FINAL Report:

Wind-Driven Rain Tests of Building Envelope Systems up to Hurricane-Strength Wind-Driven Rain Intensity

Project #: P0150337

Submitted to:

Building A Safer Florida Inc. on behalf of
Florida Department of Business and Professional Regulation
Mo Madani, Program Manager
Building Codes and Standards
2601 N Blair Stone Rd
Tallahassee, Florida 32399

Prepared by:

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

Daniel J. Smith, PhD
Executive Director
Venrisk Consulting, Boulder CO

Michael J. Louis, P.E.
Senior Principal
Simpson Gumpertz & Heger, Boston, MA

Report No. 07-20

24 July 2020

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

DISCLAIMER

The material presented in this research report has been prepared in accordance with recognized engineering principles. This report should not be used without first securing competent advice with respect to its suitability for any given application. The publication of the material contained herein does not represent or warrant on the part of the University of Florida or any other person named herein, that this information is suitable for any general or particular use or promises freedom from infringement of any patent or patents. Anyone making use of this information assumes all liability for such use.

Table of Contents

1 INTRODUCTION

This research is a continuation of a University of Florida research study initiated in 2019 and supported by the Florida Building Commission (FBC). The study examines issues related to water leakage through building envelope systems of high-rise residential buildings in order to identify potential strategies to mitigate such leakage during future design-level hurricane events. The study was developed from the outcomes of a previously concluded study authored by the Principal Investigator and briefly described in the Background section, below.

The University of Florida's research team assembled a Research Advisory Group led by a building envelope consultant and including high-rise condominium owners and managers, building envelope consultants, representatives from testing laboratories, municipal building code authorities, and fenestration and window shutter manufacturers. The aim of the group is to explore key issues related to water intrusion into high-rise residential buildings that are subjected to design-level hurricane conditions.

1.1 Background

The Florida Building Commission contracted with the University of Florida to conduct a research study following upon research conducted during the 2018-2019 fiscal year, during which the Florida Building Commission had appointed a Workgroup to evaluate Hurricane Irma Exterior Envelope Damage Reports. The motivation for that Workgroup came about because of a high number of water leakage complaints in high rise buildings in the greater Miami area, following Hurricane Irma's landfall on 10 September 2017. This hurricane event produced elevated wind speeds and heavy rain over most of the Florida peninsula. Early forecasts had Irma making landfall on the East coast, which would have created much more severe impacts in the Miami-Dade area. The number of leakage reports provided to the Workgroup were concerning because the peak wind speeds from Hurricane Irma were less than 90 mph in the Miami-Dade County. The concern arose regarding what would be the water leakage outcome for a design level event with wind speeds of 175 mph and greater.

The 10 June 2019 Workgroup report (https://bit.ly/ufWIND-07-2020) included a table of water damage related claims totaling \$12.9M from 15 high-rise residential buildings from seven through 42 stories tall). The buildings were constructed between 1968 and 2008. 14 of the 15 buildings were located in three coastal Florida counties, Palm Beach, Broward and Miami-Dade, and the National Weather Service estimated the strongest wind speeds during Hurricane Irma within the zip code location of each building came from the south-east to east-south-east direction and it did not exceed 45 mph 3-second gust wind speed at 10 m elevation in open terrain. The estimated highest wind speed at the roof level of those buildings was determined to be 64 mph. The Florida Building Code (2017) specifies the ultimate (3-second) design wind speed in these building location zip codes at around 170 mph for Category II buildings and other structures in Figure 1609.3(1) of the FBC. The Workgroup also reported other evidence of widespread water leakage into residential building units in high-rise buildings obtained from the public domain.

Another part of the Workgroup's study used data modeling from the Florida Public Hurricane Loss Model (FPHLM) to investigate the potential impact of fenestration defects on insured losses for high-rise residential structures. The analytical study showed that defects in fenestrations could have a substantial effect on insured losses for low intensity events like Irma in Southeast Florida. The analysis did not show significant performance differences between pre- and post-2002 buildings. In addition, it suggested that hurricane catastrophe models like the FPHLM might need to be recalibrated to give a truer projection of the magnitude of this problem.

1.2 Motivation and Purpose

Historically, the Governor and the Legislature of state of Florida has recognized that the Florida Building Code is an effective tool for implementing state policies. Rick Dixon, the former Executive Director of the Florida Building Commission that "A result of the insurance crisis following the 2004 and 2005 hurricanes was that the Legislature saw the impact Florida Building Codes can have on building damage and insurance losses. Last year. It revised state building code law to enhance the Code even more. The law now prioritizes property protection from hurricane winds and water intrusion and mitigation of existing buildings." https://bit.ly/ufWIND-30-2020. In order to do this, the Florida Building Commission has continued to enhance its support for research and enquiry that addresses the fundamental science essential to good engineering standards and buildings codes.

1.3 Project Goals

This project aims to characterize the major issues associated with mitigating water intrusion failures in high-rise Florida residential buildings. The intent is to create a resource document which the FBC and others may use as a reference in support of future building code changes and to direct dialogue among stakeholders. This report belongs within academic research to address and mitigate perceived future problems that are not addressed by the current building code. It is not a code change or code-compliance request and therefore it is not written as a legal document in which 100% consensus is demanded. Indeed, due to the budget and finite time available, many issues that are raised here cannot be fully explored. The moderated discussion was conducted in an open and free manner, where major participants in the design, construction and consumers of high-rise residential building units are able to air concerns about water leakage and hurricanes and more importantly to listen to the desire of other parties. The resulting effort is merely the start of a journey towards development of hurricane-resistant building envelope systems that mitigate water leakage at design-level wind speeds and wind-driven rain intensities, for the benefit of all Floridians.

From the perspective of the FBC, and notwithstanding the post-Hurricane Irma damage reports, fenestration assemblies on high-rise buildings in Florida are performing well; i.e. at tropical storm levels of wind speed and during normal operations there are no widespread reported leaks occurring into high-rise buildings. However, the high-rise homeowners' experiences from Hurricane Irma were mixed, as reported by last year's Workgroup on Water Intrusion report (https://bit.ly/ufWIND-07-2020) that raises some concern for some building envelope consultants.

This study is framed as a series of moderated discussions within the Research Advisory Group, to better understand perspectives of the key stakeholders, to review and discuss current state-of-the-practice of structural design, water-penetration resistance, installation and retrofit of fenestration assemblies and systems that are suited to hurricane-prone coastal locations.

The Research Team will frame the outcomes of the discussions, as a series of "Desired Specifications" for fenestration system/curtain wall system that, in addition to having the structural capacity to withstand design-level hurricanes, could also remain leakproof under extreme loads, and that will retain some (perhaps limited and short-term) post-hurricane performance capacity. Based on these Desired Specifications, of the Research Team, the study intends to outline the groundwork for industry guidelines to achieve hurricane-level and post-hurricane performance for fenestration assemblies.

1.4 Project Tasks

Our scope of work from the Florida Building Commission described below in Tasks "A" through "F", was established at the planning stage of the project. As the project unfolded modifications of the tasks were done, as indicated by underlining.

A. The Contractor shall assemble a Project Team consisting of a management representative of Florida homeowners of a condominium unit in a high-rise building, and if possible one owner of an apartment or condominium unit in a high-rise building located in South Florida. The Team shall be led by a licensed building envelope consultant with at least 25 years in-charge experience working on building envelope systems for high-rise structures and with experience in Florida, and a representative from an accredited testing laboratory. Other team members will be drawn from a municipal authority representative, Miami-Dade building code official familiar with the issues related to mid- to high-rise building construction., and representatives of the fenestration and building cladding manufacturing industries (e.g. EIFS, masonry, fenestration, curtain wall systems) with product offerings for high-rise construction as recommended by the DBPR Staff. <u>The scope of work was reduced to focus on fenestration and curtain wall systems as the research team realized the monumental task at hand to address whole building envelope systems within the modest time allotted for the study. Focusing on one aspect of the building envelope appeared to be a more reasonable scope within the allotted budget and time.</u>

B. The Project Team shall convene by teleconference on five occasions to discuss issues critical to prosperity of the Florida residents. The Building Envelope Consultant will lead this discussion and invite others to contribute their expertise and knowledge as appropriate. The discussion shall strive to maintain openness in highlighting desired standards and their pros and cons. If feasible the Project team will visit a hurricane testing laboratory to witness the conduct of hurricane-resistance testing. The meetings will document where different interpretations of facts about hurricane risk and water intrusion in high-rise structures exist between the lay persons and professionals in a construction team, including but not limited to the following:

   i. Florida homeowners fully aware of potential liability risks from wind and water leaks?
   ii. Did any homeowner units experience water leaks and what were the consequence?
   iii. Is sufficient knowledge available of magnitude and duration for wind-driven rain on in high-rise buildings surfaces?
   iv. Can emergency buildings or a critical facility remain leak-free during a design-level event?
   v. What are successful approaches by building envelope consultants to mitigate water leakage in FL hurricane-prone coastlines?

vi. Quantify costs to of upgraded building envelope systems to homeowners, including immediate capital costs, plus estimated damage repair costs over the life of a structure

vii. Is a 100% water-impermeable building envelope system achievable, and at what cost?

C. The Contractor shall report to the FBC on findings of the Project Team summarizing the following:

i. The Current standards for testing, product approvals that are generally accepted by building envelope consultants for installing curtain wall systems on high-rise structures in hurricane-prone regions in Florida.

ii. Defining successful tests for product approvals of fenestration and the potential incompatibility between existing testing standards during hurricanes and post-hurricane performance for building envelope systems

iii. Florida Building Code provisions (and other guidelines) that are used by Building Envelope Consultants and Building owners in developing curtain wall systems

iv. Summary of homeowner/condominium owner experience during Hurricane Irma and other recent hurricanes.

v. Current homeowner desired expectation for water infiltration and wind-driven rain resistance in condominium or apartment units of high-rise buildings. The Team will report whether any or all water infiltration is unacceptable or whether the Homeowners discern a level range of water infiltration that is tolerable.

D. The building envelope consultant shall lead a charrette with the Project Team and a handful of product manufacturers and homeowner to help develop a "Desired Specifications" for fenestration system/curtain wall system that will perform during and even after a design-level hurricane event. The desired outcomes may be incompatible with current testing and expectations for building envelope systems, but it should be helpful to frame enhanced testing criteria for future systems. The outcome of the charrette shall be a document that is understandable and acceptable to condominium owners and code officials as desired performance, as well as to building envelope product manufacturers. <u>As the research discussion progressed, the Research Team decided to omit the charette because the discussion among the Research Advisory Group uncovered more issues beyond design specification of fenestration assemblies. The consultant developed the framework for a desired specification for input by the Research Advisory Group and the resulting outline is included in Section 5 below.</u>

E. The Project Team shall use this desired specification wish list to develop guidelines for the industry to follow in develop the feasibility and required steps towards post-hurricane performance design guidelines for fenestration and building wall cladding systems. The Team shall report to the Commission on their findings to include, but not limited to:

   i. Include knowledge of current and future testing options and testing on new systems currently underway that manufacturers are willing to share with the goal of establishing reliable post-hurricane performance of curtain wall and fenestration systems.

   ii. Consider benefits of structural glazing and curtain walls - most hurricane regions now utilize curtain wall assemblies that are structural glazed to aid with glass retention; such full perimeter structural seals may likely provide the post hurricane performance that homeowners would desire. Window manufacturers currently do not structurally glaze their systems, but if they did, it would most definitely improve their post-hurricane performance.

F. Summarize findings and make recommendation in a final report to the Florida Building Commission on one or two approaches for addressing Phase II.

1.5 Deliverables

An interim report shall be prepared and delivered no later than April 15, 2020. The interim report shall address each task as enumerated above and shall summarize the project progress to date. In addition, the interim report shall be formally presented to the Commission's Structural Technical Advisory Committees at a time agreed to by the Contractor and Department's Program Manager.

A final report shall be prepared and delivered no later than June 19, 2020. The final report shall explain the purpose, approach and results of research. The final report shall include a summary of the project activities including summary of the procedure for conduction the mock-up test and summary of discussion and findings regarding the issues outlined under task e above. In addition, the final report shall be presented to the Commission's Structural Technical Advisory Committees at a time agreed to by the Contractor and Department's Program Manager. The Research Team decided to remove the detailed mockup testing from the report because it would be necessary to first expand the contributions to wall cladding systems, and waterproofing systems, contractors before this would be relevant.

2 FOCUS AREA AND RESEARCH ADVISORY GROUP

The focus of this study is on water-penetration resistance of fenestration assemblies in high-rise residential buildings in Florida. A subset of those buildings is located in South Florida. The County of Miami-Dade incorporates 34 cities, villages, and towns. www.emporis.com reports there are 1,100 existing high-rise buildings, i.e. buildings ten (10) stories and taller, in Miami-Dade County, and the cities of Ft. Lauderdale and West Palm Beach. Construction is planned for about 200 additional high-rise structures over the next 10 years. The average number of floors in high-rises is 17 and the tallest structure is 850 ft. Approximately 70% of all high-rise buildings have between 10 to 15 stories. About 60% of all of high-rise properties in this region are residential condominiums.

The city of Miami, Florida has the third-tallest skyline in the United States with over 300 high-rise buildings, 80 of which stand taller than 400 feet (120 m) Figure 1. Skyscraper.com reports that 68% (of 63) structures in Miami over 150 m tall are residential, 21% are mixed-used and 10% are office buildings. Miami is also the largest major US city with the highest design wind speeds (170 mph) and greatest threat annually of being hit by a hurricane. Many of the city's buildings and residents who live there are potentially vulnerable to water leakage through their walls and the subsequent damage to the interior.

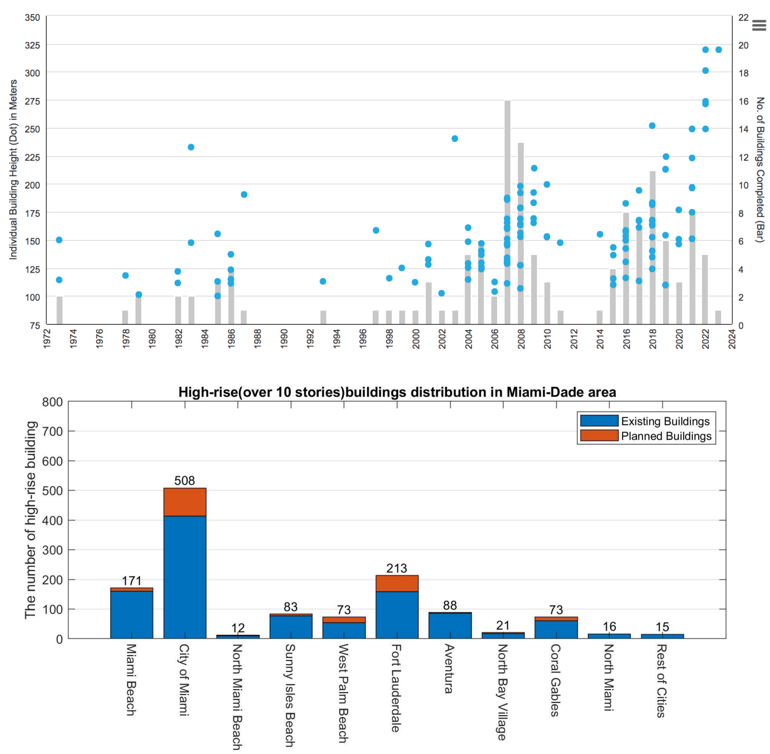


Figure 1. (a) Building Completions Timeline: 100 m+ buildings completed in Miami, FL over past 50 years; (b) location of high-rise buildings within Greater Miami, FL

The Research Advisory Group included persons with extensive professional backgrounds and knowledge in the building envelope industry and construction of high-rise buildings in Florida (see Table 1).

Table 1. Research Advisory Group Members

#	First Name	Last Name	Organization
1	Bill	Bonner	Crawford Tracey Corporation
2	Steve	Camposano	Hurricane Shutter Manufacturer
3	Rick	Chitwood	Owner
4	Anne	Cope	Insurance Institute for Business and Home Safety (IBHS)
5	Scott	Diffenderfer	Owner
6	Brad	Fevold	Marvin Consultant
7	Greg	Galloway	YKK AP America, Inc
8	Alan	Greenberg	Owner
9	Joe	Haden	Pella Corporation
10	Michael	Horst	Wiss, Janney, Elstner Associates, Inc. (WJE)
11	Peter	Iglesias	City of Coral Gables City Manager
12	Chris	Lipp	Wiss, Janney, Elstner Associates, Inc. (WJE)
13	Michael	Louis	Simpson Gumpertz & Heger Inc., Waltham, MA
14	Greg	Mckenna	Kawneer
15	Lynn	Miller	PGT Consultant
16	David	Prevatt	University of Florida, Gainesville, FL
17	Dean	Ruark	PGT Consultant
18	John	Runkle	Intertek
19	Vince	Seijas	Miami-Dade County Department of Regulatory & Economic Resources
20	Daniel	Smith	Venrisk Consulting Ltd, Boulder, CO
21	Eric	Stafford	Insurance Institute for Business and Home Safety (IBHS)
22	Dave	Stammen	Building Science Technologies, UL LLC
23	Matt	Waldren	Pella Corporation

Brief summaries of the main discussion at Advisory Group meetings are provided below. Full meeting minutes are provided in the Appendices B-F.

2.1 Meeting #1 – 21 February 2020

During Meeting #1, a project overview was presented with broad discussion of key issues associated with water intrusion. The varying perspectives of key stakeholders (industry, homeowners and researchers) regarding the issue of water intrusion during severe wind events were discussed. The project team also presented data from an analysis of building permits following Hurricane Irma (see Appendix D). At the conclusion of meeting, the

Research Advisory Group provided suggestions for future research objectives of the project. Meeting #1 minutes are attached in Appendix A.

2.2 Meeting #2 – 20 April 2020

Meeting #2 continued the perspectives discussed during Meeting #1, emphasizing the homeowner point of view and mitigation options for water ingress (see Appendix B). In addition, the meeting covered the following:

1) Successful approaches by building envelope consultants to mitigate water leakage in FL
2) Did any homeowner units experience water leaks and what were the consequence?
3) Are owners fully aware of potential liability risks from wind and water leaks?
4) Is sufficient knowledge available on magnitude/duration for WDR on high-rise surfaces?

2.3 Meeting #3 – 11 June 2020

The focus of Meeting #3 was on testing and perspectives from fenestration manufacturers (see Appendix D). A significant portion of the discussion was dedicated to reviewing the document prepared by the manufacturer's summarizing their views on the water intrusion issue and potential approaches to improve future performance. In addition, following the meeting a google spreadsheet was circulated to the group listing potential mitigation options and their pros/cons. That sheet is available at the following link: https://bit.ly/ufWIND-water01

2.4 Meeting #4 – 9 July 2020

The focus of Meeting #4 was aimed at developing a desired list of water intrusion specifications (see Appendix E). In addition, corrections to the minutes for Meeting #3 the final draft report presented to FBC were discussed. A full recording of the meeting is provided at the link below:

https://bit.ly/ufWIND32-2020

2.5 Meeting #5 – 17 July 2020

The focus of Meeting #5 was aimed at reviewing the final report to be presented to FBC for this project (see Appendix F). A full recording of the meeting is provided at the link below:

https://bit.ly/ufWIND-33-2020

3 SUMMARY OF RESEARCH ADVISORY GROUP DISCUSSIONS

The 10 June 2019 University of Florida report submitted on behalf of the FBC Workgroup on water intrusion concluded that building envelope systems in mid to high rise buildings will leak during the occurrence of wind-driven rain events in design-level hurricanes. This conclusion was based on the numerous reports of water leakage that occurred during Hurricane Irma, where the maximum wind loads were around less than 25% of the design wind loads for the building locations.

Direct evidence (available to the research team), of hurricane-induced water leakage in high-rise buildings during Hurricane Irma is limited to a few engineering and insurance claims reports, verbal reports, and statements from Condominium managers, and Condominium Associations, and building officials owners in South Florida. The dearth of available supporting field data of reported water damage costs precluded the Workgroup from assigning water leak sources to specific locations of the building envelope or estimating the volume and geographic extent of the water leakage that actually occurred. Efforts by the research team to gather data from the building permit applications during the three months following Hurricane Irma were inconclusive.

3.1 Summary of Building Permit Statistical Analysis

An indirect approach was used to test a hypothesis that water leaks through building cladding elements is associated with building permit applications pulled by condominium owners. We surmised that wind-driven rain induced leaks may produce sufficient damage to interior finishes of a residential condominium that results in the need for contractor repairs. Thus, one measure to broadly establish the effect of Hurricane Irma induced water leakage on high-rise residential building units is to quantify and compare the number of building permit applications pulled before and after hurricane landfall.

To test this hypothesis, we contacted several building code departments located within Miami-Dade, Broward and Palm Beach counties to get building permit information. We extracted the buildings permits related to construction/repair work on high-rise buildings, further identifying work related to fenestration assemblies only. The building permit databases as a rule did not report permit applications specifying the interior finishes repair of exterior walls. Details are provided in Appendix G.

We collected three years of data from 2016 through 2018, bracketing Hurricane Irma landfall date (10 September 2017). We ran a paired T-test on the data from the three months after Hurricane Irma, (~September, October and November), finding no statistically significant differences in number of building permit applications among the three years of sample. Further, when we compared the number of building permits filed within the three-month period before the Irma's landfall (i.e. June, July and August) to the numbers filed in the following three months after landfall, we did not observe any noticeable trends related to Hurricane Irma.

The building permit data we were able to collect was sparse and not normally distributed which limited the statistical power of our analysis. As discussed during our Research Advisory Group meeting, we observed that since the moderately strong wind speeds of Hurricane Irma are unlikely to cause structural damage to the fenestration assembly, homeowners are unlikely to file a building permit to repair their units. Thus, the hypothesis is not supported by the data.

3.2 Limitation of Current Water Penetration Test Standards

The 2019 Workgroup report noted that current water penetration test standards for fenestration assemblies cap the maximum wind pressures for water-penetration resistance tests at 15 to 20% of structural design pressures. Thus, the industry and contractors, building officials and homeowners lack a reliable method to ascertain the extent of water leaks through a building envelope system that will occur at or near to the design-level wind event.

Still, it is technically feasible for an experienced Building Envelope design consultant to develop the appropriate design options to achieve a client's desired level of water tightness for their building, without knowledge of a specific wind pressure or wind-driven rain intensity. The designer can use many options to minimize water leaks, some of which may have aesthetic as well as economic (cost) tradeoffs. The designer could select from several choices of cladding material, structural systems, the shape and sizes of joints, the choice of sealant and the provision and location of weep holes in order to minimize water entry. In this scenario considerations confront the Florida Building Commission now regarding the purpose of building code guidelines going forward and related to challenge of codifying procedures to assure leakproof building envelope systems at design-level hurricanes. A primary concern is whether consumers want such systems and are they willing to purchase them?

3.3 Current State of Practice (this MJL/SGH Overview Memo)

This section provides a working summary of the pertinent building codes, standards, and industry literature pertaining to the design and evaluation (where applicable) of structural performance and water penetration resistance of fenestration assemblies in Florida, prepared by Simpson Gumpertz & Heger Inc. (see Appendix I).

Florida Department of Business and Professional Regulations provides a search engine on their website to find product approvals for fenestration assemblies that meet the specific requirements for installation in Florida. The Product Approval website is: https://floridabuilding.org/pr/pr_default.aspx. Florida Approvals specifically state which fenestration products are approved/not approved for use in the High Velocity Hurricane Zone (HVHZ) in Florida.

Chapter 17 of the Florida Building Code provides guidance for Special Inspections and Tests. For successful testing and registration on the Florida Approval website, fenestration products must successfully pass selected tests from the following list: ASTM E283, ASTM E331, ASTM E330, AAMA 501, ASTM E1886, ASTM E1996, TAS-201, TAS 202 and TAS 203 (see SGH 29 April 2020 memorandum in Appendix I). Additional chapters within the Florida Building Code refer to other requirements of fenestration assemblies. Those sections are not mentioned here as they are not germane to this study

Chapter 16 of the Florida Building Code provides guidance for calculating design loads for buildings and other structures that must be met for Florida Approval. Chapter 16 refers to ASCE 7 as an accepted methodology for calculating design wind loads. Independent laboratory certifications for fenestration products are required to demonstrate compliance with these criteria.

3.3.1 *Definition of Successful Tests for Product Approvals of Fenestration*

Current industry standards for fenestration assemblies are mainly concerned with design-level structural performance as it relates to hurricanes, and not with design-level hurricane water penetration resistance. Successful testing of fenestrations is defined as passing missile impact testing followed by cyclic testing up to full design load without breaching the test specimen. Reuse of the fenestration product following impact and cyclic testing is generally not a condition to successful testing from a life-safety perspective. Such Water penetration performance at design load is not a condition of successful testing either before or after impact testing. Water penetration performance must be met at the level of industry acceptance for fenestration products which is reduced to 15-20 percent of the structural performance level for systems covered by NAFS-2017 (NAFS-2017, 2017). For fixed framing systems such as store front and curtain walls, water performance requirements are determined by the architect of record.

3.3.2 *Homeowner's Experience During Hurricanes*

End users, or homeowners of high-rise residential buildings (10 stories and taller), in general they desire a better understanding on how the rating system for fenestration products works. Some users also are confused that water penetration resistance tests are conducted at levels which are well below the design-level hurricane wind-induced pressures. Most end users would be well-served with resources to gain a better understanding of the effects of wind-driven water on building fenestrations, and simplified explanation current industry guidelines for water-penetration resistance testing. There is generally an expectation among homeowners that if their new window or door systems pass a design-level hurricane wind load test it is generally an assurance the systems would not leak at wind loads well below (~20%) of the design-level hurricane structural loads.

3.3.3 *Expectations for Improved Water Penetration Resistance in High-rise Buildings*

Performance testing for water penetration resistance at design-level hurricanes should be requirement of the Florida Building Code for buildings, and especially for high-rise buildings. Inspectional Services Departments should require a review of successful project and site-specific test reports as a precondition to their sign-off on projects. Inspectional Services should be required to review fenestration installation details to verify that they satisfy proven concepts for resisting water penetration.

Building code provisions should specify that inspections of fenestration and curtain wall assemblies should verify that the fenestration products are installed to meet structural performance requirements of the Code. In addition, inspections should also verify that there is continuity of air/water and vapor barriers to adjoining wall assemblies, roofing and other fenestration products. Such building products (and systems of products) would be certified for their water penetration resistance characteristics at the design-level hurricane.

Improved inspection can be a positive step towards better water penetration resistance. It is during the design phase where many high-rise buildings can most benefit from incorporation of proven high-performance design features. While inspections are necessary, there is a limit to their effectiveness. Some industry observers recommend the conduct of mock-up water penetration resistance testing of fenestration assemblies, before construction and randomized water testing during the construction period itself. Some observers suggest it is the most effective way to assure that specified water performance standards are consistently achieved.

Homeowners generally would find value in a Florida Building Code-sanctioned document written in layman's language that lists and explains design features that mitigate design-level hurricane water leakage through fenestration assemblies of high-rise buildings. Some fenestration manufacturers already include such communication for their customers. A collaboratively authored document collating design features from across the industry may have greater penetration and uptake by homeowners in general, when distributed by a state-government source.

The Research Advisory Group developed the following list of such design features that have a track record of "better" water penetration resistance performance. This list was compiled from the experience and observations of the Research Advisory Group members only and therefore it is neither complete nor exhaustive, but it is presented below, as an example to start building an End User document for Homeowners.

- Slab offset at door sills (the greater the offset the better the performance that can be achieved)
- Taller sill dam heights on sliding doors and windowsills (need to weigh the offset requirement vs ADA). Balcony paver and pedestal can be used. Details are used to bury door sill into structural slab and include drainage path through structure.
- Flashings for doors and windows that comply with ASTM E2112
- Transition details between wall assemblies and fenestrations (to improve weather protection between fenestrations and adjoining walls)
- Incorporation of hurricane shutters
- Balconies are sloped to drain (if concrete)
- Fixed fenestration units that are structurally glazed with silicone sealants in general tend to outperform other water management systems under extreme wind-driven rain events. Ultimately, the performance of such systems should generally by tied to performance-based test criteria rather than to prescriptive specifications, which may stifle creativity and innovation.
- Operable fenestration products that feature multi-point locking devices to help retain all sides of a vent. Such locking devices in general have demonstrated improved weather sealing. Designs that compress sash against gaskets tends to outperform those that utilize pile weather stripping alone.

Other features that mitigate design-level hurricane wind-driven rain leaks could be developed by experts in building envelope design, testing and construction and added to this list. In general, a prescriptive options list highlighting better-performing products and systems, will effectively be a limited (immediate) solution to the broader issues this study is trying to address. Given sufficient time and resources, a more robust solution is to establish performance-based design specifications for water presentation resistance during design-level hurricanes. By stipulating performance criteria in terms that end users can understand, companies would be encouraged to innovate based on consumer demand. In that way, the downside issues associated with a finite list of prescriptive requirements would be eliminated.

3.4 Research Team Summary of Discussions

A summary of the main discussion points in each meeting, broken out by stakeholder group is presented in Appendix A. The complete meeting minutes for the five meetings are included in the report in Appendices B through F. The following are the high-level discussion themes to emerge from the discussion.

1. Generally, consumers have expressed confusion about the current accepted performance criteria for fenestrations that are certified to perform structurally without failure under hurricane load and yet do not have comparable levels of expected water penetration resistance.
2. Along with the external wall cladding, fenestration assemblies are the most visible and easy to identify components of the building envelope system that consumers encounter. There are many more hidden construction materials and systems that go into a building wall. As fenestrations are manufactured and installed, some consumers may associate any water leakage with the fenestration products within the walls, when in fact leakage can occur at the perimeter interface, or directly through the wall cladding system itself, or emanate from far away locations, like the roofing or elevator shaft.
3. Current industry standards have not established water penetration resistance at design-level hurricanes as a product standard, because this is not required in the current building code. It is generally the case that without an industry standard test criteria or building code requirement for evaluating the water intrusion of a fenestration assemblies at design hurricane strength wind speed, it is impossible to ascertain how little or how much water volume will enter into through the envelopes of Miami, FL high-rise residential buildings during the next landfalling design-level event.
4. Many homeowners are confused at the performance criteria of fenestration products – the subtly of category performance certified by some existing performance specifications is generally not something that most homeowners can be easily grasp. Homeowners need to have confirmed installations and the seals need to be kept in good condition with regular maintenance. Homeowners

generally expect that a fenestration product that was structurally certified to perform in a design-level hurricane, will also be leakproof or as a minimum it would have been tested to determine its water penetration resistance at the same design-level hurricane.

5. Consumers must select among several similar-looking certified fenestration assemblies which may have windows vastly different performance characteristics. The same window product for instance could qualities – consumers struggle to understand the differences which are spelled out in industry standard guidelines.
6. There is generally no consensus on the <u>wind pressure and rain intensity levels</u> that are representative of design wind speed and wind-driven rain intensity in hurricane conditions for Florida. There exist several mitigating factors, such as the presence of fenestration storm shutters, or sheltering from an overhead balcony that can significantly reduce the wind-driven rain intensity on a fenestration. The Research Advisory Group discussed some of these methods and these a listed in Table 3.
7. Many contributing factors exist that impact the likelihood of high-rise residential building leaks during design-level hurricanes – this study specifically addressed factors associated with fenestration assemblies. Lack of maintenance, poor workmanship, and improper design and/or integration of the cladding and fenestration systems are other factors, to name a few. Limited holistic in-situ (system-wide) testing and poorly integrated flashing are also known contributions to water leaks.
8. High-rise buildings are inspected during construction in many cases by private inspection organizations who report their observations to building code officials. During occupancy, the task to assign the cause of water leak (workmanship, design flaw, homeowner-error or lack of maintenance) is a responsibility of building envelope engineer/consultants. For high-rise buildings the tasks involved can be quite complex and it is generally time-consuming and expensive.
9. Current Florida Notice of Acceptance certificates do not address sealing issues. Glazing installation standards are not well enforced. The need for more field testing and maintenance of fenestrations is important. While there are many issues that affect window performance, current water penetration testing at 10% of the structural design pressure with a factor of safety of 1.5 is far below what would be expected during a hurricane level event.

4 CLOSING REMARKS AND OBSERVATIONS

Given its geography and location, the state of Florida has unique building design and construction challenges to be addressed regarding hurricane damage mitigation. The annual hurricane threat is a real concern to Florida's 22 million population, most of whom (79%), live within coastal counties. Over time our homes have had to be adapted to minimize risks and this is an ongoing process today.

Major hurricane events have propelled changes in building codes that resulted in reduced overall building damage and loss.

In 1992, Hurricane Andrew produced extensive damage to residential single-family housing and which resulted in extensive research, changes in the insurance market and the introduction of the Florida Building Code in 2002. Hurricane Charlie in 2004 also produced design level-wind speeds in the Punta Gorda and Port Charlotte townships, but there were fewer catastrophic losses of residential construction to houses built after the FBC was implemented. Charlie pointed to a greater need for improved water penetration resistance of low-rise construction, particularly single-family residential homes. There are many features today, included in the Florida Building Code that have served to mitigate damage. Research supported by the Florida Building Commission has shown statistically significant improvements in building performance as a result.

In 2017 Hurricane Irma affected a large swath of the Florida Peninsula from the Florida Keys to the south, and as far north as Jacksonville, in the northeast. The wind speeds never reached deign level and yet the state suffered $17B in insured losses. The Florida Public Hurricane Loss Model (FPHLM) (http://fphlm.cs.fiu.edu/docs/FPHLM_05_02_2014.pdf) estimates there are about $3.6 Trillion in insured properties in Florida, of which $2 Trillion (56%) are residential. The insured losses from below design-event hurricanes in Florida are overwhelmingly borne by the residential sector, a fact which continues to be overlooked. The FPHLM model and other models considers rainwater ingress as a major source of loss. Water ingress is modeled through both damaged envelope components AND leakage through undamaged components.

Table 2. Recent Insured Losses from Hurricanes in Florida

Year	Hurricane	Landfall (yes/no)	Design-level (yes/no)	Insured losses	Major impacted sector
2016	Hermine	yes	no	$139,000,000	72% residential
2016	Matthew	no	no	$1,100,000,000	85% residential
2017	Irma	yes	no	$17,400,000,000	86% residential
2018	Michael	yes	yes	$7,400,000,000	67% residential
2019	Dorian	no	no	$19,000,000	54% residential
Source: https://www.floir.com/Office/HurricaneSeason/hurricaneresourcepage.aspx.					

While the population and state government in Florida is concerned about vulnerability to hurricanes, and the mitigation of water-induced damage, the Florida market for construction technologies is relatively small. Generously, Florida represents less than 7% of the overall US market of 328 million people. Thus, it is not surprising that Florida-specific building code changes and higher standards for construction products may not be the top priority of fenestration manufacturer's corporate goals.

The mechanism that exists to engage the construction industry and increase their awareness of our changing societal standards is through the building code process. The building code process must be informed by the demands of our consumers. It is incumbent for Florida to make a strong case that there are benefits (economic and otherwise) to be made within the construction industry from the changes being proposed. There is a sustainable consumer demand for enhanced product performance, particularly with respect to water penetration resistance both during and after a hurricane level event.

4.1 The Florida Hurricane Catastrophe Fund

The Florida Hurricane Catastrophe Fund (FHCF) is a tax-exempt trust fund created by the Florida Legislature in November 1993. Following Hurricane Andrew's landfall in August 1992, numerous problems developed in the residential property insurance market and the availability of reinsurance for hurricanes became scarce and extremely expensive. Many insurers were forced to re-evaluate their exposure in Florida. State action was deemed necessary to maintain a stable property insurance market.

The FHCF was created with the purpose of providing a stable and ongoing source of reimbursement to insurers for a portion of their catastrophic hurricane losses in order to provide additional insurance capacity for the state. The FHCF operates as a public-private partnership, supporting the private sector's role as the primary risk bearer. There are two important considerations resulting from the FHCP which affect all homeowners in Florida:

1. FHCP authorizes the levy and collection of **emergency assessments** on all property/casualty premiums (except for premiums on workers' compensation, medical malpractice, accident and health, and National Flood Insurance Program policies) **to fund debt obligations of the FHCF**
2. Provides general limits on emergency assessments:
   - 6% of premium as to losses arising out of any one contract year
   - 10% of premium as to losses from multiple contract years

As a result, every Florida homeowner has a vested interest in doing everything they can to mitigate the risks of damage to their structures and to minimize the likelihood of such damage. This is why the FBC provisions have the importance they do within the state. Decisions that are made today must be carefully weighed against what future losses can be avoided over the next few decades as Florida continues to build its high-rise residential infrastructure.

4.2 Proposal for Performance Levels of Building Envelope Systems

The poor to variable performance of wall systems that allows water entry into buildings is an anomalous condition to the construction industry. A roofing system that leaks is one which has failed. Yet the standard of water penetration resistance that is currently accepted for windows and walls is far lower.. Nevertheless, our discussion with the Research Advisory Group indicates that an attainable (but likely far off) goal is for completely leak-proof building cladding systems up to the design-level hurricane conditions of a particular location. However, there are challenges that first will need to be overcome, including to determine the appropriate wind-driven rain intensity and to develop standard test protocols. Realistically, raising current building standards up to design levels of a hurricane requires substantial research and is a goal that is not "just around the corner." In the short-term, homeowners in high-rise residential buildings can benefit from applying existing knowledge to mitigate water leaks.

4.3 Performance-Based Design for Water-Penetration Resistance

We propose employing a 3-stage performance-based design (PBD) philosophy to mitigate water penetration through fenestration assemblies, and eventually the remainder of the building envelope systems. FEMA (FEMA, 2013) defines performance-based design as a process or methodology used to create buildings that protect functionality and the continued availability of services. The performance-based design approach is not proposed as an immediate substitute for design to traditional codes, but it can be used in design to provide rational performance choices to community stakeholders that match their objectives and tolerances for risk.

For example, the level of expected performance that is appropriate from a particular fenestration assembly may be matched to the expected design-level hurricane intensity and a homeowner's tolerance to experience water leakage during the rare design-level hurricane. So, if interior finishes of a building are made of sand-cement plaster that is unaffected by intermittent wetting, and the value of the building contents is small, a homeowner may select a fenestration assembly that allows moderate to severe water leakage. On the other hand, a homeowner who is concerned about fine artwork that is sensitive to sudden humidity changes may opt for the highest performance class of the fenestration assembly, minimizing the likelihood of severe water leakage.

Figure 2 diagrammatically illustrates how a PBD matrix for water penetration resistance might be set up. Consider two condominium units in a high-rise build, one of which have storm shutters and the other does not. The homeowner of the unit without storm shutters could select fenestration assemblies from three Quality levels (Good, Better, Best) with respect to their water penetration resistance (and other) characteristics. By performing tests and measuring the amount of water leaks, a manufacturer could provide the chart in upper right of Figure 2, indicating the expectation and volume of water leaks in three different storm intensities.

The second homeowner who opted to install storm shutters could also be provided with a similar chart showing the performance level they could expect. In similar manner, since the holistic system of storm shutter, fenestration assembly and wall cladding would have be tested, homeowner would have information to make rationale choices.

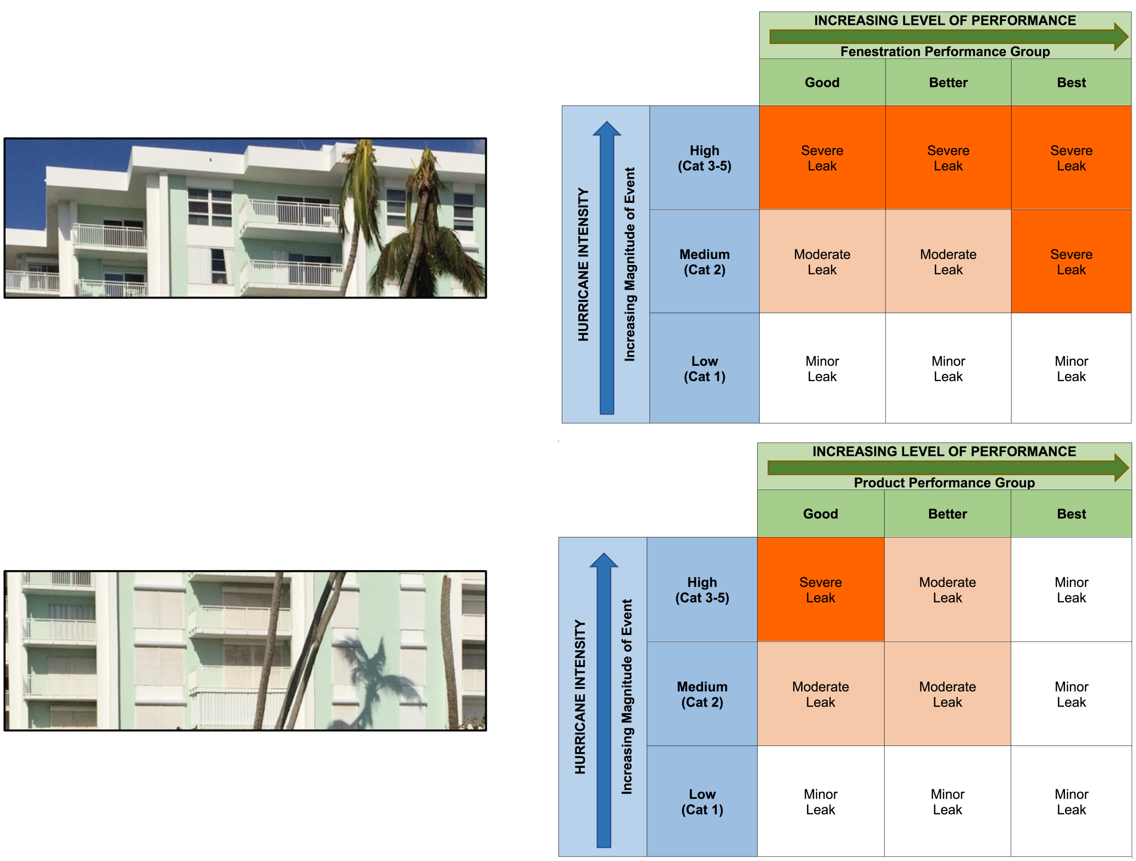


Figure 2: Performance based design criteria for water penetration resistance – how it works

As part of this performance-based design model, the current design standards used to evaluate fenestration assemblies at current “Normal” performance levels may be set as the “Good” product performance group. The “Best” product performance group standards may be related to fenestration assemblies that provide leak-proof performance at design-level hurricane wind loads and wind-driven rain intensities. The “Better” product performance group standard may be set at some intermediate between Good and Best performance levels, for example current AW-class fenestration.

The beauty of the performance-based design philosophy is that the matrix can be adjusted to cover any performance limits stakeholders may deem appropriate, once realistic testing criteria can be developed, representative of real-world loading conditions. For example, if some residual post-design-level hurricane performance is desired, the criteria for such performance could be created as a “Best-Plus” fourth product performance group.

PBD design philosophies as described here need not be limited to a single building component. In fact, when the PBD is applied to a system of components, say to evaluate water leakage through the building cladding, its adjacent fenestration assembly and joint seal system, the results can quantify performance in terms that are compatible with in-situ water penetration resistance test procedures. Straightforward results would be more easily understood by homeowners.

4.3.1 *Current Test Performance*

This includes structural design to hurricane strength and water penetration resistance to a serviceability level (say current 20 psf) thunderstorm or minimal hurricane strength. This is a life safety only consideration that assumes water intrusion damages still allow for “normal” operational service conditions. Current FBC guidelines and industry standards can easily attain this level of performance.

4.3.2 *Design Hurricane Water Penetration Resistance*

At the design-level hurricane when the structural design strengths are met, water penetration resistance under hurricane-strength wind speeds must also be achieved. There are current high-performing fenestration products in the market (AW-Class Fenestration), that are designed for higher performance levels. For water penetration resistance of AW class, the criteria is 20% of the structural performance which is 5% above the current norm. These products undergo the same structural performance testing of lower classes of windows, but also undergo mechanical and repeated use testing prior to water testing. However, the performance of AW-class window systems is limited because they are not specifically tested for the expected wind-driven rain intensities during a design-level hurricane.

4.3.3 ***Post-hurricane Window Performance***

In this scenario, design considerations of the two previous levels plus the window structural performance would be sufficient to retain some functionality after the hurricane has passed. This is to say, after structural displacement at the design level, assuming glazing isn't broken the fenestration can still be used to some effect for shelter-in-place and immediate post-hurricane protection from water penetration.

4.4 Determining Wind Driven Rain Intensity and Façade Wetting Rates

To develop a design-level hurricane water resistance test requires establishing of building façade wetting rates. In addition, the water intrusion rates would be developed for a joint probability of occurrence with the basic 3-second design wind speed for a location adjusted to building height and the design rain intensity rates. The FBC defines a design wind speed as the basic three-second gust wind speed at 33 ft (10 m) measured in open exposure. Wind speed in general varies with height in a given storm and with the roughness of the ground over which the storm has moved.

Although the United States research on wind-driven rain intensities is quite limited, Blocken and Carmeliet (Blocken and Carmeliet 2004) reviewed the extensive international research on this topic collected from researchers in twelve countries, since the 1940s. In addition, the paper presents methodologies for quantifying wind-driven rain intensity through empirical, semi-empirical methods and computational fluid dynamics (CFD) simulations. The actual wetting of the building façade by wind-driven rain is controlled by a wide array of parameters, listed below:

- building geometry
- environment topology
- position on the building facade
- wind speed
- wind direction
- turbulence intensity
- rainfall intensity
- raindrop size distribution
- rain event duration

From discussion with the Research Advisory Group, it is clear there is not currently agreement in the United States as to what levels of wetting occurs on a building façade that should be used for design-level hurricanes. Some features of wetting patterns are known from existing research:

- The windward facade is wetted whereas the other facades remain relatively dry.
- Wetting on the windward façade increases from bottom to top and from the middle to the sides. Thus, the top corners of a building will be most wetted, followed by the top edges and then the side edges.
- For tall and wide buildings, most of the windward facade will receives little wind-driven, except for the corner and the top and side edges.
- The wind-driven intensity at a given position increases approximately proportionally with wind speed and horizontal rainfall intensity.

Baheru et al. (Baheru et al. 2014) conducted an investigation to quantify hurricane-level wind-driven rain intensities based upon field measurements of raindrop size distribution (RSD) collected during 2004-05 North Atlantic hurricane seasons. The study involved experimental testing to complement the field data collected. The paper includes a procedural method of estimating target WDR rate as a function of test wind speed based on target RSD and rain rate in experimental setups. The research above can be used as the basis future studies to determine test methodologies and the appropriate design-level hurricane wind-driven rain criteria.

5 DESIGN SPECIFICATIONS FOR LEAKPROOF HURRICANE STRENGTH PERFORMANCE WINDOWS

Does a leakproof building mean creating vertical building envelope systems (walls, cladding and fenestrations) that just are as watertight as roofing systems? If so, should the level of "leak-proofness" extend throughout the entire wind pressure and rain intensity range, up to and including the design level hurricane? This is a philosophical question that consumers may wrestle with. An easy but highly impractical solution would be to wrap the entire building in a single-ply roofing membrane – this would surely work but it would be aesthetically unpleasant, excluding all external light. The building would be unlivable. Practically speaking, one of the attractions for homeowners living in high-rise residential buildings is the uninterrupted views that they are afforded through the large glazing openings in their condominium units.

There is solid, continuing growth in the high-rise residential condominium market in Miami-Dade and surrounding counties. Intuitively, by observing consumer choices of persons wanting to purchase such properties, one may conclude water leakage through windows is not the top concern of homeowners. On the other hand, consumers may generally wish to understand that their units would not be subjected to an unlimited or undefinable quantity of water ingress during a design-level hurricane. The challenge today is we do not know what the upper limit to water ingress is as there are no available standards to evaluate how fenestration assemblies perform when subjected design-level hurricane wind-driven rain intensities.

Specifying higher water resistance criterion is one reliable way to improve water penetration resistance through fenestration assemblies. But it is not the only way, and it generally will come at a higher cost, at least initially. Merely raising the test pressure used to certify windows may not, by itself improve the overall performance of the building to the levels demanded by consumers. The Research Advisory Group identified several other features of the building envelope system, (construction, maintenance, holistic field testing and improved overall design) that could be contributing factors to mitigating water leakage. Ultimately, it is the consumer who demands the level of risk avoidance they desire, and at what cost. At present those demands are unknown, as the question of benefits and costs of a design-level hurricane water resistance facade have not yet been fully investigated. To address this the Research Team recommends that consumer preferences be ascertained through structured surveys as part of future research in this area.

5.1 Specification for Improving Fenestration Performance

The aspirational goal of the research is to identify pathway(s) towards producing hurricane-resistant fenestration systems that are capable of mitigating water leakage up to the design level wind speed. Currently, it is not the charge of the Research Team to come up with a detailed specification, but it is to outline the considerations that should be further developed into a detailed specification. Later phases of the study can be recommended to further develop the specification beyond a basic outline of tasks and fenestration features that the Research Team feels will help to improve water penetration performance for buildings.

The Research Team defined four (4) categories that describe a specification for how to improve water penetration performance of fenestrations. Additional studies are required in each of the following categories: DESIGN, INSTALLATION, TESTING and ADMINISTRATION. We discuss each of these specification categories in more detail in subsections, below.

5.1.1 *Design*

Design aspects of a specification considers physical features that may be incorporated into a building design, which will help to enhance the performance of fenestrations. Some of these features are enhancements to specific fenestrations while others are enhancements to building design parameters. Some of those features discussed, include:

- Use storm shutters with fenestration products. Storm shutters will help to protect fenestration glass from wind-borne debris while also providing shielding to the effects of wind driven rain.
- Require balconies have a positive slope-to-drain to help avoid water build-up at doors and floor-to-ceiling windows.
- Require slab offsets to the sills of sliding glass doors as this helps to improve water resistance (particularly behind storm shutters). Low offsets allow water to build-up against doors and walls which can flow under storm shutters and still overwhelm door sills. Offsets of 6-8 in. or more can provide the necessary benefits for water resistance while lower offsets incrementally increase leakage risks. Where ADA requirements must also be met, exterior decking on pavers or sleepers can be designed to provide the required ½ in. or less offset between inside and outside walking surfaces while still maintaining the height for water drainage.

- Require structural silicone glazing for window and curtain wall glazing. Structural silicone helps with glass retention if the glass should break from wind-borne debris but also provides the added benefits of substantially improving air and water penetration resistance of fenestration assemblies beyond the levels prescribed by AAMA/WDMA/CSA 101/I.S.2/A440 North American Fenestration Standard (NAFS).
- Require that curtain wall assemblies utilize silicone sheet membranes to allow reliable integration to the weather barriers in adjoining opaque wall systems (where applicable). Since silicone sheet is more flexible than sealant joints alone, they create a more reliable flashing termination.
- Require that operable fenestrations utilize "better" sealing gaskets that are soft and compressible in lieu of pile weather-stripping. This is most appropriate for swinging terrace doors, and casement and awning-style windows but can also be incorporated on horizontal sliding windows and sliding glass doors with lift-and-slide hardware.
- Require that operable fenestrations utilize multi-point locking devices that engage the operable sash at more than one location along the perimeter of the sash. These devices help to compress the sash against compressible weather-strips to maximize air and water penetration resistance.

5.1.2 *Installation*

Installation aspects of a specification include guidelines for fenestration performance as part of the whole building enclosure and not just a single component that must stand on its own. Some industry guidelines for installation, include:

- Utilize industry standards such as ASTM E2112 (Standard Practice for Installation of Exterior Windows, Doors and Skylights) which provides guidance on how to install reliable flashings around fenestration to create integrated wall assemblies.
- Currently no such installation guidelines exist for curtain walls and storefronts, although manufacturers do provide well developed fabrication and installation guides, they do not address provisions for providing continuity of the air/water/thermal barriers from fenestration to adjoining construction.

5.1.3 *Testing*

Testing aspects of a specification include mandating a level of testing for any project regardless of size whether specified by a design professional or not. Testing protocols are already well defined by AAMA/WDMA/CSA 101/I.S.2/A440 North American Fenestration Standard (NAFS) and ASTM so it is not the Research Teams intent to develop a series of new tests, but more so to mandate that some level of testing takes place. Testing should not only confirm a level of acceptable performance that can be expected by the consumer, but it should also provide the consumer with a better understanding that at some defined wind speed water leakage can be expected. Some of the mandatory testing, includes:

- Require pre-installation testing to demonstrate compliance with whatever design criteria for water penetration performance we determine is acceptable for fenestrations used in Florida. This is beyond what industry standards currently require.
- Require post-installation testing as a condition that must be met before local Inspectional Services Departments signs off on a project.

5.1.4 *Administration*

Administrative aspects of a specification include educating the consumer on how the industry standards, in particular AAMA/WDMA/CSA 101/I.S.2/A440 North American Fenestration Standard (NAFS), develops performance testing requirements and why testing does not take into consideration water penetration performance for design-level hurricane events. Administrative aspects are aimed at engaging the consumer who often does not know what they are buying (and what are its limitations). Some of the administrative concerns that consumers feel would be helpful for Florida installations, include:

- Generally, consumers want to be given more options and explanations of expected performance, especially with respect to what “hurricane performance” labels actually mean to them.
- Develop hurricane performance criteria that includes higher levels of water penetration resistance above the industry accepted performance levels currently established by AAMA/WDMA/CSA 101/I.S.2/A440 North American Fenestration Standard (NAFS).
- Review past “successful” installations that have survived past hurricane events and learn what we can from those installations and assemblies and use that information to enhance design criteria and add to the design features list.
- Require improved inspection protocols to consider fenestration installation and integration with the remainder of the building envelope.
- Require post completion testing. This is testing of building fenestrations one year or longer after the building is completed for new construction or for new fenestration installation to demonstrate continued satisfactory performance. This is something that is required by LEED for enhanced commissioning of building envelopes and could be required for fenestration performance alone.

- Develop guidelines for long-term maintenance of fenestration products including: :
    - Inspection and maintenance of fenestrations at regular intervals, such as every 5 years.
    - Painting wood-framed products to maintain their integrity, such as every 7-10 years.
    - Inspecting and repairing glazing seals on a regular interval, such as every 10 years.

6 CONCLUSIONS

The 2019 Workgroup report documented economic losses from water intrusion faced by high-rise residential homeowners in Florida. It revealed reasonably large water damage claims and patterns of water leaks associated with a minimal hurricane. The wind speeds in Hurricane Irma were well below design wind speeds in the Florida Building Code. Those losses suggest a much greater problem due to water leakage will occur if the South Florida were to be struck by a design-level hurricane.

This study discussed and made recommendations about the water-penetration resistance of fenestration assemblies only. There are many other building components that are also impacted by wind-driven rain. The Research Team recommends FBC support future research studies to evaluate water penetration resistance of other components of the building envelope system (as outlined above) during design-level hurricanes. The level of acceptance of Florida homeowners to experience some leakage in design-level hurricanes should be determined.

A prudent course of action for the Florida Building Condition would be to research the feasibility of achieving leak-proof building cladding systems and offering consumers better guidance on current water penetration resistance of existing fenestration assemblies at design-level hurricanes. While in today's climate a leak-proof façade under all conditions may be impossible to achieve, consideration of the testing methods for higher-performance products will inform a performance-based design methodology for water penetration resistance.

The efforts of the Florida Public Hurricane Loss Model have resulted in catastrophe models which can estimate the impact of water damage over a portfolio of buildings. Once the FPHLM model is properly calibrated it may be able to provide a first-cut estimate of potential economic loss and the extent of the problem..

The FBC can assist in improving the communication of the vulnerabilities that high-rise building may face in future design-level hurricanes FBC should support developing consumer information packages of best practice to reduce water intrusion during all phases of design and construction. In addition, the information provided herein may be used as a resource for future building code development.

The research team recommends the FBC consider working with FEMA Mitigation Assessment Teams and develop survey methods to collect and evaluate water penetration (leaks) data from high-rise residential buildings during future hurricanes. This will enable better assessment of whether and how widespread are the systemic water leak-related problems in our high-rise residential buildings at the design-level hurricane.

The Florida Building Commission is well-positioned to encourage on-going collaboration and discussion among the many parties that have an interest in building performance, not least of which are the Florida homeowners. The deliberations of the Research Advisory Group (manufacturers, building officials, engineers and homeowners) outside of the building code-writing forum itself, provided knowledge that is useful for making state-wide longer-term plans and setting the general direction. There are no simple solutions and the problem itself remains somewhat abstract until it is more clearly defined. Other recommendations include the following:.

- Recommendations for future research studies and Round Tables to ensure other aspects (design, installation, testing and administration) are addressed for the building cladding systems, joint sealant systems and waterproofing systems.
- The studies can be tackled serially via annual sponsored research or they can be done in parallel with two or three round tables at once.
- Continue augmenting and disseminating the lists of known enhanced design features that perform well to improve water penetration resistance of fenestration assemblies.
- Improve education materials available for consumers from the industry and other stakeholders, perhaps in collaboration with the Florida Building Commission (or other trusted source.)
- Develop hurricane performance criteria for water penetration resistance that exceeds current industry accepted performance levels established by AAMA/WDMA/CSA 101/I.S.2/A440 North American Fenestration Standard (NAFS).
- Review past “successful” installations that have survived hurricane events and learn what we can from those installations and assemblies and use that information to enhance design criteria and add to the design features list.
- Require improved inspection protocols to consider fenestration installation and integration with the remainder of the building envelope.
- Require testing both before and after construction completion to inform expected levels of water penetration resistance and how that relates to wind speed.
- Develop guidelines for long-term maintenance of fenestration products.
- Conduct full-scale in-situ and/or laboratory water penetration tests to establish the performance level criteria for water penetration resistance of building envelope systems,

REFERENCES

Baheru, T., Chowdhury, A. G., Bitsuamlak, G., Masters, F. J., & Tokay, A. (2014). Simulation of wind-driven rain associated with tropical storms and hurricanes using the 12-fan Wall of Wind. *Building and Environment, 76*, 18-29.

Blocken, B., & Carmeliet, J. (2004). A review of wind-driven rain research in building science. *Journal of Wind Wngineering and Industrial Aerodynamics, 92*, 1079-1130.

FEMA. (2013). *P-424: Chapter 2: Performance-Based Design.*

NAFS-2017. (2017). *North American Fenestraition Standard/Specification for windows, doors, and skylights.* AAMA/WDMA/CSA 101.

APPENDIX A: MEETING DISCUSSION POINTS SUMMARY (REFERS TO DETAILS IN THE MINUTES)

Table 3. Key Observations of Research Advisory Group

Description	Meeting #
Homeowners:	
• Shutters are beneficial for protecting the glass from wind-driven debris and for providing a second barrier to wind-driven rainwater. • Two methods for solving water penetration problems: 1) add sill dams around doors; 2) use knee walls. • Huge perception issue of owners: Windows rated to 200 mph should not leak at 75 mph. • Balcony drain: p-trap required increases ceiling depth and reduces views. • Poor installation of retrofitted hurricane windows a very common issue. • Drains and gutters are suggested to be installed in balconies. There is no need to install dams anymore. • “Lift and slide” doors require very specialized installation, are tough for retrofit and expensive. • Install and maintenance of “lift and slide” product are major issues.	M1
• No water leakage is acceptable. • Observed leakage only in retrofitted older buildings, related to poor construction. • Main requests are not regarding water ingress, only about impact. • Improper installation of retrofitted windows causes water leak issues. • Owners of high-end condos don’t understand why a premium operable window leaks.	M2
• Owners don’t expect to go through a Category 4 hurricane with no leaks but they expect no leaks from a tropical storm in a newer building or newly installed windows. • Laypersons believe their windows are not going to leak unless there’s a catastrophic event. No water is acceptable. A little is not acceptable. • Incorrect installation of impact windows. • 80-90% of failures and/or complaints are related to installation issues, forensic work is needed on these failures going forward to document the issues. • Waste of effort to go after change of standard before maintenance/ installation issues are addressed.	M3
• Address the installation and maintenance issues before going after higher standards. • Incorrect installation of impact windows is a major problem. Many of the workers, don't know what they're doing. • Consumers do not understand all the complicated stuff – they want simple: i.e. performance criteria like “waterproof up to 100 mph wind for 3 hrs.”. • Lawmakers don’t understand the performance criteria either. • e.g. Building department approved retrofit install of hurricane windows w/o paint or anything on installation.	M4

Description	Meeting #
Window Manufacturers	

• Homeowners need to have confirmed installations and the seals need to be kept in good condition with regular maintenance.
• Shutters require that someone is on-site to either install or activate them, while windows are passive.
• Trip hazard (ADA-compliancy) issues with increasing sill height as a mitigation strategy for doors.
• First priority: proper installation to ensure no water path around fenestration.
• Second priority: Improve the water-ingress ratings for fenestration products.
• "lift and slide" doors already supplied in new construction projects to avoid water drainage from below, but it is difficult to retrofit into existing bldgs.
• Water takes path of least resistance. A good building envelope should keep water out of the building.
• Summarized several reasons for water leakage issues :
    o 1) current industry test standard ASTM 1105 is too low,
    o 2) installation is problematic because of the labor pool,
    o 3) lack of installation standards to follow through on,
    o 4) building envelope design does not couple with fenestration,
    o 5) shutters must be waterproof as well, fatigue of metal and movement of shutters may cause water leakage,
    o 6) biggest problem: design levels in current building code not high enough to meet the needs and requirements of end users.
	M1

• Discrepancy exists in defining exactly is water penetration. • Customers need more options and explanations of expected performance. • There is need for higher psf criteria for both water and air. Standards need to be more aggressive (e.g., ACHA - hospital facility standards). • Products change by addressing issues at the standards level, which then trickle through to the codes.	M2
• Manufacturers try to assist with improving installation through worker training etc. • Manufacturers continually revisit and refine the design of fenestration products. • Manufacturers wish to participate in developing installation standards. • Consider an in-situ water testing program requirement as part of building envelope inspection. • NAFS-17 should be the starting point for discussion between owner and contractor to consider field testing. • AAMA502 and 503 also have some short form specifications. • "Owners" probably must accept that some water penetration through building envelope occurs around rough openings into the building interior. • E1105 – defines what a water leak is. Should homeowners consider a leak if water does not break an interior plane of the envelope? Or is it a leak when owners do not want their floors wet? • AAMA/WMDA/ as referenced A440 – 4 grades of windows for each operator type, an upward progression of testing performance. The grade is not a code requirement, all voluntary.	M3

Description	Meeting #
• TAS standards for structural loading prior to water testing in Miami Dade: design load without impact testing. • Constraint problem in general, ADA accessible = ½ in. step lift and slab door with underslab drainage.	
• To date Research Advisory Group has not discussed analytical data to support discussions towards fenestration and the problems fenestration has. • Lack of truly objective forensic data is troubling this project. • Structural silicone, most impact resistant products are already made with wet glazed silicone on glass. • FBC has several reference installation standards. • Looking at better enforcement of standards (installation practices) developed by UF is an option. • We do have performance classes in the North American fenestration standard. • There isn't a correlation between the percentage of the structural load and water intrusion in hurricane conditions. • Suggestion: Develop a one-page Consumer Guide explaining details of fenestration performance criteria – developed with input of fenestration manufacturers. • Suggestion: Conduct post-hurricane forensic assessment of actual buildings to identify correlation between the buildings' leak resistance and fenestration and envelope construction details. • Decouple water performance tests from structural load testing criteria . • Determine the minimum criteria to avoid a lot of issues and then there may be a maximum above which you get diminishing returns to have the water pressure that highly rated. • AW-class windows and curtain wall systems have more criteria beyond just increased test pressure (workability, thermal cycling, repetitive use etc.)	M4
Building Consultants / Engineers	
• Current building codes and industry practice not focused on preventing water intrusion in the aftermath of a hurricane. The focus is on structural performance and life safety. • Windows are rated based on design pressure through AAMA (American Architecture Manufacturers Association). Fenestration can be designed to meet very high pressures (e.g., >200 mph) but the corresponding debris-impact rating is harder to achieve (at >200 mph). • Problems with shutters: 1) storing or hiding shutters not easy in high-rise buildings and 2) the air and water barrier system may be breached. • "Lift and slide" door products that have better penetration resistance. • Lack of in-situ water intrusion testing in the South Florida construction industry. • Florida market mainly concerned with structural problems and less concerned with water leakage issues. • No requirements for field testing fenestration after installation. Field testing is voluntary and used when mandated by architects and builders on large high-rise condos etc. • Implement code requirements to flash openings and integrate the fenestration perimeter water barrier systems with wall assembly.	M1

Description	Meeting #
• Bridge communication gap between the homeowners and engineering/construction. (e.g. engineers talk in psf while homeowners talk in mph.)	
• NAFS/AAMA Standard 101 A440 /CSA WDMA (performance-based document) uses thresholds @ 15-20% design, - this is low water penetration resistance compared to the wind-driven rain associated with a hurricane. • Current standards do not provide an acceptable level of water penetration for hurricane performance. • FL rating system doesn't guarantee survivability of a product following a hurricane event. • Brittle glass is the weak link regarding wind-borne debris impact. Hurricane shutters can help ensure survivability of the systems. • Structural glazed silicone is a robust option to mitigate water intrusion. • Include water intrusion mitigation strategies from the start of design process. • Shutters don't affect wind testing but FIU study show they make a difference in how much water gets to the fenestration element. • Many insurance claims following H. Irma on building located where wind speeds around 60 mph were related to water intrusion. • Typically, threshold inspection for the structural connections of the fenestration elements, but not the water intrusion resistance.	M2
• For vast majority (of claims) no noticeable impact damage – mainly water intrusion issues. • Disconnect between owner and design professional communication. • NOA rated products should be good for any hurricane, but even best rated products may only perform well in ~Category 1 storm currently. • Majority of damage claims – were not product overwhelmed but related to installation or age.	M3
• Four categories for moving forward: design, installation, testing and administration. • Education and outreach to consumer needed for clarity on industry standards in particular. • Develop performance and testing requirements and discuss why the testing does not take into consideration water penetration for hurricane level events. • Education of the consumer under the design category is very important. Need to balance desired specifications versus ADA requirements. • Recommendation for using structural silicone is beyond glass retention – added benefit of increased water penetration resistance. • Pre-installation test and post-installation testing. • Goal: performance criteria that includes higher levels of water penetration resistance than is currently stipulated by industry standards • Recommendation: workforce or group to put together post-hurricane to assess performance specifically for water intrusion. Provide state support to FEMA • Document successful installations and building performance • Develop guidelines for long term maintenance of fenestration products (e.g. regular painting wood frame products, inspecting and repairing glazing seals on regular intervals, etc.	M4

Description	Meeting #
Building Officials	
• N/A	M1
• Most high-rise buildings are inspected by private providers. • Owners assume impact rating also means no water leakage. • Difficulty in separating poor workmanship from poorly designed products. • Threshold (building envelope) inspector generally associated with structural designer with focus on structure. Glazing installation many times is not as well enforced. • NOA product approvals say nothing about sealing. Sealing products should be specified on NOAs or product approvals and verified by the authority having jurisdiction. • There are known issues with maintenance of fenestrations.	M2
• Field testing and maintenance is most important. Verify installation and design. Maintenance protocols are also very important (e.g., specify mandatory re-caulking periods) • Performance testing concept not yet applied to water intrusion.	M3
• Many issues with fenestration - testing is 10% of the window with a 1.5 safety factor aside from installation. • No reason why Florida to use tropical depression criteria be as performance standard? • Issue is the standard, not current quality of manufactured products. • Are removable sill dams successful? • To a assure water intrusion resistance requires holistic design of the building envelope.	M4
Testing Organizations	
• N/A	M1
• Getting beyond the code and look at weather data (e.g., rain, offset on outside, curbs). • Would homeowners accept water leakage after being impacted by debris? or do they expect no water for high wind event as well as after impacted by debris? (DS) • Current testing that clients are requesting - start with code required performance. It's around safety. • Most owners expect lots of leakage (in serviceability conditions) but not necessarily damage.	M2
• N/A	M3
• Water intrusion very important from insurance standpoint. Windows does not have to see structural damage to have a breach.	M4
Insurance Companies	
• N/A	M1
• Every insurer has a different protocol for water ingress, there is wiggle room in how they handle the claims depending on photos, adjusters, etc. (i.e. some level of subjectivity). • 100+ insurers in FL and each have different filing requirements in different states.	M2
• Conflict between door performance and ADA accessibility compliance.	M3

Description	Meeting #
• FEMA MAT teams review damage but primarily look at residential structures, not high-rise buildings.	M4

APPENDIX B: MEETING #1 MINUTES – 21 FEBRUARY 2020

Project Background

The University of Florida, Engineering School of Sustainable Infrastructure and Environment (ESSIE) was retained by State of Florida's Florida Building Commission (Department of Business & Professional Regulation) to conduct research to study issues related to water intrusion through mid – to high-rise building envelope systems during hurricanes. The project Manager is Mr. Mo Madani (Mo.Madani@myfloridalicense.com).

This project is led by University of Florida's Dr. David O. Prevatt, Associate Professor of Civil Engineering, dprev@ce.ufl.edu. The project was initiated following a research study last year addressing the performance of tall buildings during Hurricane Irma that struck on 10 September 2019. Last year's report can be accessed from this link: https://www.dropbox.com/s/r6a0bse7mf4kouv/Prevatt-UF-Water%20Resistance%20WorkingGroup-%20FINAL%206-10-2019.pdf?dl=0

Meeting #1 (21 February 2020) Participants

#	First	Last	Abbrev.	Contact	Present
1	Michael	Louis	ML	MJLouis@sgh.com	Yes
2	Daniel	Smith	DJS	daniel.smith@venriskltd.com	Yes
3	Vince	Seijas	VS	Vince.Seijas@miamidade.gov	No
4	Peter	Iglesias	PI	piglesias@coralgables.com	No
5	Dave	Stammen	DS	David.Stammen@ul.com	Yes
6	Bonner	Bill	BB	Williamhbonner@bellsouth.net	Yes
7	Brad	Fevold	BF	bradfev@marvin.com	Yes
8	Greg	Galloway	GG	GregGalloway@ykkap.com	No
9	Greg	Mckenna	GM	Greg.McKenna@arconic.com	Yes
10	Lynn	Miller	LM	lmiller@pgtindustries.com	Yes
11	Dean	Ruark	DR	druark@pgtindustries.com	Yes
12	Matt	Waldren	MW	waldrenmc@Pella.com	Yes
13	James	Hill	JH	jhill@sibfl.net	No
14	Weil	Lam	WL	WLam@rdh.com	No
15	Michael	Horst	MH	MHorst@wje.com	No
16	Chris	Lipp	CL	CLipp@wje.com	Yes
17	Anne	Cope	AC	acope@ibhs.org	Yes
18	Eric	Stafford	ES	estafford@ibhs.org	Yes
19	Scott	Diffenderfer	SD	scottd@compass.com	Yes
20	Rick	Chitwood	RC	rickc@trumpgroup.com	Yes

21	John	Runkle	JR	John.Runkle@Intertek.com	No
22	Alan	Greenberg	AG	Alangee96@yahoo.com	Yes

Meeting #1 - Key Questions

- The FLORIDA BUILDING COMMISSION has jurisdiction for developing future resilient structures by choice of code provision and enforcement today. How far can/should they go?
- What are manufacturers to design wind resistant windows? Are there product developments planned or underway today?
- What's the economic cost of extensive leakage of water in a high rise building?
- What do condo owners expect? Can they continue living in units?
- What does city need to plan for?
- Is insurance coverage costs limited by higher performing windows?
- Where have leaks occurred during Hurricane Irma on a building? Were they extensive or minor?
- What building permitting issues occur during Irma?

Meeting #1 Minutes

Meeting #1 provided an excellent forum to introduce the varying perspectives of key stakeholders (industry, homeowners and researchers) regarding the issue of water intrusion during severe wind events. At the conclusion of meeting, these groups also provided suggestions for future research objectives of the project.

1. Project lead Dr. David Prevatt kicked off this meeting by introducing the project team, the primary goals and a preliminary study of high-rise building repair and inspection permits before and after Hurricane Irma (Figure 3).

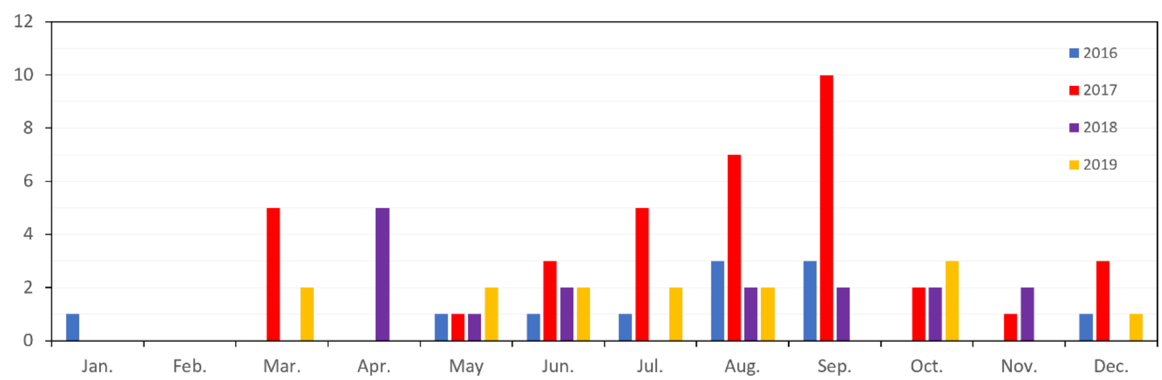


Figure 3. Number of high-rise buildings with water intrusion damage in Miami Beach, FL in the years before and after Hurricane Irma (2017)

2. Michael Louis (Senior Principal at SGH) represents the building envelope industry and led the discussion as a key team member for the project. ML notes that current codes and industry are not focused on preventing water intrusion in the aftermath of a hurricane,

instead the industry is focused only on structural performance and life safety. For example, industry may simulate the effects of debris and wind during a hurricane event via standard impact (e.g., 2x4 timber missile released by pressurized debris simulator) and load cycle testing (10,000 cycles under full design wind pressure) to evaluate the performance of glass and window frames. A successful test is recorded if the test specimen does not breach and glass stays within the window frame. In no instance of testing is the test specimen reusable after testing. Frames are severely dented and the glass is irreparably broken. The expectation is that fenestration will protect owners from debris (and keep broken glass in the frame) but is likely to require replacement post-event. ML emphasizes that per the current code provisions, industry testing aims primarily to preserve life safety. Water intrusion is not a high priority.

3. ML notes that windows are rated based on design pressure through AAMA (American Architecture Manufacturers Association). Fenestration can be designed to meet very high pressures (e.g., >200 mph) but the corresponding debris-impact rating is harder to achieve. There are examples of other applications (e.g., banks, etc.) where window products are designed to remain unbroken in extreme impact loading cases. For example, the ballistics industry has developed 6+ in glass for use in banks. This composite product is made of alternating sheets of tempered glass and a plastic interlayer to resist bullet penetration. A similar product may be able to survive in hurricanes but would require custom framing and carries substantially more weight than standard hurricane rated glass, at present.

4. Rick Chitwood (Senior VP of the Trump Group) describes his hurricane experience in Miami Beach. During hurricanes, water generally leaks from the glass sliding doors during wind-driven rain. RC notes that the sliding door products were made and installed perfectly, but the building standards have some issues. RC solves leakage issues himself, for example by replacing all the rubber seals, modifying the thresholds (water dam) seals and extending threshold heights to 6 in. This does present access issues as the step he creates is not ADA compliant, but it has been effective in addressing the water penetration issue. RC notes that sliding door sills should be required to have much deeper sills (or at least have that option) when designing for Florida weather. RC also notes that the building standards are not written to provide weather resistance for a significant weather event (neither for tropical storms or hurricanes) and that the standards that refer to hurricane-proof only relate to structural or breech performance not to water penetration resistance.

5. Alan Greenberg (Miami Beach homeowner for 10+ years) notes that in his previous home, windows and doors did not have water ingress issues because metal shutters were installed. Others without shutters did have water ingress damages. Where he lives now (farther inland, Williams Island), most residents prefer using sliding doors and installing barrier along the door to keep water out (as opposed to shutters). AG is considering shutters vs impact-rated windows and mentioned that sliding doors with shutters is a significantly cheaper option than impact-rated windows ($14k vs $35k respectively). The shutters are beneficial for protecting the glass from wind-driven debris and for providing a second barrier to wind-driven rainwater. AG notes that he wouldn't want extremely thick windows as this would obstruct the ocean views.

6. ML comments that shutters have been available in hurricane prone zones for many years, it can protect windows from impacted debris. However, he notes some problems for shutters: 1) storing or hiding shutters in an architecture design on a high-rise building is not easy and 2) the air and water barrier system may be breached because shutters need

to come into the wall for better appearance, but that may move the location for water entry into the building to the wall as opposed to the fenestration.

7. RC builds and owns high-rises in South Florida. RC notes that shutters are better for water ingress because water doesn't hit the window, but he has observed some issues with shutters. Even with shutters the fenestration is still subject to water ingress because 1) typical terraces in South Florida do not have a slope-to-drain allowing water to run off at the side of building and 2) water sometimes isn't able to drain with constant wind and therefore it gets pushed up the wall ~6" and into the sliding door threshold (i.e. above the bottom sill). RC proposes two methods to help solve building water penetration problems: 1) put metal or plastic around the bottom of all doors to keep water from coming through the bottom and/or 2) use knee walls. RC is planning to install his own water ingress mitigation system on his properties, and has a threshold strip that increases sill height (tripping hazard when not in "hurricane mode") and uses this in combination with a "water sock" on the inside. RC says there is a perception issue for owners of windows rated to 200 mph. The expectation is that they will provide full protection and functionality at those speeds, which leads to a very difficult proposition telling owners they will leak at 75 mph. RC also mentions that the problem w/ installing drains on balconies is that a p-trap is required which increases ceiling depth and reduces ocean views. ML notes that there is a drain product called corner drain that doesn't require install in middle of balcony and doesn't increase depth of balcony required.

8. Scott Diffenderfer (Homeowner, also works in real estate) lives in a 1980s high-rise and the original windows have not had any issues with water ingress. SD previously lived in a building with 1962 windows and there was no water leakage for his windows during typical Florida rainstorms, however his neighbor's hurricane windows had severe water leakage. SD points out that the hurricane windows were poorly installed (and this is a very common issue). SD also suggests that drains and gutters be installed in balconies (e.g., French drain). Water will go into the drainage system without impacting the units below. SD notes we do not need to install dams anymore.

9. Lynn Miller (PGT Consultant) provides some suggestions for addressing window leakage issues from the manufacturer's perspective. LM notes that installation and maintenance are both quite important. Homeowners need to have confirmed installations that ensure there is no path for water migration around the window during the installation and the seals need to be kept in good condition with regular maintenance. Regarding shutters, LM notes that while they offer protection, they do also require that someone is on-site to either install or activate the shutters. In comparison, windows are passive. Architectural design can also be used to alleviate some of the issues and reduce water ingress. LM also highlights the trip hazard issues with increasing sill height as a mitigation strategy for doors.

10. ML mentioned there is sliding glass doors that have better penetration resistance. The "lift and slide" product uses specialized hardware and allows door manufacturers to use better gaskets at the perimeter of doors which allow the door to fully engage against compressible gaskets instead of sliding against pile-style weather-stripping which provides a poor seal to water penetration. It is very sophisticated hardware and very expensive in the markets. There are not a lot of "lift and slide" glass doors in the market, although it would be easily adaptable to most current door designs. SD notes that "lift and slide" requires very specialized installation (tough for retrofit) and is very expensive. AG says "lift and slide" allows sliding glass door to lock down when event is coming against

compressible high-quality gaskets, much better performance (sliding wall systems use similar technology), however install and maintenance are major issues.

11. Dean Ruark (PGT Consultant) notes the first priority is proper installation to ensure no water path around fenestration. Second priority should be improving the water-ingress ratings for fenestration products. DR explained that the current test standard is static. Water nozzles apply a driven rain at steady pressure and builds up a water column. If we want to test using pressures equivalent to real hurricane pressure, we have to build a very tall water column and we need very high compression products to solve that issue.

12. Brad Fevold (Marvin Consultant) notes that some “lift and slide doors” bury part of sill so that water can be drained from below. This style of door has already been supplied in new construction projects, but it is difficult to retrofit. BF admitts there are lots of things that need to be balanced between products and challenges.

13. Chris Lipp (WJE Consultant) suggests there is a lack of in-situ water intrusion testing in the South Florida construction industry. In addition, the Florida market is mainly concerned with structural problems and less concerned with water leakage issues. For the Florida Building Code, there are no requirements for field testing fenestration after installation. Field testing is voluntary and is typically only used when mandated by architects and builders on large projects such as high-rise condos.

14. Matt Waldren (Pella Corporation) notes that water will always take the path of least resistance. A good building envelope should keep water out of the building. People have to make sure water flows down off the buildings as rapidly as possible because if there is any sealant break, the water will go in.

15. ML mentions that the overwhelming problem with leakage in buildings is not that a fenestration product fails, but oftentimes, the products were not tied in well to the barrier within the wall system. The industry only defines performance of fenestration and does not define the performance of an opening system, so manufacturers of windows and curtain walls can’t dictate how the fenestration goes into a wall opening such that it doesn’t cause leakage after installation. ML suggested we can make changes and implement requirements to flash openings and integrate the perimeter conditions of a fenestration with a wall assembly in the codes.

16. CL suggested we should bridge the gap between the homeowner group and engineering group. For example engineers always talk in pressure and homeowners only understand mph.

17. Bonner Bill (Worked for building envelope industry for 38) summarized several reasons for water leakage issues: 1) the current industry test standard ASTM 1105 is too low, 2) installation is always problematic because of the labor pool, 3) there is a lack of installation standards to follow through on, 4) building envelope design does not address coupling with fenestration, 5) the shutters must be waterproof as well, fatigue of metal and movement of shutters may cause water leakage, 6) the biggest problem is that design levels in the current building code are not high enough to meet the needs and requirements of end users.

18. The group was interested in hearing about real data on rainfall intensity and volumes of water that may flow down a wall during a hurricane event and how that information may help to inform the direction we need to move in Florida. Dr. Prevatt notes that in his studies with the University of Florida, he has assembled much of this data from notable hurricanes and he will present some of these findings to the group at the next meeting.

19. The group was interested in discussing what best practices would look like as part of this study.

APPENDIX C: MEETING #2 MINUTES – 20 APRIL 2020

Project Background

The University of Florida, Engineering School of Sustainable Infrastructure and Environment (ESSIE) was retained by State of Florida's Florida Building Commission (Department of Business & Professional Regulation) to conduct research to study issues related to water intrusion through mid – to high-rise building envelope systems during hurricanes. The project Manager is Mr. Mo Madani (Mo.Madani@myfloridalicense.com).

This project is being led by Dr. David O. Prevatt, Associate Professor of Civil Engineering, dprev@ce.ufl.edu. The project was initiated following a research study last year addressing the performance of tall buildings during Hurricane Irma that struck on 10 September 2019. Last year's report can be accessed from this link: https://www.dropbox.com/s/r6a0bse7mf4kouv/Prevatt-UF-Water%20Resistance%20WorkingGroup-%20FINAL%206-10-2019.pdf?dl=0

Meeting #2 (21 April 2020) Participants

#	First	Last	Abbrev.	Contact	Present
1	Michael	Louis	ML	MJLouis@sgh.com	Yes
2	Daniel	Smith	DJS	daniel.smith@venriskltd.com	Yes
3	Vince	Seijas	VS	Vince.Seijas@miamidade.gov	Yes
4	Peter	Iglesias	PI	piglesias@coralgables.com	No
5	Dave	Stammen	DS	David.Stammen@ul.com	Yes
6	Bonner	Bill	BB	Williamhbonner@bellsouth.net	Yes
7	Brad	Fevold	BF	bradfev@marvin.com	Yes
8	Greg	Galloway	GG	GregGalloway@ykkap.com	Yes
9	Greg	Mckenna	GM	Greg.McKenna@arconic.com	Yes
10	Lynn	Miller	LM	lmiller@pgtindustries.com	Yes
11	Dean	Ruark	DR	druark@pgtindustries.com	Yes
12	Matt	Waldren	MW	waldrenmc@Pella.com	Yes
13	Michael	Horst	MH	MHorst@wje.com	Yes
14	Chris	Lipp	CL	CLipp@wje.com	No
15	Anne	Cope	AC	acope@ibhs.org	Yes
16	Eric	Stafford	ES	estafford@ibhs.org	Yes
17	Scott	Diffenderfer	SD	scottd@compass.com	Yes
18	Rick	Chitwood	RC	rickc@trumpgroup.com	Yes

19	John	Runkle	JR	John.Runkle@Intertek.com	Yes
20	Alan	Greenberg	AG	Alangee96@yahoo.com	No
21	Scott	Warner	SW	Scott.warner@intertek.com	Yes

Meeting #2 Minutes

Meeting #1 provided an excellent forum to introduce the varying perspectives of key stakeholders (industry, homeowners and researchers) regarding the issue of water intrusion during severe wind events. At the conclusion of meeting, these groups also provided suggestions for future research objectives of the project. Meeting #2 continued this discussion, emphasizing the homeowner perspective and mitigation options for water ingress. At the start of Meeting #2, minutes from Meeting #1 were confirmed by the group.

<u>Topic 1. State of practice for building envelope consultants</u>

- Building envelope consultant Michael Lewis is going to first start off with a state of practice in in the building envelope consulting world as it relates specifically to high rise buildings in the hurricane prone areas. Okay. Here we're looking for.

<u>Topic 2. Successful approaches by building envelope consultants to mitigate water leakage in FL</u>

- Topic 2 discussion led by Michael Louis (ML). Consultants look at FBC (2017) and comply with the code (i.e. Ch. 16 - Structural Design and HVHZ missile impact). There is also AAMA Standard 101 A440 /CSA WDMA (performance-based document). This standard uses thresholds @ 15-20% design, which are not near acceptable level of water penetration because under most "normal" (i.e. non-hurricane) conditions these thresholds will work.
- There is a rating system in FL for products that meet or comply with impact resistant requirements (i.e. FBC) but it doesn't guarantee survivability of a product. Also, water penetration resistance requirements are low. Regarding impact, glass is the weak link. It will break if impacted. However, Wind screens and hurricane shades can help ensure survivability.
- Mike Horst (MH): structural glazed silicone can be robust for water intrusion mitigation. Window and door operability is a key consideration when considering mitigation options. The system is designed for what you can accommodate, e.g., raise back leg height or increasing the gasket. Additional water intrusion mitigation needs to be included from the beginning in the design process.
- John Runkle (JR): design criteria for extra-normal conditions is not typical, its above and beyond. From Michael and Irma - storm surge - not going to eliminate pressures but cuts down on the water flow. The band of actual hurricane force winds is really small, in most areas we are dealing with tropical storm winds. JR suggests getting outside the code and looking at weather data (e.g., The rains, Offset on outside, Curbs).
- MH: shutters don't affect wind testing but FIU study suggests they make a difference in how much water gets to the fenestration element.

- Greg McKenna (GM): standard product testing is done to qualify the product for general marketplace. Testing has been done and the lowest performing products not suited for high-rise buildings (8-10 lbs test range). Structural silicone systems are 15 psf and higher. Unitized structurally glassed system is 25 psf (AAMA 501.1). What are homeowners accepting as allowable water leakage? Nothing? Or is it cumulative of less than 15 ml (on the sill), etc.? Part of the issue is that there is a discrepancy in regards to what exactly water penetration is.

<u>Topic 3. Did any homeowner units experience water leaks and what were the consequence?</u>

- Scott Diffenderer (SD): suggests that no water leakage is acceptable. So many buildings don't leak, in his experience as a realtor, doesn't necessarily see a need for changing the standards. Seems to only see issues in retrofitted older buildings. Main experience is that issues are related to poor construction. As realtor, SD does not hear any requests regarding water ingress, only about impact. SD notes that improper installation of retrofitted impact windows causes water intrusion issues. Often, the (wealthy) owners aren't home during hurricane events.
- Rick Chitwood (RC): refers to the discussion from Meeting #1, has observed water 10-12 ft away inside the condo from the sliding door after hurricane events. Suggests that owners of high-end condos don't understand why a premium operable window leaks.
- MH: lots of insurance claims for newer buildings in Irma with wind speeds in the order of 60 mph related to water intrusion.
- Dave Stammen (DS): would homeowners accept water leakage after being impacted by debris, or do they expect no water for high wind event as well as after impacted by debris?
- Vince Seijas (VS): most high-rise buildings are inspected by private providers, but being part of the envelope, the threshold inspector should be inspecting the fenestrations. In general, everyone assumes impact rating also means that no water is getting in. The difficulty is separating poor workmanship from bad products.
- MH typically sees threshold inspection for the structural connections of the fenestration elements, but not the water intrusion resistance.
- VS: threshold inspector is generally associated by the structural designer and ensures high rises are built in structural compliance with the approved plans. They verify post-tension cables and all structural elements including: welds, bars, concrete, etc. The focus is structure and the glazing many times falls by the wayside or is not as well enforced. Then the other inspectors that come to verify installation assume the glazing was verified at the structural installation, and so therefore it is often missed. Then you have the human factor. Did the installer use latex caulking or silicon?

<u>Topic 4. Are owners fully aware of potential liability risks from wind and water leaks?</u>

- David Prevatt (DOP): Can we explain the details of the insurance question? i.e. that leakage must be caused by wind-induced structural damage. Without structural damage there is generally no coverage for water damage?
- Anne Cope (AC): every insurer has a different protocol for water ingress, there is wiggle room in how they handle the claims depending on photos, adjusters, etc. (i.e. some level

of subjectivity). There are 100+ insurers in FL and most have different filing requirements in different states. What do we hope to learn from this research? Is there a better demonstrative test that can be conducted in an academic setting? JR suggests that engineers are the problem, there is no consistency in how the work is scoped.

- VS: what is specified? NOA product approvals only speak to the structural installation nothing about sealing, What ASTM is used or specified to install bucks to structure and fenestration to buck? Then there are issues with maintenance of these fenestrations as well. How often are openings re-caulked and with what product? Need to caulk between structure and buck and at flange of fenestration to the buck. Also need to seal the buck and structure with a waterproofing product and again flange to buck seal/caulk. Latex caulk is not as flexible or durable as a silicon or acrylic. These products should be specified on NOAs or product approvals and verified by the authority having jurisdiction.
- DOP: it is highly likely that windows will leak in a design level event. At present there is no information to say how much (volume? rate?) such leakage will occur (water intrusion = external wind-driven rain + building runoff contribution). If we don't know the answer, how do we get it?
- DOP: will homeowners expect the structural framing of a window will survive up to design level winds? Design-level hurricane performance criteria could allow controllable level of leakage perhaps with some structural damage to framing.

<u>Topic 5. Is sufficient knowledge available on magnitude/duration for WDR on high-rise surfaces?</u>

- JR: discussion on current testing that clients are requesting. They start with code required performance. It's around safety. Argues that most owners expect to mop up a little water after a hurricane, lots of leakage (in serviceability conditions) but not necessarily damage.
- Bill Bonner (BB): has worked with engineers who use in-place standard. Regarding high rises, the dollar drives the projects. Code allows modeling in a wind tunnel, which reduces the design pressure. AAMA sets the testing standard, which is not sufficient. Taller buildings over 40 stories have higher wind loads and therefore higher design pressures. For construction, composition of the skin is important. A barrier wall is the best approach, it prevents air and water from penetrating the skin. Recessed window and door openings - products allowed to be there. On an operable basis, the locking mechanism sash or rolling mechanism or drop down lift and slide. What drives projects with lower expectation, is the code itself. The code evolution is moving in the right direction. Need to engage the customer (i.e. owners) who often don't know what they are buying (and what its limitations are). Suggests that customers need to be given more options and explanations of expected performance. Suggests also that there needs to be a higher psf criteria for both water and air. Standards need to be more aggressive (e.g., ACHA - hospital facility standards).
- Lynn Miller (LM): Suggests that products change by addressing issues at the standards level, which then trickle through to the codes.

APPENDIX D: MEETING #3 MINUTES – 11 JUNE 2020

Project Background

The University of Florida, Engineering School of Sustainable Infrastructure and Environment (ESSIE) was retained by State of Florida's Florida Building Commission (Department of Business & Professional Regulation) to conduct research to study issues related to water intrusion through mid – to high-rise building envelope systems during hurricanes. The project Manager is Mr. Mo Madani (Mo.Madani@myfloridalicense.com).

This project is being led by Dr. David O. Prevatt, Associate Professor of Civil Engineering, dprev@ce.ufl.edu. The project was initiated following a research study last year addressing the performance of tall buildings during Hurricane Irma that struck on 10 September 2019. Last year's report can be accessed from this link: https://www.dropbox.com/s/r6a0bse7mf4kouv/Prevatt-UF-Water%20Resistance%20WorkingGroup-%20FINAL%206-10-2019.pdf?dl=0

Meeting #3 Participants

#	First	Last	Abbrev.	Contact	Present
1	Michael	Louis	ML	MJLouis@sgh.com	No
2	Daniel	Smith	DJS	daniel.smith@venriskltd.com	Yes
3	Vince	Seijas	VS	Vince.Seijas@miamidade.gov	Yes
4	Peter	Iglesias	PI	piglesias@coralgables.com	No
5	Dave	Stammen	DS	David.Stammen@ul.com	No
6	Bonner	Bill	BB	Williamhbonner@bellsouth.net	No
7	Brad	Fevold	BF	bradfev@marvin.com	Yes
8	Greg	Galloway	GG	GregGalloway@ykkap.com	No
9	Greg	Mckenna	GM	Greg.McKenna@arconic.com	Yes
10	Lynn	Miller	LM	lmiller@pgtindustries.com	Yes
11	Dean	Ruark	DR	druark@pgtindustries.com	Yes
12	Matt	Waldren	MW	waldrenmc@Pella.com	Yes
13	Michael	Horst	MH	MHorst@wje.com	No
14	Chris	Lipp	CL	CLipp@wje.com	Yes
15	Anne	Cope	AC	acope@ibhs.org	Yes

16	Eric	Stafford	ES	estafford@ibhs.org	Yes
17	Scott	Diffenderfer	SD	scottd@compass.com	Yes
18	Rick	Chitwood	RC	rickc@trumpgroup.com	No
19	John	Runkle	JR	John.Runkle@Intertek.com	No
20	Alan	Greenberg	AG	Alangee96@yahoo.com	No
21	Scott	Warner	SW	Scott.warner@intertek.com	No

Meeting #3 Minutes

The focus of Meeting #3 was on testing and perspectives from fenestration manufacturers. A significant portion of the discussion was dedicated to reviewing the document prepared by the manufacturer's summarizing their views on the water intrusion issue and potential approaches to improve future performance. In addition, following the meeting a google spreadsheet was circulated to the group listing potential mitigation options and their pros/cons. That sheet is available at the following link: https://bit.ly/ufWIND-water01

Topic 1 - Discussion of manufacturer perspective document led by Brad Fevold (BF)

- Want to continue with a broad brush perspective, including fenestration but also the building envelope in general (i.e. not just about the windows)
- Installation issues are a key part of the problem
- Concern by a number of folks that install practices need to be improved, homeowner experiences suggest install issues are a problem
- Probably an opportunity to do some field testing and build upon best practices
- SD: Suggests that 80-90% of failures and/or complaints are related to installation issues, forensic work is needed on these failures going forward to document the issues. May be a waste of effort to go after changing standards before maintenance/installation issues are addressed
- Although installation issues are not directly the fault of manufacturers, they still try to assist and take ownership of that process (e.g., via training, etc.).
- When complaints/issues are identified in the field, manufacturers continually revisit and refine the design of fenestration products
- Manufacturers in general indicate they wish to participate in developing installation standards
- AG: Notes that he has heard of several instances where impact windows were not installed correctly (comment added per discussion in Meeting #4).

Topic 2 - Field testing

- BF: Suggests Florida should consider a program that would include a water testing program as part of the building envelope inspection. If there's a water intrusion test process, you will uncover some of the issues in these buildings during hurricanes (e.g., maybe the flashing is not done properly)
- DOP: Wondering where does the homeowner or the client start in figuring out what tests are appropriate for their building? Maybe a flow chart that would help a client? There are several methods and standards so how does a client, homeowner or builder who wishes to build up a high rise building know where to start?
- BF: NAFS-17 should be the starting point for discussion between owner and contractor to consider field testing. That's just focusing on fenestration I suspect there would be other standards that would be out there that could help focus on the building envelope.
- LM: AAMA502 and 503 also have some short form specifications. So that could be a starting point between a homeowner and a contractor to take a look at how they're going to approach field testing. But that does have to be negotiated early on in the building process or it becomes very difficult.
- VS: field testing and maintenance is probably the most important thing we can do going forward, verify the installation and design. Maintenance protocols are also very important (e.g., re-caulking). If you don't maintain gaskets and the material, it’s not going to perform when you need it. The same thing with backup generators. If you're not exercising the equipment properly. It isn't going to function when you need it.
- BF: We've talked a lot about homeowner expectation and whether it's zero water or some level of water that pools up on the floor or sill because of the intense storm and it seems to be the former. There’s probably going to have to be some acceptance that water penetration into the whole building envelope will find its way to the fenestration rough openings and into the building interior.
- Comparison was made to car owners – they do not expect a car will have no damage in a hail event but there’s insurance to cover it.
- SD: Suggests that no one expects to go through a Category 4 hurricane with no leaks. But you do expect a tropical storm and a newer building or newly installed windows to not leak. SD is in a 40 year old building and had a massive storm coming from the north (felt like house was in a car wash) with 40 year old windows and didn't have one single leak. But, in contrast SD knows others, with brand new windows that have a leak when it rains during a typical FL 30 mph thunderstorm.
- MW: E1105 – defines what a water leak is. What do homeowners consider a leak? If water does not break an interior plane of the envelope? Or owners do not want their floors wet?
- Water on floor or in wall cavity is bad (all agree), question is where did it come from? From product design, water system can be managed but we need forensic study to determine causes.

<u>Topic 3 – Proposed next steps</u>

- Can the Florida Building Commission view fenestration performance in three categories:
    1) Normal condition (serviceability) – current methods

2) At/near design wind level – hurricane wind speeds and extreme wind-driven rain

3) Post-event performance – following a design-level hurricane

- GM: AAMA/WMDA as referenced A440 – 4 grades of windows for each operator type, an upward progression of testing performance. Highest grade goes thru serviceability testing use and abuse, environmental and serviceability testing. The grade is not a code requirement, all voluntary.
- SD: From owner perspective we need to consider that laypersons think their windows are not going to leak unless there's a catastrophic event. No water is acceptable. A little is not acceptable.
- Current design philosophy of the building code is life safety. Should there be shift to life safety and minimized economic losses? Originally life safety only, but what does this mean for Florida's high rise buildings?
- LM: TAS standards for structural loading prior to water testing in Miami Dade: design load without impact testing.
- All: What does the team want to see for post event-testing? Will it involve understanding the performance of a fenestration after a significant design level event or does it involve field testing that certifies acceptable in-service performance and continued use?
- CL: After the storm from hurricane damage claims, the vast majority have no noticeable impact damage but do have water intrusion issues. Disconnect between owner and design professionals. NOA rated product should be good for any hurricane, but even best rated product may be a ~Category 1 storm currently.
- CL: Majority of damage claims – not the product overwhelmed but more related to installation or age. Do we underestimate the effects of age?
- All: What % of jobs getting field testing on mockup unit and also through the structure. True performance of product and install?
- SD: layperson sees the installation, it's a waste of money to strengthen standards if installs are improper.
- VS: Performance testing not a foreign concept to building codes, e.g., energy testing. The concept is out there just not yet applied to water intrusion. Precedent set with blower door test – same logic.
- All: Discussion regarding code-plus: bumped up requirements for all parts of the building. Chapters 6 and 17 of IRC and IBC respectively. Setting a minimum performance grade for the window. AAMA 101 – allows a higher design pressure that exceeds the performance grade. Ties in the water resistance of PG of 70 psf.
- ES: Conflict between door performance and ADA accessibility compliance. Now, in S. Florida with highest design pressure, cannot meet current code compliance water test.
- LM: constraint problem in general, ADA accessible = ½ in step lift and slab door with underslab drainage.
- All: Codes and requirement do not currently specify what is required in field testing (easy cost saving).

APPENDIX E: MEETING #4 MINUTES – 9 JULY 2020

Project Background

The University of Florida, Engineering School of Sustainable Infrastructure and Environment (ESSIE) was retained by State of Florida's Florida Building Commission (Department of Business & Professional Regulation) to conduct research to study issues related to water intrusion through mid – to high-rise building envelope systems during hurricanes. The project Manager is Mr. Mo Madani (Mo.Madani@myfloridalicense.com).

This project is being led by Dr. David O. Prevatt, Associate Professor of Civil Engineering, dprev@ce.ufl.edu. The project was initiated following a research study last year addressing the performance of tall buildings during Hurricane Irma that struck on 10 September 2019. Last year's report can be accessed from this link:
https://www.dropbox.com/s/r6a0bse7mf4kouv/Prevatt-UF-Water%20Resistance%20WorkingGroup-%20FINAL%206-10-2019.pdf?dl=0

Meeting #4 Participants

#	First	Last	Abbrev.	Contact	Present
1	Michael	Louis	ML	MJLouis@sgh.com	Yes
2	Daniel	Smith	DJS	daniel.smith@venriskltd.com	Yes
3	Vince	Seijas	VS	Vince.Seijas@miamidade.gov	Yes
4	Peter	Iglesias	PI	piglesias@coralgables.com	Yes
5	Dave	Stammen	DS	David.Stammen@ul.com	No
6	Bonner	Bill	BB	Williamhbonner@bellsouth.net	No
7	Brad	Fevold	BF	bradfev@marvin.com	Yes
8	Greg	Galloway	GG	GregGalloway@ykkap.com	Yes
9	Greg	Mckenna	GM	Greg.McKenna@arconic.com	Yes
10	Lynn	Miller	LM	lmiller@pgtindustries.com	Yes
11	Dean	Ruark	DR	druark@pgtindustries.com	No
12	Matt	Waldren	MW	waldrenmc@Pella.com	No
13	Michael	Horst	MH	MHorst@wje.com	Yes
14	Chris	Lipp	CL	CLipp@wje.com	Yes
15	Anne	Cope	AC	acope@ibhs.org	Yes
16	Eric	Stafford	ES	estafford@ibhs.org	Yes

17	Scott	Diffenderfer	SD	scottd@compass.com	Yes
18	Rick	Chitwood	RC	rickc@trumpgroup.com	No
19	John	Runkle	JR	John.Runkle@Intertek.com	Yes
20	Alan	Greenberg	AG	Alangee96@yahoo.com	Yes
21	Scott	Warner	SW	Scott.warner@intertek.com	No
22	Joe	Haden	JH	JAHayden@pella.com	Yes

Meeting #4 Minutes

The focus of Meeting #4 was aimed at developing a desired list of water intrusion specifications. In addition, corrections to the minutes for Meeting #3 the final draft report presented to FBC were discussed. A full recording of the meeting is provided at the link below:

https://ufl.zoom.us/rec/play/v8V4JOH9-DM3HdDAtQSDA_B_W9S4Lvms1XRIr6dZz0exByQLNFH1ZLcSYetLOrlnby8YDMCaQVWmoyOo?autoplay=true

Topic 1 - Meeting #3 Minute Corrections

- SD not manufacturers made comment re: 80-90% of failures and/or complaints are related to installation issues and comment that it would be difficult or was a waste of effort to go after changing standards before we addressed the installation and maintenance issues that are probably leading to the great many leaks that were taking place in Hurricane Irma and others. This comment wasn’t captured in the minutes.
- LM: The overload testing is not done prior to the water testing in the Miami Dade, needs updated in minutes.
- AG: Two friends have had the impact windows, they were not put in correctly. Many of the workers, don't know what they're doing. That's the major problem, that the windows are not put in the right way.

Topic 2 – Final Draft Report Review

- BF: Suggest there has been bias in the project discussions towards fenestration and the problems fenestration has and to date there hasn’t been analytical data to support that.
- DOP: Project is aimed at capturing those opinions, even if currently unsubstantiated (informs future research aims). Important to get those in writing.
- PI: As a former building official, installation certainly is an important issue and should be done correctly, but fenestration has a lot of issues and testing is 10% of the window with a 1.5 safety factor. Looking at sliding glass doors, they're going to leak in a tropical

storm. There are a lot of technical issues that have not been addressed that, aside from installation, are a huge issue. The water intrusion issue is not simply installation.

- JR: Water intrusion very important from insurance standpoint. May not have had structural damage to have a breach.
- PI: Certainly a hurricane is probably a very high performance standard, but should the criteria be a tropical depression (effectively the current)?
- JH: Section 1.1 of the report, it's troubling this project has advanced without truly objective forensic data. There's much we don't know about this and we've proceeded on this path based largely on anecdotal reports, not the root cause analysis.
- PI: I think manufacturers make products that meet the current design and that's not a defective product as far as I'm concerned. Issue is the standard.

Topic 3. Desired Specification Discussion led by Michael Louis

- ML: Four categories: design, installation, testing and administration. Also need to educate the consumer about industry standards in particular. Need to develop the performance and testing requirements and discuss why the testing does not take into consideration water penetration for hurricane level events. Education of the consumer under the design category is something that's very important. Also have to weigh desired specifications versus ADA requirements.
- LM: Re: structural silicone, most impact resistant products are already made with wet glazed silicone on glass.
- ML: Reason for using it is more for retention of the glass. It has the added benefit of water penetration resistance.
- LM: Most of the things mentioned, focused on the fenestration. Need to also look at other aspects (e.g., slab offsets) on designing some of these balcony areas to mitigate water before it even gets to the fenestration product. Important to look at the issue holistically.
- PI: There was a manufacturer providing removable dams in Miami to and trying to sell those. Not sure how successful they were.
- BF: If you look in the building code in Florida, they already do reference several installation standards.
- LM: I know for a fact that those standards were developed with physical testing samples and testing was done at the University of Florida to develop those standards. They are good installation practices but not necessarily done on every installation. Maybe looking at better enforcement is an option.
- ML: On to testing. Require in the codes pre installation testing to demonstrate compliance with the design criteria? Then you know what products are actually rated for. A lot of design professionals and architects do require that sort of testing, particularly on high rise buildings but not on smaller mid- or low-rise buildings. Suggests pre-installation test and post-installation testing. LEED requires review of the entire assembly 12 months after building has been occupied, includes façade, mechanical systems, etc. after the fact and makes sure they're still performing to the level needed.
- PI: Water intrusion requires holistic design of the building.

- ML: Now administration. We've heard over and over again that would like to have performance criteria that includes higher levels of water penetration resistance than industry standards currently provide.
- BF: That's what we drafted for the North American fenestration standard. We do have performance classes in there. Three that are tested at 15% of design pressure and another class called a W class tested at 20%, so we do have those products.
- GG: In general, there isn't necessarily a correlation between the percentage of the structural load and water intrusion in hurricane conditions. Does feel that if you've established a floor of 12 to 15 psf, you eliminate a lot of the leakage.
- SD: A consumer wants to know: “this will be waterproof up to 100 miles an hour wind for three hours”. All this other stuff talked about is completely not understandable to a layperson. Not expecting window to survive a Hurricane Andrew without a drop of water but when we have a tropical depression with gusts of 40 mph, windows shouldn’t leak. Lawmakers don’t understand the performance criteria either.
- BF: Fenestration group can discuss offline and develop a one page cheat sheet that would help provide a little bit of clarity re: performance criteria currently.
- ML: One of the better administrative items from past meetings was review of past successful installations that have survived past hurricane events to learn what we can from those installations and assemblies and use that information to inform design criteria. Suggests a workforce or group gets put together post-hurricane to assess performance specifically for water intrusion.
- BF: Agrees, finding the correlation between buildings that perform against buildings that don't perform is very important and would help guide the group.
- ES: FEMA MAT teams review damage but primarily look residential structures.
- ML: Another thing discussed in past meetings was developing guidelines for long term maintenance of fenestration products and some of those guidelines that we talked about were regular inspection and maintenance (e.g., every 3-5 years). Could include painting wood frame products, inspecting and repairing glazing seals on regular intervals, etc.
- SD: As president on board of his building is troubled that he walked around the building (Miami Beach) and noticed somebody had installed hurricane windows without paint or anything on the installation and the building department approved it and signed off on it.

<u>Topic 4 – Review of Greg Galloway Email</u>

- GG: Didn’t attend the June 26 meeting but did review the presentations and listen to the recording. Suggests decoupling water performance from structural. In the early 2000s, water ratings on residential windows we manufactured were around 5-6 psf and every time there was anything above a tropical storm received phone calls that there was water leakage. In last 12 years, with an internal minimum spec of 12 psf on commercial systems, don't get the phone calls after hurricanes. Disagrees that for hurricane impact, you need to tie the water performance to the structural. Suggests there is a minimum that will avoid a lot of issues and then there may be a maximum above which you get diminishing returns to have the water pressure that highly rated.

- DOP: Lopez's PhD dissertation done with Masters is the latest work on associations between the wind pressure and the actual water intensity rates. Will try to include some of this work in the report.
- GM: To build on what GG said, our company makes AW class windows, as well as curtain wall and it's not just the difference between 15% and 20% for an AW. There's a lot more to the testing on that type of product. Requires an initial water test at 20%, then you have to operate the window and hardware 2000 times and conduct a "use and abuse" test to simulate the window being open and being buffeted by the wind. Then an additional 2000 cycles on the vent and hardware followed by thermal cycling to simulate years of being exposed to extreme weather hot and cold. Then full design load test pressure and then must meet air and water again.

APPENDIX F: MEETING #5 MINUTES – 17 JULY 2020

Project Background

The University of Florida, Engineering School of Sustainable Infrastructure and Environment (ESSIE) was retained by State of Florida's Florida Building Commission (Department of Business & Professional Regulation) to conduct research to study issues related to water intrusion through mid – to high-rise building envelope systems during hurricanes. The project Manager is Mr. Mo Madani (Mo.Madani@myfloridalicense.com).

This project is being led by Dr. David O. Prevatt, Associate Professor of Civil Engineering, dprev@ce.ufl.edu. The project was initiated following a research study last year addressing the performance of tall buildings during Hurricane Irma that struck on 10 September 2019.

Meeting #5 Participants

#	First	Last	Abbrev.	Contact	Present
1	Michael	Louis	ML	MJLouis@sgh.com	Yes
2	Daniel	Smith	DJS	daniel.smith@venriskltd.com	Yes
3	Vince	Seijas	VS	Vince.Seijas@miamidade.gov	Yes
4	Peter	Iglesias	PI	piglesias@coralgables.com	Yes
5	Dave	Stammen	DS	David.Stammen@ul.com	No
6	Bonner	Bill	BB	Williamhbonner@bellsouth.net	No
7	Brad	Fevold	BF	bradfev@marvin.com	Yes
8	Greg	Galloway	GG	GregGalloway@ykkap.com	Yes
9	Greg	Mckenna	GM	Greg.McKenna@arconic.com	Yes
10	Lynn	Miller	LM	lmiller@pgtindustries.com	Yes
11	Dean	Ruark	DR	druark@pgtindustries.com	No
12	Matt	Waldren	MW	waldrenmc@Pella.com	Yes
13	Michael	Horst	MH	MHorst@wje.com	No
14	Chris	Lipp	CL	CLipp@wje.com	Yes
15	Anne	Cope	AC	acope@ibhs.org	Yes
16	Eric	Stafford	ES	estafford@ibhs.org	Yes
17	Scott	Diffenderfer	SD	scottd@compass.com	Yes
18	Rick	Chitwood	RC	rickc@trumpgroup.com	No
19	John	Runkle	JR	John.Runkle@Intertek.com	Yes

20	Alan	Greenberg	AG	Alangee96@yahoo.com	Yes
21	Scott	Warner	SW	Scott.warner@intertek.com	No
22	Joe	Haden	JH	JAHayden@pella.com	Yes
23	Steve	Camposano	SC		Yes
24	Jim	Shock	JS		Yes

Meeting #5 Minutes

The focus of Meeting #5 was aimed at reviewing the final report to be presented to FBC for this project. A full recording of the meeting is provided at the link below:

https://ufl.zoom.us/rec/share/2e1FE6zh6EBIQaPPxWr8ZP4ENZnrX6a8gSMY_fNbxEgQF1xRbk64XBG8tX9uuLqI

Topic 1 - Meeting #4 Minute Corrections

- Changes from Greg Galloway, no other suggested changes were requested by the group.

Topic 2 – Review Final Report Submission

Principle Investigator Dr. David Prevatt reviewed updated final report draft with the advisory group. Feedback from the group included the following:

- SC: Products that need to be deployed manually are not permitted on high-rise buildings, accordion or rolling shutters only. With accordion at perimeter, WDR doesn't reach the sliding glass doors (+-140 PSF). Designed for partially enclosed balconies.
- PI: Suggests changing cladding is not code compliant even though loads are reduced.
- SC: Agrees with PI, his company works with wind tunnel testing companies to check loads with and without cladding changes.
- LM: Are accordion systems auto-activated or are they still manual?
- SC: Can be automatic but in general requires someone there to prep for hurricane.
- DJS: Need to update report with minute changes sent by advisory group.
- PI: Need ADA access to all common areas of the building, but balcony doesn't necessarily have to comply w/ ADA because they open to unit that is enclosed. All units have minimum ADA requirements but balconies are not one of the requirements.
- DOP/LM: One of the project recommendations could be one pager from fenestration industry summarizing various levels of performance criteria (drawing from NAFS doc).
- CL: There is an AAMA 520 standard for voluntary higher levels of WDR resistance, could be used if higher levels of performance are desired.

- BF: What about buildings that have already been shown to have good performance re: WDR? We may already have “bulletproof” system in place in some cases. Need to review those well performing structures.
- BF: Suggested change to language on Page 5 above Table 8.
- DOP: All will have opportunity to provide feedback to the document
- AG: 1/3 the price to put shutter in vs sliding doors and windows

APPENDIX G: BUILDING PERMITS WATER DAMAGE HYPOTHESIS FOLLOWING HURRICANE IRMA

Direct evidence of hurricane-induced leakage in high-rise building is limited to anecdotal reports, a few engineering and insurance claims reports and statements from condominium managers, owners and residents in South Florida. The research team used an indirect approach to test an hypothesis that water leaks in a building may be associated with condominium owners' repairs and building permit applications. Given that wind-driven rain induced leaks will produce damage to cladding and interior damage to condominium units, resulting in need for repairs. Thus, we hypothesized one measure to establish the effects of Hurricane Irma on high-rise units may be to assess the number of building permit applications related to water intrusion, and/or fenestration-related construction work following Hurricane Irma. A logic flow chart explaining the approach is provided below. Findings related to this analysis (if conclusive) will be discussed in the final report.

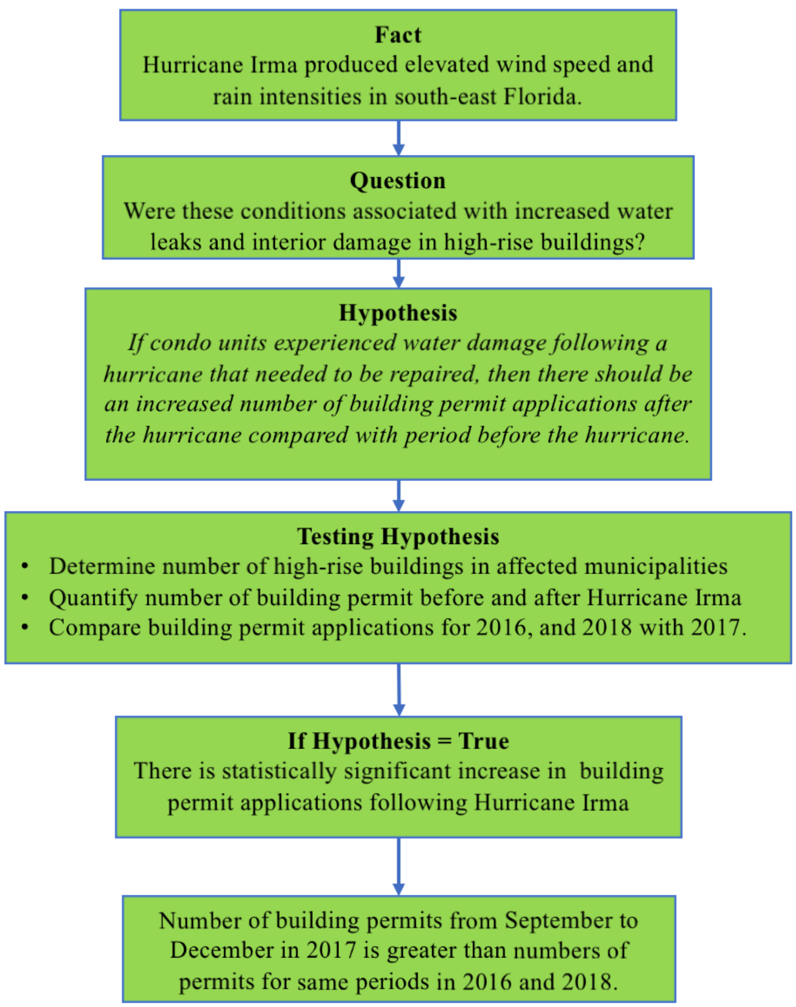


Figure 4. Flow chart explaining the Building Permits Water Damage approach

Hypothesis Testing

We examined the database of building permits submitted to building officials of several jurisdictions within the Greater Miami area, to test the hypothesis that water intrusion or leakage into high-rise condominium units, (i.e. buildings of ten stories or greater), during wind-driven rain events would lead to increases in building permit to repair the fenestration systems of the building. Thus, by examining the data from three years, 2016, 2017 and 2018 we conducted a statistical analysis for the three-month period following the 2017 Hurricane Irma.

Building Permit Acquisition

The researchers contacted Building departments in five jurisdictions (Fort Lauderdale, North Miami Beach, Miami City, and Miami Beach) to obtain permit datasets for the 2016 through 2018 period. We extracted permits related to high-rise structures which were listed in the "EMPORIS" website https://www.emporis.com/ using the building address. We then filtered the dataset to capture permits having the keywords; water intrusion, window and waterproof. Approximately 10% of the building permits pulled for high-rise structures included the selected terms. The first challenge we found was most building permits lacked description of any observed water/wind-driven rain damage in their "scope of work" section. Thus, we decided to use only building permits specifying "window/door replacements" for this analysis.

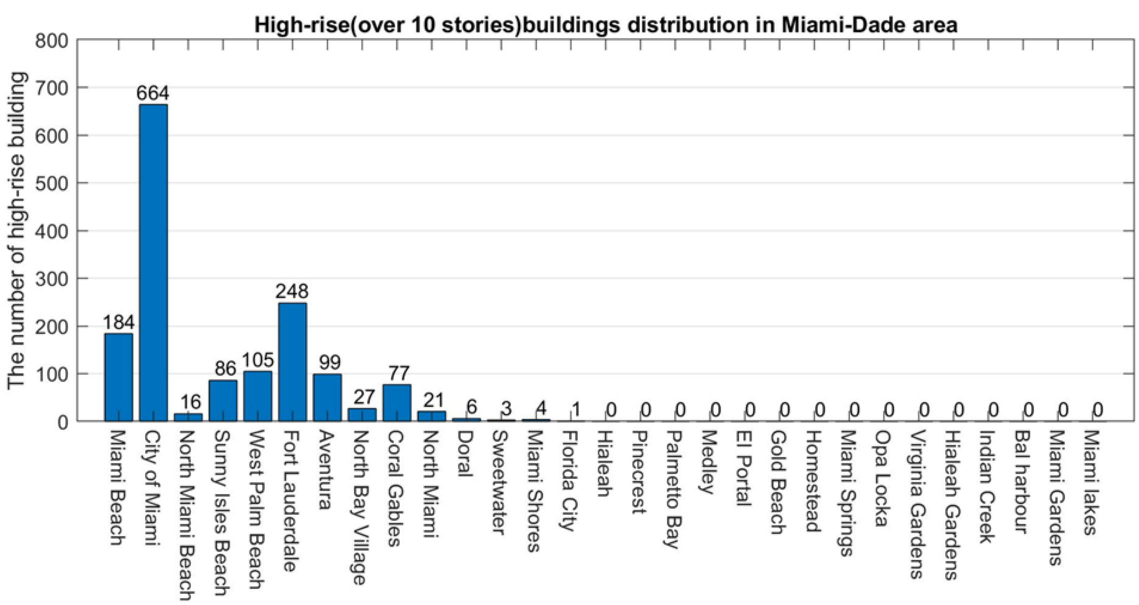


Figure 5. Distribution of high-rise building (the data is from "EMPORIS")

Data access and quality is variable among different jurisdictions. Some are able to provide sorted data while others provide total number of building permits without sorting.

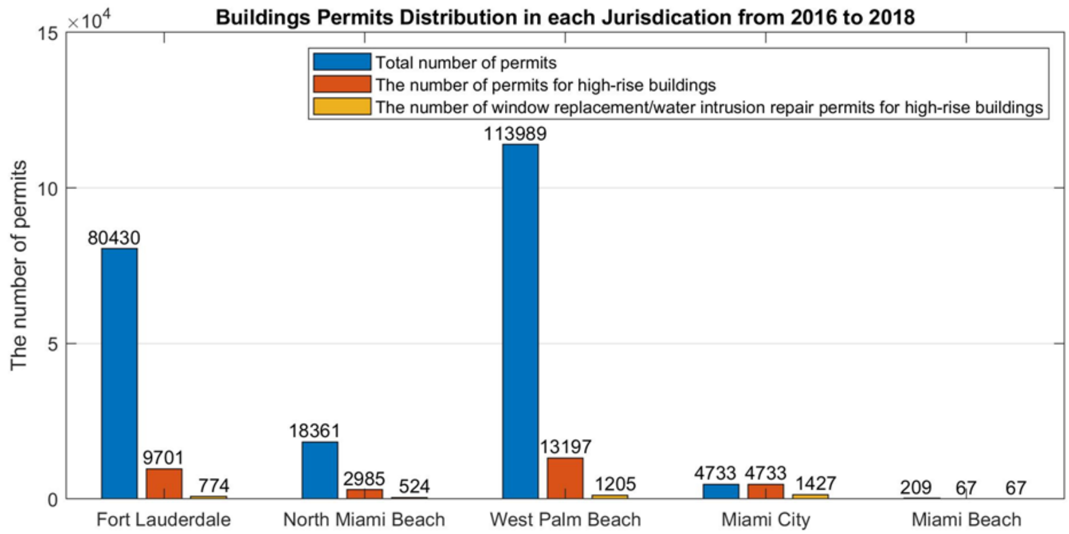


Figure 6. Building permits distribution information

Total building permits received: 217,722

Total permits related to high-rise: 30,683

Total high-rise permits related to water and repair in high-rise buildings: 3,997

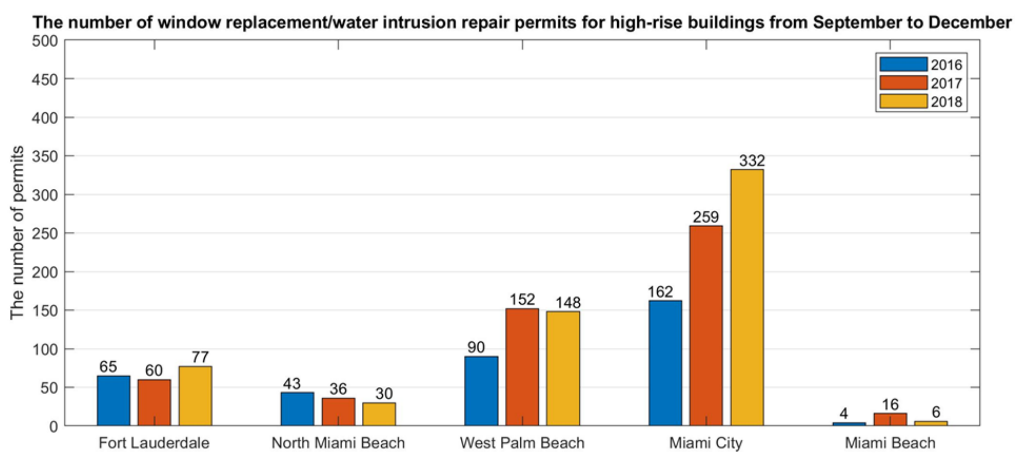


Figure 7. The number of buiding permits from September to December in each year(For example, in Fort Lauderdale, there are 65 building permits record both related to high rise building and wind replaecment repair from September to December in 2016)

Statistical Analysis

Paired T-test

The paired sample t-test is a statistical procedure used to determine whether the mean difference between two sets of observations is zero, the most common example is that subjects are tested prior to a treatment, say for high blood pressure, and the same subjects are tested again after treatment with a blood-pressure-lowering medication. In this building permit analysis, we used our building permit dataset for the years 2016, 2017, 2018 to compare the number of building permit applications for the same jurisdiction within the three-month period September through November in 2016, 2017 and 2018.

. In addition, there are three assumptions for paired t-test.

1) The dependent variable should be measured on a continuous scale.

   Solution：The number of building permits range is from 0 to infinite, the first assumption was satisfied.

2) There should be no significant outliers in the differences between the two related groups

   Solution: The boxplot can describe a dataset outlier.

3) The distribution of the differences in the variable between the two related groups should be approximately normally distributed.

   Solution: The Lilliefors test(L) can be used to determine whether the sample is drawn from a normal distribution.

Table 4. Calculation sheet

1	2 Year	3 Total window replacement permits for from Sep to Dec / year	4 Total window replacements in 3 years	5 Normalized values (C3 / C4)	6 Diff. (Z) Z = y-x
Fort Lauderdale	2016	65	774	0.084 (x)	-0.006
	2017	60		0.078 (y)	
	2018	77		0.099 (x)	-0.021
North Miami Beach	2016	43	524	0.082 (x)	-0.013
	2017	36		0.069 (y)	
	2018	30		0.057 (x)	0.012
City of Miami	2016	162	1427	0.114 (x)	0.067
	2017	259		0.181 (y)	
	2018	332		0.233 (x)	-0.052
West Palm Beach	2016	90	1205	0.075 (x)	0.051
	2017	152		0.126 (y)	
	2018	148		0.123 (x)	0.003
Miami Beach	2016	4	67	0.060 (x)	0.178
	2017	16		0.239 (y)	
	2018	6		0.089 (x)	0.148

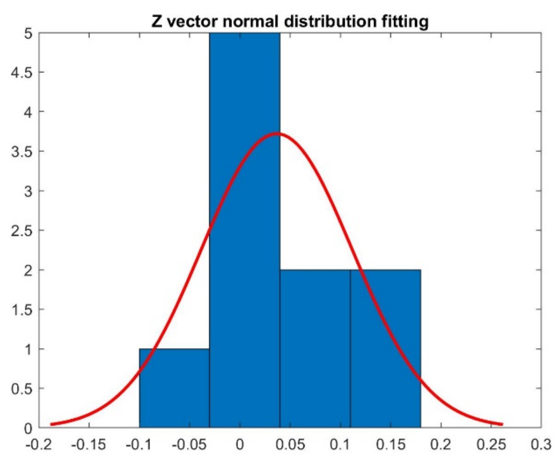
**note:*

1. The x and y are both variables, x means the normalized values which equal to the number of building permits from Sep to Dec in non-hurricane year (2016 and 2018) over the total number of building permits in 3 years. y means the normalized values which equal to the number of building *permits from Sep to Dec in non-hurricane year (2017) over the total number of building permits in 3 years.*

Procedure of Paired T-test

In order to prove building permit hypothesis, the number of window replacement permit for high rise buildings from Sep to Dec in each year in five jurisdictions was extracted from dataset and the paired t-test will be used to determine whether the number of building permits from Sep to Dec in hurricane years is greater than the number of building permits for same periods in non-hurricane year. The following lists procedure of carrying out a paired t-test.

1) Set a null hypothesis that the mean difference (Z) is zero.
2) Calculate the difference ($Z=y_i-x_i$)
3) Plot Z vector and normal distribution function to test if the sample is drawn from a normal distribution



4) Draw boxplot for Z variables vector to eliminate the extreme values disturb.
5) Calculate basic parameters and use paired of t-test formula
   - Mean of difference: $Z_{mean} = 0.0367$
   - Standard deviation $S_z = 0.0751$
   - Standard error of the mean difference:
   - $SE(Z) = \frac{S_z}{\sqrt{n}} = 0.0237$, n=10
   - Calculate the t-statistic:
     - $T = \frac{Z_{mean}}{SE(Z)} = 1.548$ on 9df (10-1=9)
   - Use tables of the t-distribution to compare value for T to the tn−1 distribution. This will give the p-value for the paired t-test.
     - $p = 0.157$

- The significant level for t-test is 0.05, the p value is larger than significant value, so the null hypothesis cannot be rejected.

Table 5. MATLAB check table

Normalized building permits difference	Paired T-test	Lilliefors test(L)
Mean of difference	0.0367	0.0367
Standard Deviation	0.0751	0.0751
Sample n	10	10
P-value	0.1565	0.1435
Significance level	0.05	0.05
Conclusion	The p-value is greater than significance level, so the null hypothesis cannot be rejected, which means the number of building permits in 2017 from Sep to Dec is not greater than number of permits in the same period in 2016 and 2018 at 0.05 significance level	The p-value is greater than significance level, so the null hypothesis cannot be rejected, which means the Normalized building permits difference is not subjected to normal distribution

Conclusions

Our analysis of the available building permits records available for high-rise buildings found no statistical evidence that associates window/door repairs with an increase in wind-driven rain or water leaks following Hurricane Irma. The data on building permits was sparse and not normally distributed which limits the statistical power of the analysis. Further, as was discussed in our Advisory Group Meeting water leaks and wind-driven rain by themselves is unlikely to cause damage to the wind system and therefore it is unlikely to lead to need for repairs unless some other damage (say damage from wind-borne debris) has also occurred.

APPENDIX H: FENESTRAITION MANUFACTURERS' PERSPECTIVE

Concepts, ideas and topics for further discussion to improve the overall performance of the building envelope during and post-hurricane events:

Installation:

- For products that leaked during a hurricane event, need documentation of type of leak (i.e. leak within the window area such as glazing leak, vent gasket leak or leak outside window area due to window frame or pan flashing leak or perimeter sealant or water barrier leak in adjacent cladding).
    - The reason this information is needed is to allow manufacturers the opportunity to conduct a forensic investigation to determine the root cause of the leakage. Without this information, it is impossible to determine the origination of the leak related to the fenestration, rough opening or the building envelope. While it is impossible to go back and investigate the buildings damaged during hurricane Irma, future investigations should be conducted immediately after a hurricane and reports should be made available to manufacturers and Floridians.
- Suggest conducting a series of field tests on existing buildings to determine if current installation practices are properly being followed. If leaks are found, conduct a forensic investigations in existing buildings envelope to determine root cause of leaks. Use this information to compare buildings that performed well versus those that underperformed.
    - This information could prove invaluable, if it leads to a better understanding of improper installation methods or if maintenance of the fenestration product was not conducted.
- Was product installed per manufacturer's instructions and approved shop drawings? Recommend installation in accordance with FMA/AAMA 100, FMA/AAMA 200, FMA/AAMA/WDMA 300, FMA/AAMA/WDMA 400.
    - Rationale
        - UF conducted much of the testing in conjunction with the fenestration industry.
        - Extensive testing of these standards proved that fenestration products performed in extreme wind/water events to ensure methodology was vetted thoroughly.
- Training and certification requirement for installation contractors to install in accordance with this method
- Suggest window installation become part of the building inspection process conducted by the building inspector, to include visual observation of:
    - Anchorage
    - Flashing
    - Sealant
- Develop pre-construction exterior building envelope/water resistance testing that relies on a certification and commission program using existing exterior envelope water test methods (similar to blower door testing required to verify building air leakage) that must be witnessed or commissioned by a third party. Test should be conducted on the first portion of the exterior wall system completed (first unit or first floor). At the completion of the building envelope construction, the contractor and architect shall certify the entire building envelope is in compliance. Insurance companies could partner with the window manufacturers to create a program that becomes an incentive to the building owners who utilize the program.

- Codes currently do not mandate performance testing of fenestrations. Such tests are typically only conducted if mandated by designers. Performance testing for water penetration resistance should be required by Code and Inspectional Services should require a review of successful project and site-specific test reports as a precondition to their sign-off on projects. Inspectional Services should be required to review fenestration installation details to verify that they satisfy proven concepts for resisting water penetration.

Testing

- As stated above, Florida should consider a program that would include a water testing program as part of the building envelope inspection early in the building process when the fenestration products are first installed.
    - Testing should include air and water penetration resistance testing and maybe even dynamic water penetration testing. The differential pressure to be applied during these tests should be established prior to testing but should include a test to failure (to the point where leakage is observed). Initial testing should be in accordance with the AAMA/WDMA/CSA 100/I.S.2/A440 NAFS standard/specification. The report for testing can show compliance to current industry standards and then provide a commentary on how much better than industry standards the fenestration performed to (if applicable). If for no other reason the end user will know to what wind rating their building should be able to perform to.
- NFRC uses thermal models for determining the efficiency of products. Could we get a modeling program to evaluate the fluid dynamics of building envelopes to show where the water flows on a structure and to help determine optimal designs for water paths?

Fenestration Product

- Consider adding a water infiltration rating to fenestration products (decoupling water from design pressure) to provide architects/specifiers the information needed to select the appropriate fenestration for the building envelope based on the location and the building design.
    - Most owners don't understand the correlation between positive Design Pressure and Water test pressure, make it clear and transparent what the water infiltration rating is on the product and how that relates to wind speed.
    - Product selection should be in accordance with the AAMA/WDMA/CSA 100/I.S.2/A440 NAFS standard/specification.

Research

- The fenestration industry uses the ASTM E1105 standard to determine water penetration, which should be reviewed and discussed with the feasibility work group so that all parties are speaking a common language when talking about fenestration product testing and performance.
- Investigate buildings that did not leak during a hurricane event and document the type of construction, maintenance, QC during construction, the perimeter sealing method to the window, the operator type, class and grade of window product used.

- Review current water test procedures (static, cyclic and dynamic) and correlate to actual environmental conditions during hurricane events, to determine where gaps may or may not exist.

Maintenance

- In the future, for buildings that do not perform as designed during a hurricane event, the age of the building should be considered and whether fenestration maintenance had been performed.

Building Design

- In the future, in buildings that do not perform as designed during a hurricane event, the building design should be carefully reviewed to determine if there was a flaw in the design and materials selected (e.g. precast concrete, brick veneer, stucco, light weight panels etc.).
- High-rise building balcony elevations relative to interior floors and drainage considerations.
- Patios/Terraces/Balconies in high-rise buildings need to be designed in a way to divert water away from the fenestration and the building envelope.
- Interior floor coverings and finishes next to the patio should be made from water resistant materials that can assist in post hurricane clean-up.
- Designers need to better educate the end user on how the rating systems for fenestration products work. Since current standards are only concerned with structural performance as it relates to hurricanes either the standards need to be updated to include post hurricane event water penetration performance or they need to better address tools such as hurricane shutters and how these devices may help to preserve post hurricane event performance.
- End users desire that testing for water penetration resistance will not be discounted from design level wind pressures. Industry manufacturers are not likely to support such a request and are more likely to get behind development of a line of fenestration products that can meet higher performance levels than current industry standards require.
- A document needs to be developed that provides guidelines on design features that serve to improve the resistance of fenestration products to the effects of wind driven rain that exceed “typical” rain events that are the current basis for fenestration rating systems. Typical features to consider include (listed in no particular order):
    - Slab offset at door sills (the greater the offset the better the performance that can be achieved)
    - Taller back dam on door and windowsills (need to offset vs ADA)
    - Flashings for doors and windows that comply with ASTM E2112
    - Transition details between wall assemblies and fenestrations (to improve weather protection between fenestrations and adjoining walls)
    - Incorporation of hurricane shutters
    - Balconies are sloped to drain (if concrete)
    - Fixed fenestration units that are structurally glazed with silicone sealants tend to outperform water management systems under extreme weather events; should there be a requirement in hurricane prone regions to only accept such fenestration products.
    - Operable units should include features such as multi-point locking devices to help retain all sides of a vent to improve weather sealing. Designs that compress sash against compressible gaskets also tend outperform those that utilize pile weatherstripping alone.

APPENDIX I: CURRENT BUILDING CODES, STANDARDS, AND INDUSTRY LITERATURE

Memorandum

SIMPSON GUMPERTZ & HEGER
Engineering of Structures and Building Enclosures

Date: 29 April 2020

To: David Prevatt and Daniel Smith; Engineering School Sustainability Infrastructure and Environment University of Florida

From: Siena B. Mamayek and Michael J. Louis

Project: 200162 – Research Study for Post-Hurricane Performance of Building Systems

Subject: Preliminary Industry Research

The following is a working list of current building codes, standards and industry literature pertaining to the design and evaluation (where applicable) to the performance of curtain walls in Florida (High Velocity Hurricane Zone).

1. CURRENT BUILDING CODES IN FLORIDA

1.1 Florida Building Code, Building 2017

(https://codes.iccsafe.org/content/FBC2017)

Hyperlinks to full code sections with some excerpts provided below:

<u>Chapter 16: Structural Design</u>

Section 1625: High-Velocity Hurricane Zones – Load Test (https://codes.iccsafe.org/content/FBC2017/chapter-16-structural-design#FBC2017_Ch16_Sec1625)

Section 1626: High-Velocity Hurricane Zones – Impact Tests for Wind-Borne Debris (https://codes.iccsafe.org/content/FBC2017/chapter-16-structural-design#FBC2017_Ch16_Sec1626)

1626.2 Large Missile Impact Tests

1626.2.1 This test shall be conducted on three specimen in accordance with test protocols TAS 201 and TAS 203. This test shall be applicable to the construction units, assemblies and materials to be used up to and including 30 ft (9.1 m) in height in any and all structures.

1626.2.3 The large missile shall be comprised of a piece of timber having nominal dimensions of 2 inches by 4 inches weighing 9 pounds.

1626.3 Small Missile Impact Test

1626.3.1 This test shall be conducted on three test specimens in accordance with test protocols TAS 201 and TAS 203. This test shall be applicable to the construction units, assemblies, and materials to be used above 30 ft (9.1 m) in height in any and all structures; Risk Category IV-Essential Facility Buildings or Structures shall follow the large missile impact testing in Section 1626.2.4 at 50 ft per second (15.2 m/s).

1626.3.3 The missile shall consist of solid steel balls each having a mass of 2 grams (0.07 oz) (+/- 5 percent) with a 5/16 in. (7.9 mm) nominal diameter.

Chapter 17: Special Inspections and Tests

Section 1709 Preconstruction Load Testing (https://codes.iccsafe.org/content/FBC2017/chapter-17-special-inspections-and-tests#FBC2017_Ch17_Sec1709)

1709.5 Exterior Windows and Door Assemblies

The design pressure rating of exterior windows and doors in buildings shall be determined in accordance with Section 1709.5.1 or 1709.5.2. For the purpose of this section, the required design pressure shall be determined using the allowable stress design load combinations of section 1605.3.

1709.5.1 Exterior Windows and Doors

Exterior windows and sliding doors shall be tested and labelled as conforming to AAMA/WDMA/CSA 101/I.S.2/A.440 or TAS 202 (HVHZ shall comply with TAS 202 and ASTM E1300 or Section 2404). The following shall also be required either on a permanent label or on a temporary supplemental label applied by the manufacturer: information identifying the manufacturer, the product model/series number, positive and negative design pressure rating, product maximum size tested, impact-resistance rating if applicable, Florida product approval number or Miami-Dade product approval number, applicable test standard(s), and approved product certification agency, testing laboratory, evaluation entity, or Miami-Dade product approval.

1709.8.4

Glazed curtain wall, window wall and storefront systems shall be tested in accordance with the requirements of this section and the laboratory test requirements of the American Architectural Manufacturers Association (AAMA) Standard 501, HVHZ shall comply with Section 2411.3.2.1.1.

Chapter 24: Glass and Glazing

Section 2410 High Velocity Hurricane Zones – General

Section 2411 High Velocity Hurricane Zones – Windows, Doors, Glass and Glazing

2411.1.9 – Replacement of any glazing or part thereof shall be designed and constructed in accordance with Chapter 34 Existing Building Provisions for High-Velocity Hurricane Zones.

2411.1.11 – Exterior lite of glass in an insulated glass unit shall be safety glazed EXCEPTION 1. Large missile impact-resistance glazed assemblies 2. Nonmissile impact units protected with shutters.

Section 2412 High Velocity Hurricane Zones – Glass Veneer

Section 2413 High Velocity Hurricane Zones – Storm Shutter/External Protective Devices

Section 2414 High Velocity Hurricane Zones – Curtain Walls (https://codes.iccsafe.org/content/FBC2017/chapter-24-glass-and-glazing#FBC2017_Ch24_Sec2414)

Section 2415 High Velocity Hurricane Zones – Structural Glazing Systems

1.2 Florida Building Code, Existing Building, 2017

Did not identify any provisions for evaluating existing curtain walls.

1.3 Florida Building Code, Test Protocols for High Velocity Hurricane Zone, 2017

Florida Building Code (FBC) Testing Application Standard (TAS) 201: Impact Test Procedure

(https://codes.iccsafe.org/content/FTPC2017/testing-application-standard-tas-201-94-impact-test-procedures)

- This protocol covers procedures for conducting the impact test of materials as required by Section 1626 of the Florida Building Code, Building. A means of determining whether a particular product used as wall cladding, exterior windows, glazing, exterior doors, skylights, glass block, shutters and any other similar device used as external protection to maintain the envelope of the building, provides sufficient resistance to windborne debris.

Florida Building Code (FBC) Testing Application Standard (TAS) 202: Criteria For Testing Impact and Nonimpact Resistant Building Envelope Components using Uniform Static Air Pressure

(https://codes.iccsafe.org/content/FTPC2017/testing-application-standard-tas-202-94-criteria-for-testing-impact-and-nonimpact-resistant-building-envelope-components-using-uniform-static-air-pressure)

- This protocol covers procedures for conducting a uniform static air pressure test for materials and products such as wall claddings, glass block, exterior doors, garage doors, skylights, exterior windows, storm shutter, and any other external components which help maintain the integrity of the building envelope. A means of determining whether a particular product listed above provides sufficient resistance to wind forces as determined by Section 1620 of the Florida Building Code, Building.

Florida Building Code (FBC) Testing Application Standard (TAS) 203: Criteria for Testing Products Subject to Cyclic Wind Pressure Loading

(https://codes.iccsafe.org/content/FTPC2017/testing-application-standard-tas-203-94-criteria-for-testing-products-subject-to-cyclic-wind-pressure-loading)

- This protocol covers procedures for conducting the cyclic wind pressure loading test required by the Florida Building Code, Building and TAS 201. This test method is a standard procedure for determining compliance with Section 1625, Table 1625.4 and Table 1626 of FBC. Method is intended to be used for installations of exterior windows, glazing, wall claddings, exterior doors, skylights, glass blocks, storm shutters, and other similar devices used as external protection of the building envelope. Method consists of chamber with differential pressure across the specimen and observing, measuring and recording the deflection, deformations and nature of any distress or failure of the specimen.

1.4 Florida Department of Business and Professional Regulations

Florida Department of Business and professional Regulations provides a search engine on their website to find product approvals for curtain wall assemblies that meet the specific requirements for installation in Florida. Product Approvals: (https://floridabuilding.org/pr/pr_default.aspx)

Approvals generally include the following for Panel Walls > Curtain Walls installed in High Velocity Hurricane Zone (HVHZ):

- Engineers Evaluation Report from a licensed professional in the State of Florida includes the following:
    - States product assembly with curtain wall size restrictions and assembly installation requirements.
    - Maximum allowable design pressure.
- Code Compliance:
    - FBC Chapter 17 – Special Inspections and Tests.
    - ASTM E283, ASTM E331, ASTM E330, AAMA 501, ASTM E1886, ASTM E1996, TAS-201, TAS 202 and TAS 203.
    - Intertek Laboratory Testing Report Numbers.
    - Job specific design wind pressures calculated in accordance to FBC Ch. 16 and ASCE 7 Minimum Design Loads for Buildings and other Structures.
    - Approvals specifically state if curtain wall is approved/not approved for use in the High Velocity Hurricane Zone (HVHZ).

2. CURRENT INDUSTRY STANDARDS FOR CURTAIN WALLS IN HURRICANE REGIONS

ASTM E1886 – Standard Test Method for Performance of Exterior Windows, Curtain walls, Doors, and Impact Protective Systems Impacted by Missile(s) ad Exposed to Cyclic Pressure Differential

- The performance determined by this test method relates to the ability of elements of the building envelope to remain unbreached during a windstorm.

ASTM E1996 – Standard Specification for Performance of Exterior Windows, Curtain Walls, Doors, and Impact Protective Systems Impacted by Windborne Debris in Hurricanes

- This standard provides the information required to conduct Test Method E1886. Provides a basis for judgement of the ability of the applicable element of the building envelope to remain unbreached during a hurricane; thereby minimizing the damaging effects of the hurricane on the building interior and reducing the magnitude of internal pressurizations.

AAMA 506 – Voluntary Specification for Hurricane Impact and Cycle Testing of Fenestration Products

- This standard uses existing ASTM test methods (ASTM E1886 and ASTM E1996) to qualify windows, doors and skylights as "impact resistant."

AAMA 501 – Method of Test for Exterior Walls

- This standard and those referenced in this publication are used to evaluate the structural adequacy of wall systems and their ability to resist water penetration and air leakage.

ASTM E283 – Standard Test Method for Determining Rate of Air Leakage Through Exterior Windows, Skylights, Curtain Walls, and Doors Under Specified Pressure Differences Across the Specimen

- This method covers a standard laboratory procedure for determining the air leakage rates of exterior windows, skylights, curtain walls and doors under specified differential pressure conditions across the specimen. Reference ASTM E783 for the equivalent field testing.

ASTM E783 – Standard Test Method for Field Measurement of Air Leakage Through Installed Exterior Windows and Doors

- This standard provides the field procedure for determining the air leakage rates of installed exterior windows and doors.

ASTM E331 – Standard Test Method for Water Penetration of Exterior Windows, Skylights, Doors, and Curtain Walls by Uniform Static Air Pressure Difference

- This method covers a standard laboratory procedure for determining the resistance of exterior windows, curtain walls, skylights, and doors to water penetration when water is applied to the outdoor face and exposed edges simultaneously with a uniform static air pressure at the outdoor face higher than the pressure at the indoor face. Reference ASTM E1105 for the equivalent field testing.

ASTM E1105 – Standard Test method for Field Determination of Water Penetration of Installed Exterior Windows Skylights, Doors, and Curtain Walls, by Uniform or Cyclic Static Air Pressure Difference

- This method covers the determination of the resistance of installed exterior windows, curtain walls, skylights, and doors to water penetration when water is applied to the outdoor face and exposed edges simultaneously with a static air pressure at the outdoor face higher than the pressure at the indoor face.

ASTM E330 – Standard Test Method for Structural Performance of Exterior Windows, Doors, Skylights and Curtain Walls by Uniform Static Air Pressure Difference

- This method covers a standard laboratory procedure for determining the structural performance of exterior windows, doors, skylights, and curtain walls under uniform static air pressure differences, using a test chamber.

GANA Glazing Manual 50th Edition

- While chemically strengthened glass is often used monolithically, it can be used in laminated construction for security, detention, hurricane/cyclic wind-resistance, blast and ballistic-resistant glazing applications (p. 21).

- Laminated glass resists glass fall-out from seismic activity and windborne debris induced cracking in hurricane/cyclic-windstorm prone areas and provides various levels of security protection in seismic, blast-resistance, bullet-resistance and burglary-resistance applications (p. 32).

- Hurricane/cyclic wind-resistant laminates are commonly specified using one or more of the following standards and protocols:

    - ASTM E 1886 – Standard Test Method for Performance of Exterior Windows, Curtain Walls, Doors, and Impact Protective Systems Impacted by Missile(s) and Exposed to Cyclic Pressure Differentials.
    - ASTM E 1996 – Standard Specification for Performance of Exterior Windows Curtain Walls, Doors and Impact Protective Systems Impacted by Windborne Debris in Hurricanes.
    - Florida Building Code – Test Protocols for High Velocity Hurricane Zones.
    - IBC and IRC Southern Building Code (SSTD 12-97) Note: SBCCI Test Standard for Determining Impact Resistance From Windborne Debris SSTD-12-97 was withdrawn in 2008.
    - ASTM C 1172 – Standard Specification for Laminated Architectural Flat Glass; is the industry standard for quality requirement for cut sizes of flat laminated glass consisting of two or more lites of glass bonded with an interlayer material for use in building glazing.

3. CURRENT STANDARDS FOR EVALUATING CURTAIN WALL PERFORMANCE POST HURRICANE

None identified to date.

4. INDUSTRY LITERATURE

Advances in Hurricane Engineering: Learning from our Past: Proceedings of the 2012 ATC & SEI Conference on Advances in Hurricane Engineering, October 24-26, 2012, Miami, Florida (David Prevatt on Conference Steering Committee)

1. Separating Junk Science from Sound Engineering Principals during Forensic Assessments of Hurricane Damage.
2. A Parametric Representation of Wind-Driven rain in Experimental Setups.
3. Engineering Standards for Glazing Performance.
4. Protection and Performance Before, During and After the Storm.
5. Hazard Mitigation of the Building Envelope, Are our Building Envelopes Ready for a Powerful Storm.
6. Forensic Studies of Surface-Damaged Curtain Wall Glass.
7. Anatomy of Glass Damage in Urban Areas during Hurricanes.
8. Structural Wind Engineering of High-Rise Towers in Hurricane-Prone Regions.
9. Wind Engineering of the Shanghai Center Tower.
10. An Examination of Wind-Related Design Criteria and their Applications in Hurricane Regions.

I:\BOS\Projects\2020\200162.00-WIND\WP\001SBMamayek-M-200162.00.ras.docx