**Scope of Work**

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

The State of Florida Department of Business and Professional Regulation

Florida Building Commission

And

University of Florida, Engineering School of Sustainable Infrastructure and Environment

(ESSIE)

Project Leader: David O. Prevatt, PhD Civil Eng., F. ASCE, Univ. of Florida

# Introduction

The University of Florida, Engineering School of Sustainable Infrastructure and Environment (ESSIE) shall conduct research to study issues related to water intrusion through building envelope systems during hurricanes. This project will be led by Dr. David O. Prevatt, Associate Professor of Civil Engineering, in collaboration with Dr. Jean-Paul Pinelli of Florida Institute of Technology.

# Relevant Sections of the Code (and related documents)

* 2017 Florida Building Code- Building, Sixth Edition, Chapter 14 “Exterior wall’, this chapter establishes minimum requirements for exterior walls, exterior wall coverings; exterior wall openings, exterior windows and doors, architecture trim, balconies. This chapter refers to
  + ASTM 226 standard test for water-resistive barrier.
  + ASTM E2273 standard test for exterior windows and doors,
  + ASTM E331 and ASTM E547 standard test for exterior windows, skylights, doors, and curtain walls.
* 2017 Florida Building Code- Building, Sixth Edition, Chapter 17 “Special installations and Test.” This chapter governs the quality workmanship and requirements for materials covered. Materials of construction and tests shall conform to the applicable standards listed in this code. This chapter refers to
  + TAS 200 tests for exterior windows and doors,
  + ASTM E330 Standard test for garage door and rolling door.
* 2017 Florida Building Code- Building, Sixth Edition, Residential
  + Chapter 6: Fenestrations and Wall Construction,
  + Chapter 7: Wall Covering
  + Chapter 9: Roof Assemblies
* Related documents:

**ASTM E2112 – 19b** “Standard Practice for Installation of Exterior Windows, Doors and Skylights.” ASTM International, West Conshohocken, PA, 2016, [www.astm.org](http://www.astm.org)

**ASTM E331 – 00** “Standard Test Method for Water Penetration of Exterior Windows, Skylights, Doors, and Curtain Walls by Uniform Static Air Pressure.’’ ASTM International, West Conshohocken, PA, 2016, [www.astm.org](http://www.astm.org)

**ASTM E547 - 00** “Standard Test Method for Water Penetration of Exterior Windows, Skylights, Doors, and Curtain Walls by Cyclic Static Air Pressure Difference”. ASTM International, West Conshohocken, PA, 2016, [www.astm.org](http://www.astm.org)

**ASTM C1601 -14a** “Standard Test Method for Field Determination of Water Penetration of Masonry Wall surfaces. ASTM International, West Conshohocken, PA, 2017, [www.astm.org](http://www.astm.org)

**ASTM E330** “Standard Test Method for Structural Performance of Exterior Windows, Doors, Skylights and Curtain Walls by Uniform Static Air Pressure Difference”. ASTM International, West Conshohocken, PA, 2016, www.astm.org

**ASTM E2273-18** “Standard Test Method for Determining the Drainage Efficiency of Exterior Insulation and Finish Systems (EIFS) Clad Wall Assemblies”. ASTM International, West Conshohocken, PA, 2017, www.astm.org

**TAS 202 – 94** “Criteria for Testing Impact and Nonimpact Resistant Building Envelope Components Using Uniform Static Air Pressure.” 2017 Florida Building Code – Test Protocols for high Velocity Hurricane Zone, Sixth Edition.

**ASTM D226/D226M—17** “Standard Specification for Asphalt-Saturated Organic Felt Used in Roofing and Waterproofing.’’ ASTM International, West Conshohocken, PA, 2017, [www.astm.org](http://www.astm.org)

**AAMA/WDMA/CSA101/I.S.2**: NAFS-North American Fenestration Standard/ Specification for windows, doors, and skylights.

# Scope of Work

This research shall shed light on the apparent water leakage issues in mid to high-rise buildings occurring during Hurricane Irma and as discussed in Phase I of the Workgroup. The investigation of common cladding systems used in Florida for mid- to high-rise building envelope systems will provide a reference in building water intrusion characteristics. The scope includes the following:

### ESSIE shall assemble a Project Team consisting of representatives of Florida homeowners of a condominium or apartment unit in a high-rise building, the Condominium management team, a building envelope consultant, a municipal authority representative and a researcher with the Florida Public Hurricane Loss Model (FPHLM) program. As a minimum, the Project Team will include a homeowner of an apartment unit, a building owner of condominium association representative, a professional building envelope consultant with at least 25 years in-charge experience and a Miami-Dade building official familiar with the issues related to mid- to high-rise building construction. Details are provided in Section 11 below, of this proposal.

### Project Team Task 1

### The Project Team’s first task is meeting to discuss the issues that are critical to prosperity of the Florida residents. The discussion shall strive to determine what different interpretations of facts about hurricane risk and water intrusion exist between the lay-persona and professionals in a construction team.

### The Project Team shall identify two or three common building envelope systems (stucco, EIFS curtain wall, brick) used in mid to high-rise Florida construction by interviewing building officials and architects in Metro-Dade, Tampa, and Orlando areas. The typical systems shall be typical of construction exposed to high winds in Hurricane Irma of 2017.

### The Project Team will discuss and explain the procedures for conducting mock-up tests (per ASTM E547, C1601or similar) to homeowners and condominium association representatives, as well as provide an assessment of current expectations for water intrusion (quantify and volume) for the systems.

1. Project Team’s Task 2 🡪 Discuss the Issues
   1. Are Florida homeowners fully aware of potential liability risks from wind and water leaks?
   2. Is knowledge available of magnitude and duration for wind-driven rain on surfaces?
   3. Can emergency buildings or a critical facility remain leak-free during a design-level event?
   4. What are successful approaches by building envelope consultants to mitigate water leakage in FL hurricane-prone coastlines?
   5. 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
   6. Is a 100% water-impermeable building envelope system achievable, and at what cost?
   7. How can we collect data on water leaks during hurricanes?
   8. What additional information is needed to calibrate the FPHLM?
2. Project Team’s Task 3 🡪 Envelope mockup contract specifications
   * Identify a building in South Florida and work with a client, building consultants, building cladding element manufacturers, architect
   * Participate in the design and testing of building envelope including a full-scale two-story mockup having all major building envelope elements
     + Building cladding
     + Sealants and Joints
     + Fenestration (fixed and operable)
     + Spandrel panels
     + Structural framing
   * Witness/observe the mock-up test done in accordance with client’s specification per contract specifications
   * Continue mock-up testing beyond the contractual test limits as far as Project Team considers reasonable at same test facility
   * Document the locations, leak paths and quantity of water leakage
3. Project Team’s Task 4 🡪 FPHLM Calibration
   * Use results from mockups to calibrate the loss models of the FPHLM
   * Use FPHLM to predict economic losses expected in a) minimal to b) moderate hurricane event (as defined by Project Team)
   * Develop a scenario for conditions to explain to homeowners and municipal managers of the extent of disruptions in simulated hurricane events
   * Report findings and discuss with Municipal representatives and Homeowner representative and FDEM
   * Report to the Workgroup and Florida Building Commission on the following:
     + Review of the test results from above.
     + Adjust the building cladding defects sizes in the FPHLM to achieve similar amounts of water penetration as documented by the tests.
     + Run portfolios of mid/high-rise buildings (above 4 stories) through the FPHLM, and compare the resulting losses due to water ingress through defects of the fenestration, to observed losses from hurricane Irma, and claim data if available.
     + Repeat the cycle as needed to achieve a reasonable match between FPHLM projected losses and data.
     + Document the influence of the recalibration on average annual loss (AAL) and 100-year probable maximum loss (PML).

### The Project Team shall present to the Workgroup a summary presentation on outcomes of their work within each Project Team’s area of expertise.

### The Contractor shall support the Workgroup deliberations in proposing recommendations for FBC to improve current water intrusion test standard and recommendations for mitigating high-rise building water leakage issues in relatively low intensity hurricane.

# Method of Payment

A purchase order will be issued to the University of Florida/Engineering School of Sustainable Infrastructure and Environment (ESSIE). This project shall start on the date of execution of the purchase order and end at midnight on June 30, 2020 and shall not exceed $147,000 or $283,000 (includes option for mock-up curtainwall test) and shall cover all costs for labor, materials, and overhead. Payment will be made for the study after the Contract Manager, Program Manager and Commission’s Structural Technical Advisory Committee have approved the final report.

# Deliverables

### An interim report shall be prepared and delivered no later than April 15, 2020 and shall summarize the results of tasks and the current status of project. The interim report should include the following:

1. A summary of current Florida high-rise building envelope system
2. Full scale mock-up test results at 15% (if original envelope systems was not previously tested), 25%, 50%, 60%, 75% (if feasible) of structural design pressure
3. An analysis of test result and decision whether on-site tests are necessary should be incorporated in the report.

### A final report shall be prepared and delivered no later than June 19, 2020 comprising of the information in the interim report augmented by TAC feedback on the following:

### On-site test results and an analysis of test results (if on-site tests are necessary).

1. Recommendation for current water intrusion test.
2. Mitigation methods for fenestration water leakage issues.

# Performance Measures and Financial Consequences

ESSIE is solely and uniquely responsible for the satisfactory performance of the tasks and completion of the deliverables as described in this Scope of work.

Failure to complete the task and deliverables in the time and manner specified in Sections 3 and 5 shall result in a non-payment of invoice until corrective action is completed as prescribed by the program manager or contract manager.

# Contract Manager and Program Manager

The Contract Manager for this purchase order is Barbara Bryant and the Program Manager is Mo Madani.

# Goals

The goals of this research are the following:

### Report on current homeowner expectations for water leakage during hurricanes and the repair of buildings following a design level event in Miami-Dade County.

### Summarize common building envelope systems for high-rise Florida buildings.

### Verify whether existing code could adequately prevent water leakage during extreme weather, by conducting water intrusion tests at approval facility at 15% (if original envelope systems was not previously tested), 25%, 50%, 60% and 75% (if feasible) of structural design pressure

### Recalibrate Florida Public Hurricane Loss Model with mock-up test results.

# Background

According to the real estate data mining group Emporis ([www.emporis.com](https://www.emporis.com/)), the City of Miami, Florida, has the country's third-tallest skyline with over 300 high-rises, 80 of which stand taller than 400 feet (120 m). In addition, the city has a very large number of mid-rise buildings, which house a substantial part of the city’s population, and represent a substantial exposure value. Miami is also the largest major US city with the highest design wind speeds (170 mph 3-second gust) and greatest threat of being hit by a hurricane.

Many of the city’s residents live in mid-rise or high-rise buildings, which are potentially highly vulnerable to water leakage through their facades and the subsequent damage to the interior and contents but the extent of this vulnerability is unknown. In one survey, [www.skyscraper.com](https://www.skyscrapercenter.com/city/miami) reported that 68% (of 63) Miami structures that are over 150 m tall are residential, 21% are mixed-used and 10% are office buildings. There is a growing trend for increasingly taller buildings here, and in the next four years 17 more buildings standing well above 100 m will be added to the Miami skyline.

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| Fig.1 Building Completions Timeline: 100 m+ buildings Completed in Miami, FL over past 50 years ([www.skyscraper.com](http://www.skyscraper.com)) |

The [University of Florida’s report to the Water Intrusion Work Group](https://www.dropbox.com/s/rkjdf76gg6n0wby/Prevatt-UF-Water%20Resistance%20WorkingGroup-%20FINAL%2007-08-2019.pdf?dl=0) concluded that building envelope systems in mid to high rise buildings (i.e. buildings with more than 4 stories) will leak during the occurrence of wind-driven rain events such as design-level hurricanes. The wind loads in Miami, during Hurricane Irma were about 25% of the design loads for most buildings and yet several engineers and building officials observed widespread water leakage in several buildings. The UF report was less clear on identifying specific locations or envelope systems through which the leaks occurred, on the quantity of water leakage that actually occurred or the economic costs to repair the damage.

It was noted too, that current water penetration test standards cap their test pressures around 15 to 20% of structural design pressures, and so both the industry and contractors, building officials and homeowners lack reliable information to ascertain the extent of water leaks through a building envelope system that will occur at or near to the design-level wind pressures.

It is technically possible for an experienced Building Envelope design consultant to develop the appropriate design options to achieve a client’s desired level of water tightness for their building, minimizing water leaks, but with aesthetic as well as economic (cost) tradeoffs. The designer could select from several choices of cladding material, structural systems, the shape and sizes of joints, the choice of sealant and the provision and location of weep holes in order to minimize water entry. The designers would also be aware that wind pressures on a building quadruple every time the wind velocity doubles. So, any cladding system and components that work up to say 20 ft or 30 ft, are likely to leak spectacularly when used for apartment units at 100 ft or 200 ft above grade, whether or not the structural system is undamaged.

In this scenario several questions confront the Florida Building Commission regarding the purpose of building code guidelines going forward.

* Is water leakage acceptable for any structure designed in accordance with the Florida Building Code within the structural load range from 25% to 100 % of the design structural load?
* Are Miami apartment and condominium residents in high rise structures aware that water leakage is highly likely, and will probably occur into their apartment units in every wind driven rain event?
* What is the total economic loss due to water leakage to the state of Florida from water leaks due to a less than design-event hurricane and who pays?
* Will water leaks during a hurricane be sufficient to render a home unlivable, unfit to shelter in place and prompt its residents to evacuate? How many would be affected? What would be the cost of the additional living expenses?
* When water leaks occur will that water damage other structural or MEP systems?
* Is water leakage a concern among residents of high-rise buildings and how much are they willing to pay to ensure a dry post–hurricane building?
* How does the insurance industry compensate policyholders for property damage due to water leaks when no structural damage has occurred during the event?

Hurricane Irma made landfall on 10 September 2017 in the Florida Keys and then on the west coast of Florida near Marco Island. Irma was a minimal mainland hurricane event in Florida but its path and size of the rain bands produced elevated winds and heavy rains over the Florida peninsula from south to north. Although wind speeds in Miami and environs were less than 88 mph, over thousands of condo/apartment units experienced leaks in one survey of 15 buildings presented to the Workgroup. The leak paths and or volume or extent of the leaks were not determined. Irma’s strength was only that of a minimal hurricane in the Miami area.

The issues of water leaks through building envelope systems in such below design level low/moderate wind pressure events is not new, as available studies have documented the likelihood of water leaks, since at least 2005. What is still undetermined is the extent of such leakage on the buildings and their residents in a hurricane-strength wind/rain event. The UF report identified a potential disconnect between the insurance models that are used to predict hurricane damage and the observed damage from Irma. It is clear that more information is required by the Florida Building Commission to better understand the scope of the problem, and in order to determine whether or not a building code solution exists or is warranted to protect Floridians faced with the annual threat of hurricane landfalls.

As previously reported, the University of Florida orchestrated a comprehensive study of water leakage characteristics for low-rise residential structures (Salzano et al. 2010) (Lopez et al. 2011). That study identified principal leakage paths and it ranked the wind-driven rain resistance of many wind systems and cladding materials used in Florida construction. In concept, a similar study is proposed here adapted to the information needed to ascertain the performance of building envelope systems in high-rise coastal structures.

# Motivation

If one objective of the Florida Building Code is to minimize the economic losses and disruption to Florida homeowners from hurricanes it would be necessary, as a minimum to establish through research how wind-driven rain from hurricanes affects the hundreds of high-rise buildings in our three largest urban areas (Miami-Dade, Tampa and Orlando).

The current product approval standards for water intrusion do not extend up to the structural design wind pressure of building envelope systems. The scientific justification for the current accepted test pressure is clouded with the passage of time. Further, it is unclear if building envelope systems ought to be holistically tested including their windows and doors to establish water leak performance. Further, there is some debate as to the selection of an appropriate fluctuating wind pressure and water wetting rain that represents conditions occurring during the peak hours of a strong hurricane.

The only observations of water resistance performance at design wind pressures will come during actual hurricane-force conditions of future events. As a result, the residents and building owners of high-rise condo and apartment units cannot be provided with any plausible information as what to expect in terms of quantity of water leakage during the next hurricane.

The Workgroup has limited information on the process of building envelope design or of the experience from actual Floridian homeowners who have witnessed a hurricane impact. Therefore we propose to obtain input from them.

This proposal from the University of Florida (The Contractor) will offer data and guidance to the Florida Building Commission so that it could achieve that goal.

# Scope of Work

This research shall shed light on the apparent water leakage issues in mid to high-rise buildings occurring during Hurricane Irma and as discussed in Phase I of the Workgroup. The investigation of common cladding systems used in Florida for mid- to high-rise building envelope systems will provide a reference in building water intrusion characteristics.

The scope includes the following:

* Formation of a Project Team consisting of a Building Envelope Consultant, a Building Official from the Miami district, a representative from the Condominium Association of high-rise building and a Condominium owner and a representative of a Test Approval Organization.
* Wind-driven-rain tests of full-scale mock-ups of building cladding of at least a two-story tall mockup of building envelope system of a high-rise building that includes horizontal and vertical sealant joints, spandrel panel, cladding systems and fenestration. The system will be selected from a proposed or existing building, or developed by the building envelope consultant
* Results for full-scale tests will be applied to FPHLM models and used to predict the potential economic losses to be expected from a minimal to moderate hurricane strength event that does not reach or exceed the design wind speed.
* Project Team will develop a presentation to the Workgroup on their expertise and expectations.
  + The Condo Association representative will provide their historical observations and what they expect from a new home,
  + The homeowner will provide their experience with direct insurance and repairing of their house and the impact on quality of life after a hurricane.
  + the building consultant will describe how the process of design proceeds and with examples of what is adopted for the Florida conditions
  + The Building Official will discuss the expectations for their community in terms of losses, evacuation and housing of populations in high-rise buildings experiencing a design level storm
  + Dr. Pinelli will present the projections of the FPHLM regarding the potential losses Florida could experience.

The formation of the Project Team may be unconventional as it is important for the Workgroup to receive the unfiltered input from typical homeowners and building owners who will be living through hurricanes in these high-rise structures along coastal Florida. The most important consideration is how thousands of Floridians sheltering in mid to high rise buildings will deal with water-intrusion during a design-level hurricane. Our research shows that members of the public hold misconceptions as to the extent of potential damage from hurricanes – mainly reflected in optimistic biases as to potential damage. The public’s interpretation of building code guidelines are not necessarily aligned with the interpretations of experts in building construction. The Workgroup and the Florida Building Commission should hear from our Florida residents in their own words, free from special interpretations by engineers, contractors, product manufacturers or other construction professionals.

The results can be reduced to a table with water test pressures and probabilities of water leakage failure of the fenestrations, joints and cladding systems. Homeowners provided with this information will have the possibility to choose “how much damage they are willing to accept from any strength of wind-driven rain event”, essentially promoting performance-based design. The tests results can also be used to calibrate the FPHLM water penetration model, to better capture the influence of fenestration defects on insured losses. A properly calibrated FPHLM can incorporate mitigation measures to quantify their benefits as the difference between the damage without and with mitigation. Finally, a preliminary benefit/cost analysis on selected apartment buildings can be carried out.

It is anticipated there will be several important milestones before obtaining the green-light for full-scale mock-up tests. It is likely these tests are not achievable within the first year of Phase II as there are many legal and or contractual restrictions to the use of existing building mockups for this unique purpose. The Project Team will work with University of Florida to develop an approach, identify a building owner, and products manufacturers who are willing to work with us. The cooperating parties will agree to share contract documents and specifications for the building envelope façade and approval test procedures.

# Current Test Methods for Water intrusion in Building Envelope Systems

The standard water intrusion test is ASTM E331-00 (Reapproved 2016) which test water penetration of exterior windows, skylights, doors when water is applied to the outdoor face and exposed edges simultaneously with a 2.86psf uniform static air pressure at the outdoor face higher than pressure at the indoor face. ASTM E547-00(Reapproved 2016) tests is also similar to the ASTM E331-00 with exception of the cyclic air pressure applied.

AAMA (American Architectural manufacturers Association) created a table “Water Test Pressure Equivalent Wind Velocities for Windows Tested to the Nationally- Recognized Standard” in 2005. This table applies to R(residential), LC (light commercial), C (commercial) HC (high commercial) performance class windows & doors, which recommend to use 15% design structural pressure (minimum 2.86 psf; max 12 psf) for water penetration test.

However, current test methods apply 15% design structural pressure to test fenestrations water leakage performance. Whereas realistic wind pressure in extreme weather is much higher than 15% design pressure. How the windows & doors behave under 25%, 50%, 75% design pressure is unknown, although the assumption is the leakage issues may be more serious with pressure increasing.

AAMA published a note titled “Storm-Driven Rain Penetration of Windows and Doors,” dated 28 November 2005 that addressed questions raised by residents who experienced wind-driven rain through windows and doors (that otherwise remained unbroken and structurally intact) following hurricanes and tropical storms. In Table 1 of this note (see Appendix B), captioned “Water Test Pressure Equivalent Wind Velocities for Windows Tested to Nationally-Recognized Standard,” we noted the following:

* **Footnote 2** regarding water test pressure states: *Applies to R, LC, C and HC performance class windows and doors (15% of design pressure; minimum 2.86 psf; max 12 psf); AW performance class is tested for water penetration at 20% design pressure.*
* **Footnote 4** of Table 1 which applies to four highest levels of Design Pressure Ratings (85 psf, 90 psf, 95 psf and 100 psf) where water test pressure exceeded 12 psf, states: *For comparison only: the national standard caps water test pressure at 12 psf.*

The above information led the research team to conclude that at that time AAMA had established a water intrusion testing standard for windows and doors capped at 12 psf related to a wind velocity of about 68 mph (see Appendix B). We were told, during the June 2019 review of the final report submitted to the Workgroup, that these water test pressure values had since been increased to 15 psf (design pressure rating of 100 psf).

The research team concluded that the current approval test criteria for water penetration in windows and doors employed in the manufacturing and design of fenestrations was not developed to evaluate the water resistance of fenestrations at the structural design pressures imposed by design level (hurricane-strength) winds. Further, it is not clear where building envelope systems are also subjected to leakage tests. Thus, there is an expectation of water leakage at or around design wind pressures for Florida structures.

The current water test pressure criteria cannot adequately protect the public from water intrusion in a hurricane prone-region, as the water penetration resistance of building envelope systems and fenestrations at or around structural design pressures for windows and doors cannot be inferred from a water test conducted at 15 psf, or 20% of the structural design wind pressure. Furthermore, it should be noted that the design wind pressure at 10 m (or 33 ft), as the FBC specifies through ASCE-7, and the corresponding wind-driven rain intensity, increase logarithmically with height, so that fenestration at the upper floors of a high-rise building is at much greater risk of water leakage. ADD REFERENCE Masters on rain intensity with height

The current standard for water intrusion testing is too low to assure water resistance during hurricane-force winds for the following reasons: 1) the testing is for brand-new assembly installed and tested in a laboratory environment, 2) there are no provisions or requirements for in situ testing after installation, and 3) there is no justification for the selection of 15% of design pressure to be used as a standard.

Contact Building Managers Associations to survey regarding damage?

# Anticipated Budget and Justification

The UF is a land-grant institution that is today a large public university offering a full spectrum of educational opportunities. The Engineering School for Sustainable Infrastructure and Environment is working with Florida Technical College.

# Budget Estimate (To be Completed after receiving directive from the FBC Staff)

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| Test agency budget | UF Budget Breakdown |
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# UF Budget Breakdown by Labor Hours

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| --- | --- | --- | --- | --- | --- | --- |
| **Person** | **Hours** | **Hourly Rate** | **Fringe** | **Tuition** | **IDC** | **Total** |
| D. Prevatt |  |  |  |  |  |  |
| Admin Assistant |  |  |  |  |  |  |
| Grad Student |  |  |  |  |  |  |
| Undergraduate Students |  |  |  |  |  |  |

**Budget**

# References

Katsaros, J. D., and Carll, C. G. (2009). "Extreme Exposure Fenestration Installations—The Florida Challenge." *Journal of ASTM International*, 6(5), 1-17.

Lopez, C., Masters, F. J., and Bolton, S. (2011). "Water penetration resistance of residential window and wall systems subjected to steady and unsteady wind loading." *Building and Environment*, 46(7), 1329-1342.

Salzano, C. T., Masters, F. J., and Katsaros, J. D. (2010). "Water penetration resistance of residential window installation options for hurricane-prone areas." *Building and Environment*, 45(6), 1373-1388.