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

Project #: P0150337

Submitted to:

Florida Department of Business and Professional Regulation

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EXECUTIVE SUMMARY

This project investigates water intrusion issues in high-rise buildings and is a Phase II continuation of research conducted in 2019 by the University of Florida, on behalf of the Florida Building Commission. The research team, led by Dr. David O. Prevatt, assembled a Project Advisory Group including high-rise condominium owners and managers, building envelope consultants, representatives from testing laboratories, municipal authorities, and fenestration and cladding manufacturing industries with product offerings for high-rise construction. The aim of the group was to explore key issues related to water intrusion and provide recommendations to FBC.

Due to COVID-19, this project was delayed significantly. This report transmits the findings to date, which comprise approximately 75% of the total scope of work. Key milestones herein include the following:

- Meeting #1, #2 and #3 descriptions and summaries of stakeholder input
- Draft pro/con table of water intrusion mitigation options (i.e. based on advisory group input)
- Building permit study in relation to water intrusion following Hurricane Irma
- Summary document describing fenestration manufacturer's perspective on water intrusion issues
- Review of current building code, standards and industry literature with respect to water intrusion

Remaining work to be completed includes two meetings with the advisory group and summary document of "desired specifications", to be finalized upon completion of the final meetings.

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1. OVERVIEW AND SCOPE OF WORK

1.1 Background

In the 2018-2019 fiscal year, the Florida Building Commission appointed a Working Group on Hurricane Irma Exterior Envelope Damage Reports. The motivation for forming the Working Group came 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 Working Group were concerning because the peak wind speeds from Hurricane Irma were less than 90 mph in the Miami region. 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 Working Group reported that leakage often occurs at or around windows and doors and in general more frequently at interfaces in building envelope systems, although the limited forensic information was insufficient to establish cause and effect. Another part of the study used data modeling from the Florida Public Hurricane Loss Model (FPHLM) to investigate the potential impact of fenestration defects on insured losses. The 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.

This research is a continuation of the 2019 work. Led by the University of Florida, the research team assembled a Project Advisory Group led by a building envelope consultant and including high-rise condominium owners and managers, building envelope consultants, and representatives from testing laboratories, municipal authorities, and fenestration and cladding manufacturing industries with product offerings for high-rise construction. The aim of the group is to explore key issues related to water intrusion and provide recommendations to FBC.

1.2 Motivation and Purpose

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. Subsequently, state building code law was revised further from the 2002 changes to enhance the impact of the code. The state law of Florida now prioritizes property protection from hurricane winds and water intrusion and mitigation of existing buildings. In order to do this, the Florida Building Commission continues to focus on developing 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 buildings. The aspirational goal is to identify a pathway towards hurricane-resistant building envelope systems that are capable of mitigating water leakage up to the design level wind speed. The work is framed as a series of moderated discussions within the Advisory Group, to better understand perspectives of the key stakeholders, review and discussion of current state-of-the-practice methods of wind fenestration design and installation and retrofit of building systems suited to hurricane-prone coastal locations.

As a result of this discussions, a “Desired Specifications” for fenestration system/curtain wall system that would withstand a design-level hurricane remaining waterproof during the event and in-tact for post-hurricane performance shall be developed.

Based on the Specification, create industry guidelines to achieve an appropriate post-hurricane performance of fenestration and building wall cladding systems accounting for the feasibility of proposed measures.

1.4 Project Tasks

To accomplish the goals of the project, 6 main groups of tasks from “A” through “F” were set at the planning stage of the project:

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.

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.

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

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

2 PROJECT TEAM (TASK A)

A diverse advisory group was assembled for this project, including members with a variety of roles and backgrounds. The table below lists the team members' names, roles, contact information, and affiliations.

Table 1. Advisory team members

#	First Name	Last Name	Contacts	Organization
1	Michael	Louis	MJLouis@sgh.com	Simpson Gumpertz & Heger
2	Daniel	Smith	daniel.smith@venriskltd.com	Venrisk Consulting
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4	Peter	Iglesias	piglesias@coralgables.com	City of Coral Gables City Manager
5	Dave	Stammen	David.Stammen@ul.com	UL LLC Northbrook, IL
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20	Rick	Chitwood	rickc@trumpgroup.com	Owner
21	John	Runkle	John.Runkle@Intertek.com	Intertek
22	Alan	Greenberg	Alangee96@yahoo.com	Owner

3 ADVISORY GROUP MEETINGS AND DISCUSSIONS (TASK B)

3.1 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 advisory group provided suggestions for future research objectives of the project. Meeting #1 minutes are attached in Appendix A.

3.2 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?

Based on the discussion in Meeting #2, the project team and advisory group drafted a table of mitigation options for water intrusion including pros/cons. This table is being refined by the advisory group. However, a draft of the current version is provided in Table 2 below.

Table 2. Mitigation options for controlling water intrusion through fenestration

Item No.	Description	Details and Notes	Pros	Cons
1	Code compliance	- 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).	- For water intrusion, the standard uses thresholds @ 15-20% design, which work in most "normal" conditions.	- Impact resistance requirements don't ensure survivability - Current water intrusion thresholds are not near acceptable for hurricanes.
2	Window protection (e.g. shutters)	- Regarding impact, glass is the weak link.	- Wind screens and hurricane shades can help ensure survivability and have some water intrusion benefits due to reduced volume of water reaching the fenestration (see FIU study).	
3	Structural glazed silicon	Window and door operability is a key consideration. The system is designed for what you can accommodate, e.g., raise back leg height or increasing the gasket. Additional water intrusion		

Item No.	Description	Details and Notes	Pros	Cons
		mitigation needs to be included from the beginning in the design process.		
4	Improved inspection protocols	- Threshold inspector is generally associated with the structural designer and is meant to ensure high rises are built in structural compliance with the approved plans. - Also have the human factor. Did the installer use latex caulking or silicon?	- If done properly, can catch issues related to improper installation	- The focus of inspection is generally the structure and the glazing many times falls by the wayside or is not as well enforced. Then other inspectors that come to verify installation assume the glazing was verified at the structural installation, and so therefore it is often missed.
5	Improved install and maintenance of seals	Proper initial install and long-term maintenance of seals over time - 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.	- Seals age, ensuring they are maintained could go a long way to reducing water intrusion - This is a very inexpensive mitigation practice	- Using the wrong sealing product can be a major issue
6	Enhanced codes and standards	Increase thresholds and requirements of codes and standards w/ respect to fenestration - Re product testing, clients start with code required performance. It's around safety. - Products change by addressing issues at the standards level, which then trickle through to the codes.		- Increased building costs?
7	Education	Provide owners with more information on their options - 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.		
8	DIY options	Actions owners can take themselves - for example by replacing all the rubber seals, modifying the thresholds (water dam) seals and extending threshold heights to 6 in.	- can be very effective in addressing the water penetration issue	- Can present access issues as the step created is not ADA compliant
9	"Lift and slide" doors	Specialized sliding glass door - 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.	- 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.	- It is very sophisticated hardware and very expensive in the markets. - requires very specialized installation (tough for retrofit) - maintenance can be a major issue

3.3 Meeting #3 – 11 June 2020

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

3.4 Remaining Meetings - TBD

Based on the research and feedback from advisory group members to date, the Project Team will generate a draft protocol for maximizing or ensuring little or no water intrusion occurs through fenestration of high-rise buildings. We propose this will set a standard that satisfies the most risk-averse client, with no budget restrictions. The rationale here is to explore what possible solutions may exist whether or not it is currently popular. In the past such high-end or turn-key engineering that may initially be cost-prohibitive might be produced more economically-affordably should the broad market seek such solutions. This protocol will be reviewed by high-rise building owners and building officials and the feedback will be incorporated into a revised document for review by the advisory group.

Based on the outcomes of the above, the Building Envelope Consultant will lead the development of a "desired specifications" document for fenestration system/curtain wall system performance during and 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 resultant document will be understandable and acceptable to condominium owners and code officials as desired performance, as well as to building envelope product manufacturers.

4 CODE PROVISIONS, GUIDELINES AND PRODUCT TESTING STANDARDS (TASK C)

Simpson Gumpertz & Heger, Inc. prepared as review 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). The summary is included in Appendix E.

5 REMAINING TASKS (TASK D AND E)

5.1 Desired Specifications and Industry Guidelines

Further work is still underway

The Project Team will use the desired specification wish list from Task D to develop guidelines for community leaders, the public and the industry participants to consider in developing the feasibility and required steps towards hurricane-level performance and if possible post-hurricane performance design guidelines for fenestration and building wall cladding systems.

Two Advisory Group meetings will be scheduled for further discussion. There is available technology today that maximizes leak-resistance of windows, including specifying highest quality fenestration, rigorous testing and coordination between the building envelope consultant with the architect and owner, and water testing of windows during the construction. There also exist some passive methods that will reduce the wind-driven rain intensity.

5.2 Overall Project Summary

The following sections provide a summary of findings to date. These will be expanded upon and finalized as the project draws to a close.

5.2.1 The current standards for testing, product approvals that are generally accepted by building envelope consultants

The review of the 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) was prepared by Simpson Gumpertz & Heger in their 29 April 2020 memorandum (attached in Appendix).

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 the following tests: 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)

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.

5.2.2 Definition of successful tests for product approvals of fenestration

Current standards are only concerned with structural performance as it relates to hurricanes. Successful testing of fenestrations is defined as passing missile impact testing followed by cyclic testing at full design load without breaching the test specimen. Reuse of the fenestration product following impact and cyclic testing is not a condition to successful testing. 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.

5.2.3 Homeowner's experience during Hurricanes

End users desire a better understanding on how the rating system for fenestration products works. Users also desire that testing for water penetration resistance will not be discounted from design level wind pressures. End users would like to gain a better understanding of the effects of wind driven water on building fenestrations through fenestration testing beyond current industry guidelines (such as those outlined through AAMA). There is an expectation that if a window or door passes a design wind load test it is a guarantee that it would not leak.

Following a design level weather event, end users would like to see better documentation to record the reason(s) for leakage whether from product design or from installation. This can form the basis for lobbying for improved design and/or installation requirements through standards and local Codes.

5.2.4 Homeowners expectations for water infiltration resistance in high-rise buildings

Codes currently do not mandate performance testing of fenestrations and such tests are typically only conducted if mandated by designers. Performance testing for water penetration resistance should be required by Code and 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.

End users desire that fenestrations be inspected by the designer (typically an Architect) and the Inspectional Services Department to not only verify that the fenestration products are installed to meet structural performance requirements of the Code, but also to verify that there is continuity of air/water and vapor barriers to adjoining wall assemblies, roofing and other fenestration products. The proposed inspections should also verify that specific design features, such as those noted below, are incorporated to the extent possible.

End users would like to see a document 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. Design features to consider in such a document, include:

- 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). 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 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 fenestration 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 gaskets tends to outperform those that utilize pile weatherstripping alone.

APPENDIX A. **MEETING #1 MINUTES**

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
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14	Weil	Lam	WL	WLam@rdh.com	No
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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. Note these minutes are currently in draft form and will be confirmed by the Advisory Group (with any required edits) during Meeting #2.

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 1).

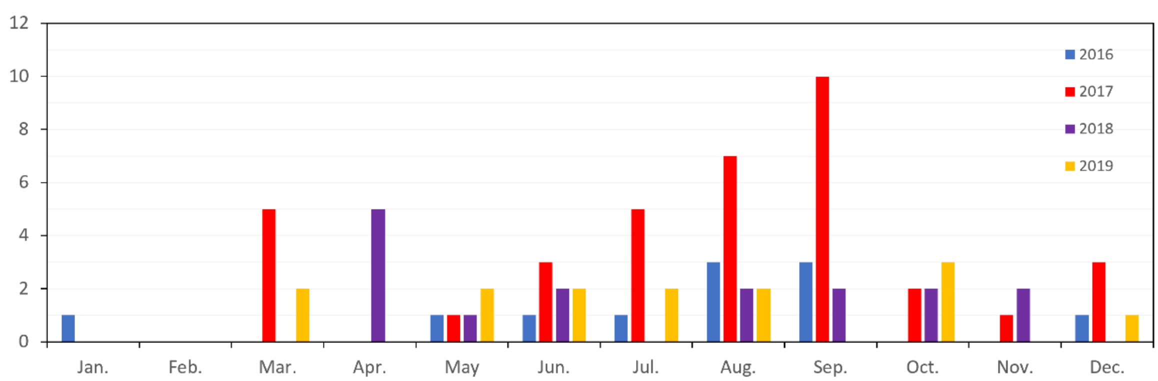

Figure 1. Number of high-rise buildings with water intrusion damage in Miami Beach, FL in the years before and after Hurricane Irma (2017)

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 admits 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 B. **MEETING #2 MINUTES**

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 → Click Here:

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
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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 Overview

Meeting #1 provided a 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.

Meeting #2 Minutes

Topic 1. Successful approach by building envelope consultants to mitigate water leakage in FL

- Topic 1 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., rain, 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.

Topic 2. Did any homeowner units experience water leaks and what were the consequence?

- 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?

Topic 3. Are owners fully aware of potential liability risks from wind and water leaks?

- 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.

Topic 4. Is sufficient knowledge available on magnitude/duration for WDR on high-rise surfaces?

- 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 C. **MEETING #3 MINUTES**

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 (11 June 2020) Participants

#	First	Last	Abbrev.	Contact	Present
1	Michael	Louis	ML	MJLouis@sgh.com	No
2	Daniel	Smith	DJS	daniel.smith@venriskltd.com	Yes
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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
- Suggest 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
- 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

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 of water penetration in the whole building envelope, including whether some of that water comes in around a rough opening.
- 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.

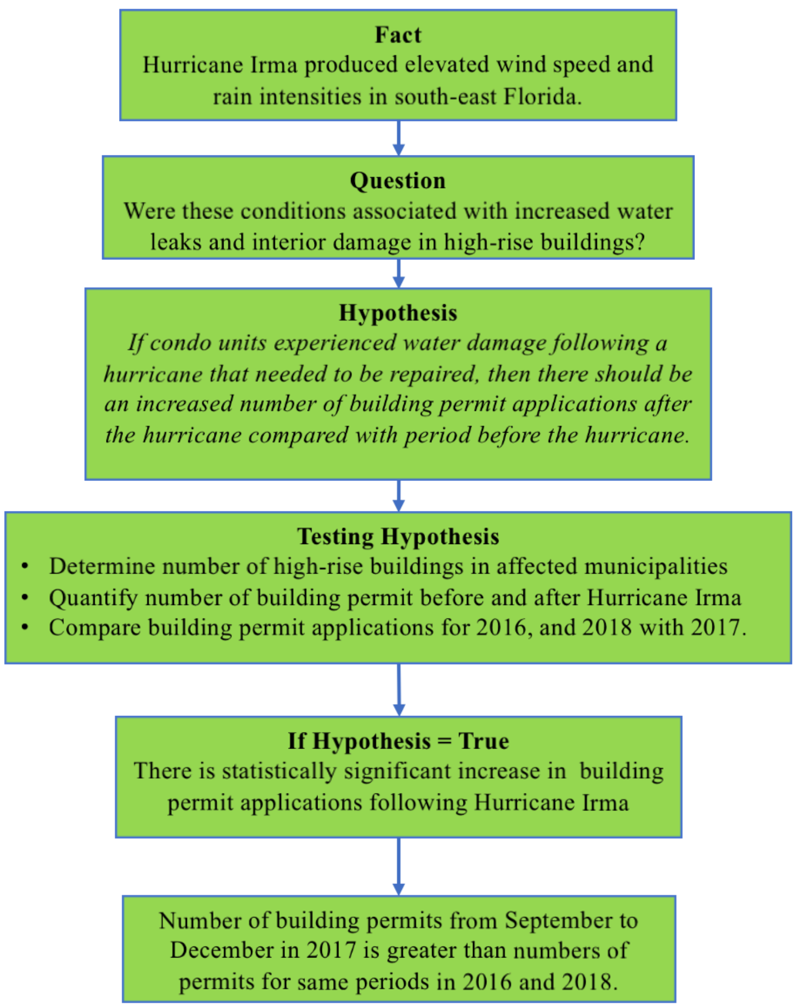
<u>Topic 3 – Proposed next steps</u>

- 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 – structural overload and 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 D. **BUILDING PERMITS ANALYSIS POST-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.



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.

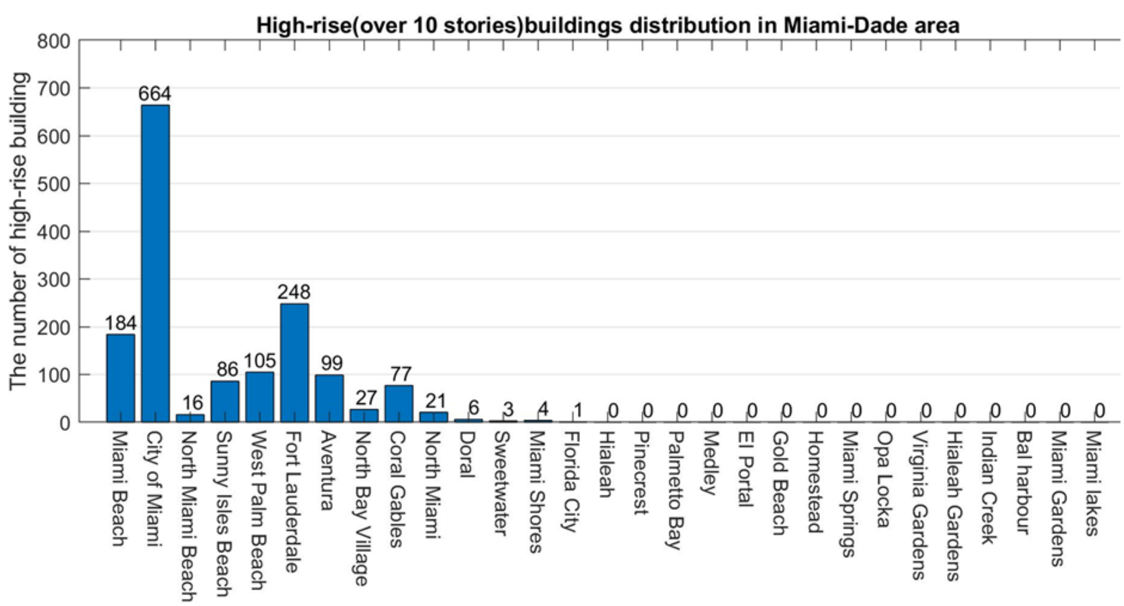


Figure 1. Distribution of high-rise building (the data is from "EMPORIS")

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.

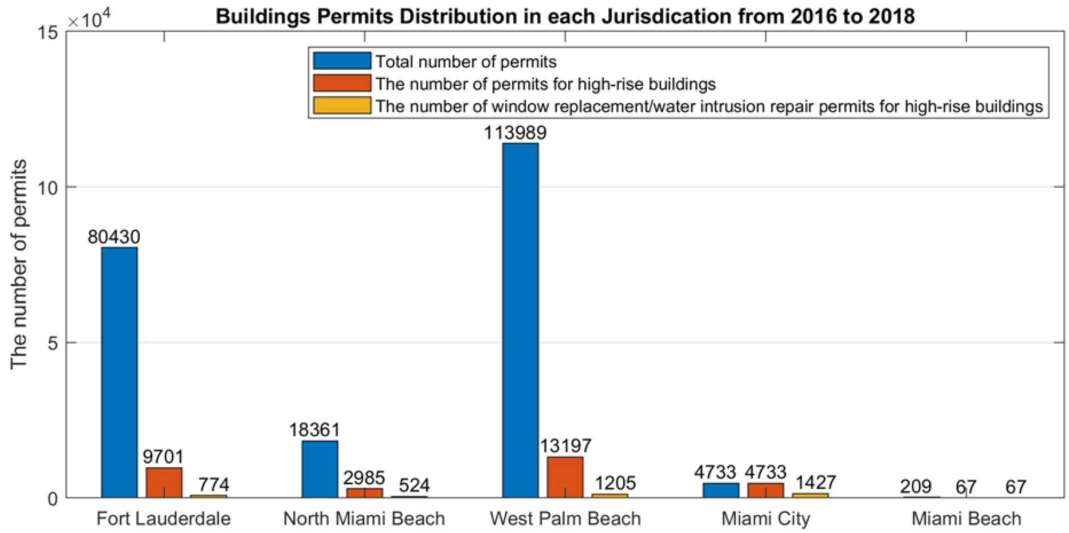


Figure 2. Building permits distribution information

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

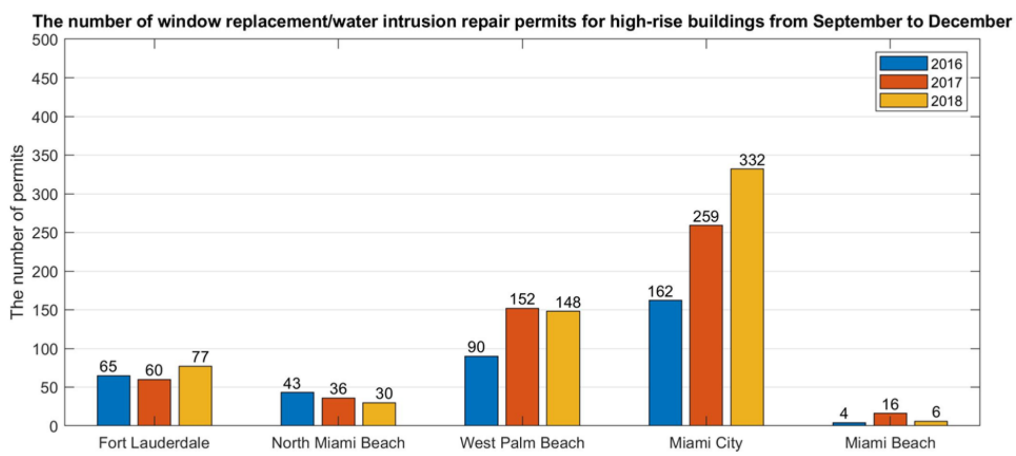


Figure 3. The number of buiding permits from September to December in each year(For example, in Fort Lauderdale, there are 65 building permits record both related to high rise building and wind replaecment repair from September to December in 2016)

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 2. 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

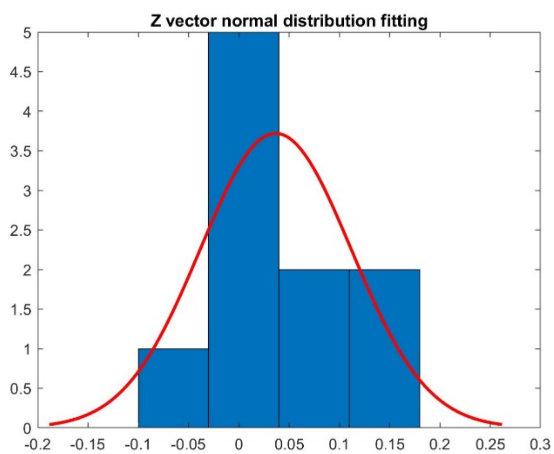
**note:*

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 3. 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 E. **FENESTRATION 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).
  - o 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.
  - o 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 F. 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:

Chapter 16: Structural Design

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).

SIMPSON GUMPERTZ & HEGER INC.
480 Totten Pond Road, Waltham, MA 02451 main: 781.907.9000 fax: 781.907.9009 www.sgh.com
Boston | Chicago | Houston | New York | San Francisco | Southern California | Washington, DC

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.

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