	0.0289	0.0329	0.0228	0.0141	0.0100
Yes	No	Regular	8d@6/6	Straps	Weak	0.0134	0.0153	0.0105	0.0065	0.0048
Yes	No	Regular	8d@6/6	Straps	Strong	0.0129	0.0150	0.0103	0.0064	0.0047
No	Yes	Jalousie	6d@6/12	Toe-nails	Weak	0.0188	0.0203	0.0139	0.0087	0.0063
No	Yes	Jalousie	6d@6/12	Toe-nails	Strong	0.0184	0.0202	0.0137	0.0086	0.0063
No	Yes	Jalousie	6d@6/12	Straps	Weak	0.0148	0.0155	0.0104	0.0065	0.0048
No	Yes	Jalousie	6d@6/12	Straps	Strong	0.0145	0.0152	0.0102	0.0064	0.0047
No	Yes	Jalousie	8d@6/12	Toe-nails	Weak	0.0184	0.0201	0.0136	0.0086	0.0063
No	Yes	Jalousie	8d@6/12	Toe-nails	Strong	0.0182	0.0200	0.0136	0.0085	0.0062
No	Yes	Jalousie	8d@6/12	Straps	Weak	0.0125	0.0141	0.0096	0.0061	0.0046
No	Yes	Jalousie	8d@6/12	Straps	Strong	0.0120	0.0138	0.0094	0.0060	0.0044
No	Yes	Jalousie	8d@6/6	Toe-nails	Weak	0.0184	0.0201	0.0136	0.0086	0.0063
No	Yes	Jalousie	8d@6/6	Toe-nails	Strong	0.0182	0.0200	0.0136	0.0085	0.0063
No	Yes	Jalousie	8d@6/6	Straps	Weak	0.0124	0.0140	0.0096	0.0061	0.0045
No	Yes	Jalousie	8d@6/6	Straps	Strong	0.0119	0.0137	0.0094	0.0060	0.0044
No	Yes	Regular	6d@6/12	Toe-nails	Weak	0.0212	0.0261	0.0173	0.0103	0.0072

Secondary Water Resistance	Shutter	Window Type	Sheathing Nails	Roof/Wall Connection	Metal Fastener	Terrain Surface Roughness (m)				
						0.03	0.15	0.35	0.7	1
No	Yes	Regular	6d@6/12	Toe-nails	Strong	0.0209	0.0260	0.0172	0.0103	0.0071
No	Yes	Regular	6d@6/12	Straps	Weak	0.0131	0.0143	0.0093	0.0057	0.0042
No	Yes	Regular	6d@6/12	Straps	Strong	0.0128	0.0141	0.0091	0.0055	0.0041
No	Yes	Regular	8d@6/12	Toe-nails	Weak	0.0209	0.0260	0.0172	0.0103	0.0071
No	Yes	Regular	8d@6/12	Toe-nails	Strong	0.0207	0.0259	0.0172	0.0102	0.0071
No	Yes	Regular	8d@6/12	Straps	Weak	0.0099	0.0113	0.0076	0.0049	0.0037
No	Yes	Regular	8d@6/12	Straps	Strong	0.0094	0.0110	0.0074	0.0047	0.0036
No	Yes	Regular	8d@6/6	Toe-nails	Weak	0.0209	0.0260	0.0172	0.0103	0.0070
No	Yes	Regular	8d@6/6	Toe-nails	Strong	0.0207	0.0259	0.0172	0.0102	0.0072
No	Yes	Regular	8d@6/6	Straps	Weak	0.0098	0.0112	0.0076	0.0049	0.0037
No	Yes	Regular	8d@6/6	Straps	Strong	0.0093	0.0110	0.0074	0.0047	0.0036
No	No	Jalousie	6d@6/12	Toe-nails	Weak	0.0314	0.0263	0.0182	0.0115	0.0085
No	No	Jalousie	6d@6/12	Toe-nails	Strong	0.0312	0.0262	0.0182	0.0115	0.0083
No	No	Jalousie	6d@6/12	Straps	Weak	0.0212	0.0197	0.0139	0.0091	0.0067
No	No	Jalousie	6d@6/12	Straps	Strong	0.0208	0.0194	0.0137	0.0089	0.0066
No	No	Jalousie	8d@6/12	Toe-nails	Weak	0.0312	0.0262	0.0181	0.0114	0.0084
No	No	Jalousie	8d@6/12	Toe-nails	Strong	0.0311	0.0261	0.0180	0.0113	0.0082
No	No	Jalousie	8d@6/12	Straps	Weak	0.0179	0.0179	0.0129	0.0084	0.0063
No	No	Jalousie	8d@6/12	Straps	Strong	0.0174	0.0176	0.0126	0.0083	0.0062
No	No	Jalousie	8d@6/6	Toe-nails	Weak	0.0312	0.0263	0.0181	0.0114	0.0083
No	No	Jalousie	8d@6/6	Toe-nails	Strong	0.0311	0.0261	0.0181	0.0113	0.0082
No	No	Jalousie	8d@6/6	Straps	Weak	0.0178	0.0178	0.0129	0.0085	0.0063
No	No	Jalousie	8d@6/6	Straps	Strong	0.0174	0.0175	0.0127	0.0083	0.0062
No	No	Regular	6d@6/12	Toe-nails	Weak	0.0292	0.0329	0.0229	0.0142	0.0100
No	No	Regular	6d@6/12	Toe-nails	Strong	0.0290	0.0328	0.0229	0.0141	0.0100
No	No	Regular	6d@6/12	Straps	Weak	0.0179	0.0185	0.0123	0.0075	0.0054
No	No	Regular	6d@6/12	Straps	Strong	0.0176	0.0183	0.0122	0.0074	0.0053
No	No	Regular	8d@6/12	Toe-nails	Weak	0.0290	0.0329	0.0229	0.0141	0.0100
No	No	Regular	8d@6/12	Toe-nails	Strong	0.0290	0.0328	0.0228	0.0141	0.0100
No	No	Regular	8d@6/12	Straps	Weak	0.0136	0.0154	0.0105	0.0066	0.0048
No	No	Regular	8d@6/12	Straps	Strong	0.0131	0.0151	0.0103	0.0064	0.0047
No	No	Regular	8d@6/6	Toe-nails	Weak	0.0289	0.0329	0.0229	0.0141	0.0100
No	No	Regular	8d@6/6	Toe-nails	Strong	0.0289	0.0328	0.0228	0.0141	0.0100
No	No	Regular	8d@6/6	Straps	Weak	0.0135	0.0153	0.0105	0.0066	0.0048
No	No	Regular	8d@6/6	Straps	Strong	0.0130	0.0150	0.0104	0.0064	0.0047

Table 6-11: Normalized Average Annual Losses for One-Story Buildings with Standing Seam Metal Gable Roofs and Wood Frame Walls

Secondary Water Resistance	Shutter	Window Type	Sheathing Nails	Roof/Wall Connection	Metal Fastener	Terrain Surface Roughness (m)				
						0.03	0.15	0.35	0.7	1
Yes	Yes	Jalousie	6d@6/12	Toe-nails	Weak	0.0219	0.0251	0.0167	0.0099	0.0071
Yes	Yes	Jalousie	6d@6/12	Toe-nails	Strong	0.0215	0.0249	0.0165	0.0098	0.0069
Yes	Yes	Jalousie	6d@6/12	Straps	Weak	0.0157	0.0156	0.0099	0.0061	0.0046
Yes	Yes	Jalousie	6d@6/12	Straps	Strong	0.0154	0.0154	0.0098	0.0060	0.0044
Yes	Yes	Jalousie	8d@6/12	Toe-nails	Weak	0.0195	0.0238	0.0156	0.0091	0.0063
Yes	Yes	Jalousie	8d@6/12	Toe-nails	Strong	0.0192	0.0236	0.0154	0.0089	0.0061
Yes	Yes	Jalousie	8d@6/12	Straps	Weak	0.0095	0.0107	0.0069	0.0043	0.0032
Yes	Yes	Jalousie	8d@6/12	Straps	Strong	0.0088	0.0102	0.0065	0.0040	0.0030
Yes	Yes	Jalousie	8d@6/6	Toe-nails	Weak	0.0196	0.0237	0.0157	0.0092	0.0063
Yes	Yes	Jalousie	8d@6/6	Toe-nails	Strong	0.0192	0.0235	0.0155	0.0089	0.0062
Yes	Yes	Jalousie	8d@6/6	Straps	Weak	0.0090	0.0103	0.0067	0.0042	0.0032
Yes	Yes	Jalousie	8d@6/6	Straps	Strong	0.0083	0.0099	0.0063	0.0039	0.0029
Yes	Yes	Regular	6d@6/12	Toe-nails	Weak	0.0229	0.0263	0.0172	0.0100	0.0071
Yes	Yes	Regular	6d@6/12	Toe-nails	Strong	0.0227	0.0262	0.0170	0.0099	0.0070

Secondary Water Resistance	Shutter	Window Type	Sheathing Nails	Roof/Wall Connection	Metal Fastener	Terrain Surface Roughness (m)				
						0.03	0.15	0.35	0.7	1
Yes	Yes	Regular	6d@6/12	Straps	Weak	0.0158	0.0156	0.0098	0.0060	0.0045
Yes	Yes	Regular	6d@6/12	Straps	Strong	0.0155	0.0154	0.0097	0.0058	0.0044
Yes	Yes	Regular	8d@6/12	Toe-nails	Weak	0.0211	0.0253	0.0164	0.0093	0.0064
Yes	Yes	Regular	8d@6/12	Toe-nails	Strong	0.0207	0.0251	0.0161	0.0091	0.0062
Yes	Yes	Regular	8d@6/12	Straps	Weak	0.0088	0.0098	0.0064	0.0041	0.0031
Yes	Yes	Regular	8d@6/12	Straps	Strong	0.0082	0.0094	0.0061	0.0038	0.0029
Yes	Yes	Regular	8d@6/6	Toe-nails	Weak	0.0209	0.0253	0.0163	0.0093	0.0064
Yes	Yes	Regular	8d@6/6	Toe-nails	Strong	0.0207	0.0251	0.0160	0.0091	0.0062
Yes	Yes	Regular	8d@6/6	Straps	Weak	0.0085	0.0096	0.0063	0.0040	0.0031
Yes	Yes	Regular	8d@6/6	Straps	Strong	0.0078	0.0091	0.0059	0.0038	0.0028
Yes	No	Jalousie	6d@6/12	Toe-nails	Weak	0.0279	0.0291	0.0197	0.0117	0.0083
Yes	No	Jalousie	6d@6/12	Toe-nails	Strong	0.0278	0.0291	0.0195	0.0117	0.0081
Yes	No	Jalousie	6d@6/12	Straps	Weak	0.0204	0.0190	0.0122	0.0073	0.0053
Yes	No	Jalousie	6d@6/12	Straps	Strong	0.0202	0.0188	0.0121	0.0072	0.0052
Yes	No	Jalousie	8d@6/12	Toe-nails	Weak	0.0263	0.0282	0.0186	0.0109	0.0075
Yes	No	Jalousie	8d@6/12	Toe-nails	Strong	0.0259	0.0279	0.0184	0.0107	0.0074
Yes	No	Jalousie	8d@6/12	Straps	Weak	0.0131	0.0134	0.0087	0.0053	0.0038
Yes	No	Jalousie	8d@6/12	Straps	Strong	0.0124	0.0129	0.0084	0.0050	0.0036
Yes	No	Jalousie	8d@6/6	Toe-nails	Weak	0.0262	0.0281	0.0185	0.0109	0.0075
Yes	No	Jalousie	8d@6/6	Toe-nails	Strong	0.0258	0.0280	0.0185	0.0107	0.0073
Yes	No	Jalousie	8d@6/6	Straps	Weak	0.0124	0.0129	0.0084	0.0052	0.0038
Yes	No	Jalousie	8d@6/6	Straps	Strong	0.0118	0.0125	0.0081	0.0049	0.0035
Yes	No	Regular	6d@6/12	Toe-nails	Weak	0.0276	0.0318	0.0212	0.0123	0.0085
Yes	No	Regular	6d@6/12	Toe-nails	Strong	0.0273	0.0318	0.0211	0.0124	0.0084
Yes	No	Regular	6d@6/12	Straps	Weak	0.0186	0.0193	0.0122	0.0072	0.0052
Yes	No	Regular	6d@6/12	Straps	Strong	0.0184	0.0192	0.0120	0.0071	0.0051
Yes	No	Regular	8d@6/12	Toe-nails	Weak	0.0261	0.0313	0.0205	0.0117	0.0079
Yes	No	Regular	8d@6/12	Toe-nails	Strong	0.0256	0.0312	0.0204	0.0116	0.0077
Yes	No	Regular	8d@6/12	Straps	Weak	0.0107	0.0125	0.0080	0.0049	0.0036
Yes	No	Regular	8d@6/12	Straps	Strong	0.0101	0.0120	0.0076	0.0046	0.0034
Yes	No	Regular	8d@6/6	Toe-nails	Weak	0.0261	0.0312	0.0204	0.0117	0.0079
Yes	No	Regular	8d@6/6	Toe-nails	Strong	0.0257	0.0311	0.0203	0.0115	0.0078
Yes	No	Regular	8d@6/6	Straps	Weak	0.0103	0.0120	0.0078	0.0048	0.0036
Yes	No	Regular	8d@6/6	Straps	Strong	0.0096	0.0116	0.0074	0.0045	0.0033
No	Yes	Jalousie	6d@6/12	Toe-nails	Weak	0.0219	0.0251	0.0167	0.0099	0.0071
No	Yes	Jalousie	6d@6/12	Toe-nails	Strong	0.0215	0.0249	0.0165	0.0098	0.0069
No	Yes	Jalousie	6d@6/12	Straps	Weak	0.0157	0.0156	0.0099	0.0061	0.0046
No	Yes	Jalousie	6d@6/12	Straps	Strong	0.0155	0.0154	0.0098	0.0060	0.0044
No	Yes	Jalousie	8d@6/12	Toe-nails	Weak	0.0195	0.0238	0.0156	0.0091	0.0063
No	Yes	Jalousie	8d@6/12	Toe-nails	Strong	0.0192	0.0236	0.0155	0.0089	0.0061
No	Yes	Jalousie	8d@6/12	Straps	Weak	0.0095	0.0107	0.0069	0.0043	0.0032
No	Yes	Jalousie	8d@6/12	Straps	Strong	0.0088	0.0102	0.0065	0.0040	0.0030
No	Yes	Jalousie	8d@6/6	Toe-nails	Weak	0.0196	0.0237	0.0157	0.0092	0.0063
No	Yes	Jalousie	8d@6/6	Toe-nails	Strong	0.0192	0.0235	0.0154	0.0089	0.0062
No	Yes	Jalousie	8d@6/6	Straps	Weak	0.0090	0.0103	0.0067	0.0042	0.0032
No	Yes	Jalousie	8d@6/6	Straps	Strong	0.0083	0.0099	0.0063	0.0039	0.0029
No	Yes	Regular	6d@6/12	Toe-nails	Weak	0.0229	0.0263	0.0172	0.0101	0.0071
No	Yes	Regular	6d@6/12	Toe-nails	Strong	0.0227	0.0262	0.0170	0.0099	0.0070
No	Yes	Regular	6d@6/12	Straps	Weak	0.0158	0.0156	0.0098	0.0060	0.0045
No	Yes	Regular	6d@6/12	Straps	Strong	0.0156	0.0154	0.0097	0.0059	0.0044
No	Yes	Regular	8d@6/12	Toe-nails	Weak	0.0211	0.0253	0.0164	0.0092	0.0063
No	Yes	Regular	8d@6/12	Toe-nails	Strong	0.0207	0.0251	0.0161	0.0091	0.0062

Secondary Water Resistance	Shutter	Window Type	Sheathing Nails	Roof/Wall Connection	Metal Fastener	Terrain Surface Roughness (m)				
						0.03	0.15	0.35	0.7	1
No	Yes	Regular	8d@6/12	Straps	Weak	0.0088	0.0099	0.0064	0.0041	0.0031
No	Yes	Regular	8d@6/12	Straps	Strong	0.0082	0.0094	0.0060	0.0038	0.0029
No	Yes	Regular	8d@6/6	Toe-nails	Weak	0.0209	0.0253	0.0163	0.0093	0.0064
No	Yes	Regular	8d@6/6	Toe-nails	Strong	0.0207	0.0251	0.0160	0.0090	0.0063
No	Yes	Regular	8d@6/6	Straps	Weak	0.0085	0.0096	0.0063	0.0040	0.0031
No	Yes	Regular	8d@6/6	Straps	Strong	0.0077	0.0091	0.0059	0.0038	0.0028
No	No	Jalousie	6d@6/12	Toe-nails	Weak	0.0279	0.0292	0.0197	0.0117	0.0083
No	No	Jalousie	6d@6/12	Toe-nails	Strong	0.0278	0.0292	0.0195	0.0117	0.0081
No	No	Jalousie	6d@6/12	Straps	Weak	0.0205	0.0190	0.0122	0.0073	0.0053
No	No	Jalousie	6d@6/12	Straps	Strong	0.0202	0.0189	0.0121	0.0072	0.0052
No	No	Jalousie	8d@6/12	Toe-nails	Weak	0.0263	0.0282	0.0186	0.0109	0.0075
No	No	Jalousie	8d@6/12	Toe-nails	Strong	0.0259	0.0279	0.0184	0.0107	0.0074
No	No	Jalousie	8d@6/12	Straps	Weak	0.0131	0.0135	0.0087	0.0053	0.0038
No	No	Jalousie	8d@6/12	Straps	Strong	0.0124	0.0130	0.0083	0.0050	0.0036
No	No	Jalousie	8d@6/6	Toe-nails	Weak	0.0262	0.0281	0.0186	0.0109	0.0075
No	No	Jalousie	8d@6/6	Toe-nails	Strong	0.0258	0.0280	0.0185	0.0107	0.0074
No	No	Jalousie	8d@6/6	Straps	Weak	0.0124	0.0130	0.0084	0.0052	0.0038
No	No	Jalousie	8d@6/6	Straps	Strong	0.0118	0.0125	0.0081	0.0049	0.0035
No	No	Regular	6d@6/12	Toe-nails	Weak	0.0276	0.0318	0.0212	0.0124	0.0085
No	No	Regular	6d@6/12	Toe-nails	Strong	0.0273	0.0318	0.0211	0.0123	0.0084
No	No	Regular	6d@6/12	Straps	Weak	0.0187	0.0193	0.0122	0.0072	0.0052
No	No	Regular	6d@6/12	Straps	Strong	0.0184	0.0192	0.0120	0.0071	0.0051
No	No	Regular	8d@6/12	Toe-nails	Weak	0.0261	0.0313	0.0205	0.0117	0.0079
No	No	Regular	8d@6/12	Toe-nails	Strong	0.0256	0.0311	0.0204	0.0116	0.0077
No	No	Regular	8d@6/12	Straps	Weak	0.0107	0.0125	0.0080	0.0049	0.0036
No	No	Regular	8d@6/12	Straps	Strong	0.0101	0.0120	0.0077	0.0046	0.0034
No	No	Regular	8d@6/6	Toe-nails	Weak	0.0260	0.0312	0.0204	0.0117	0.0079
No	No	Regular	8d@6/6	Toe-nails	Strong	0.0257	0.0311	0.0203	0.0115	0.0078
No	No	Regular	8d@6/6	Straps	Weak	0.0103	0.0120	0.0078	0.0048	0.0036
No	No	Regular	8d@6/6	Straps	Strong	0.0096	0.0115	0.0074	0.0046	0.0033

Table 6-12: Normalized Average Annual Losses for Two-Story Buildings with Standing Seam Metal Gable Roofs and Wood Frame Walls

Secondary Water Resistance	Shutter	Window Type	Sheathing Nails	Roof/Wall Connection	Metal Fastener	Terrain Surface Roughness (m)				
						0.03	0.15	0.35	0.7	1
Yes	Yes	Jalousie	6d@6/12	Toe-nails	Weak	0.0311	0.0324	0.0240	0.0165	0.0129
Yes	Yes	Jalousie	6d@6/12	Toe-nails	Strong	0.0307	0.0322	0.0238	0.0163	0.0128
Yes	Yes	Jalousie	6d@6/12	Straps	Weak	0.0207	0.0210	0.0144	0.0092	0.0069
Yes	Yes	Jalousie	6d@6/12	Straps	Strong	0.0202	0.0206	0.0140	0.0088	0.0066
Yes	Yes	Jalousie	8d@6/12	Toe-nails	Weak	0.0299	0.0317	0.0233	0.0161	0.0125
Yes	Yes	Jalousie	8d@6/12	Toe-nails	Strong	0.0298	0.0314	0.0231	0.0159	0.0123
Yes	Yes	Jalousie	8d@6/12	Straps	Weak	0.0160	0.0170	0.0117	0.0074	0.0055
Yes	Yes	Jalousie	8d@6/12	Straps	Strong	0.0154	0.0166	0.0113	0.0071	0.0053
Yes	Yes	Jalousie	8d@6/6	Toe-nails	Weak	0.0299	0.0318	0.0233	0.0162	0.0125
Yes	Yes	Jalousie	8d@6/6	Toe-nails	Strong	0.0297	0.0314	0.0231	0.0159	0.0123
Yes	Yes	Jalousie	8d@6/6	Straps	Weak	0.0156	0.0167	0.0114	0.0073	0.0056

Secondary Water Resistance	Shutter	Window Type	Sheathing Nails	Roof/Wall Connection	Metal Fastener	Terrain Surface Roughness (m)				
						0.03	0.15	0.35	0.7	1
Yes	Yes	Jalousie	8d@6/6	Straps	Strong	0.0150	0.0162	0.0110	0.0070	0.0052
Yes	Yes	Regular	6d@6/12	Toe-nails	Weak	0.0315	0.0350	0.0256	0.0172	0.0132
Yes	Yes	Regular	6d@6/12	Toe-nails	Strong	0.0312	0.0348	0.0254	0.0171	0.0131
Yes	Yes	Regular	6d@6/12	Straps	Weak	0.0188	0.0195	0.0130	0.0081	0.0061
Yes	Yes	Regular	6d@6/12	Straps	Strong	0.0182	0.0192	0.0126	0.0078	0.0058
Yes	Yes	Regular	8d@6/12	Toe-nails	Weak	0.0308	0.0346	0.0251	0.0168	0.0128
Yes	Yes	Regular	8d@6/12	Toe-nails	Strong	0.0305	0.0346	0.0250	0.0166	0.0126
Yes	Yes	Regular	8d@6/12	Straps	Weak	0.0143	0.0154	0.0102	0.0064	0.0048
Yes	Yes	Regular	8d@6/12	Straps	Strong	0.0137	0.0149	0.0097	0.0060	0.0045
Yes	Yes	Regular	8d@6/6	Toe-nails	Weak	0.0308	0.0347	0.0251	0.0168	0.0128
Yes	Yes	Regular	8d@6/6	Toe-nails	Strong	0.0304	0.0345	0.0250	0.0167	0.0126
Yes	Yes	Regular	8d@6/6	Straps	Weak	0.0139	0.0151	0.0100	0.0063	0.0048
Yes	Yes	Regular	8d@6/6	Straps	Strong	0.0134	0.0147	0.0096	0.0059	0.0044
Yes	No	Jalousie	6d@6/12	Toe-nails	Weak	0.0413	0.0391	0.0293	0.0201	0.0155
Yes	No	Jalousie	6d@6/12	Toe-nails	Strong	0.0412	0.0390	0.0291	0.0201	0.0154
Yes	No	Jalousie	6d@6/12	Straps	Weak	0.0289	0.0265	0.0189	0.0124	0.0094
Yes	No	Jalousie	6d@6/12	Straps	Strong	0.0285	0.0260	0.0185	0.0120	0.0090
Yes	No	Jalousie	8d@6/12	Toe-nails	Weak	0.0406	0.0386	0.0286	0.0197	0.0151
Yes	No	Jalousie	8d@6/12	Toe-nails	Strong	0.0405	0.0385	0.0285	0.0195	0.0149
Yes	No	Jalousie	8d@6/12	Straps	Weak	0.0224	0.0216	0.0155	0.0102	0.0077
Yes	No	Jalousie	8d@6/12	Straps	Strong	0.0217	0.0211	0.0151	0.0098	0.0073
Yes	No	Jalousie	8d@6/6	Toe-nails	Weak	0.0407	0.0387	0.0287	0.0196	0.0152
Yes	No	Jalousie	8d@6/6	Toe-nails	Strong	0.0406	0.0384	0.0285	0.0195	0.0149
Yes	No	Jalousie	8d@6/6	Straps	Weak	0.0218	0.0211	0.0152	0.0100	0.0076
Yes	No	Jalousie	8d@6/6	Straps	Strong	0.0212	0.0206	0.0148	0.0097	0.0072
Yes	No	Regular	6d@6/12	Toe-nails	Weak	0.0383	0.0437	0.0331	0.0227	0.0172
Yes	No	Regular	6d@6/12	Toe-nails	Strong	0.0383	0.0439	0.0329	0.0225	0.0170
Yes	No	Regular	6d@6/12	Straps	Weak	0.0243	0.0252	0.0171	0.0106	0.0077
Yes	No	Regular	6d@6/12	Straps	Strong	0.0239	0.0248	0.0167	0.0103	0.0074
Yes	No	Regular	8d@6/12	Toe-nails	Weak	0.0379	0.0436	0.0329	0.0224	0.0168
Yes	No	Regular	8d@6/12	Toe-nails	Strong	0.0376	0.0436	0.0328	0.0223	0.0168
Yes	No	Regular	8d@6/12	Straps	Weak	0.0191	0.0195	0.0132	0.0082	0.0060
Yes	No	Regular	8d@6/12	Straps	Strong	0.0185	0.0190	0.0128	0.0078	0.0057
Yes	No	Regular	8d@6/6	Toe-nails	Weak	0.0378	0.0437	0.0327	0.0223	0.0169
Yes	No	Regular	8d@6/6	Toe-nails	Strong	0.0375	0.0435	0.0327	0.0222	0.0167
Yes	No	Regular	8d@6/6	Straps	Weak	0.0186	0.0190	0.0130	0.0080	0.0059
Yes	No	Regular	8d@6/6	Straps	Strong	0.0181	0.0186	0.0125	0.0077	0.0056
No	Yes	Jalousie	6d@6/12	Toe-nails	Weak	0.0311	0.0324	0.0240	0.0165	0.0129
No	Yes	Jalousie	6d@6/12	Toe-nails	Strong	0.0307	0.0322	0.0238	0.0163	0.0128
No	Yes	Jalousie	6d@6/12	Straps	Weak	0.0208	0.0210	0.0144	0.0092	0.0069
No	Yes	Jalousie	6d@6/12	Straps	Strong	0.0202	0.0206	0.0140	0.0088	0.0066
No	Yes	Jalousie	8d@6/12	Toe-nails	Weak	0.0299	0.0317	0.0233	0.0161	0.0125
No	Yes	Jalousie	8d@6/12	Toe-nails	Strong	0.0297	0.0314	0.0231	0.0159	0.0123
No	Yes	Jalousie	8d@6/12	Straps	Weak	0.0161	0.0171	0.0117	0.0075	0.0056
No	Yes	Jalousie	8d@6/12	Straps	Strong	0.0154	0.0166	0.0113	0.0071	0.0053
No	Yes	Jalousie	8d@6/6	Toe-nails	Weak	0.0299	0.0318	0.0233	0.0162	0.0125
No	Yes	Jalousie	8d@6/6	Toe-nails	Strong	0.0297	0.0314	0.0231	0.0159	0.0123
No	Yes	Jalousie	8d@6/6	Straps	Weak	0.0157	0.0167	0.0115	0.0073	0.0055
No	Yes	Jalousie	8d@6/6	Straps	Strong	0.0150	0.0162	0.0111	0.0070	0.0052
No	Yes	Regular	6d@6/12	Toe-nails	Weak	0.0315	0.0350	0.0256	0.0172	0.0132
No	Yes	Regular	6d@6/12	Toe-nails	Strong	0.0312	0.0348	0.0254	0.0171	0.0131
No	Yes	Regular	6d@6/12	Straps	Weak	0.0189	0.0195	0.0130	0.0081	0.0061

Secondary Water Resistance	Shutter	Window Type	Sheathing Nails	Roof/Wall Connection	Metal Fastener	Terrain Surface Roughness (m)				
						0.03	0.15	0.35	0.7	1
No	Yes	Regular	6d@6/12	Straps	Strong	0.0183	0.0192	0.0126	0.0078	0.0058
No	Yes	Regular	8d@6/12	Toe-nails	Weak	0.0308	0.0346	0.0251	0.0168	0.0128
No	Yes	Regular	8d@6/12	Toe-nails	Strong	0.0305	0.0346	0.0250	0.0166	0.0126
No	Yes	Regular	8d@6/12	Straps	Weak	0.0144	0.0155	0.0102	0.0064	0.0048
No	Yes	Regular	8d@6/12	Straps	Strong	0.0138	0.0149	0.0097	0.0060	0.0044
No	Yes	Regular	8d@6/6	Toe-nails	Weak	0.0308	0.0347	0.0251	0.0168	0.0128
No	Yes	Regular	8d@6/6	Toe-nails	Strong	0.0304	0.0345	0.0250	0.0166	0.0126
No	Yes	Regular	8d@6/6	Straps	Weak	0.0140	0.0152	0.0100	0.0063	0.0047
No	Yes	Regular	8d@6/6	Straps	Strong	0.0134	0.0147	0.0096	0.0059	0.0044
No	No	Jalousie	6d@6/12	Toe-nails	Weak	0.0413	0.0391	0.0293	0.0201	0.0156
No	No	Jalousie	6d@6/12	Toe-nails	Strong	0.0412	0.0389	0.0291	0.0201	0.0154
No	No	Jalousie	6d@6/12	Straps	Weak	0.0290	0.0265	0.0190	0.0125	0.0094
No	No	Jalousie	6d@6/12	Straps	Strong	0.0285	0.0261	0.0186	0.0121	0.0090
No	No	Jalousie	8d@6/12	Toe-nails	Weak	0.0406	0.0386	0.0286	0.0197	0.0151
No	No	Jalousie	8d@6/12	Toe-nails	Strong	0.0405	0.0385	0.0285	0.0195	0.0149
No	No	Jalousie	8d@6/12	Straps	Weak	0.0225	0.0216	0.0156	0.0103	0.0077
No	No	Jalousie	8d@6/12	Straps	Strong	0.0218	0.0211	0.0151	0.0098	0.0074
No	No	Jalousie	8d@6/6	Toe-nails	Weak	0.0407	0.0386	0.0287	0.0196	0.0152
No	No	Jalousie	8d@6/6	Toe-nails	Strong	0.0406	0.0384	0.0284	0.0194	0.0149
No	No	Jalousie	8d@6/6	Straps	Weak	0.0219	0.0211	0.0153	0.0100	0.0076
No	No	Jalousie	8d@6/6	Straps	Strong	0.0212	0.0206	0.0148	0.0097	0.0072
No	No	Regular	6d@6/12	Toe-nails	Weak	0.0383	0.0437	0.0331	0.0227	0.0172
No	No	Regular	6d@6/12	Toe-nails	Strong	0.0384	0.0439	0.0329	0.0225	0.0170
No	No	Regular	6d@6/12	Straps	Weak	0.0243	0.0252	0.0171	0.0106	0.0077
No	No	Regular	6d@6/12	Straps	Strong	0.0239	0.0248	0.0167	0.0103	0.0075
No	No	Regular	8d@6/12	Toe-nails	Weak	0.0379	0.0436	0.0329	0.0224	0.0168
No	No	Regular	8d@6/12	Toe-nails	Strong	0.0376	0.0436	0.0328	0.0222	0.0168
No	No	Regular	8d@6/12	Straps	Weak	0.0192	0.0195	0.0132	0.0082	0.0060
No	No	Regular	8d@6/12	Straps	Strong	0.0185	0.0190	0.0128	0.0078	0.0057
No	No	Regular	8d@6/6	Toe-nails	Weak	0.0378	0.0437	0.0328	0.0223	0.0169
No	No	Regular	8d@6/6	Toe-nails	Strong	0.0375	0.0436	0.0327	0.0222	0.0167
No	No	Regular	8d@6/6	Straps	Weak	0.0186	0.0191	0.0130	0.0081	0.0059
No	No	Regular	8d@6/6	Straps	Strong	0.0181	0.0186	0.0125	0.0077	0.0055

Table 6-13: Normalized Average Annual Losses for One-Story Buildings with Standing Seam Metal Hip Roofs and Wood Frame Walls

Secondary Water Resistance	Shutter	Window Type	Sheathing Nails	Roof/Wall Connection	Metal Fastener	Terrain Surface Roughness (m)				
						0.03	0.15	0.35	0.7	1
Yes	Yes	Jalousie	6d@6/12	Toe-nails	Weak	0.0118	0.0151	0.0092	0.0052	0.0035
Yes	Yes	Jalousie	6d@6/12	Toe-nails	Strong	0.0118	0.0151	0.0093	0.0052	0.0035
Yes	Yes	Jalousie	6d@6/12	Straps	Weak	0.0079	0.0095	0.0060	0.0037	0.0028
Yes	Yes	Jalousie	6d@6/12	Straps	Strong	0.0076	0.0094	0.0060	0.0037	0.0027
Yes	Yes	Jalousie	8d@6/12	Toe-nails	Weak	0.0117	0.0152	0.0093	0.0052	0.0035
Yes	Yes	Jalousie	8d@6/12	Toe-nails	Strong	0.0116	0.0150	0.0092	0.0051	0.0035
Yes	Yes	Jalousie	8d@6/12	Straps	Weak	0.0072	0.0091	0.0059	0.0036	0.0027
Yes	Yes	Jalousie	8d@6/12	Straps	Strong	0.0069	0.0090	0.0058	0.0036	0.0027

Secondary Water Resistance	Shutter	Window Type	Sheathing Nails	Roof/Wall Connection	Metal Fastener	Terrain Surface Roughness (m)				
						0.03	0.15	0.35	0.7	1
Yes	Yes	Jalousie	8d@6/6	Toe-nails	Weak	0.0117	0.0151	0.0093	0.0051	0.0035
Yes	Yes	Jalousie	8d@6/6	Toe-nails	Strong	0.0116	0.0150	0.0092	0.0051	0.0035
Yes	Yes	Jalousie	8d@6/6	Straps	Weak	0.0072	0.0091	0.0059	0.0036	0.0027
Yes	Yes	Jalousie	8d@6/6	Straps	Strong	0.0069	0.0090	0.0058	0.0036	0.0027
Yes	Yes	Regular	6d@6/12	Toe-nails	Weak	0.0143	0.0176	0.0102	0.0054	0.0036
Yes	Yes	Regular	6d@6/12	Toe-nails	Strong	0.0143	0.0174	0.0101	0.0053	0.0036
Yes	Yes	Regular	6d@6/12	Straps	Weak	0.0069	0.0087	0.0056	0.0036	0.0027
Yes	Yes	Regular	6d@6/12	Straps	Strong	0.0066	0.0087	0.0056	0.0035	0.0027
Yes	Yes	Regular	8d@6/12	Toe-nails	Weak	0.0143	0.0176	0.0102	0.0054	0.0036
Yes	Yes	Regular	8d@6/12	Toe-nails	Strong	0.0142	0.0175	0.0102	0.0053	0.0036
Yes	Yes	Regular	8d@6/12	Straps	Weak	0.0057	0.0080	0.0054	0.0035	0.0026
Yes	Yes	Regular	8d@6/12	Straps	Strong	0.0054	0.0079	0.0053	0.0034	0.0026
Yes	Yes	Regular	8d@6/6	Toe-nails	Weak	0.0144	0.0176	0.0102	0.0054	0.0036
Yes	Yes	Regular	8d@6/6	Toe-nails	Strong	0.0142	0.0175	0.0101	0.0053	0.0036
Yes	Yes	Regular	8d@6/6	Straps	Weak	0.0057	0.0079	0.0053	0.0035	0.0027
Yes	Yes	Regular	8d@6/6	Straps	Strong	0.0054	0.0078	0.0053	0.0034	0.0026
Yes	No	Jalousie	6d@6/12	Toe-nails	Weak	0.0188	0.0178	0.0108	0.0060	0.0041
Yes	No	Jalousie	6d@6/12	Toe-nails	Strong	0.0185	0.0177	0.0108	0.0060	0.0041
Yes	No	Jalousie	6d@6/12	Straps	Weak	0.0112	0.0120	0.0077	0.0046	0.0033
Yes	No	Jalousie	6d@6/12	Straps	Strong	0.0110	0.0119	0.0076	0.0046	0.0033
Yes	No	Jalousie	8d@6/12	Toe-nails	Weak	0.0187	0.0176	0.0108	0.0060	0.0041
Yes	No	Jalousie	8d@6/12	Toe-nails	Strong	0.0186	0.0176	0.0108	0.0059	0.0041
Yes	No	Jalousie	8d@6/12	Straps	Weak	0.0101	0.0115	0.0075	0.0045	0.0033
Yes	No	Jalousie	8d@6/12	Straps	Strong	0.0098	0.0114	0.0074	0.0045	0.0033
Yes	No	Jalousie	8d@6/6	Toe-nails	Weak	0.0187	0.0177	0.0108	0.0060	0.0041
Yes	No	Jalousie	8d@6/6	Toe-nails	Strong	0.0186	0.0176	0.0108	0.0059	0.0041
Yes	No	Jalousie	8d@6/6	Straps	Weak	0.0101	0.0115	0.0075	0.0045	0.0033
Yes	No	Jalousie	8d@6/6	Straps	Strong	0.0098	0.0114	0.0074	0.0045	0.0033
Yes	No	Regular	6d@6/12	Toe-nails	Weak	0.0192	0.0215	0.0127	0.0067	0.0044
Yes	No	Regular	6d@6/12	Toe-nails	Strong	0.0191	0.0214	0.0127	0.0066	0.0044
Yes	No	Regular	6d@6/12	Straps	Weak	0.0089	0.0113	0.0072	0.0044	0.0032
Yes	No	Regular	6d@6/12	Straps	Strong	0.0086	0.0112	0.0071	0.0043	0.0032
Yes	No	Regular	8d@6/12	Toe-nails	Weak	0.0192	0.0215	0.0127	0.0066	0.0044
Yes	No	Regular	8d@6/12	Toe-nails	Strong	0.0191	0.0215	0.0127	0.0066	0.0044
Yes	No	Regular	8d@6/12	Straps	Weak	0.0074	0.0105	0.0068	0.0042	0.0031
Yes	No	Regular	8d@6/12	Straps	Strong	0.0071	0.0103	0.0067	0.0042	0.0031
Yes	No	Regular	8d@6/6	Toe-nails	Weak	0.0192	0.0215	0.0127	0.0066	0.0044
Yes	No	Regular	8d@6/6	Toe-nails	Strong	0.0191	0.0215	0.0127	0.0066	0.0044
Yes	No	Regular	8d@6/6	Straps	Weak	0.0074	0.0104	0.0068	0.0042	0.0031
Yes	No	Regular	8d@6/6	Straps	Strong	0.0071	0.0103	0.0068	0.0042	0.0031
No	Yes	Jalousie	6d@6/12	Toe-nails	Weak	0.0118	0.0151	0.0092	0.0052	0.0035
No	Yes	Jalousie	6d@6/12	Toe-nails	Strong	0.0118	0.0151	0.0093	0.0052	0.0035
No	Yes	Jalousie	6d@6/12	Straps	Weak	0.0079	0.0095	0.0060	0.0037	0.0028
No	Yes	Jalousie	6d@6/12	Straps	Strong	0.0076	0.0094	0.0060	0.0037	0.0027
No	Yes	Jalousie	8d@6/12	Toe-nails	Weak	0.0117	0.0152	0.0092	0.0052	0.0035
No	Yes	Jalousie	8d@6/12	Toe-nails	Strong	0.0116	0.0150	0.0092	0.0051	0.0035
No	Yes	Jalousie	8d@6/12	Straps	Weak	0.0072	0.0091	0.0059	0.0036	0.0027
No	Yes	Jalousie	8d@6/12	Straps	Strong	0.0069	0.0090	0.0058	0.0036	0.0027
No	Yes	Jalousie	8d@6/6	Toe-nails	Weak	0.0117	0.0151	0.0093	0.0051	0.0035
No	Yes	Jalousie	8d@6/6	Toe-nails	Strong	0.0116	0.0150	0.0093	0.0051	0.0035
No	Yes	Jalousie	8d@6/6	Straps	Weak	0.0072	0.0091	0.0059	0.0036	0.0027
No	Yes	Jalousie	8d@6/6	Straps	Strong	0.0069	0.0090	0.0058	0.0036	0.0027

Secondary Water Resistance	Shutter	Window Type	Sheathing Nails	Roof/Wall Connection	Metal Fastener	Terrain Surface Roughness (m)				
						0.03	0.15	0.35	0.7	1
No	Yes	Regular	6d@6/12	Toe-nails	Weak	0.0143	0.0176	0.0102	0.0054	0.0036
No	Yes	Regular	6d@6/12	Toe-nails	Strong	0.0143	0.0174	0.0101	0.0053	0.0036
No	Yes	Regular	6d@6/12	Straps	Weak	0.0069	0.0087	0.0056	0.0036	0.0027
No	Yes	Regular	6d@6/12	Straps	Strong	0.0066	0.0086	0.0056	0.0035	0.0027
No	Yes	Regular	8d@6/12	Toe-nails	Weak	0.0143	0.0176	0.0102	0.0054	0.0036
No	Yes	Regular	8d@6/12	Toe-nails	Strong	0.0142	0.0175	0.0102	0.0053	0.0036
No	Yes	Regular	8d@6/12	Straps	Weak	0.0057	0.0080	0.0054	0.0035	0.0026
No	Yes	Regular	8d@6/12	Straps	Strong	0.0054	0.0079	0.0053	0.0034	0.0026
No	Yes	Regular	8d@6/6	Toe-nails	Weak	0.0144	0.0176	0.0102	0.0054	0.0036
No	Yes	Regular	8d@6/6	Toe-nails	Strong	0.0142	0.0175	0.0101	0.0053	0.0036
No	Yes	Regular	8d@6/6	Straps	Weak	0.0057	0.0080	0.0054	0.0035	0.0026
No	Yes	Regular	8d@6/6	Straps	Strong	0.0054	0.0078	0.0053	0.0034	0.0026
No	No	Jalousie	6d@6/12	Toe-nails	Weak	0.0188	0.0178	0.0108	0.0060	0.0041
No	No	Jalousie	6d@6/12	Toe-nails	Strong	0.0185	0.0176	0.0108	0.0060	0.0041
No	No	Jalousie	6d@6/12	Straps	Weak	0.0112	0.0120	0.0077	0.0046	0.0033
No	No	Jalousie	6d@6/12	Straps	Strong	0.0110	0.0119	0.0076	0.0046	0.0033
No	No	Jalousie	8d@6/12	Toe-nails	Weak	0.0187	0.0176	0.0108	0.0060	0.0041
No	No	Jalousie	8d@6/12	Toe-nails	Strong	0.0186	0.0176	0.0108	0.0059	0.0041
No	No	Jalousie	8d@6/12	Straps	Weak	0.0101	0.0115	0.0075	0.0045	0.0033
No	No	Jalousie	8d@6/12	Straps	Strong	0.0098	0.0114	0.0074	0.0045	0.0033
No	No	Jalousie	8d@6/6	Toe-nails	Weak	0.0187	0.0177	0.0108	0.0060	0.0041
No	No	Jalousie	8d@6/6	Toe-nails	Strong	0.0186	0.0176	0.0108	0.0060	0.0041
No	No	Jalousie	8d@6/6	Straps	Weak	0.0101	0.0115	0.0075	0.0045	0.0033
No	No	Jalousie	8d@6/6	Straps	Strong	0.0098	0.0114	0.0074	0.0045	0.0033
No	No	Regular	6d@6/12	Toe-nails	Weak	0.0192	0.0215	0.0127	0.0067	0.0044
No	No	Regular	6d@6/12	Toe-nails	Strong	0.0191	0.0214	0.0127	0.0066	0.0044
No	No	Regular	6d@6/12	Straps	Weak	0.0089	0.0113	0.0072	0.0043	0.0032
No	No	Regular	6d@6/12	Straps	Strong	0.0086	0.0112	0.0071	0.0043	0.0032
No	No	Regular	8d@6/12	Toe-nails	Weak	0.0192	0.0215	0.0127	0.0066	0.0044
No	No	Regular	8d@6/12	Toe-nails	Strong	0.0191	0.0215	0.0127	0.0066	0.0044
No	No	Regular	8d@6/12	Straps	Weak	0.0074	0.0105	0.0068	0.0042	0.0031
No	No	Regular	8d@6/12	Straps	Strong	0.0071	0.0103	0.0067	0.0042	0.0031
No	No	Regular	8d@6/6	Toe-nails	Weak	0.0192	0.0215	0.0127	0.0066	0.0044
No	No	Regular	8d@6/6	Toe-nails	Strong	0.0191	0.0215	0.0127	0.0066	0.0044
No	No	Regular	8d@6/6	Straps	Weak	0.0074	0.0104	0.0068	0.0042	0.0031
No	No	Regular	8d@6/6	Straps	Strong	0.0071	0.0103	0.0068	0.0042	0.0031

Table 6-14: Normalized Average Annual Losses for Two-Story Buildings with Standing Seam Metal Hip Roofs and Wood Frame Walls

Secondary Water Resistance	Shutter	Window Type	Sheathing Nails	Roof/Wall Connection	Metal Fastener	Terrain Surface Roughness (m)				
						0.03	0.15	0.35	0.7	1
Yes	Yes	Jalousie	6d@6/12	Toe-nails	Weak	0.0194	0.0213	0.0146	0.0091	0.0066
Yes	Yes	Jalousie	6d@6/12	Toe-nails	Strong	0.0190	0.0212	0.0144	0.0090	0.0066
Yes	Yes	Jalousie	6d@6/12	Straps	Weak	0.0158	0.0169	0.0113	0.0071	0.0051
Yes	Yes	Jalousie	6d@6/12	Straps	Strong	0.0155	0.0166	0.0111	0.0069	0.0051

Secondary Water Resistance	Shutter	Window Type	Sheathing Nails	Roof/Wall Connection	Metal Fastener	Terrain Surface Roughness (m)				
						0.03	0.15	0.35	0.7	1
Yes	Yes	Jalousie	8d@6/12	Toe-nails	Weak	0.0190	0.0211	0.0143	0.0089	0.0066
Yes	Yes	Jalousie	8d@6/12	Toe-nails	Strong	0.0188	0.0209	0.0142	0.0089	0.0065
Yes	Yes	Jalousie	8d@6/12	Straps	Weak	0.0133	0.0154	0.0104	0.0066	0.0049
Yes	Yes	Jalousie	8d@6/12	Straps	Strong	0.0129	0.0151	0.0103	0.0065	0.0048
Yes	Yes	Jalousie	8d@6/6	Toe-nails	Weak	0.0190	0.0211	0.0143	0.0090	0.0065
Yes	Yes	Jalousie	8d@6/6	Toe-nails	Strong	0.0188	0.0209	0.0142	0.0089	0.0065
Yes	Yes	Jalousie	8d@6/6	Straps	Weak	0.0132	0.0153	0.0105	0.0066	0.0049
Yes	Yes	Jalousie	8d@6/6	Straps	Strong	0.0128	0.0150	0.0102	0.0065	0.0048
Yes	Yes	Regular	6d@6/12	Toe-nails	Weak	0.0215	0.0266	0.0177	0.0106	0.0073
Yes	Yes	Regular	6d@6/12	Toe-nails	Strong	0.0213	0.0265	0.0176	0.0105	0.0073
Yes	Yes	Regular	6d@6/12	Straps	Weak	0.0139	0.0156	0.0101	0.0061	0.0044
Yes	Yes	Regular	6d@6/12	Straps	Strong	0.0136	0.0154	0.0099	0.0059	0.0043
Yes	Yes	Regular	8d@6/12	Toe-nails	Weak	0.0213	0.0265	0.0176	0.0105	0.0073
Yes	Yes	Regular	8d@6/12	Toe-nails	Strong	0.0211	0.0264	0.0176	0.0105	0.0073
Yes	Yes	Regular	8d@6/12	Straps	Weak	0.0106	0.0124	0.0083	0.0053	0.0040
Yes	Yes	Regular	8d@6/12	Straps	Strong	0.0101	0.0121	0.0081	0.0051	0.0039
Yes	Yes	Regular	8d@6/6	Toe-nails	Weak	0.0212	0.0265	0.0176	0.0105	0.0072
Yes	Yes	Regular	8d@6/6	Toe-nails	Strong	0.0210	0.0264	0.0176	0.0105	0.0073
Yes	Yes	Regular	8d@6/6	Straps	Weak	0.0105	0.0123	0.0083	0.0053	0.0040
Yes	Yes	Regular	8d@6/6	Straps	Strong	0.0100	0.0120	0.0081	0.0051	0.0038
Yes	No	Jalousie	6d@6/12	Toe-nails	Weak	0.0321	0.0274	0.0191	0.0121	0.0089
Yes	No	Jalousie	6d@6/12	Toe-nails	Strong	0.0319	0.0273	0.0190	0.0120	0.0087
Yes	No	Jalousie	6d@6/12	Straps	Weak	0.0228	0.0215	0.0151	0.0098	0.0072
Yes	No	Jalousie	6d@6/12	Straps	Strong	0.0223	0.0211	0.0149	0.0096	0.0071
Yes	No	Jalousie	8d@6/12	Toe-nails	Weak	0.0318	0.0273	0.0189	0.0120	0.0087
Yes	No	Jalousie	8d@6/12	Toe-nails	Strong	0.0317	0.0272	0.0189	0.0119	0.0086
Yes	No	Jalousie	8d@6/12	Straps	Weak	0.0192	0.0195	0.0140	0.0091	0.0068
Yes	No	Jalousie	8d@6/12	Straps	Strong	0.0187	0.0192	0.0138	0.0090	0.0067
Yes	No	Jalousie	8d@6/6	Toe-nails	Weak	0.0318	0.0273	0.0189	0.0120	0.0087
Yes	No	Jalousie	8d@6/6	Toe-nails	Strong	0.0317	0.0272	0.0189	0.0119	0.0086
Yes	No	Jalousie	8d@6/6	Straps	Weak	0.0191	0.0194	0.0140	0.0092	0.0068
Yes	No	Jalousie	8d@6/6	Straps	Strong	0.0187	0.0191	0.0138	0.0090	0.0067
Yes	No	Regular	6d@6/12	Toe-nails	Weak	0.0295	0.0335	0.0234	0.0145	0.0102
Yes	No	Regular	6d@6/12	Toe-nails	Strong	0.0294	0.0333	0.0233	0.0144	0.0102
Yes	No	Regular	6d@6/12	Straps	Weak	0.0190	0.0202	0.0134	0.0080	0.0058
Yes	No	Regular	6d@6/12	Straps	Strong	0.0187	0.0199	0.0132	0.0079	0.0056
Yes	No	Regular	8d@6/12	Toe-nails	Weak	0.0293	0.0334	0.0233	0.0144	0.0102
Yes	No	Regular	8d@6/12	Toe-nails	Strong	0.0293	0.0334	0.0232	0.0143	0.0102
Yes	No	Regular	8d@6/12	Straps	Weak	0.0145	0.0168	0.0115	0.0071	0.0051
Yes	No	Regular	8d@6/12	Straps	Strong	0.0141	0.0166	0.0113	0.0070	0.0050
Yes	No	Regular	8d@6/6	Toe-nails	Weak	0.0292	0.0334	0.0233	0.0144	0.0102
Yes	No	Regular	8d@6/6	Toe-nails	Strong	0.0292	0.0333	0.0232	0.0143	0.0102
Yes	No	Regular	8d@6/6	Straps	Weak	0.0144	0.0168	0.0115	0.0071	0.0051
Yes	No	Regular	8d@6/6	Straps	Strong	0.0139	0.0165	0.0113	0.0070	0.0050
No	Yes	Jalousie	6d@6/12	Toe-nails	Weak	0.0194	0.0213	0.0146	0.0091	0.0066
No	Yes	Jalousie	6d@6/12	Toe-nails	Strong	0.0191	0.0212	0.0143	0.0090	0.0066
No	Yes	Jalousie	6d@6/12	Straps	Weak	0.0158	0.0169	0.0113	0.0070	0.0051
No	Yes	Jalousie	6d@6/12	Straps	Strong	0.0155	0.0166	0.0111	0.0069	0.0051
No	Yes	Jalousie	8d@6/12	Toe-nails	Weak	0.0190	0.0211	0.0143	0.0090	0.0066
No	Yes	Jalousie	8d@6/12	Toe-nails	Strong	0.0188	0.0209	0.0142	0.0089	0.0065
No	Yes	Jalousie	8d@6/12	Straps	Weak	0.0134	0.0154	0.0105	0.0066	0.0049
No	Yes	Jalousie	8d@6/12	Straps	Strong	0.0129	0.0151	0.0103	0.0065	0.0048
No	Yes	Jalousie	8d@6/6	Toe-nails	Weak	0.0190	0.0211	0.0143	0.0090	0.0066

Secondary Water Resistance	Shutter	Window Type	Sheathing Nails	Roof/Wall Connection	Metal Fastener	Terrain Surface Roughness (m)				
						0.03	0.15	0.35	0.7	1
No	Yes	Jalousie	8d@6/6	Toe-nails	Strong	0.0188	0.0209	0.0142	0.0089	0.0065
No	Yes	Jalousie	8d@6/6	Straps	Weak	0.0133	0.0153	0.0104	0.0066	0.0049
No	Yes	Jalousie	8d@6/6	Straps	Strong	0.0128	0.0150	0.0102	0.0065	0.0048
No	Yes	Regular	6d@6/12	Toe-nails	Weak	0.0215	0.0266	0.0177	0.0106	0.0073
No	Yes	Regular	6d@6/12	Toe-nails	Strong	0.0213	0.0265	0.0176	0.0105	0.0073
No	Yes	Regular	6d@6/12	Straps	Weak	0.0139	0.0156	0.0101	0.0061	0.0044
No	Yes	Regular	6d@6/12	Straps	Strong	0.0136	0.0154	0.0099	0.0059	0.0044
No	Yes	Regular	8d@6/12	Toe-nails	Weak	0.0213	0.0265	0.0176	0.0105	0.0073
No	Yes	Regular	8d@6/12	Toe-nails	Strong	0.0211	0.0263	0.0176	0.0105	0.0073
No	Yes	Regular	8d@6/12	Straps	Weak	0.0106	0.0124	0.0083	0.0052	0.0039
No	Yes	Regular	8d@6/12	Straps	Strong	0.0101	0.0121	0.0081	0.0051	0.0038
No	Yes	Regular	8d@6/6	Toe-nails	Weak	0.0213	0.0265	0.0176	0.0105	0.0072
No	Yes	Regular	8d@6/6	Toe-nails	Strong	0.0210	0.0263	0.0176	0.0105	0.0073
No	Yes	Regular	8d@6/6	Straps	Weak	0.0105	0.0123	0.0083	0.0053	0.0040
No	Yes	Regular	8d@6/6	Straps	Strong	0.0101	0.0121	0.0081	0.0051	0.0038
No	No	Jalousie	6d@6/12	Toe-nails	Weak	0.0321	0.0274	0.0191	0.0121	0.0089
No	No	Jalousie	6d@6/12	Toe-nails	Strong	0.0319	0.0273	0.0190	0.0120	0.0087
No	No	Jalousie	6d@6/12	Straps	Weak	0.0228	0.0215	0.0152	0.0098	0.0072
No	No	Jalousie	6d@6/12	Straps	Strong	0.0224	0.0211	0.0150	0.0097	0.0071
No	No	Jalousie	8d@6/12	Toe-nails	Weak	0.0318	0.0273	0.0189	0.0120	0.0087
No	No	Jalousie	8d@6/12	Toe-nails	Strong	0.0317	0.0272	0.0189	0.0119	0.0086
No	No	Jalousie	8d@6/12	Straps	Weak	0.0193	0.0195	0.0141	0.0092	0.0068
No	No	Jalousie	8d@6/12	Straps	Strong	0.0187	0.0192	0.0138	0.0090	0.0067
No	No	Jalousie	8d@6/6	Toe-nails	Weak	0.0318	0.0273	0.0190	0.0120	0.0087
No	No	Jalousie	8d@6/6	Toe-nails	Strong	0.0317	0.0272	0.0189	0.0119	0.0086
No	No	Jalousie	8d@6/6	Straps	Weak	0.0192	0.0195	0.0140	0.0092	0.0068
No	No	Jalousie	8d@6/6	Straps	Strong	0.0187	0.0192	0.0138	0.0090	0.0067
No	No	Regular	6d@6/12	Toe-nails	Weak	0.0295	0.0335	0.0234	0.0145	0.0102
No	No	Regular	6d@6/12	Toe-nails	Strong	0.0293	0.0333	0.0233	0.0144	0.0102
No	No	Regular	6d@6/12	Straps	Weak	0.0191	0.0202	0.0134	0.0081	0.0057
No	No	Regular	6d@6/12	Straps	Strong	0.0187	0.0199	0.0132	0.0080	0.0056
No	No	Regular	8d@6/12	Toe-nails	Weak	0.0293	0.0334	0.0233	0.0144	0.0102
No	No	Regular	8d@6/12	Toe-nails	Strong	0.0293	0.0333	0.0232	0.0143	0.0102
No	No	Regular	8d@6/12	Straps	Weak	0.0146	0.0168	0.0115	0.0071	0.0051
No	No	Regular	8d@6/12	Straps	Strong	0.0141	0.0166	0.0113	0.0070	0.0050
No	No	Regular	8d@6/6	Toe-nails	Weak	0.0293	0.0334	0.0233	0.0144	0.0102
No	No	Regular	8d@6/6	Toe-nails	Strong	0.0292	0.0333	0.0232	0.0143	0.0102
No	No	Regular	8d@6/6	Straps	Weak	0.0145	0.0168	0.0115	0.0071	0.0051
No	No	Regular	8d@6/6	Straps	Strong	0.0140	0.0165	0.0113	0.0070	0.0050

Table 6-15: Normalized Average Annual Losses for Buildings with Concrete Gable Roofs and Unreinforced Masonry Walls

No. of Stories	Secondary Water Resistance	Shutter	Window Type	Terrain Surface Roughness (m)				
				0.03	0.15	0.35	0.7	1
One	No	Yes	Jalousie	0.0075	0.0096	0.0061	0.0038	0.0028
	No	Yes	Regular	0.0055	0.0081	0.0054	0.0035	0.0027
	No	No	Jalousie	0.0111	0.0127	0.0082	0.0049	0.0035
	No	No	Regular	0.0076	0.0111	0.0072	0.0044	0.0032
Two	No	Yes	Jalousie	0.0129	0.0153	0.0104	0.0066	0.0049
	No	Yes	Regular	0.0097	0.0117	0.0079	0.0050	0.0038
	No	No	Jalousie	0.0195	0.0199	0.0144	0.0095	0.0071
	No	No	Regular	0.0142	0.0169	0.0115	0.0071	0.0051

Table 6-16: Normalized Average Annual Losses for Buildings with Concrete Hip Roofs and Unreinforced Masonry Walls

No. of Stories	Secondary Water Resistance	Shutter	Window Type	Terrain Surface Roughness (m)				
				0.03	0.15	0.35	0.7	1
One	No	Yes	Jalousie	0.0073	0.0094	0.0059	0.0036	0.0027
	No	Yes	Regular	0.0053	0.0079	0.0053	0.0034	0.0026
	No	No	Jalousie	0.0108	0.0124	0.0080	0.0047	0.0034
	No	No	Regular	0.0074	0.0110	0.0071	0.0043	0.0032
Two	No	Yes	Jalousie	0.0128	0.0151	0.0103	0.0065	0.0048
	No	Yes	Regular	0.0096	0.0117	0.0078	0.0049	0.0037
	No	No	Jalousie	0.0193	0.0197	0.0143	0.0093	0.0069
	No	No	Regular	0.0141	0.0168	0.0114	0.0070	0.0051

Table 6-17: Normalized Average Annual Losses for One-Story Buildings with Gable Roof Plywood Roof Decks with an Elastomeric Roof Covering and Unreinforced Masonry Walls

Secondary Water Resistance	Shutter	Window Type	Sheathing Nails	Roof/Wall Connection	Terrain Surface Roughness (m)				
					0.03	0.15	0.35	0.7	1
No	Yes	Jalousie	6d@6/12	Toe-nails	0.0315	0.0336	0.0233	0.0146	0.0105
No	Yes	Jalousie	6d@6/12	Straps	0.0164	0.0146	0.0086	0.0048	0.0034
No	Yes	Jalousie	8d@6/12	Toe-nails	0.0310	0.0334	0.0231	0.0143	0.0103
No	Yes	Jalousie	8d@6/12	Straps	0.0123	0.0121	0.0069	0.0038	0.0026
No	Yes	Jalousie	8d@6/6	Toe-nails	0.0310	0.0334	0.0231	0.0143	0.0103
No	Yes	Jalousie	8d@6/6	Straps	0.0121	0.0120	0.0068	0.0038	0.0026
No	Yes	Regular	6d@6/12	Toe-nails	0.0314	0.0336	0.0235	0.0146	0.0106
No	Yes	Regular	6d@6/12	Straps	0.0166	0.0147	0.0086	0.0048	0.0034
No	Yes	Regular	8d@6/12	Toe-nails	0.0310	0.0334	0.0233	0.0144	0.0104
No	Yes	Regular	8d@6/12	Straps	0.0130	0.0124	0.0070	0.0038	0.0026

Secondary Water Resistance	Shutter	Window Type	Sheathing Nails	Roof/Wall Connection	Terrain Surface Roughness (m)				
					0.03	0.15	0.35	0.7	1
No	Yes	Regular	8d@6/6	Toe-nails	0.0310	0.0334	0.0233	0.0143	0.0104
No	Yes	Regular	8d@6/6	Straps	0.0129	0.0124	0.0069	0.0038	0.0026
No	No	Jalousie	6d@6/12	Toe-nails	0.0368	0.0401	0.0289	0.0185	0.0132
No	No	Jalousie	6d@6/12	Straps	0.0216	0.0178	0.0105	0.0057	0.0039
No	No	Jalousie	8d@6/12	Toe-nails	0.0364	0.0399	0.0287	0.0183	0.0130
No	No	Jalousie	8d@6/12	Straps	0.0176	0.0143	0.0082	0.0044	0.0030
No	No	Jalousie	8d@6/6	Toe-nails	0.0364	0.0399	0.0287	0.0183	0.0130
No	No	Jalousie	8d@6/6	Straps	0.0174	0.0141	0.0081	0.0043	0.0029
No	No	Regular	6d@6/12	Toe-nails	0.0358	0.0406	0.0292	0.0186	0.0133
No	No	Regular	6d@6/12	Straps	0.0206	0.0187	0.0110	0.0058	0.0040
No	No	Regular	8d@6/12	Toe-nails	0.0354	0.0405	0.0291	0.0184	0.0132
No	No	Regular	8d@6/12	Straps	0.0175	0.0159	0.0089	0.0046	0.0031
No	No	Regular	8d@6/6	Toe-nails	0.0355	0.0405	0.0291	0.0184	0.0132
No	No	Regular	8d@6/6	Straps	0.0174	0.0159	0.0089	0.0046	0.0031

Table 6-18: Normalized Average Annual Losses for Two-Story Buildings with Gable Roof Plywood Roof Decks with an Elastomeric Roof Covering and Unreinforced Masonry Walls

Secondary Water Resistance	Shutter	Window Type	Sheathing Nails	Roof/Wall Connection	Terrain Surface Roughness (m)				
					0.03	0.15	0.35	0.7	1
No	Yes	Jalousie	6d@6/12	Toe-nails	0.0392	0.0379	0.0287	0.0208	0.0168
No	Yes	Jalousie	6d@6/12	Straps	0.0261	0.0234	0.0155	0.0095	0.0070
No	Yes	Jalousie	8d@6/12	Toe-nails	0.0384	0.0374	0.0282	0.0202	0.0162
No	Yes	Jalousie	8d@6/12	Straps	0.0195	0.0180	0.0113	0.0065	0.0045
No	Yes	Jalousie	8d@6/6	Toe-nails	0.0384	0.0374	0.0282	0.0202	0.0162
No	Yes	Jalousie	8d@6/6	Straps	0.0192	0.0178	0.0111	0.0063	0.0044
No	Yes	Regular	6d@6/12	Toe-nails	0.0385	0.0378	0.0287	0.0206	0.0167
No	Yes	Regular	6d@6/12	Straps	0.0250	0.0237	0.0157	0.0095	0.0070
No	Yes	Regular	8d@6/12	Toe-nails	0.0378	0.0374	0.0282	0.0201	0.0162
No	Yes	Regular	8d@6/12	Straps	0.0195	0.0198	0.0124	0.0069	0.0047
No	Yes	Regular	8d@6/6	Toe-nails	0.0377	0.0374	0.0282	0.0201	0.0162
No	Yes	Regular	8d@6/6	Straps	0.0193	0.0196	0.0123	0.0068	0.0046
No	No	Jalousie	6d@6/12	Toe-nails	0.0486	0.0497	0.0388	0.0285	0.0227
No	No	Jalousie	6d@6/12	Straps	0.0363	0.0307	0.0214	0.0136	0.0099
No	No	Jalousie	8d@6/12	Toe-nails	0.0481	0.0494	0.0385	0.0281	0.0223
No	No	Jalousie	8d@6/12	Straps	0.0300	0.0239	0.0160	0.0096	0.0066
No	No	Jalousie	8d@6/6	Toe-nails	0.0481	0.0494	0.0385	0.0281	0.0223
No	No	Jalousie	8d@6/6	Straps	0.0297	0.0236	0.0157	0.0093	0.0064
No	No	Regular	6d@6/12	Toe-nails	0.0466	0.0505	0.0399	0.0292	0.0233

Secondary Water Resistance	Shutter	Window Type	Sheathing Nails	Roof/Wall Connection	Terrain Surface Roughness (m)				
					0.03	0.15	0.35	0.7	1
No	No	Regular	6d@6/12	Straps	0.0335	0.0316	0.0221	0.0139	0.0100
No	No	Regular	8d@6/12	Toe-nails	0.0461	0.0503	0.0396	0.0288	0.0229
No	No	Regular	8d@6/12	Straps	0.0290	0.0268	0.0180	0.0107	0.0073
No	No	Regular	8d@6/6	Toe-nails	0.0461	0.0503	0.0396	0.0288	0.0229
No	No	Regular	8d@6/6	Straps	0.0288	0.0266	0.0179	0.0106	0.0072

Table 6-19: Normalized Average Annual Losses for One-Story Buildings with Hip Roof Plywood Roof Decks with an Elastomeric Roof Covering and Unreinforced Masonry Walls

Secondary Water Resistance	Shutter	Window Type	Sheathing Nails	Roof/Wall Connection	Terrain Surface Roughness (m)				
					0.03	0.15	0.35	0.7	1
No	Yes	Jalousie	6d@6/12	Toe-nails	0.0187	0.0222	0.0133	0.0068	0.0044
No	Yes	Jalousie	6d@6/12	Straps	0.0095	0.0095	0.0057	0.0033	0.0024
No	Yes	Jalousie	8d@6/12	Toe-nails	0.0185	0.0221	0.0132	0.0068	0.0044
No	Yes	Jalousie	8d@6/12	Straps	0.0065	0.0075	0.0049	0.0031	0.0023
No	Yes	Jalousie	8d@6/6	Toe-nails	0.0185	0.0221	0.0132	0.0068	0.0044
No	Yes	Jalousie	8d@6/6	Straps	0.0065	0.0075	0.0049	0.0031	0.0023
No	Yes	Regular	6d@6/12	Toe-nails	0.0189	0.0224	0.0134	0.0069	0.0044
No	Yes	Regular	6d@6/12	Straps	0.0090	0.0093	0.0056	0.0033	0.0024
No	Yes	Regular	8d@6/12	Toe-nails	0.0187	0.0224	0.0133	0.0069	0.0044
No	Yes	Regular	8d@6/12	Straps	0.0056	0.0072	0.0048	0.0031	0.0023
No	Yes	Regular	8d@6/6	Toe-nails	0.0187	0.0224	0.0133	0.0069	0.0044
No	Yes	Regular	8d@6/6	Straps	0.0056	0.0072	0.0048	0.0030	0.0023
No	No	Jalousie	6d@6/12	Toe-nails	0.0261	0.0274	0.0169	0.0088	0.0057
No	No	Jalousie	6d@6/12	Straps	0.0139	0.0122	0.0071	0.0040	0.0027
No	No	Jalousie	8d@6/12	Toe-nails	0.0259	0.0274	0.0169	0.0088	0.0056
No	No	Jalousie	8d@6/12	Straps	0.0093	0.0098	0.0061	0.0036	0.0025
No	No	Jalousie	8d@6/6	Toe-nails	0.0259	0.0274	0.0169	0.0088	0.0056
No	No	Jalousie	8d@6/6	Straps	0.0092	0.0098	0.0061	0.0036	0.0025
No	No	Regular	6d@6/12	Toe-nails	0.0252	0.0291	0.0181	0.0094	0.0060
No	No	Regular	6d@6/12	Straps	0.0117	0.0120	0.0070	0.0039	0.0027
No	No	Regular	8d@6/12	Toe-nails	0.0251	0.0290	0.0180	0.0093	0.0059
No	No	Regular	8d@6/12	Straps	0.0071	0.0091	0.0058	0.0035	0.0025
No	No	Regular	8d@6/6	Toe-nails	0.0252	0.0290	0.0180	0.0093	0.0059
No	No	Regular	8d@6/6	Straps	0.0070	0.0091	0.0058	0.0035	0.0025

Table 6-20: Normalized Average Annual Losses for Two-Story Buildings with Hip Roof Plywood Roof Decks with an Elastomeric Roof Covering and Unreinforced Masonry Walls

Secondary Water Resistance	Shutter	Window Type	Sheathing Nails	Roof/Wall Connection	Terrain Surface Roughness (m)				
					0.03	0.15	0.35	0.7	1
No	Yes	Jalousie	6d@6/12	Toe-nails	0.0243	0.0269	0.0179	0.0108	0.0075
No	Yes	Jalousie	6d@6/12	Straps	0.0190	0.0178	0.0110	0.0063	0.0044
No	Yes	Jalousie	8d@6/12	Toe-nails	0.0236	0.0265	0.0176	0.0106	0.0074
No	Yes	Jalousie	8d@6/12	Straps	0.0121	0.0119	0.0077	0.0046	0.0033
No	Yes	Jalousie	8d@6/6	Toe-nails	0.0236	0.0265	0.0176	0.0106	0.0074
No	Yes	Jalousie	8d@6/6	Straps	0.0118	0.0118	0.0076	0.0046	0.0033
No	Yes	Regular	6d@6/12	Toe-nails	0.0232	0.0278	0.0186	0.0111	0.0077
No	Yes	Regular	6d@6/12	Straps	0.0174	0.0175	0.0107	0.0062	0.0043
No	Yes	Regular	8d@6/12	Toe-nails	0.0226	0.0276	0.0184	0.0110	0.0076
No	Yes	Regular	8d@6/12	Straps	0.0103	0.0106	0.0068	0.0042	0.0031
No	Yes	Regular	8d@6/6	Toe-nails	0.0226	0.0276	0.0184	0.0110	0.0076
No	Yes	Regular	8d@6/6	Straps	0.0102	0.0105	0.0068	0.0042	0.0031
No	No	Jalousie	6d@6/12	Toe-nails	0.0389	0.0381	0.0279	0.0180	0.0130
No	No	Jalousie	6d@6/12	Straps	0.0297	0.0253	0.0168	0.0100	0.0070
No	No	Jalousie	8d@6/12	Toe-nails	0.0384	0.0378	0.0276	0.0177	0.0128
No	No	Jalousie	8d@6/12	Straps	0.0178	0.0170	0.0117	0.0072	0.0051
No	No	Jalousie	8d@6/6	Toe-nails	0.0384	0.0378	0.0276	0.0177	0.0128
No	No	Jalousie	8d@6/6	Straps	0.0175	0.0168	0.0116	0.0072	0.0051
No	No	Regular	6d@6/12	Toe-nails	0.0368	0.0420	0.0310	0.0204	0.0148
No	No	Regular	6d@6/12	Straps	0.0259	0.0250	0.0162	0.0094	0.0065
No	No	Regular	8d@6/12	Toe-nails	0.0365	0.0418	0.0309	0.0203	0.0147
No	No	Regular	8d@6/12	Straps	0.0149	0.0152	0.0100	0.0060	0.0042
No	No	Regular	8d@6/6	Toe-nails	0.0365	0.0418	0.0309	0.0203	0.0147
No	No	Regular	8d@6/6	Straps	0.0146	0.0150	0.0099	0.0060	0.0042

Table 6-21: Normalized Average Annual Losses for One-Story Buildings with Gable Roof Plywood Roof Decks with an Elastomeric Roof Covering and Wood Frame Walls

Secondary Water Resistance	Shutter	Window Type	Sheathing Nails	Roof/Wall Connection	Terrain Surface Roughness (m)				
					0.03	0.15	0.35	0.7	1
No	Yes	Jalousie	6d@6/12	Toe-nails	0.0317	0.0338	0.0235	0.0147	0.0106
No	Yes	Jalousie	6d@6/12	Straps	0.0171	0.0155	0.0092	0.0051	0.0036
No	Yes	Jalousie	8d@6/12	Toe-nails	0.0311	0.0336	0.0233	0.0144	0.0104
No	Yes	Jalousie	8d@6/12	Straps	0.0126	0.0127	0.0073	0.0040	0.0028
No	Yes	Jalousie	8d@6/6	Toe-nails	0.0311	0.0336	0.0232	0.0144	0.0104
No	Yes	Jalousie	8d@6/6	Straps	0.0124	0.0126	0.0072	0.0040	0.0028
No	Yes	Regular	6d@6/12	Toe-nails	0.0316	0.0338	0.0236	0.0147	0.0107
No	Yes	Regular	6d@6/12	Straps	0.0171	0.0155	0.0091	0.0051	0.0036

Secondary Water Resistance	Shutter	Window Type	Sheathing Nails	Roof/Wall Connection	Terrain Surface Roughness (m)				
					0.03	0.15	0.35	0.7	1
No	Yes	Regular	8d@6/12	Toe-nails	0.0311	0.0336	0.0235	0.0145	0.0105
No	Yes	Regular	8d@6/12	Straps	0.0133	0.0130	0.0074	0.0040	0.0028
No	Yes	Regular	8d@6/6	Toe-nails	0.0311	0.0336	0.0235	0.0144	0.0105
No	Yes	Regular	8d@6/6	Straps	0.0131	0.0130	0.0073	0.0040	0.0028
No	No	Jalousie	6d@6/12	Toe-nails	0.0370	0.0402	0.0290	0.0185	0.0133
No	No	Jalousie	6d@6/12	Straps	0.0225	0.0189	0.0112	0.0061	0.0042
No	No	Jalousie	8d@6/12	Toe-nails	0.0365	0.0400	0.0288	0.0184	0.0131
No	No	Jalousie	8d@6/12	Straps	0.0181	0.0150	0.0087	0.0046	0.0031
No	No	Jalousie	8d@6/6	Toe-nails	0.0365	0.0400	0.0288	0.0184	0.0131
No	No	Jalousie	8d@6/6	Straps	0.0178	0.0149	0.0086	0.0046	0.0031
No	No	Regular	6d@6/12	Toe-nails	0.0359	0.0407	0.0293	0.0187	0.0134
No	No	Regular	6d@6/12	Straps	0.0211	0.0196	0.0116	0.0062	0.0042
No	No	Regular	8d@6/12	Toe-nails	0.0355	0.0406	0.0292	0.0185	0.0132
No	No	Regular	8d@6/12	Straps	0.0177	0.0166	0.0094	0.0048	0.0032
No	No	Regular	8d@6/6	Toe-nails	0.0355	0.0406	0.0292	0.0185	0.0132
No	No	Regular	8d@6/6	Straps	0.0176	0.0165	0.0093	0.0048	0.0032

Table 6-22: Normalized Average Annual Losses for Two-Story Buildings with Gable Roof Plywood Roof Decks with an Elastomeric Roof Covering and Wood Frame Walls

Secondary Water Resistance	Shutter	Window Type	Sheathing Nails	Roof/Wall Connection	Terrain Surface Roughness (m)				
					0.03	0.15	0.35	0.7	1
No	Yes	Jalousie	6d@6/12	Toe-nails	0.0395	0.0382	0.0290	0.0210	0.0170
No	Yes	Jalousie	6d@6/12	Straps	0.0271	0.0247	0.0165	0.0102	0.0075
No	Yes	Jalousie	8d@6/12	Toe-nails	0.0386	0.0376	0.0284	0.0203	0.0163
No	Yes	Jalousie	8d@6/12	Straps	0.0201	0.0190	0.0119	0.0069	0.0047
No	Yes	Jalousie	8d@6/6	Toe-nails	0.0385	0.0376	0.0284	0.0203	0.0163
No	Yes	Jalousie	8d@6/6	Straps	0.0197	0.0186	0.0117	0.0067	0.0046
No	Yes	Regular	6d@6/12	Toe-nails	0.0387	0.0381	0.0290	0.0208	0.0169
No	Yes	Regular	6d@6/12	Straps	0.0257	0.0247	0.0165	0.0101	0.0074
No	Yes	Regular	8d@6/12	Toe-nails	0.0379	0.0376	0.0284	0.0202	0.0163
No	Yes	Regular	8d@6/12	Straps	0.0200	0.0205	0.0129	0.0072	0.0049
No	Yes	Regular	8d@6/6	Toe-nails	0.0379	0.0376	0.0284	0.0202	0.0163
No	Yes	Regular	8d@6/6	Straps	0.0196	0.0203	0.0128	0.0071	0.0048
No	No	Jalousie	6d@6/12	Toe-nails	0.0488	0.0499	0.0390	0.0286	0.0229
No	No	Jalousie	6d@6/12	Straps	0.0376	0.0324	0.0228	0.0145	0.0106
No	No	Jalousie	8d@6/12	Toe-nails	0.0482	0.0496	0.0386	0.0282	0.0224
No	No	Jalousie	8d@6/12	Straps	0.0307	0.0251	0.0169	0.0101	0.0070
No	No	Jalousie	8d@6/6	Toe-nails	0.0482	0.0496	0.0386	0.0282	0.0224

Secondary Water Resistance	Shutter	Window Type	Sheathing Nails	Roof/Wall Connection	Terrain Surface Roughness (m)				
					0.03	0.15	0.35	0.7	1
No	No	Jalousie	8d@6/6	Straps	0.0304	0.0248	0.0166	0.0099	0.0068
No	No	Regular	6d@6/12	Toe-nails	0.0468	0.0506	0.0400	0.0293	0.0234
No	No	Regular	6d@6/12	Straps	0.0343	0.0329	0.0231	0.0146	0.0105
No	No	Regular	8d@6/12	Toe-nails	0.0462	0.0504	0.0397	0.0289	0.0230
No	No	Regular	8d@6/12	Straps	0.0294	0.0276	0.0187	0.0111	0.0076
No	No	Regular	8d@6/6	Toe-nails	0.0462	0.0504	0.0397	0.0289	0.0230
No	No	Regular	8d@6/6	Straps	0.0292	0.0274	0.0185	0.0110	0.0075

Table 6-23: Normalized Average Annual Losses for One-Story Buildings with Hip Roof Plywood Roof Decks with an Elastomeric Roof Covering and Wood Frame Walls

Secondary Water Resistance	Shutter	Window Type	Sheathing Nails	Roof/Wall Connection	Terrain Surface Roughness (m)				
					0.03	0.15	0.35	0.7	1
No	Yes	Jalousie	6d@6/12	Toe-nails	0.0189	0.0225	0.0135	0.0070	0.0045
No	Yes	Jalousie	6d@6/12	Straps	0.0102	0.0103	0.0062	0.0036	0.0026
No	Yes	Jalousie	8d@6/12	Toe-nails	0.0187	0.0225	0.0135	0.0070	0.0045
No	Yes	Jalousie	8d@6/12	Straps	0.0070	0.0082	0.0053	0.0033	0.0024
No	Yes	Jalousie	8d@6/6	Toe-nails	0.0187	0.0225	0.0135	0.0070	0.0045
No	Yes	Jalousie	8d@6/6	Straps	0.0070	0.0082	0.0053	0.0033	0.0024
No	Yes	Regular	6d@6/12	Toe-nails	0.0190	0.0228	0.0136	0.0070	0.0046
No	Yes	Regular	6d@6/12	Straps	0.0095	0.0102	0.0061	0.0036	0.0025
No	Yes	Regular	8d@6/12	Toe-nails	0.0189	0.0227	0.0136	0.0070	0.0046
No	Yes	Regular	8d@6/12	Straps	0.0059	0.0078	0.0052	0.0033	0.0024
No	Yes	Regular	8d@6/6	Toe-nails	0.0189	0.0227	0.0136	0.0070	0.0046
No	Yes	Regular	8d@6/6	Straps	0.0059	0.0078	0.0052	0.0033	0.0024
No	No	Jalousie	6d@6/12	Toe-nails	0.0263	0.0278	0.0172	0.0090	0.0058
No	No	Jalousie	6d@6/12	Straps	0.0149	0.0134	0.0078	0.0043	0.0029
No	No	Jalousie	8d@6/12	Toe-nails	0.0261	0.0277	0.0171	0.0089	0.0058
No	No	Jalousie	8d@6/12	Straps	0.0100	0.0107	0.0067	0.0039	0.0027
No	No	Jalousie	8d@6/6	Toe-nails	0.0261	0.0277	0.0171	0.0089	0.0058
No	No	Jalousie	8d@6/6	Straps	0.0099	0.0107	0.0067	0.0039	0.0027
No	No	Regular	6d@6/12	Toe-nails	0.0254	0.0293	0.0183	0.0095	0.0060
No	No	Regular	6d@6/12	Straps	0.0125	0.0131	0.0076	0.0042	0.0029
No	No	Regular	8d@6/12	Toe-nails	0.0253	0.0293	0.0183	0.0095	0.0060
No	No	Regular	8d@6/12	Straps	0.0075	0.0100	0.0063	0.0037	0.0026
No	No	Regular	8d@6/6	Toe-nails	0.0253	0.0293	0.0183	0.0095	0.0060
No	No	Regular	8d@6/6	Straps	0.0075	0.0099	0.0063	0.0037	0.0027

Table 6-24: Normalized Average Annual Losses for Two-Story Buildings with Hip Roof Plywood Roof Decks with an Elastomeric Roof Covering and Wood Frame Walls

Secondary Water Resistance	Shutter	Window Type	Sheathing Nails	Roof/Wall Connection	Terrain Surface Roughness (m)				
					0.03	0.15	0.35	0.7	1
No	Yes	Jalousie	6d@6/12	Toe-nails	0.0247	0.0274	0.0183	0.0111	0.0077
No	Yes	Jalousie	6d@6/12	Straps	0.0200	0.0191	0.0119	0.0068	0.0047
No	Yes	Jalousie	8d@6/12	Toe-nails	0.0239	0.0270	0.0179	0.0109	0.0075
No	Yes	Jalousie	8d@6/12	Straps	0.0129	0.0131	0.0084	0.0050	0.0036
No	Yes	Jalousie	8d@6/6	Toe-nails	0.0239	0.0270	0.0179	0.0109	0.0075
No	Yes	Jalousie	8d@6/6	Straps	0.0126	0.0129	0.0084	0.0050	0.0036
No	Yes	Regular	6d@6/12	Toe-nails	0.0235	0.0283	0.0190	0.0114	0.0079
No	Yes	Regular	6d@6/12	Straps	0.0181	0.0186	0.0115	0.0067	0.0046
No	Yes	Regular	8d@6/12	Toe-nails	0.0228	0.0280	0.0187	0.0112	0.0077
No	Yes	Regular	8d@6/12	Straps	0.0110	0.0116	0.0075	0.0046	0.0033
No	Yes	Regular	8d@6/6	Toe-nails	0.0228	0.0280	0.0187	0.0112	0.0077
No	Yes	Regular	8d@6/6	Straps	0.0108	0.0115	0.0074	0.0046	0.0033
No	No	Jalousie	6d@6/12	Toe-nails	0.0393	0.0386	0.0283	0.0183	0.0132
No	No	Jalousie	6d@6/12	Straps	0.0313	0.0271	0.0182	0.0109	0.0076
No	No	Jalousie	8d@6/12	Toe-nails	0.0387	0.0383	0.0280	0.0180	0.0130
No	No	Jalousie	8d@6/12	Straps	0.0192	0.0186	0.0128	0.0078	0.0055
No	No	Jalousie	8d@6/6	Toe-nails	0.0387	0.0383	0.0280	0.0180	0.0130
No	No	Jalousie	8d@6/6	Straps	0.0188	0.0184	0.0127	0.0078	0.0055
No	No	Regular	6d@6/12	Toe-nails	0.0370	0.0422	0.0312	0.0205	0.0149
No	No	Regular	6d@6/12	Straps	0.0269	0.0266	0.0174	0.0102	0.0070
No	No	Regular	8d@6/12	Toe-nails	0.0366	0.0421	0.0311	0.0204	0.0148
No	No	Regular	8d@6/12	Straps	0.0159	0.0166	0.0109	0.0065	0.0046
No	No	Regular	8d@6/6	Toe-nails	0.0366	0.0421	0.0311	0.0204	0.0148
No	No	Regular	8d@6/6	Straps	0.0156	0.0164	0.0108	0.0065	0.0045

Table 6-25: Normalized Average Annual Losses for One-Story Buildings with Gable Shingle Roofs and Wood Frame Walls

Secondary Water Resistance	Shutter	Sheathing Nails	Roof/Wall Connection	Terrain Surface Roughness (m)				
				0.03	0.15	0.35	0.7	1
No	No	6d@6/12	Straps	0.0262	0.0185	0.0115	0.0072	0.0055
No	Yes	6d@6/12	Straps	0.0187	0.0129	0.0085	0.0058	0.0048
No	No	6d@6/12	Toe-nails	0.0293	0.0266	0.0171	0.0097	0.0070
No	Yes	6d@6/12	Toe-nails	0.0195	0.0142	0.0094	0.0061	0.0049
No	No	8d@6/12	Straps	0.0227	0.0150	0.0089	0.0055	0.0043
No	Yes	8d@6/12	Straps	0.0149	0.0099	0.0066	0.0045	0.0037
No	No	8d@6/12	Toe-nails	0.0281	0.0262	0.0162	0.0090	0.0063
No	Yes	8d@6/12	Toe-nails	0.0168	0.0128	0.0080	0.0051	0.0041

Secondary Water Resistance	Shutter	Sheathing Nails	Roof/Wall Connection	Terrain Surface Roughness (m)				
				0.03	0.15	0.35	0.7	1
No	No	8d@6/6	Straps	0.0181	0.0118	0.0060	0.0030	0.0020
No	Yes	8d@6/6	Straps	0.0075	0.0050	0.0028	0.0017	0.0014
No	No	8d@6/6	Toe-nails	0.0246	0.0237	0.0143	0.0070	0.0045
No	Yes	8d@6/6	Toe-nails	0.0106	0.0085	0.0046	0.0024	0.0018
Yes	No	6d@6/12	Straps	0.0239	0.0170	0.0100	0.0059	0.0043
Yes	Yes	6d@6/12	Straps	0.0146	0.0102	0.0064	0.0042	0.0034
Yes	No	6d@6/12	Toe-nails	0.0272	0.0255	0.0159	0.0086	0.0059
Yes	Yes	6d@6/12	Toe-nails	0.0156	0.0117	0.0072	0.0046	0.0035
Yes	No	8d@6/12	Straps	0.0185	0.0122	0.0063	0.0033	0.0024
Yes	Yes	8d@6/12	Straps	0.0057	0.0046	0.0027	0.0019	0.0016
Yes	No	8d@6/12	Toe-nails	0.0246	0.0246	0.0145	0.0074	0.0048
Yes	Yes	8d@6/12	Toe-nails	0.0095	0.0085	0.0046	0.0026	0.0020
Yes	No	8d@6/6	Straps	0.0170	0.0112	0.0054	0.0025	0.0016
Yes	Yes	8d@6/6	Straps	0.0041	0.0034	0.0017	0.0011	0.0009
Yes	No	8d@6/6	Toe-nails	0.0237	0.0234	0.0139	0.0066	0.0042
Yes	Yes	8d@6/6	Toe-nails	0.0082	0.0072	0.0037	0.0018	0.0014

Table 6-26: Normalized Average Annual Losses for Two-Story Buildings with Gable Shingle Roofs and Wood Frame Walls

Secondary Water Resistance	Shutter	Sheathing Nails	Roof/Wall Connection	Terrain Surface Roughness (m)				
				0.03	0.15	0.35	0.7	1
No	No	6d@6/12	Straps	0.0395	0.0300	0.0213	0.0146	0.0119
No	Yes	6d@6/12	Straps	0.0254	0.0198	0.0149	0.0111	0.0094
No	No	6d@6/12	Toe-nails	0.0434	0.0379	0.0281	0.0198	0.0157
No	Yes	6d@6/12	Toe-nails	0.0277	0.0222	0.0164	0.0121	0.0102
No	No	8d@6/12	Straps	0.0375	0.0276	0.0188	0.0126	0.0098
No	Yes	8d@6/12	Straps	0.0209	0.0164	0.0119	0.0087	0.0075
No	No	8d@6/12	Toe-nails	0.0426	0.0373	0.0272	0.0189	0.0150
No	Yes	8d@6/12	Toe-nails	0.0255	0.0204	0.0146	0.0105	0.0087
No	No	8d@6/6	Straps	0.0348	0.0250	0.0158	0.0092	0.0066
No	Yes	8d@6/6	Straps	0.0121	0.0096	0.0058	0.0036	0.0029
No	No	8d@6/6	Toe-nails	0.0403	0.0353	0.0251	0.0167	0.0121
No	Yes	8d@6/6	Toe-nails	0.0189	0.0154	0.0096	0.0061	0.0048
Yes	No	6d@6/12	Straps	0.0377	0.0284	0.0194	0.0124	0.0098
Yes	Yes	6d@6/12	Straps	0.0204	0.0158	0.0114	0.0079	0.0066
Yes	No	6d@6/12	Toe-nails	0.0417	0.0366	0.0264	0.0179	0.0139
Yes	Yes	6d@6/12	Toe-nails	0.0231	0.0185	0.0129	0.0090	0.0074
Yes	No	8d@6/12	Straps	0.0347	0.0251	0.0156	0.0092	0.0063

Secondary Water Resistance	Shutter	Sheathing Nails	Roof/Wall Connection	Terrain Surface Roughness (m)				
				0.03	0.15	0.35	0.7	1
Yes	Yes	8d@6/12	Straps	0.0086	0.0078	0.0044	0.0026	0.0020
Yes	No	8d@6/12	Toe-nails	0.0402	0.0355	0.0250	0.0164	0.0124
Yes	Yes	8d@6/12	Toe-nails	0.0175	0.0144	0.0088	0.0056	0.0043
Yes	No	8d@6/6	Straps	0.0342	0.0245	0.0152	0.0084	0.0059
Yes	Yes	8d@6/6	Straps	0.0070	0.0066	0.0034	0.0017	0.0012
Yes	No	8d@6/6	Toe-nails	0.0398	0.0350	0.0246	0.0162	0.0116
Yes	Yes	8d@6/6	Toe-nails	0.0164	0.0136	0.0080	0.0048	0.0036

Table 6-27: Normalized Average Annual Losses for One-Story Buildings with Hip Shingle Roofs and Wood Frame Walls

Secondary Water Resistance	Shutter	Sheathing Nails	Roof/Wall Connection	Terrain Surface Roughness (m)				
				0.03	0.15	0.35	0.7	1
No	No	6d@6/12	Straps	0.0222	0.0152	0.0090	0.0054	0.0041
No	Yes	6d@6/12	Straps	0.0150	0.0100	0.0064	0.0044	0.0036
No	No	6d@6/12	Toe-nails	0.0248	0.0198	0.0112	0.0061	0.0045
No	Yes	6d@6/12	Toe-nails	0.0155	0.0112	0.0069	0.0046	0.0037
No	No	8d@6/12	Straps	0.0203	0.0138	0.0082	0.0049	0.0039
No	Yes	8d@6/12	Straps	0.0138	0.0088	0.0060	0.0042	0.0035
No	No	8d@6/12	Toe-nails	0.0244	0.0193	0.0109	0.0059	0.0044
No	Yes	8d@6/12	Toe-nails	0.0147	0.0106	0.0066	0.0044	0.0035
No	No	8d@6/6	Straps	0.0160	0.0107	0.0054	0.0027	0.0019
No	Yes	8d@6/6	Straps	0.0068	0.0045	0.0025	0.0016	0.0013
No	No	8d@6/6	Toe-nails	0.0205	0.0173	0.0087	0.0040	0.0024
No	Yes	8d@6/6	Toe-nails	0.0079	0.0067	0.0034	0.0019	0.0015
Yes	No	6d@6/12	Straps	0.0191	0.0134	0.0073	0.0039	0.0029
Yes	Yes	6d@6/12	Straps	0.0094	0.0066	0.0040	0.0026	0.0022
Yes	No	6d@6/12	Toe-nails	0.0218	0.0183	0.0097	0.0048	0.0033
Yes	Yes	6d@6/12	Toe-nails	0.0099	0.0080	0.0045	0.0028	0.0023
Yes	No	8d@6/12	Straps	0.0162	0.0113	0.0059	0.0032	0.0024
Yes	Yes	8d@6/12	Straps	0.0056	0.0044	0.0029	0.0021	0.0018
Yes	No	8d@6/12	Toe-nails	0.0210	0.0177	0.0093	0.0045	0.0030
Yes	Yes	8d@6/12	Toe-nails	0.0070	0.0067	0.0038	0.0024	0.0019
Yes	No	8d@6/6	Straps	0.0151	0.0102	0.0050	0.0024	0.0016
Yes	Yes	8d@6/6	Straps	0.0041	0.0033	0.0018	0.0012	0.0010
Yes	No	8d@6/6	Toe-nails	0.0197	0.0170	0.0084	0.0037	0.0022
Yes	Yes	8d@6/6	Toe-nails	0.0055	0.0056	0.0028	0.0015	0.0012

Table 6-28: Normalized Average Annual Losses for Two-Story Buildings with Hip Shingle Roofs and Wood Frame Walls

Secondary Water Resistance	Shutter	Sheathing Nails	Roof/Wall Connection	Terrain Surface Roughness (m)				
				0.03	0.15	0.35	0.7	1
No	No	6d@6/12	Straps	0.0339	0.0247	0.0165	0.0108	0.0085
No	Yes	6d@6/12	Straps	0.0210	0.0161	0.0116	0.0085	0.0070
No	No	6d@6/12	Toe-nails	0.0382	0.0306	0.0210	0.0136	0.0104
No	Yes	6d@6/12	Toe-nails	0.0217	0.0174	0.0123	0.0088	0.0072
No	No	8d@6/12	Straps	0.0320	0.0235	0.0153	0.0100	0.0080
No	Yes	8d@6/12	Straps	0.0200	0.0151	0.0108	0.0081	0.0068
No	No	8d@6/12	Toe-nails	0.0377	0.0309	0.0211	0.0133	0.0103
No	Yes	8d@6/12	Toe-nails	0.0211	0.0169	0.0120	0.0085	0.0070
No	No	8d@6/6	Straps	0.0286	0.0199	0.0116	0.0064	0.0045
No	Yes	8d@6/6	Straps	0.0108	0.0082	0.0048	0.0032	0.0025
No	No	8d@6/6	Toe-nails	0.0352	0.0280	0.0182	0.0103	0.0070
No	Yes	8d@6/6	Toe-nails	0.0124	0.0106	0.0065	0.0038	0.0029
Yes	No	6d@6/12	Straps	0.0308	0.0219	0.0133	0.0076	0.0053
Yes	Yes	6d@6/12	Straps	0.0123	0.0096	0.0060	0.0038	0.0030
Yes	No	6d@6/12	Toe-nails	0.0354	0.0283	0.0184	0.0108	0.0075
Yes	Yes	6d@6/12	Toe-nails	0.0131	0.0113	0.0068	0.0043	0.0032
Yes	No	8d@6/12	Straps	0.0283	0.0201	0.0114	0.0061	0.0043
Yes	Yes	8d@6/12	Straps	0.0069	0.0065	0.0036	0.0023	0.0019
Yes	No	8d@6/12	Toe-nails	0.0346	0.0285	0.0182	0.0103	0.0071
Yes	Yes	8d@6/12	Toe-nails	0.0099	0.0094	0.0054	0.0032	0.0024
Yes	No	8d@6/6	Straps	0.0278	0.0192	0.0108	0.0056	0.0036
Yes	Yes	8d@6/6	Straps	0.0059	0.0053	0.0027	0.0015	0.0011
Yes	No	8d@6/6	Toe-nails	0.0346	0.0275	0.0176	0.0096	0.0064
Yes	Yes	8d@6/6	Toe-nails	0.0086	0.0083	0.0045	0.0024	0.0017

Section 7. Model Validation and Calibration

After integrating the new hazard and vulnerability data developed for Puerto Rico and the U.S. Virgin Islands, the updated Hazus Hurricane Wind Model was used to develop estimated losses for Hurricanes Irma and Maria in those two territories. The modeled losses were then compared to published data on observed damage and loss in both territories for both events, but primarily for Hurricane Maria in Puerto Rico. Based on these comparisons, some adjustments were made to the building stock model to achieve better agreement between the modeled and observed losses. The final results for the two events are summarized in Section 7.6.

7.1 Impacts of Hurricanes Irma and Maria in PR and USVI

This section provides brief summaries of the impacts of Hurricanes Irma and Maria in Puerto Rico and the U.S. Virgin Islands.

7.1.1 Hurricane Irma

Hurricane Irma made its third landfall on the island of Virgin Gorda in the British Virgin Islands at 1630 UTC on September 6, 2017, as a 155 knot category 5 hurricane. Irma tracked to the west northwest, passing the northern coasts of St. John and St. Thomas in the U.S. Virgin Islands and then about 50 nautical miles off the northern shore of Puerto Rico. The track of the storm as it passed near the U.S. Virgin Islands and Puerto Rico is shown in Figure 7-1.

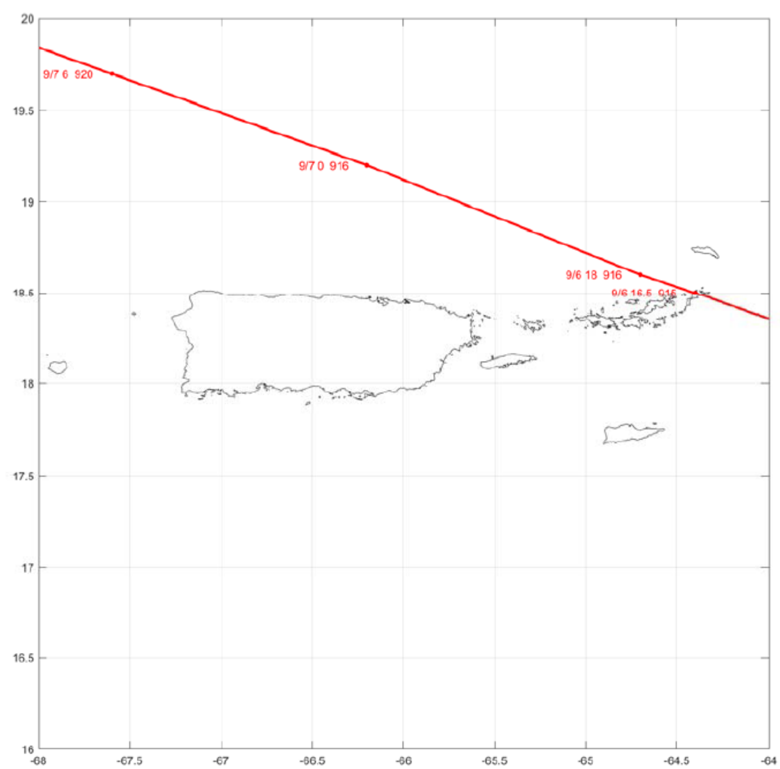

Figure 7-1: Hurricane Irma Track (Mudd et al., 2019)

Based on a post-event wind field analysis by Mudd et al. (2019), Hurricane Irma was estimated to have produced peak, 3-second gusts at 10 m above ground in flat, open terrain of up to 165 mph in the USVI and up to 113 mph on the Puerto Rican island of Culebra. With the effects of topographic speed-ups included, the peak gusts were estimated to be up to 263 mph in the USVI and up to 166 mph in Culebra, Puerto Rico.

Cangialosi et al. (2018) document widespread catastrophic damage reported on both St. Thomas and St. John, including numerous reports of collapsed homes, businesses, fire and police stations, and power lines. In St. Croix, damage was less severe, but about 70% of homes and other structures suffered damage. In Puerto Rico, there were widespread power outages and generally minor damage to homes and businesses.

7.1.2 Hurricane Maria

Just two weeks after Hurricane Irma passed the U.S. Virgin Islands, Hurricane Maria reached its peak intensity of 150 knots while centered about 25 nautical miles south of St. Croix, USVI, and made landfall in Puerto Rico near Yabucoa at about 1015 UTC on September 20, 2017, with an intensity of 135 knots (Pasch et al., 2019). Nearly 8 hours later, Maria exited Puerto Rico with an estimated intensity of 95 knots. The track of the storm as it passed near the U.S. Virgin Islands and Puerto Rico is shown in Figure 7-2.

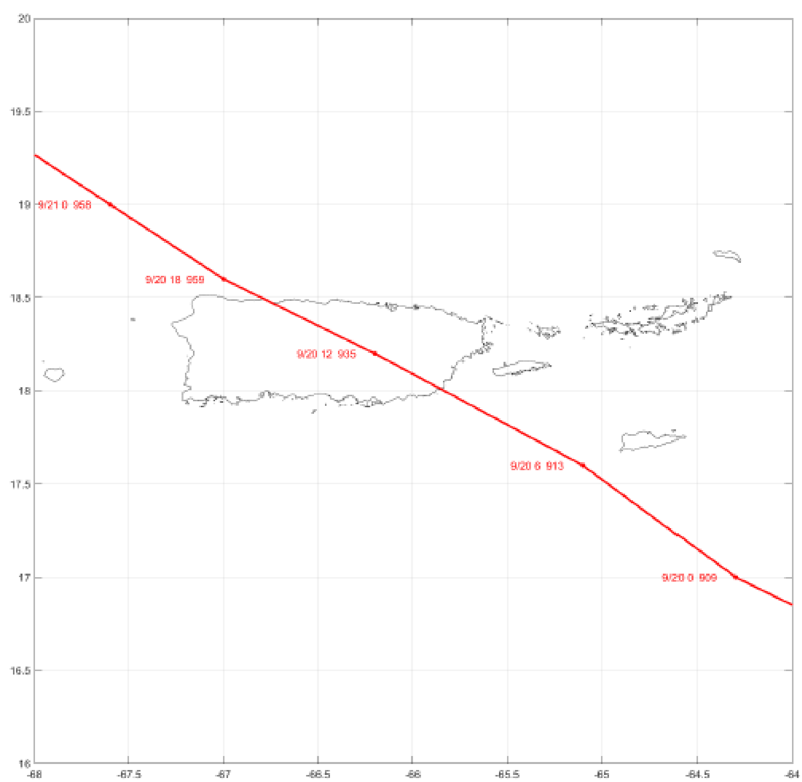

Figure 7-2: Hurricane Maria Track (Mudd et al., 2019)

Based on a post-event wind field analysis by Mudd et al. (2019), Hurricane Maria was estimated to have produced peak, 3-second gusts at 10 m above ground in flat, open terrain of up to 153 mph in St. Croix, USVI, and up to 142 mph in Puerto Rico. With the effects of topographic speed-ups included, the peak gusts were estimated to be up to 201 mph in St. Croix and up to 225 mph in Puerto Rico. Heavy rainfall, flooding, and mud slides also occurred, with one location in Puerto Rico recording a total of almost 38 inches of rainfall.

Pasch et al. (2019) found wind damage was reported across the entire island of St. Croix, including widespread roof damage and complete destruction of many wooden houses. In Puerto Rico, Hurricane Maria was the most destructive hurricane in modern times, producing extensive damage to buildings, homes, agriculture, and infrastructure. Nearly all of the island's 3.4 million residents experienced loss of power and nearly half were still without power at the end of 2017. On the island Vieques, it was reported that all wooden structures were either damaged or destroyed.

7.2 Damage and Loss Metrics for Model Validation and Calibration

Specific damage and loss metrics available for Hazus model validation and calibration are provided in this section. For the purposes of this study, the metrics of greatest interest were the number of damaged housing structures and the total losses to housing buildings and their contents. The primary reference is a Homeland Security Operational Analysis Center (HSOAC) report by Fishbach et al. (2020), which documents the impacts of Hurricane Maria in Puerto Rico in considerable detail. Another key source is the NOAA National Centers for Environmental Information (NCEI) Billion-Dollar Weather and Climate Disasters database (Smith et al., 2021). The selected metrics obtained from each reference are summarized below.

7.2.1 HSOAC Report

The HSOAC report (Fishbach et al., 2020) synthesizes and extrapolates damage and loss data from a number of sources, including: FEMA, HUD, USACE, and the Small Business Administration (SBA). For this Hazus validation and calibration study, the primary focus is on housing-related damage and loss metrics.

Specific metrics obtained from the HSOAC Report are presented below. Table 7-1 provides the HSOAC's estimate of costs to repair housing in Puerto Rico damaged by Hurricane Maria. The total cost to repair all damaged housing was estimated to be $33.9 billion, with $28.5 billion, or 84.1%, of the damage occurring outside of mapped 100-year floodplains. Table 7-1 also provides the HSOAC's estimated breakout of damage to multi-family buildings (19.8%) vs. single-family homes and duplexes (80.2%).

Table 7-1: Costs to Repair Housing Structures in Puerto Rico Damaged by Hurricane Maria (Derived from HSOAC Tables 11.11 and 11.12, Fishbach et al. (2020))

Occupancy Group	Cost ($b)	% of All
Housing Outside the Floodplain	28.5	84.1%
All Housing	33.9	100.0%
All Multi-Family Housing (3+ Units)	6.7	19.8%
All Single-Family and Duplex Housing	27.2	80.2%

Table 7-2 summarizes the HSOAC's breakout of damage states as defined by their Real Property FEMA-Verified Loss (RPFVL) levels. As of May 2018, damage inspections had been performed on approximately 435,000 housing structures in Puerto Rico, for which Individual Assistance (IA) applications had been filed by owner-occupants. This group represents approximately 55.3% of the estimated 786,000 owner-occupied housing structures in Puerto Rico. Approximately 286,000 of the 435,000 inspected owner-occupied structures were verified as having been damaged (65.7%). An additional 120,000 structures had unconfirmed real property damage indicated on their IA applications. This suggests a total of up to 406,000 damaged owner-occupied housing structures (up to 51.7% of the estimated 786,000 total). Approximately 7,000 inspected owner-occupied housing structures were categorized as either structurally damaged or destroyed (1.6% of the 435,000 inspected owner-occupied housing structures, or 0.9% of the total population).

Table 7-2: Damage States of Owner-Occupied Housing Structures in Puerto Rico as of May 2018 (Derived from HSOAC Tables 11.3 and 11.5, Fishbach et al. (2020))

FEMA IA Status	Damage State Description	Real Property FEMA Verified Loss (RPFVL)	Count	% of Inspected	% of IA Apps.	% of Total
No IA Application	No Application for Individual Assistance (IA)	N/A	19,000	N/A	N/A	2.4%
Not Inspected	IA Application Did Not Indicate Real Property Damage	N/A	212,000	N/A	27.6%	27.0%
	IA Application Indicated Real Property Damage	N/A	120,000	N/A	15.6%	15.3%
Inspected	No Damage	$0	149,000	34.3%	19.4%	19.0%
	Affected (Generally Habitable)	$1 to $3,499	236,000	54.3%	30.8%	30.0%
	System Damage (Includes Electrical or HVAC)	$3,500 to $16,999	43,000	9.9%	5.6%	5.5%
	Structural Damage	≥$17,000	3,000	0.7%	0.4%	0.4%
	Destroyed	Varies	4,000	0.9%	0.5%	0.5%
Total			786,000	100.0%	100.0%	100.0%

HSOAC Table 11.7 provides a total estimate of $14.08 billion in full repair costs for owner-occupied housing structures with FEMA inspections. This estimate was developed using SBA verified losses from approximately 82,000 households. When divided by the 286,000 inspected owner-occupied housing structures with verified damage, the result is an average severity of about $49,200 per damaged structure. This simple check provides a general sense of the significant difference between full repair cost and the RPFVL figures shown in Table 7-2, which suggest an average RPFVL severity on the order of $4,000 to $6,000 per damaged structure. As noted in the HSOAC report, however, “FVL does not capture the full cost to repair. Instead, FVL is designed to measure the cost of making a residential structure safe and habitable” (Fishbach et al., 2020, p. 237). The report further notes that “SBA inspection is akin to that done by an insurance adjuster, with the goal of estimating the full repair cost.” Additional details on how SBA-verified losses are used to “scale up” the RPSVL to approximate full repair costs can be found in the full HSOAC report; the differing values are presented here to provide context in validating Hazus results.

7.2.2 NOAA NCEI Weather and Climate Disasters Database

Loss estimates in the NOAA NCEI Billion-Dollar Weather and Climate Disasters database are derived from multiple sources, including: the National Weather Service, FEMA, U.S. Department of Agriculture, National Interagency Fire Center, USACE, individual state emergency management agencies, state and regional climate centers, media reports, and insurance industry estimates (NOAA NCEI, 2021).

The total estimated costs of Hurricane Maria in the U.S. were estimated to be 90 billion dollars in 2017 dollars, making it the third costliest hurricane in U.S. history (Smith et al., 2021). Although specific estimates for Puerto Rico and the USVI could not be obtained from the NCEI website, the site does report a range of $1 to $2 billion for the USVI (NOAA NCEI, 2021). Since Hurricane Maria by-passed the mainland U.S. and produced only tropical storm force winds and moderate storm surge along the coasts of North Carolina and Virginia (Pasch et al., 2019), it is presumed for the purposes of this study that essentially all the remaining $88 to $89 billion in estimated U.S. losses occurred in Puerto Rico.

The total estimated costs of Hurricane Irma in the U.S. are estimated to be 50 billion dollars in 2017 dollars, making it the fifth costliest hurricane in U.S. history (Smith et al., 2021). However, a majority of the U.S. losses occurred in Florida. Although specific estimates for Puerto Rico and the USVI could not be obtained from the NCEI website, the site does report a range of $10 to $20 billion for the USVI and a range of $0.5 to $1.0 billion is reported for Puerto Rico (NOAA NCEI, 2021).

Note that the Hazus Hurricane Wind Model does not produce estimates of losses to infrastructure or agriculture, to the same extent as NOAA NCEI. Therefore, it is expected that Hazus will produce total direct economic losses that are at the lower end of the NOAA NCEI ranges or possibly even less than the lower bound of the NOAA NCEI estimate.

7.2.3 Selected Metrics

Based on the data sources and metrics identified above and the capabilities now available in the Hazus Hurricane Wind Model, the following metrics were selected for the model validation and calibration task:

1. Percentage of single-family and duplex housing structures in Puerto Rico affected (with at least minor damage) by Hurricane Maria. Based on the values in the “Percent of Total” column of Table 7-2, the target range for this metric is estimated to be 36% to 52%.
2. Percentage of single-family and duplex housing in Puerto Rico structurally damaged or destroyed by Hurricane Maria. Based on the values in the “Percent of Total” column of Table 7-2, the target range for this metric is estimated to be 0.9% to 1.3%.
3. Costs to repair housing structures in Puerto Rico damaged by Hurricane Maria. Based on the values in Table 7-1, the target range for this metric is taken to be $28.5 to 33.9 billion in 2017 dollars.
4. Total direct losses in Puerto Rico due to Hurricane Maria. Based on the NOAA NCEI estimate, the estimated range for this metric is taken to be $59 to $118 billion in 2017 dollars after subtracting out the $1 to $2 billion estimated for the USVI from the overall estimate of $60 to $120 billion.
5. Total direct losses in the USVI due to Hurricane Maria. Based on the NOAA NCEI estimate, the estimated range for this metric is taken to be $1 to $2 billion in 2017 dollars.
6. Total direct losses in the USVI due to Hurricane Irma. Based on the NOAA NCEI estimate, the estimated range for this metric is taken to be $10 to $20 billion in 2017 dollars.

7. Total direct losses in Puerto Rico due to Hurricane Irma. Based on the NOAA NCEI estimate, the estimated range for this metric is taken to be $0.5 to $1.0 billion in 2017 dollars.

7.3 Initial Model Results

After integrating the versions of hazard and vulnerability data described in Section 3 through 6 into the Hazus Hurricane Wind Model, losses were estimated for Hurricanes Irma and Maria in Puerto Rico and the U.S. Virgin Islands.

The values of the key modeled metrics for Hurricane Maria are summarized in Table 7-3. The modeled values for five of the seven metrics are within or very near to the observed ranges. The two exceptions are Metric 2, the percentage of severely damaged or destroyed homes in Puerto Rico for Hurricane Maria, and Metric 5, the total direct economic losses in the USVI for Hurricane Irma. The most likely explanations for the overestimate of Metric 2 include: (1) overestimates in the initial WBC percentages of weak roof cover attachments, roof deck attachments, and roof-to-wall connections in Puerto Rico, and (2) differences in damage state definitions assigned to the FEMA RPFVL categories and the damage state definitions defined in Table 5-44 of the *Hazus Hurricane Model Technical Manual* (FEMA 2021). Possible explanations for the overestimate of Metric 5 include: (1) overestimates in the initial WBC percentages of weak roof cover attachments, roof deck attachments, and roof-to-wall connections in the USVI, (2) overestimates in the wind speeds produced by Hurricane Maria on St. Croix, and/or (3) overestimates in the building inventory replacement value on St. Croix.

Table 7-3: Initial Model Results for Hurricane Maria and Hurricane Irma

Metric	Territory	Event	Observed	Modeled
1. % of single-family and duplex structures affected	PR	Maria	36%-52%	40%
2. % of single-family and duplex severely damaged or destroyed	PR	Maria	0.9%-1.3%	13%
3. Costs to repair housing structures	PR	Maria	$28.5b-$33.9b	$34.1b
4. Total direct economic losses	PR	Maria	$59b-$118b	$56.3b
5. Total direct economic losses	USVI	Maria	$1b-$2b	$5.7b
6. Total direct economic losses	USVI	Irma	$10b-$20b	$10.0b
7. Total direct economic losses	PR	Irma	$0.5b-$1.0b	$1.0b

7.4 Adjustments to Wind Building Characteristic Weights

Based on the initial results, several adjustments to the single-family (i.e., WSF1, WSF2, MSF1, and MSF2) WBC weights were investigated. The primary objective was to improve the agreement in Metrics 2 and 5 without significantly degrading the level of agreement in the remaining five metrics. The adjustment or calibration of WBC weights was limited to WBCs for which objective data were not available, and any modifications to the WBC percentages were restricted to what were judged to be plausible limits.

After several iterations, the final adjustments for Puerto Rico included:

- Modified the distribution of roof types on wood frame houses (WSF1 and WSF2) from 100% corrugated metal to 80% corrugated metal and 20% standing seam metal
- Modified the distribution of roof types on single-story masonry houses (MSF1) from 100% concrete to 87% concrete, 12% corrugated metal, and 1% standing seam metal
- Modified the distribution of roof types on multi-story masonry houses (MSF2) from 100% concrete to 78% concrete, 20% corrugated metal, and 2% standing seam metal
- Modified the distribution of metal roof fasteners from 100% weak to 80% weak
- Modified the distribution of roof-to-wall connection from 100% weak (toenail) to 80% weak
- Modified the distribution of plywood roof deck attachment from 100% weak (6d nails @ 6/12 spacing) to 80% weak

For the U.S. Virgin Islands, the final adjustments included:

- Modified the distribution of metal roof fasteners from 100% weak to 0% weak
- Modified the distribution of roof-to-wall connection from 100% weak (toenail) to 20% weak
- Modified the distribution of plywood roof deck attachment from 100% weak (6d nails @ 6/12 spacing) to 20% weak

7.5 Revised Model Results

After making the WBC adjustments noted in Section 7.4, the model was run again to produce the final revised metrics summarized in Table 7-4. As intended, there is some improvement in Metrics 2 and 5, but it was not possible to completely close the gaps while still keeping the WBC percentages within plausible limits. The remaining five metrics are either within their observed range or within what is judged to be a reasonable margin of the lower bound given that the Hazus Hurricane Wind Model does not produce estimates of losses to the same categories of critical infrastructure or agriculture as the observed results.

Table 7-4: Revised Model Results for Hurricane Maria and Hurricane Irma

Metric	Territory	Event	Observed	Modeled
1. % of single-family and duplex structures affected	PR	Maria	36%-52%	37%
2. % of single-family and duplex severely damaged or destroyed	PR	Maria	0.9%-1.3%	11%
3. Costs to repair housing structures	PR	Maria	$28.5b-$33.9b	$28.8b
4. Total direct economic losses	PR	Maria	$59b-$118b	$47.3b
5. Total direct economic losses	USVI	Maria	$1b-$2b	$4.0b
6. Total direct economic losses	USVI	Irma	$10b-$20b	$7.6b
7. Total direct economic losses	PR	Irma	$0.5b-$1.0b	$0.7b

7.6 Known Limitations

There are at least three key limitations in this methodology to consider in any validation efforts:

1. The standard Hazus building valuation methodology is likely overstating the replacement value of informal construction. Although the standard Hazus Methodology for estimating square footage and the replacement cost per square foot of housing does consider the median household income level in each Census block, it does not explicitly account for the high frequency of informal residential construction in Puerto Rico.
2. The analysis conducted to date likely understates the impact of topographic speed-ups on losses. The peak wind gusts provided in Hazus for Hurricane Maria are the sped-up winds from Mudd et al. (2019) averaged over the known building locations to produce a single wind speed value for each Census tract. However, because losses increase nonlinearly with wind speed, the average losses in Census tracts with topographic speed-ups are expected to be larger than the losses produced by the average sped-up winds.
3. The damage state definitions used by FEMA IA and the Hazus Hurricane Wind Model differ from each other, and there is not a simple, one-to-one mapping between them. A robust and validated methodology for mapping Hazus damage states to FEMA IA damages states is needed to generate more useful Hazus output reports and to support future model validation efforts. Currently, the Hazus Hurricane Wind Model Quick Assessment Report directly maps the four Hazus damage states (Minor, Moderate, Severe, and Complete) on a one-to-one basis to the four FEMA Preliminary Damage Assessment (PDA) categories (Affected, Minor, Major and Destroyed). A more refined approach would be to develop a matrix that maps some fraction of buildings in each Hazus damage state to each PDA damage category for model output reporting and maps the inverse for model validation. As discussed above in Section 7.2.1, the categorization of FEMA IA inspection results from Hurricane Maria into damage states was based on RPFVL, which differed markedly from the SBA full repair costs. It is not clear whether the damage state descriptions given in Table 7-2 are intended to align with the FEMA PDA categories.

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