Interim Report for Project Entitled:

Assessing the Need to Modernize Water Penetration Resistance Test Procedures
PO Number C07078

Performance Period: 08/01/2022 – 6/30/2023

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Presented to the

Florida Building Commission
State of Florida Department of Business and Professional Regulation

by

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1. Executive Summary

This interim report details progress to date on all tasks. The investigator began by convening an advisory group to guide the research program. With feedback from the advisory group, a test matrix was developed to study parameters that influence water penetration through generic slot openings. The slot openings were subject to pressure sine sweeps of varying amplitude to investigate potential amplitude-dependent threshold frequencies above which applied pressure fluctuations no longer affect the water flow through the building envelope. The application of extreme wetting rates was also studied to determine if a maximum upper bound for wetting exists. Initial staging and setup of the testing area was completed. Generic slot specimens and their fixtures were designed and fabricated. Initial testing was completed, and summary data are presented in the report. The investigator will present the research program to the Florida Building Commission's (FBC) Hurricane Research Advisory Committee by teleconference on March 23, 2023. Two additional rounds of experimental testing are planned on real fenestration units with final input from the advisory group to be provided during the next advisory group teleconference. Data from all rounds of testing will be analyzed and presented to the advisory group for interpretation. From the resulting analysis, guidance will be developed regarding the implementation of improved standard testing procedures. A method to correlate existing testing procedures to new methods of testing based on the results from the research will also be developed.

2. Disclaimers

- This report presents the findings of research performed by the University of Florida. Any opinions, findings, and conclusions or recommendations expressed in this paper are those of the authors and do not necessarily reflect the views of the sponsors, partners, and contributors. The FBC's Hurricane Research Advisory Committee will provide a final disposition on the implications for applicable testing standards.
- The testing presented herein is not intended (i) to be performed in accordance with any then-current or -applicable industry standards, laws, rules, regulations, building codes, or other guidelines for products of this type, or (ii) to determine whether the tested products comply with then current or -applicable industry standards, laws, rules, regulations, building codes, or other guidelines for products of this type. The testing is intended to apply UF's facilities, knowledge, research, and other information regarding unexpected hurricane and other unusual storm related conditions to various products to identify new testing procedures that do not currently exist and which may enable manufacturers to improve their products.

3. Applicable Water Penetration Test Procedures

- TAS 202-94 – Criteria for Testing Impact and Nonimpact Resistant Building Envelope Components Using Uniform Static Air Pressure Loading
- ASTM E 331 – Standard Test Method for Water Penetration of Exterior Windows, Skylights, Doors, and Curtain Walls by Uniform Static Air Pressure Difference
- 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
- ASTM E2128 – Standard Guide for Evaluating Water Leakage of Building Walls
- ASTM E 547 – Standard Test Method for Water Penetration of Exterior Windows, Skylights, Doors, and Curtain Walls by Cyclic Static Air Pressure Difference

4. Scope of Work

- Task 1 - Form a stakeholder advisory group to guide the research program

- Task 2 - Simulate hurricane-like wind pressure loading and wind-driven rain events from available data with input from the advisory group for application on selected building envelope systems, apply standard static and cyclic testing to produce a baseline for comparison, and apply pressure sine sweeps to determine the (amplitude-dependent) threshold frequency at which applied pressure fluctuations no longer affect the flow through the building envelope
- Task 3 - Analyze the data collected during the physical testing campaign at UF and proceed with data interpretation in a format that can be utilized by the FBC and industry
- Task 4 - Develop guidance regarding the implementation of improved standard testing procedures based on results from the test campaign, and develop a method to correlate existing testing procedures to new methods of testing based on the results from the research

5. Deliverables

- Interim report by February 28, 2023 – Interim report detailing progress to date on all tasks. The report will serve as a progress update that details the current state of research, preliminary results, and descriptions of any issues that may have been encountered. In addition, the interim report will be formally presented to the FBC's Hurricane Research Advisory Committee at a time agreed to by the Contractor and Department's Program Manager. The due date may be extended with the approval of the Department's Program Manager.
- Final report by June 1, 2023 containing deliverables of the four tasks discussed in Section 4. This will include summary and analysis of data acquisition, wind pressure/wetting time histories, and water infiltration and displacement time histories. In addition, the final report will be formally presented to the FBC's Hurricane Research Advisory Committee at a time agreed to by the Contractor and Department's Program Manager. The due date may be extended with the approval of the Department's Program Manager.

6. Status of Project

Activities to date are summarized below:

- As part of Task 1, the investigator convened an advisory group formed by members of the Building Envelope Science Institute (BESI), the American Wood Council (AWC), the Insurance Institute for Business and Home Safety (IBHS), the Miami-Dade Product Control Division, and fenestration manufactures to discuss issues related to water ingress through building envelop systems. One teleconference was held on February 02, 2023. The group agreed to proceed with the Round 1 test plan discussed herein. The group also agreed that additional standard test procedures (e.g., ASTM E331) should be performed on all fenestrations to provide a baseline for comparison – these will be included in future tests Round 2 and 3. Major activities (conducted with the assistance of laboratory staff) have included:
    - Initial staging and setup of the testing area, including tuning of the experimental equipment's closed-loop control system to apply sinusoidal pressure fluctuations, was performed along with inspection checkouts of the individual system components
    - Design of test specimens was completed with fabrication followed shortly thereafter. Detail sheets for the reconfigurable assembly can be found in **Appendix A**
- Task 2 is broken up into the three rounds of testing mentioned. For Round 1, the experimental equipment is described in Section 7, the test matrix is shown in Section 8, and the test results are presented in Section 9. Focus areas include pressure sine sweep testing to determine the (amplitude-dependent) threshold frequency at which applied pressure fluctuations no longer affect the flow through the building envelope. The application of extreme wetting rates exceeding the industry-accepted 5 gph/sf was also studied to determine if a maximum upper bound for wetting exists. To explore these phenomena, Round 1 uses a reconfigurable experimental setup with generic features to ensure that the findings are generalizable to real fenestrations in subsequent

rounds of hurricane-like wind pressure testing.

7. Experimental Equipment

Time-varying pressure sequences are applied to window and door specimens using the closed-loop control system of the High Airflow Pressure Loading Actuator (HAPLA) that receives feedback from an absolute pressure transducer located within the test chamber (see Figure 1). The system actuates a high-performance bi-directional valve which can produce rapid pressure changes. The face of the pressure chamber accepts a test specimen, typically a timber frame wall unit (**Appendix B**) with an integrated window or door. Use of this wall unit ensures that structural displacements under fluctuating wind loads, and thus changes to specimen leakage, are similar to "real-world" conditions. Water is applied to the specimen surfaces using a rain rack system mounted inside the test chamber and calibrated to approximate field measurements of wind-driven rain intensities. If needed, structural displacements are measured using a set of laser displacement sensors targeted at points of interest on each specimen. Water infiltration is measured using a high-resolution scale and water collection system to detect water quantities ranging from single droplets to gallons of flow per minute. The specimen and test matrix are described in the next section.

Figure 1. HAPLA with timber frame wall unit and installed Round 1 test specimen.

8. Specimen and Test Matrix

Round 1 of experimental testing is broken into two parts (1A and 1B). Round 1A investigates the relationships between applied sinusoidal pressure fluctuations with varying wind-driven rain intensities and horizontal opening types that represent a range of generic operable window/door configurations. This experimental setup consists of slots with fixed width (w = 48 inches) and variable height (h), a trough, and variable height risers (h_R) to contain the water flowing through the slots. Figure 2 shows a schematic view of the experimental setup with test panel geometry called out and an applied pressure sine sweep trace input depicted near the top. Applied pressure (P_{M}), wetting (R_{WDR}), and instantaneous flowrate ($Q(t)$) through the specimens were measured for each test. Only one opening type (i.e., horizontal or vertical) is tested at a time. The other opening is sealed with a blank plate.

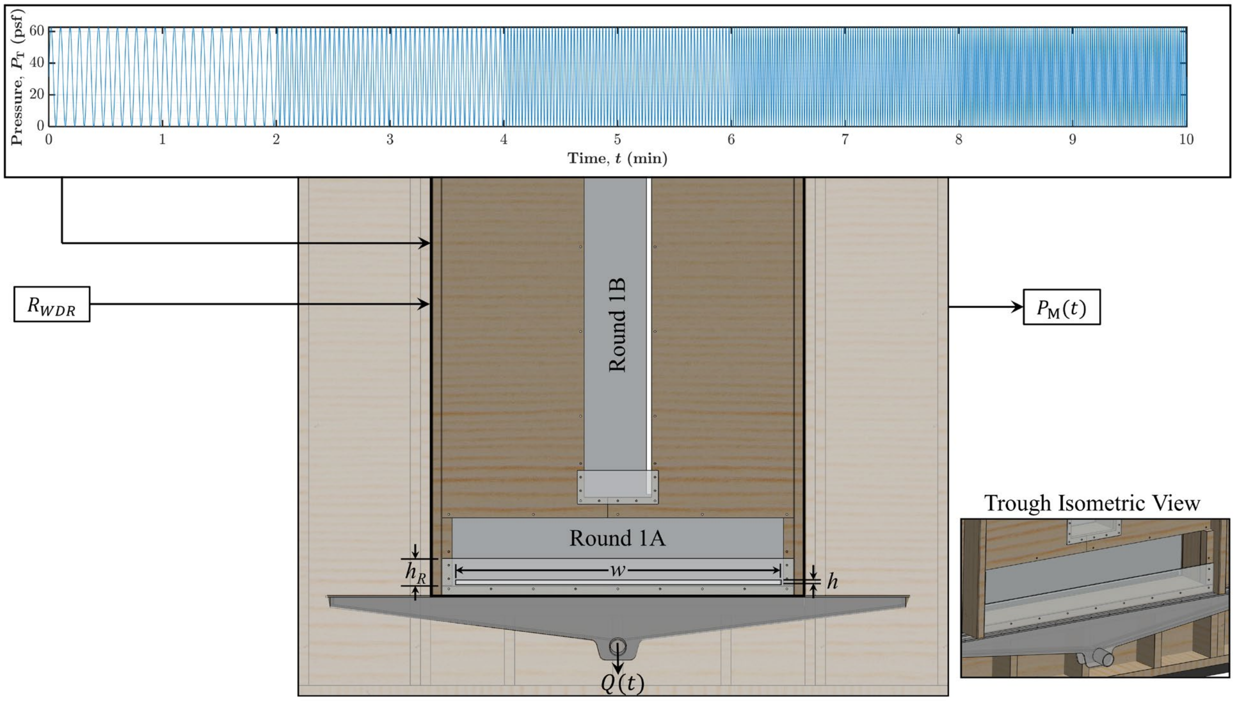


Figure 2. Schematic diagram of Round 1 experimental setup.

Table 1 shows the relevant test variables. In Round 1A, three (3) horizontal opening specimens of varying slot height h were evaluated under various pressure, wetting, and riser conditions. Each test was 10 minutes in duration and swept through five (5) frequencies of pressure from low to high for two (2) minutes at each frequency. For each specimen, three (3) pressure amplitudes were tested at each of three (3) wetting rates for a total of nine (9) tests. Additionally, each specimen was tested with four (4) riser conditions resulting in a total of 36 tests per specimen.

The total set of tests run was 108 for a total of approximately 20 test hours (not including reconfiguration time). Time permitting, additional horizontal opening specimens will be added to Round 1A. Round 1B will follow the Round 1A test matrix for a vertical opening and will be completed shortly after submission of the interim report.

Table 1. Round 1 configurations and experimental parameters.

	Sine Sweep Frequencies	Pressure Amplitudes	Wetting Rates	Slot Heights	Openings	Riser Heights
Nomenclature	f	A	R_{WDR}	h	N/A	h_R
Units	Hz	psf	gph/sf	inch	N/A	inch
Quantity	5	3	3	3	2	4
Variable	0.2,0.4,0.6, 0.8,1.0	5.22,15.67,31.34	2.5,5.0,7.5	1/16,1/8,1/4	Horizontal, Vertical	0.5,1.0,2.0,4.0

9. Results and Discussion

In accordance with Task 3, preliminary data analysis from Round 1A of testing is presented in Figures 3-6. An example of one sine sweep segment is shown in Figure 3 to illustrate the sine sweep process, which occurs as follows: a sinusoidal pressure trace is input into the control system; the proportional integral derivative (PID) controller follows the trace; and the resulting applied pressure and flow out of the system is measured. The three subplots in the figure show the target pressure (P_{T}) and measured pressure (P_{M}) fluctuations produced by the closed-loop HAPLA control system, the measured water ingress (W_{IN}) using the high-resolution scale, and the flow rate (Q) calculated by the taking the time derivative of the scale measurement. The observed water ingress behavior is complex, but in general the behavior of the system to catch water and permit drainage during lulls in the pressure is observed as expected. This can be observed in Figure 3C, where the flowrate increases and decreases in response to the applied pressure (with phase lag caused by the travel time from the trough to the scale).

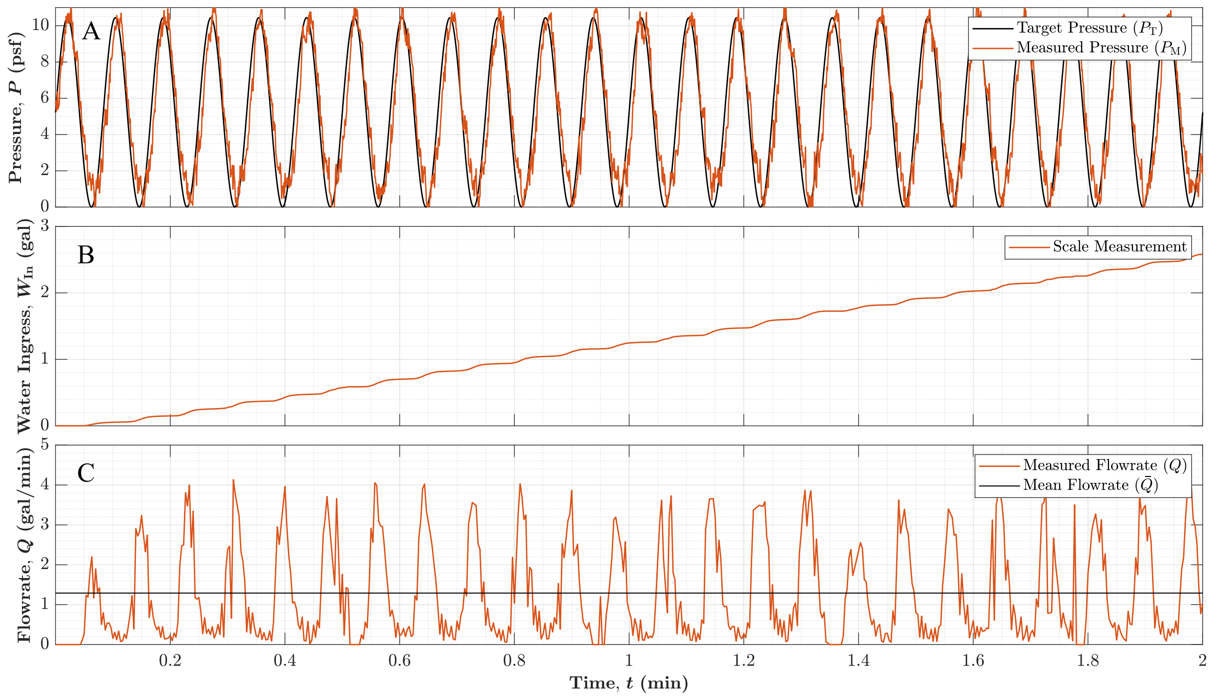


Figure 3. Example application of a two minute 0.2 Hz pressure trace to h = 1/8 inch slot specimen with a peak pressure of 10.44 psf, a 0.5 inch riser height, and a 7.5 gph/sf wetting rate: A) applied pressure trace; B) water ingress from scale measurement; and C) calculated flowrate.

Results from each experimental configuration (see Table 1) are plotted in Figures 4-6. Each figure contains 12 subplots, one for each combination of riser heights (4) and applied peak pressures (3). Within each subplot, the three wetting rates (3) are shown. An individual subplot shows the frequency-dependent average flowrate ($\bar{Q}$) for a given test configuration. The results from Round 1A indicate that a threshold wetting rate has not been reached since all tests for which there is significant water ingress show increases in ingress as wetting increases even beyond 5 gph/sf. The results also indicate that a threshold (maximum) frequency has not yet been reached and in some cases the water ingress begins to increase at the maximum applied frequency. This indicates that frequencies higher than 1 Hz may need to be included in the hurricane wind pressure simulation traces. One clear trend is the effectiveness of risers in reducing average flowrate ($\bar{Q}$) regardless of the other test parameters. Also, riser effectiveness reduces as pressure increases (i.e., counteracting the backpressure created by the riser).

Data from the h = 1/16 inch slot opening is shown in Figure 4. The general trend for this slot opening is for water ingress to increase as frequency increases, which is counterintuitive since the overall system hydraulic/pneumatic impedance should increase as frequency increases. Data from the slot opening h = 1/8 inch is shown in Figure 5. In general, as riser height increases, flow through the system decreases as expected, and as peak pressure increases, flowrate through the system increases. In some cases, water ingress reaches a minimum at 0.8 Hz before increasing again. Data from the slot opening h = 1/4 inch is shown in Figure 6. In these tests, the riser is an effective strategy for preventing water ingress for all slot openings. Data from these tests will be shared with the advisory group.

The trends discussed above will be confirmed in subsequent rounds of testing.

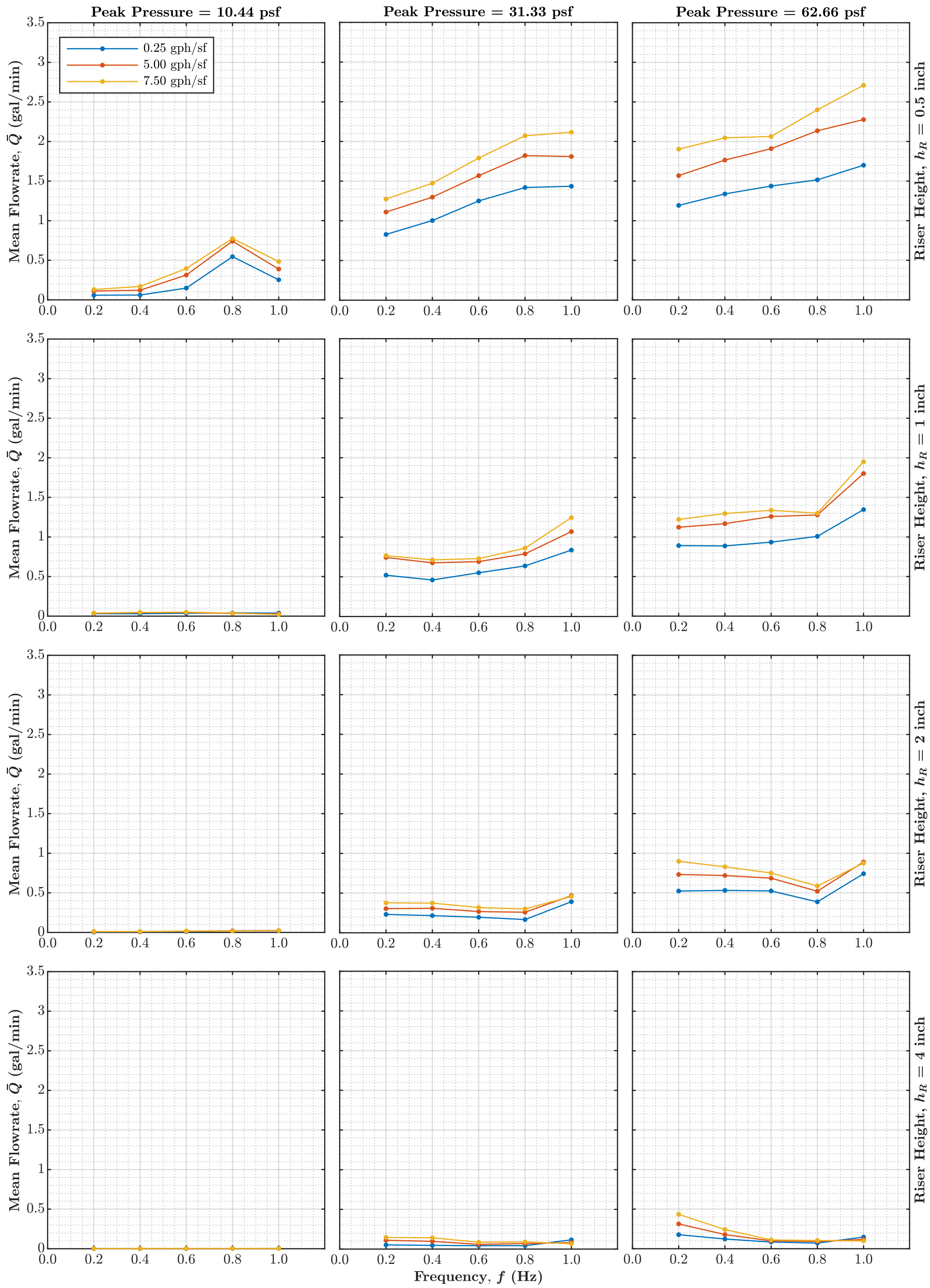


Figure 4. Slot opening (h = 1/16 inch) pressure sine sweeps. Each subplot shows three wetting rates for each test configuration of peak pressure amplitude and riser height.

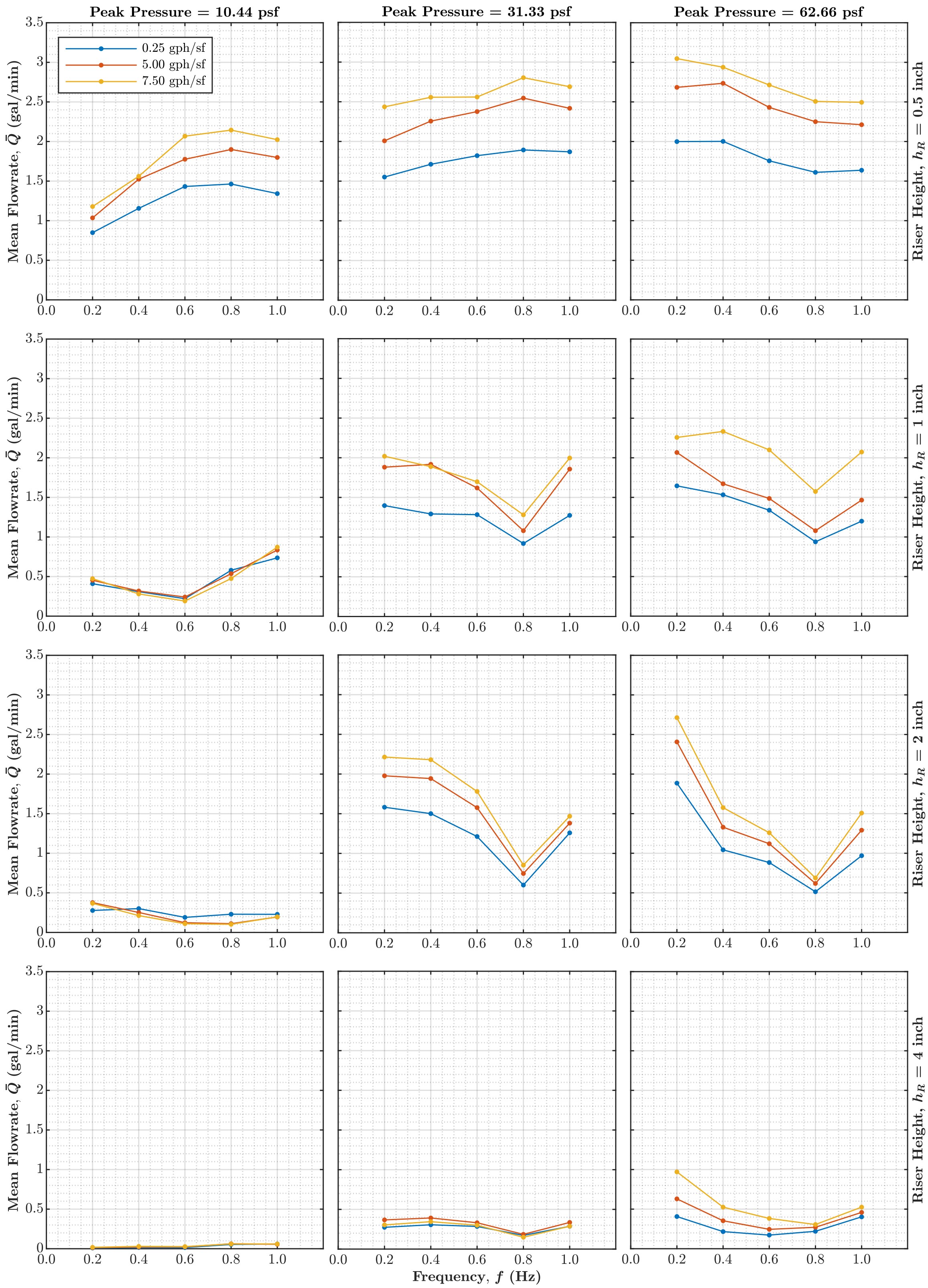


Figure 5. Slot opening (h = 1/8 inch) pressure sine sweeps. Each subplot shows three wetting rates for each test configuration of peak pressure amplitude and riser height.

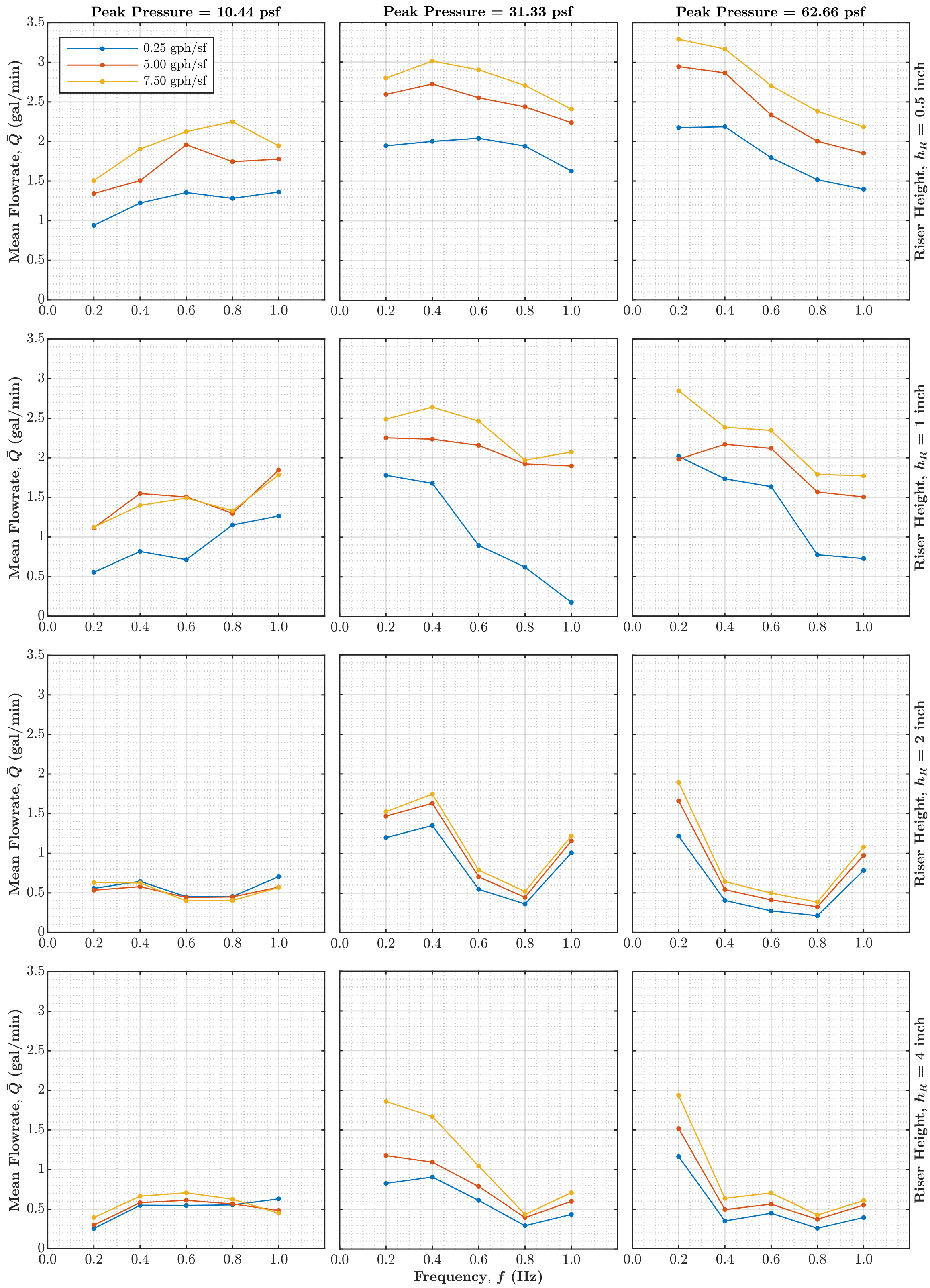


Figure 6. Slot opening (h = 1/4 inch) pressure sine sweeps. Each subplot shows three wetting rates for each test configuration of peak pressure amplitude and riser height.

10. Remaining Tasks

Development: To expand on Task 2 with “real world” loading conditions, the investigator will complete development of methodologies built on prior work (Kopp et al., 2010; Lopez et al., 2011) to simulate hurricane-like wind pressure loading events for application on building envelope systems in upcoming rounds of testing. Fluctuating applied pressure sequences will be synthesized from available data as follows:

- Wind speed records will be derived empirically from historical hurricane track and intensity records from intense hurricanes representative of a design-level event
- Fluctuating surface pressure coefficient records will be extracted from boundary layer wind tunnel modeling of low-rise buildings. Many wind directions will be considered to determine a representative worst-case mean pressure time history tap location for a worst-case marine and/or open exposure.
- The model-scale pressure coefficient record will be converted to an equivalent full-scale dynamic pressure
- Velocity-dependent wetting rates will be derived from available sources (e.g., climatological studies)

Experiment: The following two (2) rounds of experimental testing are planned with final input from the advisory group to be provided during the next advisory group teleconference. Key aspects of hurricane-like wind pressure loading simulation for application on building envelope systems will be discussed with the knowledge gained during Round 1 informing decisions regarding maximum wetting rates and applied cutoff frequencies.

Round 2. A total of up to five (5) non-sealing operable window systems will be tested. The specimens will be selected to be representative of the available products within the market. The final number of window specimens tested will be dependent on time and availability of laboratory staff. Baseline testing including ASTM standard tests and sine sweeps will be performed on each specimen prior to hurricane passage simulation.

Round 3. A total of up to three (3) non-sealing door systems will be tested. The specimens will be selected to be representative of the available products within the market. The final number of door specimens tested will be dependent on time and availability of laboratory staff. Baseline testing including ASTM standard tests and sine sweeps will be performed on each specimen prior to hurricane passage simulation.

Analysis: Data from all rounds of testing will be analyzed and presented to the advisory group for interpretation. The data will be presented in a format that can be utilized by the FBC and industry. From the resulting analysis, guidance will be developed regarding the implementation of improved standard testing procedures. A method to correlate existing testing procedures to new methods of testing based on the results from the research will also be developed.

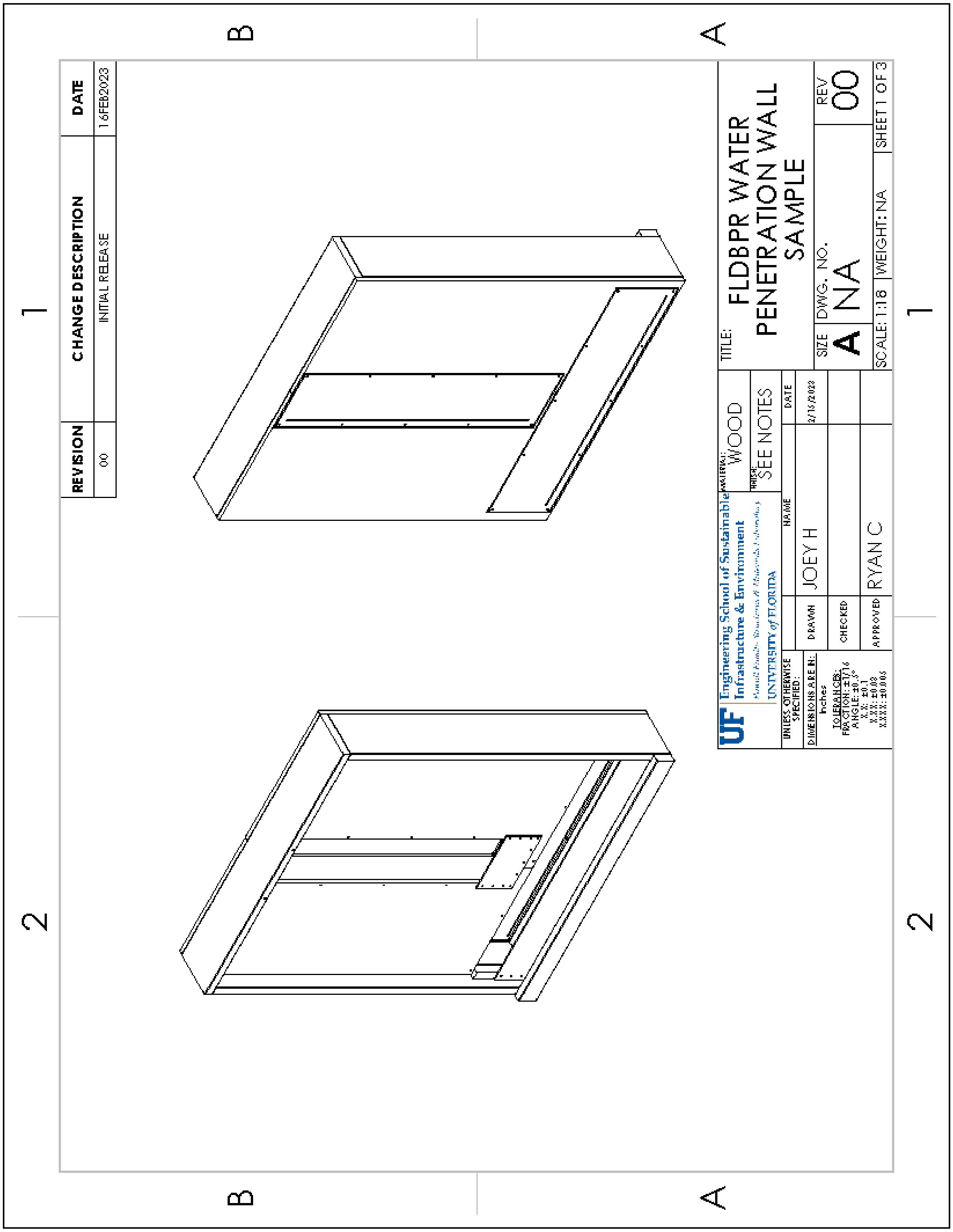
The investigator will present the research program to the FBC’s Hurricane Research Advisory Committee by teleconference on March 23, 2023. A draft final report will be made available by early May 2023 for the advisory group on the project to review.

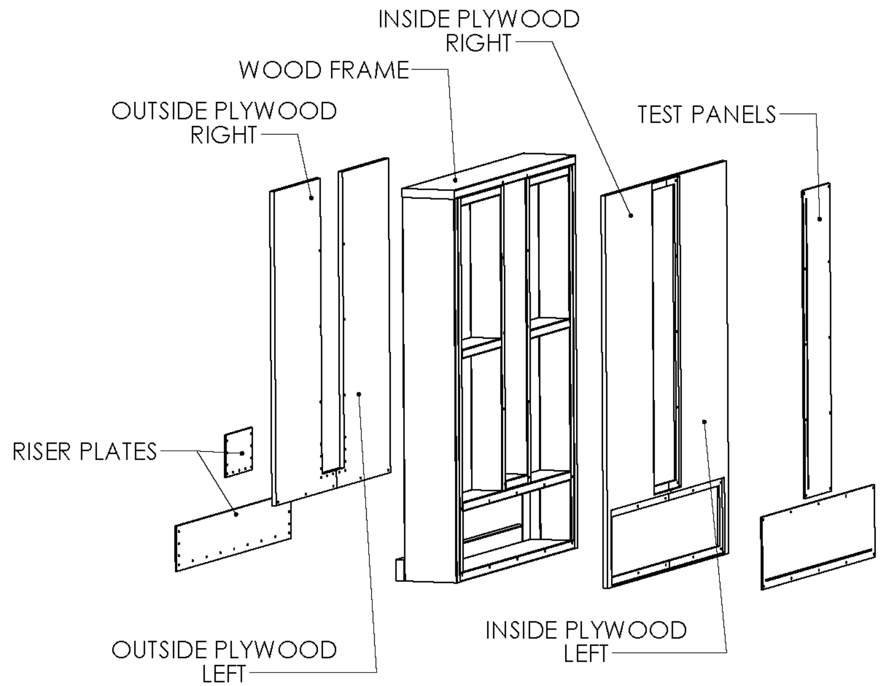
11. References

- ASTM E331-00 (2016) Standard Test Method for Water Penetration of Exterior Windows, Skylights, Doors, and Curtain Walls by Uniform Static Air Pressure Difference.
- ASTM E547-00 (2016) Standard Test Method for Water Penetration of Exterior Windows, Skylights, Doors, and Curtain Walls by Cyclic Static Air Pressure Difference.

- ASTM E1105-15 (2016) 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.
- ASTM E2128-20 (2020) Standard Guide for Evaluating Water Leakage of Building Walls.
- TAS 202-94 (2007) Criteria for Testing Impact and Nonimpact Resistant Building Envelope Components Using Uniform Static Air Pressure Loading.
- ISO 15927-3 (2009) Hygrothermal Performance of Buildings–Calculation and Presentation of Climatic Data–Part 3: Calculation of a Driving Rain Index for Vertical Surfaces from Hourly Wind and Rain Data.
- Kopp, G. A., Morrison, M. J., Gavanski, E., Henderson, D. J., & Hong, H. P. (2010). “Three little pigs” project: hurricane risk mitigation by integrated wind tunnel and full-scale laboratory tests. Natural Hazards Review, 11(4), 151-161.
- Lopez, C., Masters, F. J., & 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.

Appendix A. Round 1 Reconfigurable Test Specimen Details





EXPLODED VIEW

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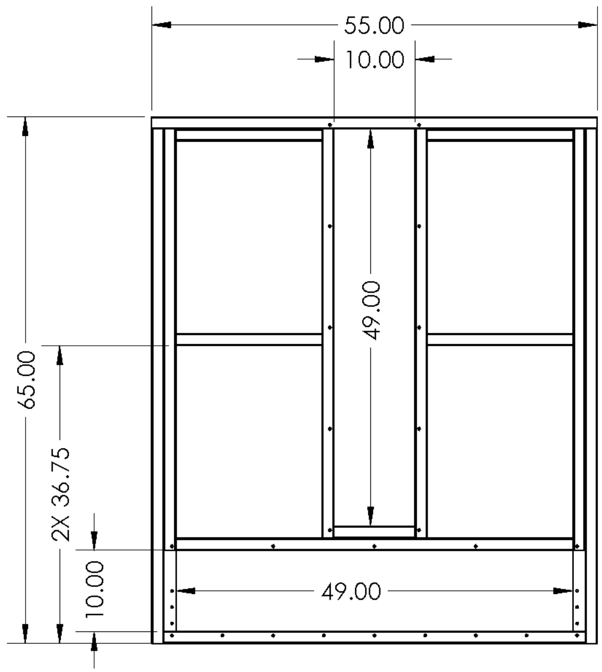

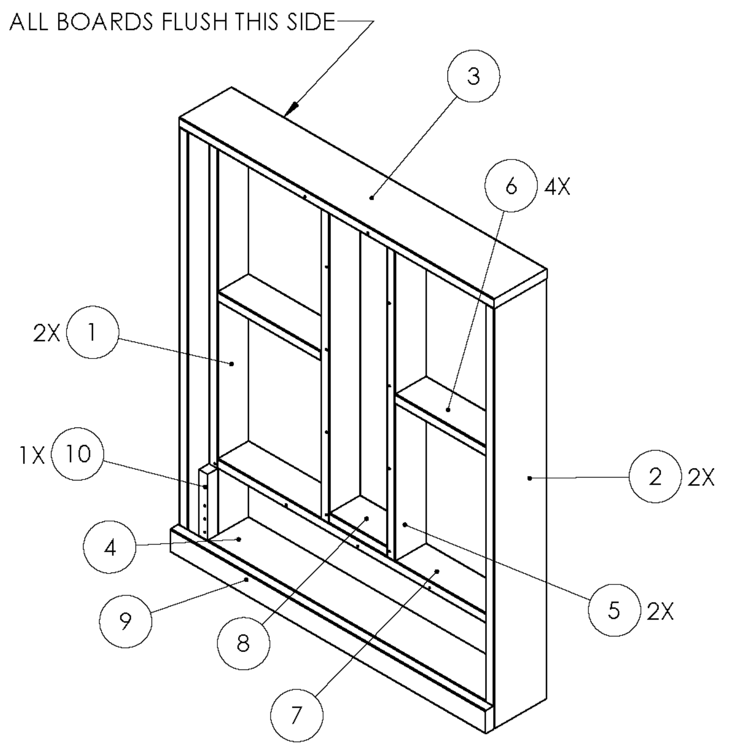

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6	4	2X6 PINE LUMBER	18
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8	1	2X6 PINE LUMBER	10
9	1	2X4 PINE LUMBER	55
10	1	2X2 PINE LUMBER	10

FRAME DETAIL

TITLE: FLDBPR WATER PENETRATION WALL SAMPLE	DWG. NO. NA
SCALE: 1:18 SIZE **A**	REV 00 SHEET 3 OF 3

Appendix B. Wall Specimen Detail for Round 1 Experimental Configuration