A Resource for the State of Florida

HURRICANE LOSS REDUCTION
FOR
HOUSING IN FLORIDA:

Section 2

PRELIMINARY INVESTIGATION OF WIND-DRIVEN RAIN INTRUSION THROUGH SOFFITS

A Research Project Funded by
The State of Florida Department of Community Affairs
Through Contract # 06RC-A%-13-00-05-261

Prepared by:

Forrest Masters, PhD
Assistant Professor of Civil and Environmental Engineering
Florida International University

In Partnership with:
The International Hurricane Research Center
Florida International University

1 Introduction

Damage reconnaissance studies conducted after the 2004 and 2005 hurricanes found that many single-family low-rise homes remain vulnerable to wind-driven water intrusion through soffits (IBHS 2004, FEMA 2006). While many homes survived structurally, they experienced enough rain penetration to require interior restoration and in some cases, occupant displacement until the completion of repairs. This study investigates this phenomenon, ultimately to take the first step towards

1. Establishing wind and wind-driven rain resistance design requirements for soffit performance in a design-level hurricane event using full-scale testing techniques
2. Based on these findings,
    a. Developing (i) design solutions for new homes and (ii) retrofitting techniques for existing homes using the most efficient combination of bracing, anchorage, blocking and modified panel shapes from common construction materials
    b. Developing a scope of work for future testing in Wall of Wind apparatuses
3. Creating a strong industry partnership with stakeholders in engineering, homebuilding, insurance and product manufacturing to
    a. Conduct open, unbiased research
    b. Conjoin individual stakeholder interpretations into an "industry-wide" consensus
    c. Propose modifications to TAS 100(A)-95 and D4756-03 if merited

2 Experimental Configuration

To simulate wind-driven rain intrusion through a soffit, the Phase I Wall of Wind testing apparatus was utilized to create a wind and wind-driven rain field sufficiently large enough to envelop a partial mockup of a house wall/roof system. This section elaborates on these systems. All testing took place at the Eastside Campus of the University of Florida. The four major rounds of testing were completed in 2006 during January 2-6, March 16-17, May 22-23 and July 26-28.

2.1 The Phase I Wall of Wind

The wind generator—known as the Phase I Wall of Wind—is a portable two-engine array fabricated by Diamondback Airboats in the spring of 2005. The Wall of Wind was developed by Florida International University; funding was provided by the Florida Department of Community Affairs through the Residential Construction Mitigation Program. Vertically stacked PCM 496 in^3 motors drive counter-rotating planetary drive units, which turn two 70+ in airboat carbon fiber propellers. At the exit, a water injection system creates wind-driven rain which travels through 12 ft wall enclosures before impinging on the test subject. Major modifications were carried out in the spring to improve testing capabilities.

These include:

- Replacement of the 3 in mufflers with 4 in silencers that decreased the sound intensity from 120 dB to 110 dB but did not decrease engine performance
- Replacement of the manual cable system with digital, titanium-gear, coreless, ball-bearing servos to actuate the throttle body. National Instruments boards were first used to send out pulse width modulation commands through counters. These were later replaced with a Pololu USB servo-controller that is operated with serial port commands
- The addition of a 5 gpm hydraulic pump, a solenoid-operated proportional flow control valve, a custom hydraulic cylinder and a rotary potentiometer to measure angular displacement to move the rudder system quickly and accurately (currently in development)
- The addition of water injection system fed by two 8 hp pumps connected to a custom recirculating pipe system connected to two 550 gallon tanks. 10 minutes of operation required approximately one tank. A Hall Effect flowmeter was also installed to monitor the flow rate (Figure 1)
- Complete rewiring and ruggedization of all cabling and conduit to expedite transport and setup. Military specification connections were added and all wiring terminated into a junction box. Two 50 pin cables now connect the Wall of Wind to a portable trailer, where the data acquisition and control equipment are stored in a climate controlled environment (Figure 2)

Figure 1 Water Injection System

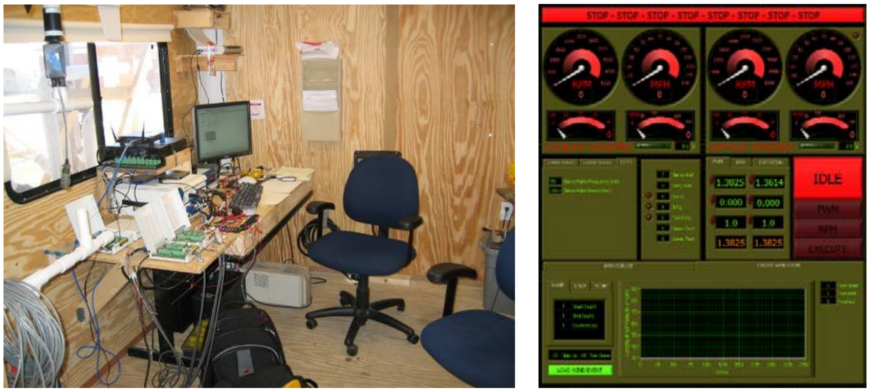

Figure 2 Control Room and Labview Control Software

2.2 The Soffit Testing Rig

For this investigation, Mr. Richard Reynolds (with the support of the Institute for Business and Home Safety) designed and built a roof and wall assembly that could be quickly and easily adjusted to create overhangs of various fixed lengths for flat and 6:12 slopes. The rig has four components: wall assembly, pitched roof structure, and plumb-cut and square-cut rafter tail assemblies. The experimental configuration used in this study (6:12 slope, 1 ft overhang, plumb-cut rafters) is shown below.

Figure 3 Soffit Testing Rig (Built by Mr. Richard Reynolds)

The wall component served to provide support for the roof assembly and was secured to a 2X4 framing to prevent overturning. Diagonal 1X4 bracing resisted collapse, and wall and ceiling (in lieu of drywall for water resistance) were made out of ½” CDX plywood screwed at 6” O.C. on the edges and 12” O.C. on the field. Bracing was also added on the backside of the rig to prevent racking during transport.

The test rig was comprised of two pieces: the pitched roof structure and either the plumb-cut or the square-cut rafter assembly. The purpose of the pitched roof structure was to extend or contract the rafter tails to simulate 6”, 12”, 18”, 24” and 30” overhangs without having to replace the entire roof assembly. The square-cut and plumb-cut rafter assembly could also be quickly switched out with this configuration. The clear space between the interior rafters was 22.5” and the bottom chord was secured to the wall with hurricane ties and screws. The plumb-cut rafter tail was installed for this study to produce a plumb fascia in order to expedite removal/installation of soffit material. Finally, GAF Liberty Self-Adhering 90 lb Cap Sheet was applied to the roof and folded over the fascia board. Pictures of the installation and the final setup are shown in Figures 4 and 5, respectively.

Figure 4 Installation of Soffit Rig

Figure 5 Final Wall of Wind Configuration

2.3 Roles and Responsibilities of Research Personnel during Testing

1. **Control**. Responsible for (a) design of the wind and wind-driven rain fields prior to the test, (b) execution of the control program to reproduce these conditions and (c) data acquisition. The Control did not directly observe the experiment because of the limited field of view provided by the trailer. The Engine/Rig Bosses served as his "eyes and ears"

2. **Engine Boss**. Responsible for (a) clearing all project personnel from the engine shroud, inside the tunnel walls and near the rig prior to the test, (b) starting and stopping the engines at the instruction of Control, (b) monitoring the performance of the engines and hydraulics, and (c) interrupting or ceasing operation of the Wall of Wind at any sign of malfunction or incipient danger

3. **Rig Boss**. Responsible for setting up the experiment and coordinating the various individuals tasked to carry out the experiment:

   a. **Rain Operator**. Attends to the water injection system during each test. He or she will operate a gate valve to divert the flow from the water injection system back into the reservoir when wind-driven rain is not required
   b. **Camera Operator**. Responsible for the installation, maintenance and operation of all camera equipment and lighting. This person must be prepared for recording all mediums prior to the test (i.e. transfer all imagery from the high speed camera buffer to the laptop and have adequate film in the other cameras)
   c. **Investigation Team**. This is the group (comprised of regular and visiting personnel) that will observe the experiment from inside the test rig or in any place that physical danger is not present

4. **Recorder**. Pre-testing, responsible for logging the experimental configuration, instrument locations and the names of attendees. During testing, responsible for monitoring instrument behavior. After testing, responsible for organizing the results (including the output from the data acquisition system)

3 Testing Procedures

Among the researchers involved in this project, it was wholly agreed that given the scale and safety issues and the long-term nature of the project, the development of efficient, repeatable and observable tests in hurricane conditions was a high priority. A number of novel approaches were attempted, before a standard methodology was adopted to investigate the intrusion of wind-driven rain through the soffit. This section discusses new insights into these techniques and presents the adopted procedure.

3.1 Visualization

Prior to conducting tests to quantify wind-driven rain intrusion, visualization experiments were carried out to assist with their development. This section details this work.

3.1.1 Smoke Visualization

An Aerolab Smoke Generator was deployed in front of the soffit rig to determine its viability as a visualization tool. During tests, the tuft wand was placed 6” to 24” from the soffit rig (shown in Figure 6). The smoke patterns were highly variable, and it was generally agreed by all of the attending investigators, its use was highly unadvisable. First, turbulence produced from the counter-rotating propellers and rudders in a static position was sufficient to compromise its effectiveness as a visualization tool. Second, the danger of using flammable liquids (and the propensity of the tip to catch on fire) is an unnecessary danger, given the safety issues already involved with the Wall of Wind.

Figure 6 Smoke Visualization

3.1.2 High-Speed Camera Imagery

A Photron Ultima 512 camera captured high-speed video in the soffit space (above the soffit and below the rafters as shown in Figure 7). At 1000 fps, the capabilities of the camera allowed for 6 s of 512 X 512 pixel frame footage before the circular buffer rewrote the first frame. These high speed videos will shortly be available on the IHRC website (www.ihrc.fiu.edu) for the soffits tested in this study.

Distinguishable raindrop patterns were evident, and several commonly observed trajectories are overlaid onto the frame in Figure 8. In the perforated vinyl soffits, particles entering near the eave were often carried directly into the attic space, while the remainder struck the wall assembly before gravity forced the rain to collect into puddles at the channel. Water buildup was also evident on top of the soffits (especially in the hidden vent soffit) and multiple observations were made of these puddles “erupting” with sufficient force to send water particles into the channel of air that passed over the wall into the attic space. Constricting the area of this channel was later attempted with baffling to mitigate the rate of intrusion, but little effect was observed.

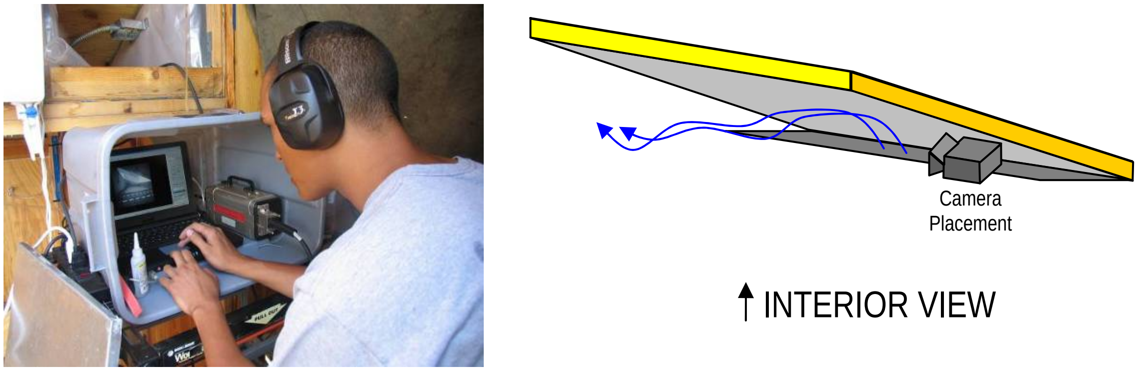

Figure 7 High Speed Camera Imagery

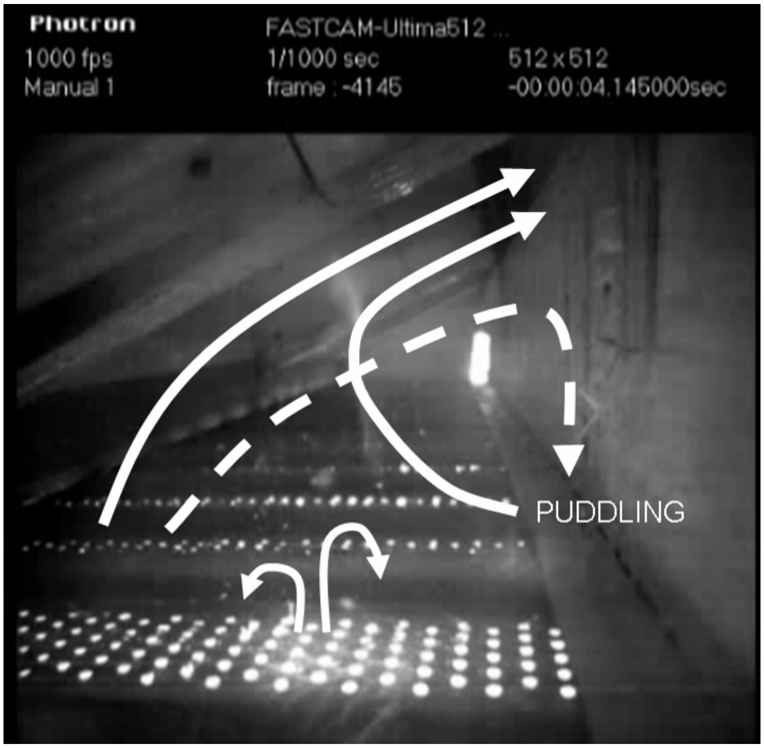

Figure 8 Typical Primary and Secondary Raindrop Paths

3.1.3 Fluorescent Tracer Dye

To aid in visualization, a fluorescent tracer dye used for leak detection was added to the water supply and the attic area was enclosed to produce a dark room. First, Figure 9 presents pictures of the attic space under full enclosure (on the left) and in partial daylight (on the right, particles are in midflight). In both cases, the use of the fluorescent tracer dye proved to be an excellent forensic tool as the tracer particulates neither adhered to the interior of the soffit rig nor required any major cleanup. The distribution of the droplets on the attic floor was also evident (e.g., a greater deposition near the soffit/attic space interface was observed using the hidden vent soffit). The fluorescing agent also made it possible to visualize the water that collected on the underside of the roof decking in the attic space. It was found that very little of this water gravity fed back into the soffit space. Instead, large drops were observed descending into the channel of air feeding into the attic space, which forced them farther into the test assembly. It was also observed that smaller particles of water normally unnoticed by the human eye were highly visible with the addition of the tracer dye. The low-cost ($100 treats 1 million gallons) also makes its use an appealing approach for future investigations.

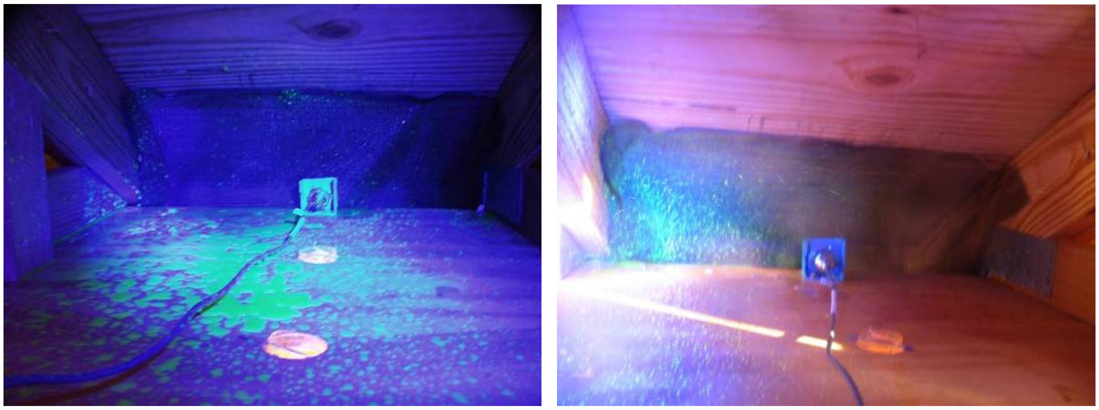

Figure 9 Visualization with Fluorescent Tracer Dye

3.2 Quantification of Wind-Driven Rain Intrusion

3.2.1 Test Specimens

A total of six soffit systems were tested. Three commonly used ventilated soffits were chosen for this experiment:

1. Hidden vent soffit (9.19 in^2/ft^2 free space area)
2. Perforated vinyl soffit (5.87 in^2/ft^2 free space area)
3. Perforated aluminum soffit (15 in^2/ft^2 free space area)

The fourth and fifth soffits were hybrid perforated systems and the sixth specimen was custom fabricated:

4. The perforated vinyl soffit was tested in conjunction with an insect screen across the threshold of the attic and soffit space (shown below)

Figure 10 Use of Insect Screen to Retard Wind-Driven Intrusion into the Attic Space

5. 2.25” deflectors were added to the hidden vent soffits (as shown in Figure 11)

Figure 11 Hidden Vent Soffit (original on left) with the deflectors (modified on right)

6. The baffled system proposed by Lstiburek (2004) to “reduce air pressure driving forces and facilitate the use of air pressure changes to deposit rain in soffit assemblies rather than in attic spaces” was also tested. The vents in the soffit were sealed and a 1 inch slot was cut through the middle of the panels. 2X4 blocking (baffling) was also added at the basin entrance, and a combination of flashing and plumber’s putty created a watertight seal

Figure 12 Slot Vent and Baffle System (Existing Soffit Vents were Sealed)

3.2 Development of Testing Procedures

Research personnel iteratively improved the measurement approach until a suitable method was identified. Figure 13 shows the first attempt to measure wetting using carpet rebond cushion material (high-density urethane foam).

Figures 13 A Poor Choice for Wetting Measurements: Carpet Rebond

Four sliding mesh trays held the rebond in a vertical position against the drywall, which prevented air intrusion through the wall. This idea was quickly discarded as the exterior rebond saturated within tens of seconds while the interior rebond remained nearly dry. The difference in wetting between the interior and exterior was found to be an order of a magnitude in difference. Slicing and weighing the rebond was also a time-consuming task, and inevitably water dripped out of the rebond before it could be weighed. As shown in Figure 14, the second approach was to install drip trays in the attic space with weighted plastic sheets attached to the rafters.

Figure 14 A Poor Choice for Wetting Measurements: Drip Pans

This design, however, failed as an instrument because (1) the air current through the attic space carried rain beyond the basin into the open environment and (2) removal and replacement was sufficiently time-consuming to be prohibitive.

The third approach was to install ¼ inch PVC foamboard catch basins that occupied the entire attic space between the rafters in the soffit rig (shown in Figure 15). The basins were given a slight slope to allow water to drain to the back edge of the basin, and spigots were installed to ease extraction. Rain-X was applied to the interior surface to improve its water repellency and a compressed air wand was used to drive all of the water out through the spigot.

Figure 15 Catch Basins

This approached appeared to work well until the highly porous aluminum soffit was tested. Research personnel estimated that greater than 50% of the water was driven out the opening through wind action. For the next rounds of testing, a flap made out of the soffit material under testing was added to the back of the basin (Figures 16-17). This approach was beneficial for two reasons. First, with the aid of the compressed air wand, this setup prevented water from exiting the rear of the basin for all of the soffits tested. The wind action was sufficient to hold the flap in place during testing. Second, the area of the soffit flap was approximately equal to the area of the soffit between the rafters, which created equal openings at the intake (of the soffit area between the rafters) and the exit (the area the flap occupied). To further improve testing, changes were made to the test protocol to ensure that the soffit space accumulated water at least once prior to the first test. The duration of the wetting cycle was increased to 180 s and the soffit rig was wetted for one minute at 70 mph prior to each test. The final procedure is provided in the following section.

Figure 16 Collection of Water in Catch Basins

Figure X Measurement of Water in Catch Basins

3.3 Final Test Protocol

1. The Wall of Wind engines were warmed up to acceptable operating temperature
2. After the engines warmed up, the wind speeds were raised to 70 mph and the structure was wetted for 1 minute. Afterward, the Rig Boss dried the catch basins
3. An engine RPM corresponding to a known wind speed was established and the Labiew software armed to execute the following sequence
    a. Ramp up from 30 mph to the target wind speed in 30 s
    b. Activate a flashing light to notify the pump operator to open the gate valve and to release wind-driven rain
    c. Maintain this target RPM for 180 s

    d. Deactivate the flashing light to notify the pump operator to close the gate valve and to stop the wind-driven rain
    e. Ramp down to 30 mph in 15 s
4. The average flow rate of the pumps was recorded
5. The Rig Boss raised the flaps and used the air wand to drive the water to the spigot, and an assistant recorded the water accumulation with a graduated cylinder
6. Steps 2-5 were repeated until at least two tests were conducted at three wind speeds corresponding to 3400, 3950 and 4500 RPM
7. The Wall of Wind engines were warmed down for two minutes before being shut down. Fuels tanks were refueled on the engines and on the generators
8. The soffit was replaced with a new specimen

With this method, a complete soffit test required 60-90 minutes of operation, four research personnel and approximately 500 gallons of water.

4 Results

Tables 1-2 provide the results from the initial protocol (90 s) and revised protocol (180 s) tests. Key results are summarized below:

Collectively, for the unmodified soffits,

- The perforated vinyl soffit outperformed the hidden vent and the perforated aluminum soffits, but it also had the lowest free space area
- The perforated aluminum soffit outperformed the hidden vent soffit although it had a 63% larger free space area

In the testing of the hidden vent soffit,

- Considerable pooling of water was observed on the top of the soffit panels. Conducting tests with the soffit initially “dry” or “wet” produced dramatically different accumulations. For this reason, the test duration was increased to 180 s and the soffits were pre-wetted (the basins were dried out prior to collection). The perforated soffits did not appear to be affected commensurately
- Modifying the hidden vent system with deflectors reduced the rate of intrusion by 69-79% compared to the unmodified system. In fact, the measured rates were lower than the perforated vinyl soffit, which has 63% of the free space area of the hidden vent soffit

In the testing of the perforated vinyl soffit,

- Very little difference between the percentage of the wind-driven rain that entered the soffit between the 90 s and 180 s runs were observed
- The insect screen applied to the interface of the attic and soffit space reduced the rate of intrusion by 79-86% when the soffit material flaps were used. The exclusion of the flaps, however, caused the screens to lose their effectiveness

In the testing of the perforated aluminum soffit,

- The material flaps on the back of the catch basin had a dramatic effect. Collection rates increased by approximately 360% in the lower two wind regimes and 600% at 115 mph

In the testing of the slot vent and baffle design,

- The baffle system as installed was the worst performer, but the investigation was only limited to one configuration
- Tuning the aperture at the soffit and at the soffit/attic interface for best performance was not attempted due to time constraints
- The vent at the soffit was tested in an open configuration and as such, does not meet code compliance. A screen or vinyl perforated vent would be necessary, and either modification may dramatically improve its resistance to wind-driven rain

Soffit Style	Free Air Space Area	Wind Speed		Wetting Duration	Water Flow Rate	Rain Rate (in/hr)			Water Collected in Basin 1	Water Collected in Basin 2	Total Volume of Water Collected in Both Basins		Volumetric Rate of Water Intrusion		Volumetric Rate / Area of Soffit (576 in^2)	Normalized by Freestream Wind-Driven Rain	Average % of Freestream WDR that Enters Soffit
		Engine RPM	Est. mph			Freestream Wind-Driven Rain (in/hr)	Wall Coefficient (% Rain that Wets Structure)										
	(in^2 / ft^2)			sec	gpm		20%	30%	mL	mL	mL	in^3	in^3/sec	in^3/hr	in/hr	%	
Perforated Vinyl	5.87	3400	87	90	43.6	32.8	6.6	9.8	46	56	102	6.22	0.07	249.0	0.4	1.3%	
	5.87	3400	87	90	46.2	34.7	6.9	10.4	65	94	159	9.70	0.11	388.1	0.7	1.9%	
	5.87	3400	87	90	46.2	34.7	6.9	10.4	102	116	218	13.30	0.15	532.1	0.9	2.7%	
	5.87	3400	87	90	39.4	29.6	5.9	8.9	95	118	213	13.00	0.14	519.9	0.9	3.0%	
	5.87	3400	87	90	38.0	28.6	5.7	8.6	62	92	154	9.40	0.10	375.9	0.7	2.3%	2.2%
	5.87	3950	101	90	38.4	28.9	5.8	8.7	100	127	227	13.85	0.15	554.1	1.0	3.3%	
	5.87	3950	101	90	38.1	28.7	5.7	8.6	107	155	262	15.99	0.18	639.5	1.1	3.9%	
	5.87	3950	101	90	44.5	33.5	8.3	12.4	145	165	310	18.92	0.21	756.7	1.3	3.9%	
	5.87	3950	101	90	43.6	32.8	6.6	9.8	135	142	277	16.90	0.19	676.1	1.2	3.6%	3.7%
	5.87	4100	105	90	45.0	33.8	6.8	10.2	57	55	112	6.83	0.08	273.4	0.5	1.4%	
	5.87	4100	105	90	50.2	37.8	7.6	11.3	65	115	180	10.98	0.12	439.4	0.8	2.0%	1.7%
	5.87	4500	115	90	43.2	32.5	6.5	9.7	158	175	333	20.32	0.23	812.8	1.4	4.3%	
	5.87	4500	115	90	44.1	33.2	6.6	9.9	50	106	156	9.52	0.11	380.8	0.7	2.0%	
	5.87	4500	115	90	45.6	34.3	6.9	10.3	105	116	221	13.49	0.15	539.5	0.9	2.7%	
	5.87	4500	115	90	45.0	33.8	6.8	10.2	38	105	143	8.73	0.10	349.1	0.6	1.8%	
	5.87	4500	115	90	37.4	28.1	5.6	8.4	44	75	119	7.26	0.08	290.5	0.5	1.8%	
	5.87	4500	115	90	36.7	27.6	5.5	8.3	77	133	210	12.82	0.14	512.6	0.9	3.2%	2.6%
Hidden Vent	9.19	2800	72	90	45.4	34.1	6.8	10.2	65	27	92	5.61	0.06	224.6	0.4	1.1%	
	9.19	2800	72	90	44.3	33.3	6.7	10.0	73	45	118	7.20	0.08	288.0	0.5	1.5%	1.3%
	9.19	3400	87	90	44.1	33.2	6.6	9.9	270	178	448	27.34	0.30	1093.5	1.9	5.7%	
	9.19	3400	87	90	44.5	33.5	6.7	10.0	136	121	257	15.68	0.17	627.3	1.1	3.3%	
	9.19	3400	87	90	44.5	33.5	6.7	10.0	199	148	347	21.18	0.24	847.0	1.5	4.4%	
	9.19	3400	87	90	43.6	32.8	6.6	9.8	173	139	312	19.04	0.21	761.6	1.3	4.0%	4.4%
	9.19	3950	101	90	44.0	33.1	6.6	9.9	250	230	480	29.29	0.33	1171.7	2.0	6.1%	
	9.19	3950	101	90	44.3	33.3	6.7	10.0	195	200	395	24.10	0.27	964.2	1.7	5.0%	
	9.19	3950	101	90	43.9	33.0	6.6	9.9	195	197	392	23.92	0.27	956.9	1.7	5.0%	5.4%
	9.19	4500	115	90	44.9	33.8	6.8	10.1	269	297	566	34.54	0.38	1381.6	2.4	7.1%	
	9.19	4500	115	90	45.5	34.2	6.8	10.3	189	272	461	28.13	0.31	1125.3	2.0	5.7%	
	9.19	4500	115	90	43.8	32.9	6.6	9.9	148	170	318	19.41	0.22	776.2	1.3	4.1%	5.6%
Perforated Aluminum	15	3400	87	90	45.5	34.2	6.8	10.3	19.5	29	49	2.96	0.03	118.4	0.2	0.6%	
	15	3400	87	90	44.4	33.4	6.7	10.0	28	39	67	4.09	0.05	163.5	0.3	0.9%	
	15	3400	87	90	44.2	33.2	6.6	10.0	20	32	52	3.17	0.04	126.9	0.2	0.7%	0.7%
	15	3950	101	90	43.9	33.0	6.6	9.9	24	43	67	4.09	0.05	163.5	0.3	0.9%	
	15	3950	101	90	44.2	33.2	6.6	10.0	19	33.5	53	3.20	0.04	128.2	0.2	0.7%	
	15	3950	101	90	44.1	33.2	6.6	9.9	18.5	38	57	3.45	0.04	137.9	0.2	0.7%	0.8%
	15	4500	115	90	44.2	33.2	6.6	10.0	18.5	38.5	57	3.48	0.04	139.1	0.2	0.7%	
	15	4500	115	90	43.9	33.0	6.6	9.9	11.5	25	37	2.23	0.02	89.1	0.2	0.5%	
	15	4500	115	90	43.8	32.9	6.6	9.9	14.5	36	51	3.08	0.03	123.3	0.2	0.6%	0.6%

Table 1 Results from Initial Testing (90 s duration)

Soffit Style	Free Air Space Area	Wind Speed		Wetting Duration	Water Flow Rate	Rain Rate (in/hr)			Water Collected in Basin 1	Water Collected in Basin 2	Total Volume Collected in Basins		Volumetric Rate of Water Intrusion		Volumetric Rate / Area of Soffit (576 in^2)	Normalized by Freestream Wind-Driven Rain	Average % of Freestream WDR that Enters Soffit
		Engine RPM	Est. mph			Freestream Wind-Driven Rain (in/hr)	Wall Coefficient (% Rain that Wets Structure)										
	(in^2 / ft^2)			sec	gpm		20%	30%	mL	mL	mL	in^3	in^3/sec	in^3/hr	in/hr	%	
Perforated Vinyl	5.87	3400	87	180	45.8	34.4	6.9	10.3	138	139	277	16.90	0.09	338.1	0.6	1.7%	
	5.87	3400	87	180	38.4	28.9	5.8	8.7	244	135	379	23.13	0.13	462.6	0.8	2.8%	2.2%
	5.87	3950	101	180	46.4	34.9	7.0	10.5	209	123	332	20.26	0.11	405.2	0.7	2.0%	
	5.87	3950	101	180	39.1	29.4	5.9	8.8	258	171	429	26.18	0.15	523.6	0.9	3.1%	
	5.87	3950	101	180	46.1	34.7	6.9	10.4	176	120	296	18.06	0.10	361.3	0.6	1.8%	2.3%
	5.87	4500	115	180	47.2	35.5	7.1	10.6	200	280	480	29.29	0.16	585.8	1.0	2.9%	
	5.87	4500	115	180	46.9	35.3	7.1	10.6	231	150	381	23.25	0.13	465.0	0.8	2.3%	2.6%
Hidden Vent	9.19	3400	87	180	46.8	35.2	7.0	10.6	336	340	676	41.25	0.23	825.0	1.4	4.1%	
	9.19	3400	87	180	49.9	37.5	7.5	11.3	405	345	750	45.77	0.25	915.4	1.6	4.2%	4.2%
	9.19	3950	101	180	46.5	35.0	7.0	10.5	245	620	865	52.79	0.29	1055.7	1.8	5.2%	
	9.19	3950	101	180	47.8	35.9	7.2	10.8	525	800	1325	80.86	0.45	1617.1	2.8	7.8%	6.5%
	9.19	4500	115	180	47.4	35.6	7.1	10.7	535	905	1440	87.87	0.49	1757.5	3.1	8.6%	
	9.19	4500	115	180	47.4	35.6	7.1	10.7	490	905	1395	85.13	0.47	1702.6	3.0	8.3%	
	9.19	4500	115	180	46.7	35.1	7.0	10.5	511	840	1351	82.44	0.46	1648.9	2.9	8.2%	8.3%
						0.0											
Perforated Aluminum	15	3400	87	180	46.8	35.2	7.0	10.6	212	195	407	24.84	0.14	496.7	0.9	2.5%	
	15	3400	87	180	37	27.8	5.6	8.3	232	117	349	21.30	0.12	425.9	0.7	2.7%	2.6%
	15	3950	101	180	47.2	35.5	7.1	10.6	185	228	413	25.20	0.14	504.1	0.9	2.5%	
	15	3950	101	180	44.7	33.6	6.7	10.1	230	240	470	28.68	0.16	573.6	1.0	3.0%	2.7%
	15	4500	115	180	46.1	34.7	6.9	10.4	337	238	575	35.09	0.19	701.8	1.2	3.5%	
	15	4500	115	180	46.9	35.3	7.1	10.6	402	268	670	40.89	0.23	817.7	1.4	4.0%	3.8%
Vinyl Perforated with Insect Screen	5.87	3400	87	180	40.7	30.6	6.1	9.2	15	24	39	2.38	0.01	47.6	0.1	0.3%	
	5.87	3400	87	180	40.0	30.1	6.0	9.0	22	30	52	3.17	0.02	63.5	0.1	0.4%	0.3%
	5.87	3950	101	180	38.6	29.0	5.8	8.7	20	39	59	3.60	0.02	72.0	0.1	0.4%	
	5.87	3950	101	180	47.1	35.4	7.1	10.6	30	45	75	4.58	0.03	91.5	0.2	0.4%	0.4%
	5.87	4500	115	180	39.2	29.5	5.9	8.8	30	51	81	4.94	0.03	98.9	0.2	0.6%	
	5.87	4500	115	180	47.8	35.9	7.2	10.8	32	54	86	5.25	0.03	105.0	0.2	0.5%	0.5%
Hidden Vent with Deflector	9.19	3950	101	180	39	29.3	5.9	8.8	64	154	218	13.30	0.07	266.1	0.5	1.6%	
	9.19	3950	101	180	43.7	32.9	6.6	9.9	45	105	150	9.15	0.05	183.1	0.3	1.0%	1.3%
	9.19	3400	87	180	39	29.3	5.9	8.8	51	135	186	11.35	0.06	227.0	0.4	1.3%	
	9.19	3400	87	180	48.4	36.4	7.3	10.9	43	107	150	9.15	0.05	183.1	0.3	0.9%	1.1%
	9.19	4500	115	180	46.3	34.8	7.0	10.4	132	191	323	19.71	0.11	394.2	0.7	2.0%	
	9.19	4500	115	180	48.4	36.4	7.3	10.9	94	170	264	16.11	0.09	322.2	0.6	1.5%	1.8%
Baffle System	9.19	3950	101	180	48.7	36.6	7.3	11.0	816	565	1381	84.27	0.47	1685.5	2.9	8.0%	
	9.19	3400	87	180	9.1	6.8	1.4	2.1	522	645	1167	71.21	0.40	1424.3	2.5	36.1%	22.1%
	9.19	4500	115	180	47.6	35.8	7.2	10.7	1235	714	1949	118.94	0.66	2378.7	4.1	11.5%	
	9.19	4500	115	180	51.3	38.6	7.7	11.6	1235	635	1870	114.11	0.63	2282.3	4.0	10.3%	10.9%

Table 2 Results from Revised Testing Protocol (180 s Duration) for Modified and Unmodified Soffits

5 Conclusions and Recommendations

- Achieving an accurate raindrop size distribution in the flow field was not possible in these limited tests. First, no such "target" measurements have been made near the earth's surface in a landfalling hurricane because standard disdrometers are calibrated for raindrops falling at terminal velocity, not in hurricane-force winds. Second, standard emitters produce constant-slope droplet spectra, not the skewed distributions observed in the literature. Future tests should quantify the effect of raindrop size distribution and water intrusion to enhance testing application standards, as none to the author's knowledge address this issue
- The volumetric flow rate of the pumps varied as much as 5 gpm during the 180 s duration and the high demand quickly emptied the storage tanks, which produced unnecessarily inconsistent rain delivery. A better approach may be to build an elevated, pressurized water tank that keeps a constant head with the aid of water and air pumps under the control of a PID system

6 Acknowledgements

The lead investigator wishes to thank the following individuals for their support:

- FIU student research assistants Randall Blanchette, Collette Blessing, Ivan Canino, Jimmy Erwin and Bo Yu
- Mr. Richard Reynolds, President, R.G. Reynolds Homes, Inc.
- Dr. Tim Reinhold, Vice President of Engineering, Institute for Business and Home Safety
- Dr. Kurt Gurley, Associate Professor of Civil and Coastal Engineering, University of Florida, and his research assistants: Jorel Vaccaro, Johann Weekes, Jesus Jayaro, Justin Griffin and Steve Eckoff
- Mr. Dave Johnston, Technical Director, Vinyl Siding Institute, Inc.

7 References

ASTM D4756-03 "Standard Practice for Installation of Rigid Poly(Vinyl Chloride) (PVC) Siding and Soffit," American Society for Testing and Materials, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA, 19428

FEMA (2006). "Summary Report on Building Performance: Hurricane Katrina," Report 548, Federal Emergency Management Agency, 500 C Street SW, Washington, D.C. 20472

IBHS (2004), "Preliminary Damage Observations: Hurricanes Charley, Frances & Ivan," Institute for Business and Home Safety, 4775 East Fowler Avenue, Tampa, FL 33617

Lstiburek, L.W. (2005). "Rainwater Management Performance of Newly Constructed Residential Building Enclosures during August and September 2004," Building Science Corporation, 70 Main Street, Westford, MA 01886

TAS 100(A)-95, "Testing Application Standard (TAS) No. 100(A)-95. Test Procedure for Wind and Wind Driven Rain Resistance and/or Increased Windspeed

Resistance of Soffit Ventilation Strip and Continuous or Intermittent Ventilation System Installed at the Ridge Area," Florida Building Code Test Protocols for High-Velocity Hurricane Zones, Department of Community Affairs Building Codes and Standards, 2555 Shumard Oak Boulevard, Tallahassee, Florida, 32399