PHASE II: Experimental Evaluation of Pressure Equalization Factors and Wind Resistance of Vinyl Siding Systems Using a Multi-Chamber Pressure Test Bed

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EXECUTIVE SUMMARY

The objective of this research study is to conduct experimental studies identifying the effects of spatio-temporally varying loads on the net pressure distributions on vinyl siding wall systems. Phase I of this project developed a pressure test chamber and methodology suitable for performing the experimental testing. Phase II of the project focuses on performing the experimental testing on multiple vinyl siding systems, using the Spatio-Temporal Loading Actuator, to explore pressure equalization effects under a range of pressure loading conditions.

The experimental tasks of the project have unfortunately been critically inhibited by the onset of the health crisis caused by the COVID-19 pandemic. Due to the COVID-19 pandemic, for health and safety reasons the University of Florida facilities were closed to our experimental research for three months from March 15, 2020 through June 12, 2020. Work only resumed as of June 15, 2020, providing insufficient time to complete all experimental tasks. This report contains a review of the background literature and test standards, the framework of our testing, and some preliminary measurements captured prior to the university shutdown, but additional time is necessary before testing can be completed, data processed, and results presented. Through discussion with the Sponsor we will request a time extension to submit the updated report including full details of the experiments and its results in our final report.

TABLE OF CONTENTS

List of Tables

List of Figures

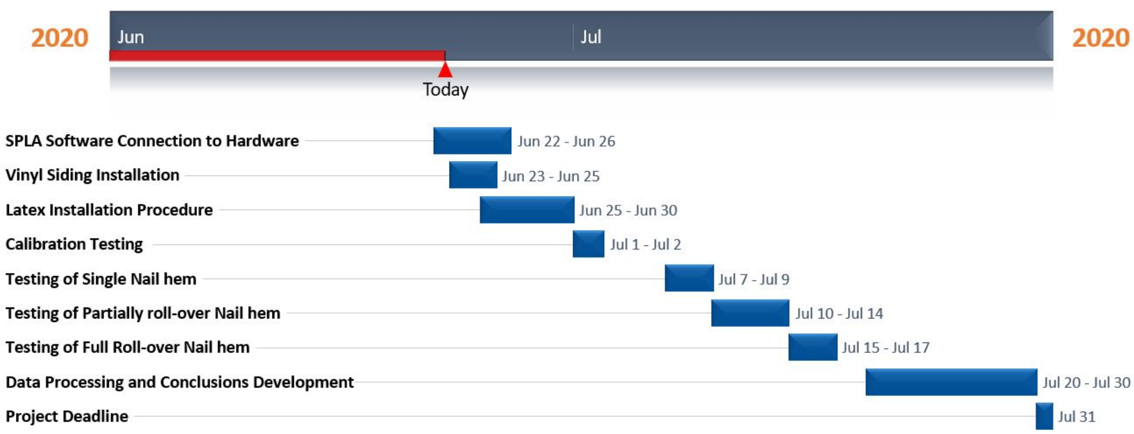
1 INTRODUCTION

Vinyl siding systems are among a class of discontinuous cladding systems, whereby open joints between individual vinyl cladding panels allow air flow from outside to inside and vice versa, enabling pressure equalization to occur. This pressure equalization modifies the net pressure loading on the cladding system. The ratio of the net pressure to peak external wind pressure is defined as the Pressure Equalization Factor (PEF) value. The PEF value is a modifier to the external design wind pressure, determined from the ASCE 7 minimum design load provisions or from wind tunnel tests. The current wind resistance test standard for vinyl siding systems is the ASTM D5206 test protocol. Recent research by the Insurance Institute for Business and Home Safety (IBHS), Florida International University and others have provided new data on the variability of PEFs on buildings.

The aim of this research is to investigate a laboratory-based experimental method that will reproduce the spatial pressure distribution and simultaneous temporal changes that occur on vinyl cladding systems installed on real residential-scale buildings. Specifically, the project aims to provide a diverse dataset establishing the relationship between external and net pressures on a variety of vinyl cladding systems, over a diversity of spatially and temporally varying pressure load scenarios. An experimental device consisting of four pressure chambers will be used to recreate realistic spatio-temporal pressure distributions.

2 BACKGROUND

The second phase of this project mainly involves the testing of vinyl siding walls in the test bed. Due to the COVID-19 pandemic, for health and safety reasons the University of Florida facilities were closed to our experimental research for three months March 15, 2020 through June 12, 2020. We resumed work last week, and after discussion with the Sponsor, we have been seeking to recapture lost time. This report contains the framework of our testing, but we have requested additional time before we will have our results for presentation. The current project schedule we have proposed to complete the experimental testing is presented below.



The research described in this report has been guided by a Research Advisory Group, formed to provide input and support to the research team. The Advisory Group consists of the following persons:

Table 1. Research Advisory Group members

NAME	ORGANIZATION
Matthew Dobson	Vinyl Siding Institute
Sara Krompholz	Vinyl Siding Institute
Stan Hathorn	Royal Building Products
Zach Priest	PRI Construction Materials Technologies
Anne Cope	IBHS
Murray Morrison	IBHS
T. Eric Stafford	IBHS (T. Eric Stafford & Associates, LLC)
Greg Kopp	Western University
Neil J. Sexton	CertainTeed LLC

3 LITERATURE REVIEW

3.1 Current Testing Standards for Vinyl Siding

3.1.1 ASTM D5206

The resistance of vinyl siding panels is tested following ASTM D5206. The loading methodology consists of applying a uniform pressure difference across the test specimen in increments of 5 psf, holding it for 30 seconds before each increment, and continuing until the specimen fails. The pressure at which the specimen fails (ultimate pressure) and the failure mode are recorded. The highest pressure that was sustained for 30 seconds is the maximum sustained static pressure. Pressure equalization on the vinyl siding panels is eliminated by installing an airtight barrier between the vinyl siding panel and the wall substrate or insulating layer.

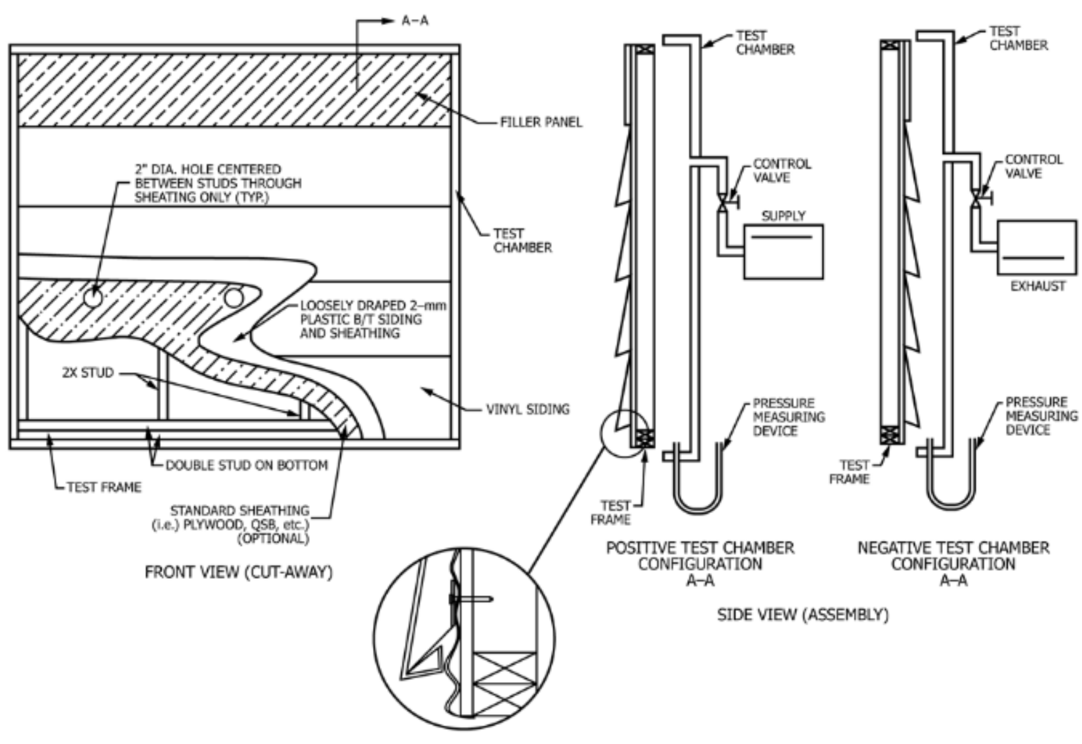


Figure 1. Test chamber assembly for ASTM D5206-13 (from (ASTM D5206 2013)

3.1.2 ASTM D3679

ASTM D3679 establishes the requirements and test methods for materials, dimensions, shrinkage, warp, impact strength, expansion, appearance and wind loads of vinyl siding panels (ASTM D3679 2017). Annex A1 of the design standard shows an example of how the wind load resistance is calculated from design pressure values obtained from ASCE 7 Components and Cladding methodology. The design pressure is multiplied by a pressure equalization factor (PEF) of 0.5, a ratio of net pressures to total external pressures, and a safety factor from ASD (American Society of Civil Engineers 2019). The result of this multiplication is referred to as the required test pressure. The limit-state pressures obtained from ASTM D5206 must be equal or less than the required test pressure for a safe design.

3.2 Full-scale Wind Tunnel Testing of Vinyl Siding

Cope et al. (2012) conducted full- scale testing of residential structures with multilayer wall systems with vinyl siding cladding. The walls had both wood and foam sheathing and the testing was conducted at the Insurance Institute for Business & Home Safety (IBHS). The tests were performed on a 30 ft wide by 40 ft long structure with a mean roof height of 17 ft, and a gable/hip roof configuration. Pressures were monitored at both the exterior surface of the vinyl siding panels and in the inside surface of the panel. Vinyl siding experienced 75 percent to 80 percent of the applied external pressures.

Morrison et al. (2015) also performed testing at IBHS on a single story building. Each of the four walls of the building were divided into two sections separated both structurally and aerodynamically by using an air seal as the dividing line. The divisions allowed for the testing of different siding products (vinyl, foam backed vinyl, wood siding, cement siding). The pressures on the walls were measured similar to Cope et al. (2012). Results showed that an optimal value for design pressure for vinyl siding should be around 55 percent to 60 percent of the external pressure (PEF of 0.55- 0.6).

Moravej et al. (2016) conducted an experimental study to observe wind effects on vinyl siding installed on low-rise buildings. The study was conducted at the Wall of Wind (WOW) facility at Florida International University and the low-rise building had dimensions of 8 ft wide by 9 ft long and 7.5 ft eave height (exact dimensions were on SI units). PEFs were calculated by measuring pressures in the exterior and interior surfaces of the vinyl siding cladding. Results suggest a 0.75 PEF for a vinyl siding wall with a 1 m^2 tributary areas, and a 0.85 for smaller tributary areas (0.2 m^2) to prevent localized failures of connections.

3.3 Component Testing of Vinyl Siding

One example of initial component testing systems was the BRERWULF by. Cook et al. (1988) which allowed the application of realistic fluctuating surface pressures of a nominally airtight building component or cladding material via pressure chamber testing. More recently, Kopp et. al (2010) developed a testing methodology focused on replicating the surface pressure distributions created when wind flows over a structure. The methodology focused on being able to replicate realistic wind pressure fluctuations (temporal variation) which led to the developement of Pressure Loading Actuators (PLA). A PLA mainly consists of a blower fan, a valve with a rotating disk, and a servomotor which regulates pressure (Figure 2). The PLA approach allowed (i) better frequency response of the pressure controlling valve, (ii) high fidelity even with leakage through the building component or cladding, (iii) multiple units to be mounted in close proximity due to the reductino in size of each unit (Kopp et al. 2012).

According to Kopp et al. (2010) the limitations of the PLA methodology are:

- PLA approach replicates only pressure fields, not the flow field.
- Use of pressure chambers.
  - When very flexible cladding needs to be tested, like vinyl siding, the need of mechanical attachment requires that only one pressure chamber is used, and that it must surround the test area without contacting the surface of the cladding (no spatial variation).
  - Maximum displacement of the cladding is limited by the depth of the pressure chamber.
  - Small elements cannot be tested due to minimum size limitations for the pressure chamber.
- Visual limitations of the experiment since mostly the pressure chambers can be observed rather than the actual building component or cladding.

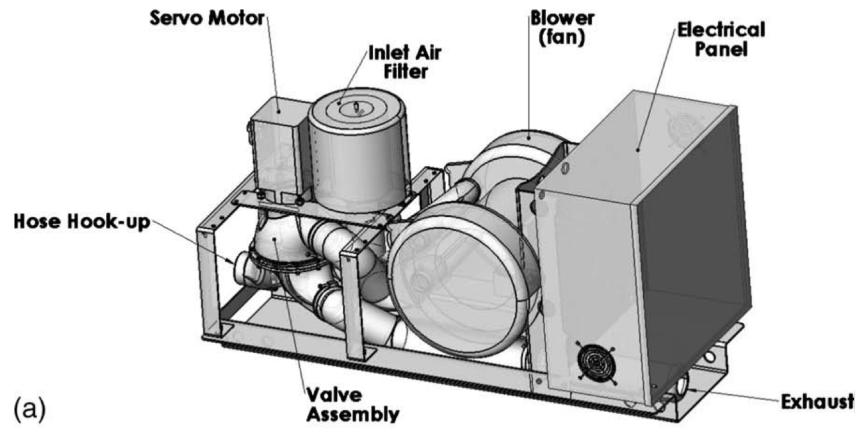


Figure 2. Pressure loading actuator system (PLA) (Kopp et al. 2010)

Kopp and Gavanski (2011) utilized PLAs to conduct an experimental study of full-scale wood-framed residential component wall sections to determine failure capacities under suction loads. Realistic fluctuating loads (dynamic) were applied to single and multilayer wood -framed residential structure walls. The level of pressure equalization was highly dependent on the details of the wall construction of the various layers (i.e. presence of housewrap). In general, vinyl siding equalized almost perfectly under temporally-varying loads only (PEF = 0). Spatial variation however was not considered in this study.

Some of the limitations of the PLA approach were overcome with the development of flexible air-box system that attached to the building surface (Kopp et al. 2012). Each air-box consisted of a steel-frame, an inlet duct with an air-filter, rigid modular lid and a flexible vinyl membrane glued to the lid and the surface of the specimen and allowing it to displace. Miller et al. (2017) extended the experimental setup to utilize a latex barrier glued to the surface of a multilayer vinyl siding cladding wall. In this approach, divisions were created between five adjacent air-boxes minimizing the unloaded surfaces on the surface of vinyl siding panels. The latex material was nominally air-tight, strong enough to resist test pressures, flexible, easily installed, and repeatable. Pressure traces from full-scale experiments at IBHS were replicated in each air-box or pressure chamber. Thus, spatial variation without altering external pressure gradients and appropriate dynamic fluctuating pressures were applied to the vinyl siding wall. Results from this experiment showed PEF values close to 0.7 which agreed with the full-scale experiments at IBHS.

4 MULTI-CHAMBER TEST BED AND THE SPLA SETUP

Based on the literature review and advice from the advisory group, the experiment was designed to seek a feasible laboratory-based experimental method that will reproduce the spatial pressure distribution and simultaneous temporal changes that occur on vinyl cladding systems installed on real residential-scale buildings. A test bed was designed as is described in this section, vinyl siding panels were selected, and instrumentation and software were selected and designed to collect the data. The test can accommodate a vinyl siding wall specimen, subject it to up to four different pressure variations along the length of the wall, and, by using plexiglass sheets in the pressure chamber, allow researchers to visualize how the vinyl panels are reacting to the applied pressures.

4.1 Performance Characteristics of Multi-chamber Pressure Test Bed

The experimental testing proposed is being conducted at the University of Florida's Powell Structures Laboratory, using the Spatio-temporal Pressure Loading Actuator (SPLA). The multi-chamber pressure test bed was constructed in Phase 1 of this project during FY2018-2019. A link to the final report for that work can be found here (https://bit.ly/ufWIND-02-2020). To date we have done the following:

- Installed a vinyl siding panel system, instrumented with pressure transducers measuring the gap pressure (between vinyl siding and wood sheathing).
- Demonstrated a method for sealing the pressure chambers using latex sheets adhered to siding and wrapped onto the aluminum frame of test chamber. This setup provides individually-sealed pressure chambers without restricting the movement of the vinyl siding itself.
- Developed control software in LabView software (by National Instruments) to control the four pressure loading actuators.
- Conducted preliminary measurements to evaluate the performance characteristics of the test setup under various leakage conditions (i.e., extent to which the cavity between the vinyl siding cladding and wood sheathing substrate is open to atmosphere).

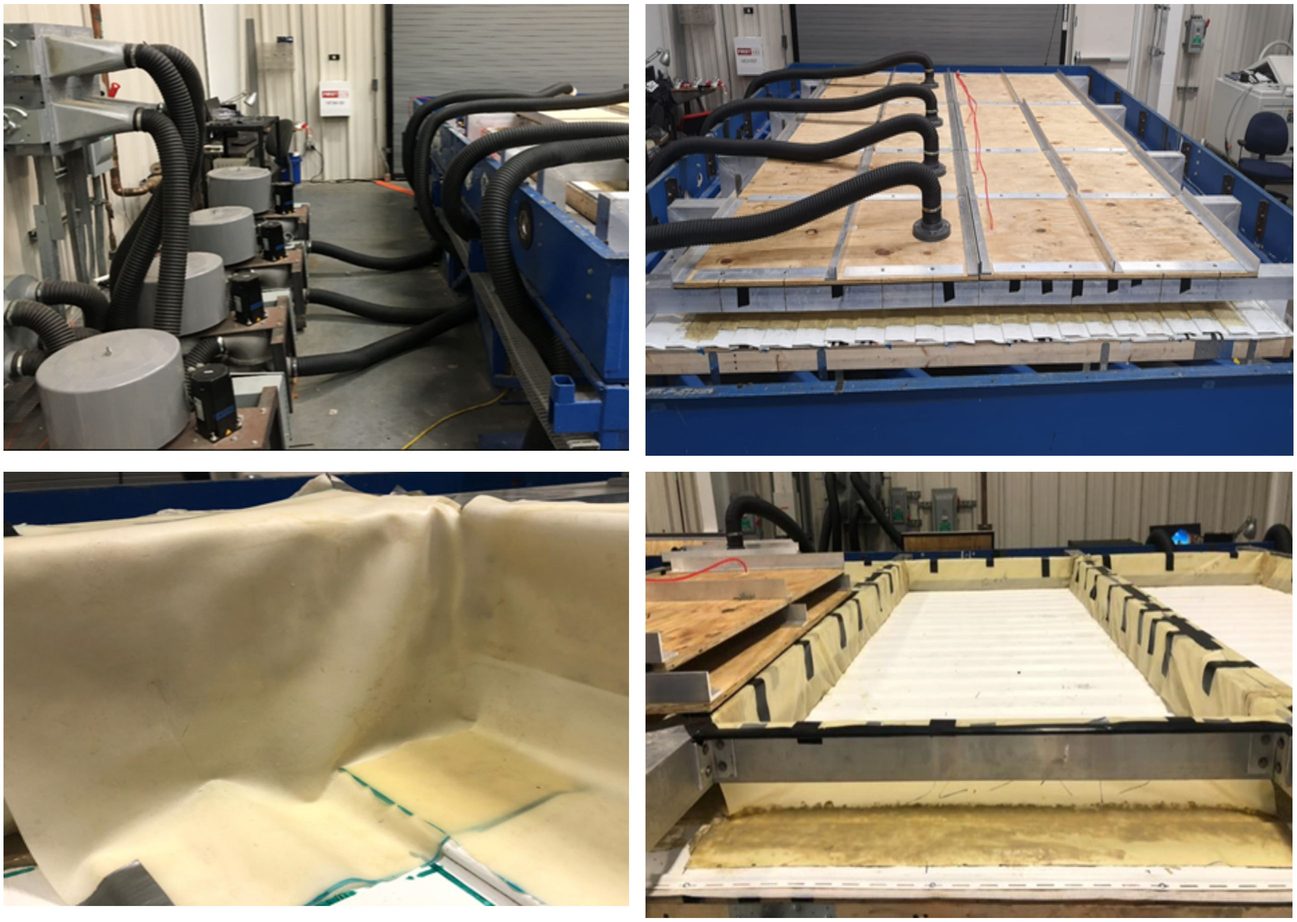


Figure 3. Details of the Experimental test bed and specimen installation. Figure 1a- the four PLAs attached to pressure chambers, Figure 1b – overview of test bed set up with first vinyl siding panel; Figure 1c – corner detail showing the overlapping and sealing of latex to vinyl siding panel and to test frame; Figure 1-d – overview of a single pressure chamber showing installed latex edge seals prior to placing top cover.

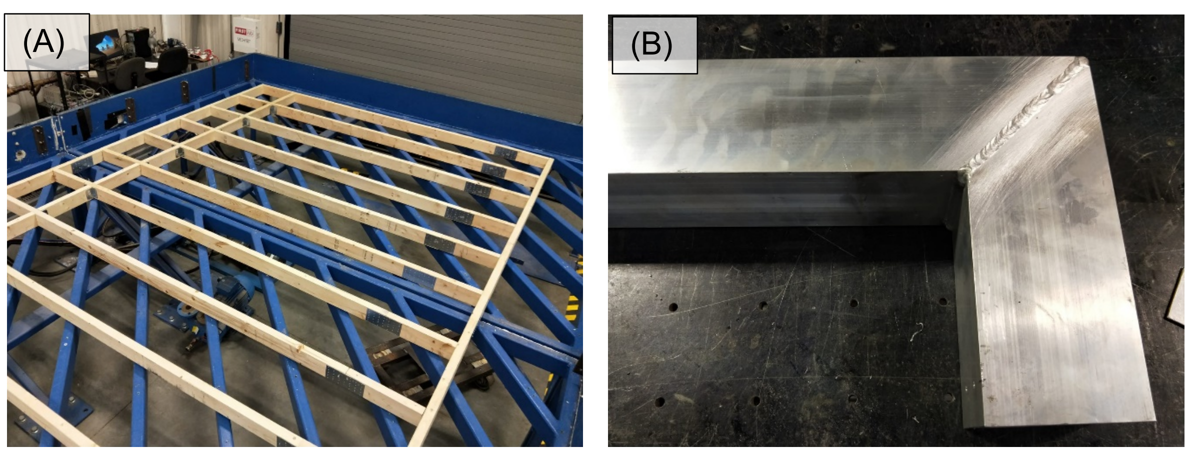


Figure 4. Testing details to ensure sealed pressure chambers and properly constructed wood frame walls. Figure 4a- the rigid support frame used to place the walls during testing, Figure 4b – HSS aluminum frames used to create pressure chambers; Figure 4c – constructed wood frame with plastic sheet shown between the studs and the plywood panels; Figure 4-d – plywood panels arranged over the studs and plastic sheet; Figure 4-e – section picture of the wall plate, plastic sheet, plywood

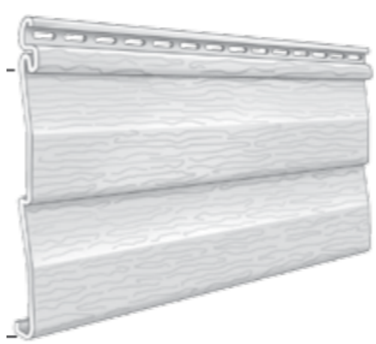
panel, and building paper (housewrap); Figure 4-f – six wood frame walls constructed and ready for vinyl siding installation; Figure 4-g – beginning of latex installation to vinyl siding and HSS frames at the test bed; Figure 4-h – test assembly sealed and closed with SPLAs connected.

4.2 Vinyl Siding Systems

Three vinyl siding systems were selected following advice from the Vinyl Siding Institute. These systems represent typical products used in Florida for both standard zones and Hurricane High Velocity Zones and each have a Florida product approval number on file. The products vary in thickness and nail hem shape which is one important area related to panel failures. The vinyl siding systems will be installed following directions from a Certified Vinyl Siding installer using remote technologies.

Single nail- hem

- FL# XXXXX
- 0.04 in. panel thickness and ½ in. panel projection
- VSI SDPR 55.6 psf



Partially Roll-over nail- hem

- FL# XXXXX; FL HVHZ# XXXXX
- 0.044 in. panel thickness
- VSI SDPR 55.1 psf

Full Roll-over nail- hem

- FL# XXXXX; NOA XX-XXXX.XX
- 0.046 in. panel thickness
- VSI SDPR 89.4 psf

Figure 5. Types of vinyl siding panels selected.

4.2.1 Installation of Vinyl Siding

The Vinyl Siding Institute working with research team has provided a Certified Vinyl Siding System Product/Install Trainer to work with the research team via video conference. It is still uncertain that the University of Florida will allow others on-campus during this initial phase of re-opening. The following requirements have been identified from the VSI installation manual and will be discussed with the certified installer:

- Use size #8 truss head or pan head galvanized or aluminum screws with 1-1/2 in length (corrosion- resistant, self-tapping sheet metal type) at 16 in o.c spacing.
- Screws need to penetrate at least 1-1/4 in into the wood framing plus wood sheathing.
- Screws must be centered on the nail slot of the vinyl siding with approximately 1/32 in space between the screw head and the vinyl.
- Panels should be overlapped by at least one inch where two panels join.
- Siding end laps should be staggered so that no two courses align vertically.

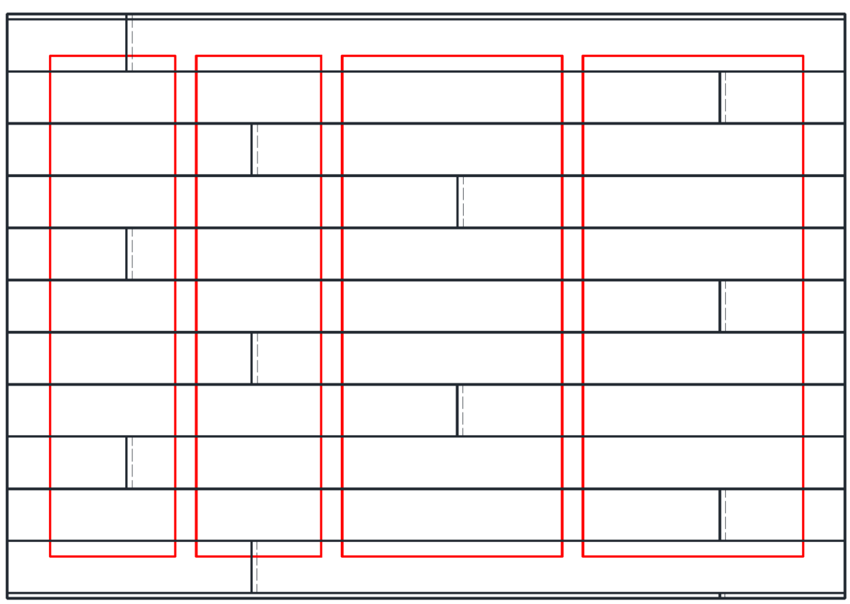


Figure 6. Vinyl siding layout with location of pressure chambers shown in red. The overlaps between panels were distributed as equally as possible to reduce differences in air leakage between the chambers

4.3 Pressure Readings and Data Acquisition

During the experiments, pressures are to be monitored at eight different locations for each wood frame wall. Each pressure chamber has two pressure taps at its center. One pressure tap monitors the pressure withing the pressure chambers which is referred to as “external pressure” experienced by the vinyl siding panel. The other pressure tap is located under the vinyl siding panel and monitors the cavity pressure.

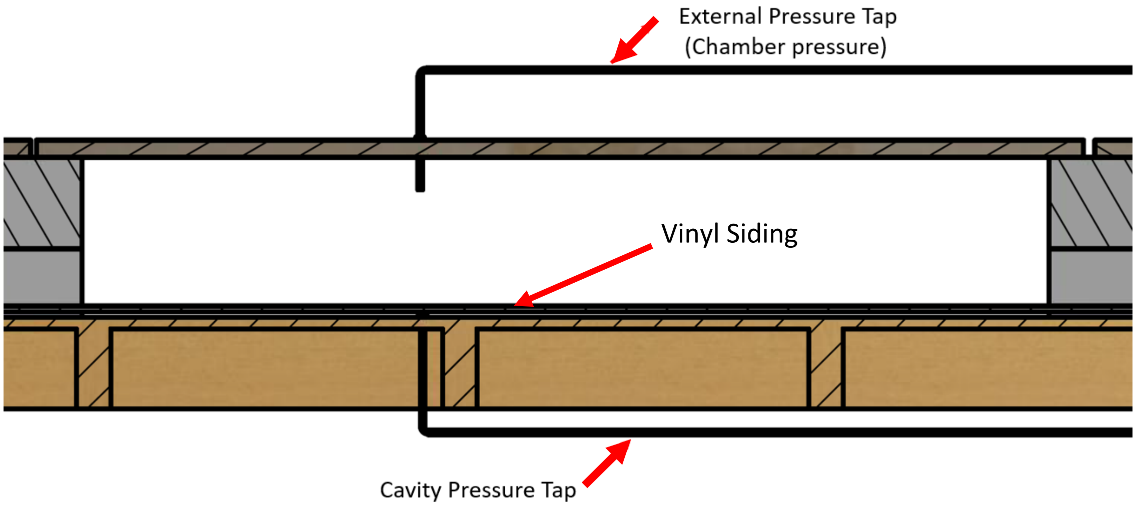


Figure 7. Section view of chamber pressure and cavity pressure taps.

To monitor these pressure readings, two types of pressure sensors are used for the external pressures and the cavity pressures. For the external pressures, four OMEGA PX 409 pressure sensors are used with a +/- 1 psi range and a response time less than one millisecond. A fast response time allows the sensor to mechanically adjust with sufficient time to inform the control operations of the PLA system how to adjust valve positions to follow input pressure traces to conduct the tests. For the cavity pressure, Setra 264 differential pressure transducers with a range of +/- 50 psf and a response time between 15-50 milliseconds is used. These sensors are connected to a NI CDAQ 9174 data acquisition system, which is a terminal meant to collect incoming data, convert it from an analog signal to a digital signal, and output it to a computer. NI LabView software is used to manipulate the applied pressures in each pressure chamber, collect the data from each test used, and perform statistical analysis.

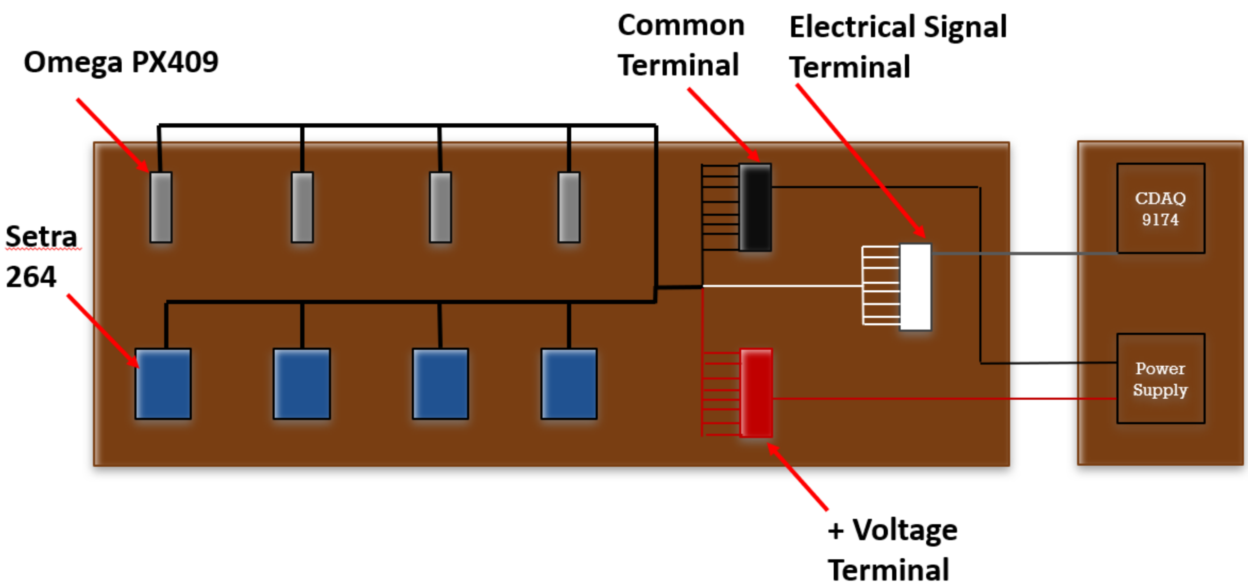


Figure 8. Sketch of pressure sensors, wires and terminal connections to data acquisition system and power supply.

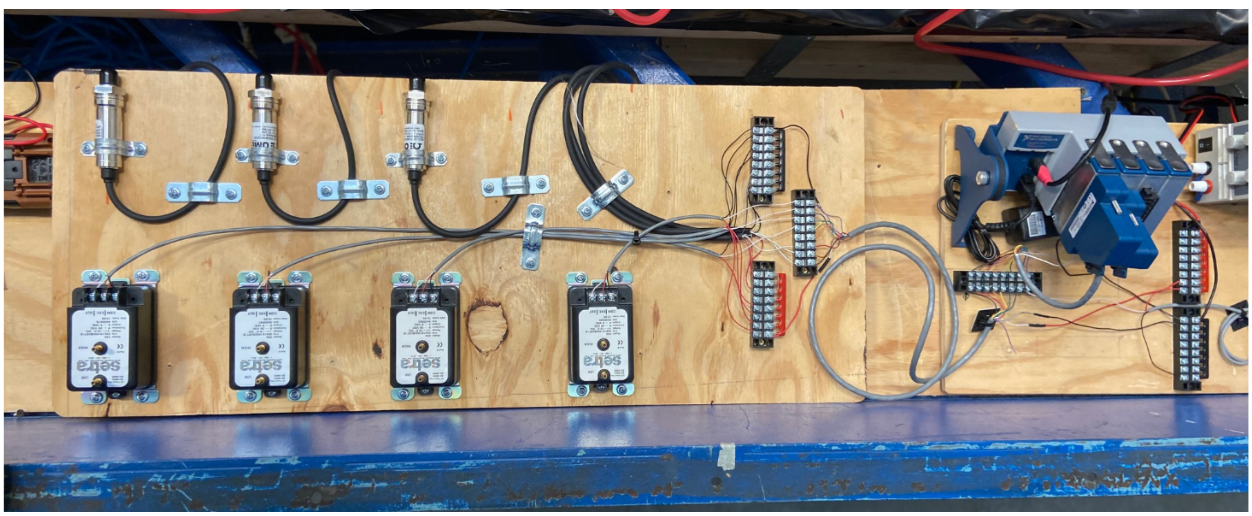


Figure 9. Picture of pressure sensors, wires and terminal connections to data acquisition system and power supply (note one Omega transducer is not installed in this photo).

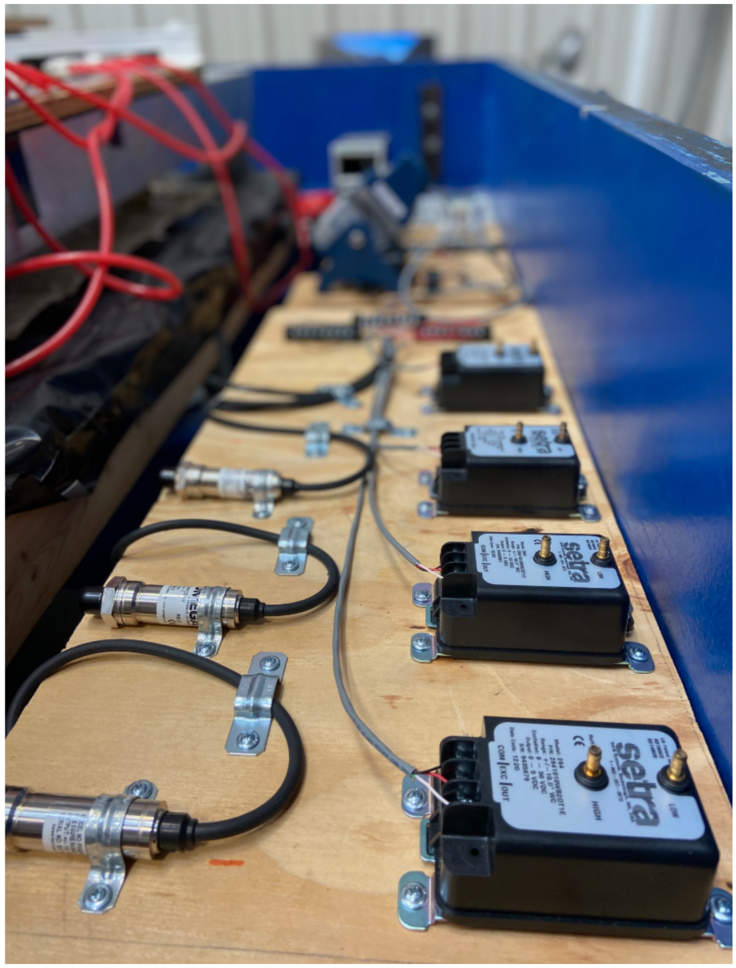


Figure 10. Picture of Omega PX409 and Setra 264 pressure sensors.

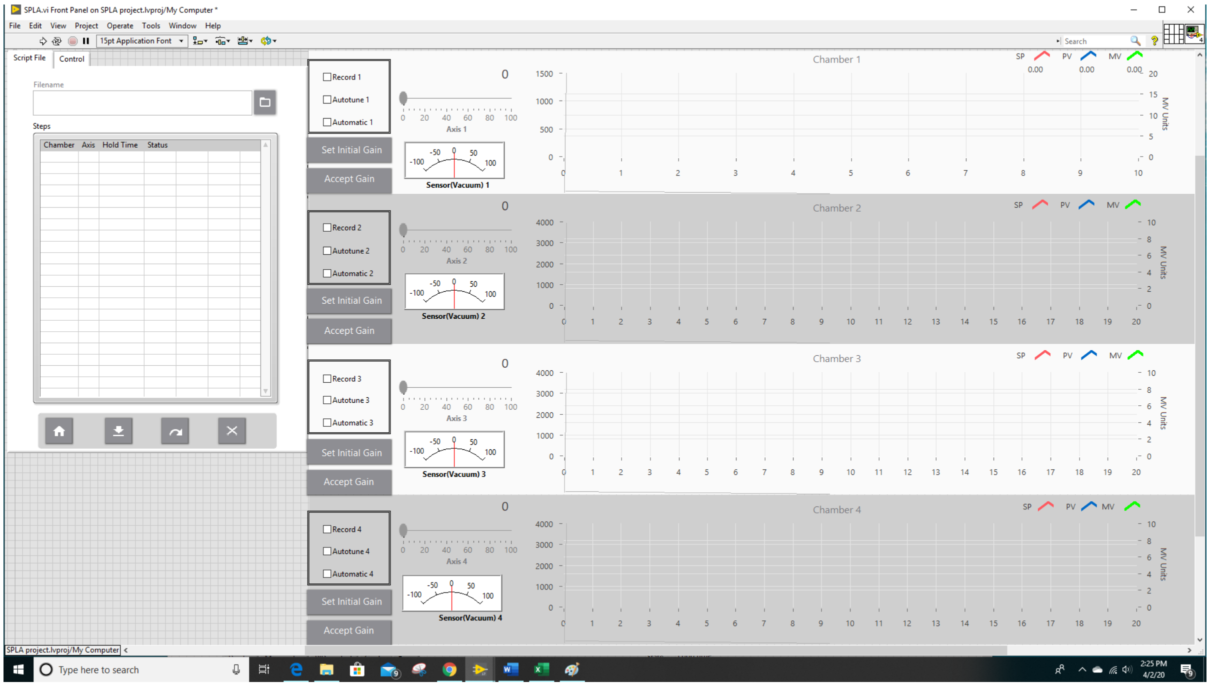


Figure 11. LabVIEW VI user interface developed to manipulate and read the pressures in each chamber.

4.4 Test Protocol

The proposed test matrix will subject each specimen to a series of static and dynamic pressure traces. Uniform pressure tests will replicate the current ASTM D 5206, *Test Method for Wind Load Resistance of Rigid Plastic Siding.* Other tests will employ spatially varying external pressure distributions, that following upon results developed by IBHS and Western University. Details of the proposed test matrix are included in Appendix B. We anticipate conducting the test series at three peak-pressure levels of 0.5 kPa, 1.0 kPa, and 1.5 kPa to explore whether the magnitude of external pressure has any effect on distribution or magnitude PEF values.

The last test on each panel will be the ASTM D 5206 which is a destructive test to failure, used to confirm the performance of our testbed set and for correlating with existing documented performances.

Table 2. Proposed Test Matrix

Level	Description	Trace ID
Level 1 – peak pressure magnitude = -0.5 kPa	Benchmark	SID-L1-B-1
	Uniform static tests	SID-L1-US-n*
	Benchmark	SID-L1-B-2
	Spatially-varying static tests	SID-L1-VS-n*
	Benchmark	SID-L1-B-3
	Spatially-varying sine wave tests	SID-L1-VSW-n*
	Benchmark	SID-L1-B-4
	Spatially-varying wind traces – Run2071 – side wall	SID-L1-SVW-2071S
	Benchmark	SID-L1-B-5
	Spatially-varying wind traces – Run2071 – leeward wall	SID-L1-SVW-2071L
	Benchmark	SID-L1-B-6
	Spatially-varying wind traces – Run279 – side wall	SID-L1-SVW-279S
	Benchmark	SID-L1-B-7
	Spatially-varying wind traces – Run279 – leeward wall	SID-L1-SVW-279L
Level 2 – peak pressure magnitude = -1.0 kPa	Benchmark	SID-L2-B-1
	Uniform static tests	SID-L2-US-n*
	Benchmark	SID-L2-B-2
	Spatially-varying static tests	SID-L2-VS-n*
	Benchmark	SID-L2-B-3
	Spatially-varying sine wave tests	SID-L2-VSW-n*
	Benchmark	SID-L2-B-4
	Spatially-varying wind traces – Run2071 – side wall	SID-L2-SVW-2071S
	Benchmark	SID-L2-B-5
	Spatially-varying wind traces – Run2071 – leeward wall	SID-L2-SVW-2071L
	Benchmark	SID-L2-B-6
	Spatially-varying wind traces – Run279 – side wall	SID-L2-SVW-279S
	Benchmark	SID-L2-B-7
	Spatially-varying wind traces – Run279 – leeward wall	SID-L2-SVW-279L
Level 3 – peak pressure magnitude = -1.5 kPa	Benchmark	SID-L3-B-1
	Uniform static tests	SID-L3-US-n*
	Benchmark	SID-L3-B-2
	Spatially-varying static tests	SID-L3-VS-n*
	Benchmark	SID-L3-B-3
	Spatially-varying sine wave tests	SID-L3-VSW-n*
	Benchmark	SID-L3-B-4
	Spatially-varying wind traces – Run2071 – side wall	SID-L3-SVW-2071S
	Benchmark	SID-L3-B-5
	Spatially-varying wind traces – Run2071 – leeward wall	SID-L3-SVW-2071L
	Benchmark	SID-L3-B-6
	Spatially-varying wind traces – Run279 – side wall	SID-L3-SVW-279S
	Benchmark	SID-L3-B-7
	Spatially-varying wind traces – Run279 – leeward wall	SID-L3-SVW-279L
	Benchmark	SID-D5206-B1
-	ASTM D5206	SID-D5206

Notes:
- SID indicates the specimen ID
- n* indicates a specific configuration within the trace family

5 PRELIMINARY TESTING

- We conducted an initial two-day round of preliminary testing on 17 and 18 February 2020 to better establish performance characteristics of the test setup and inform development of the full test matrix. This test series was not part of the complete test matrix but did generate preliminary data useful to understanding the performance of the system.
- The preliminary measurements confirmed functioning of the control equipment and that instrumentation can capture the net pressures thereby enabling the PEFs to be determined.
- The Advisory Group members are invited to witness future testing and the Research team will coordinate the schedules to provide prior information. Further we requested suggestions from the Advisory Group members from the Vinyl siding industry, of names of certified vinyl siding installers who may assist with installation in accordance with respective manufacturer's specifications.

5.1 Preliminary Measurements

- Preliminary testing was conducted by applying a series of static pressure tests, including both spatially-varying and spatially-uniform pressure distributions across the four pressure chambers. Tests were conducted with the cavity (gap between vinyl siding and wood sheathing) both open to atmosphere at the ends of the test specimen, and nominally sealed.
- With the cavity open to atmospheric, the SPLA was able to generate static differential pressures up to –1.5 kPa across the vinyl siding with the SPLA only performing at ~50% of maximum capacity. We anticipate being able to apply spatially-varying or uniform static suction pressures exceeding 2-3 kPa across the vinyl siding.
- Pressure Equalization Factors (PEF) were calculated by using two differential pressure readings with respect to atmospheric pressure for each chamber pressure and for each box pressure

$$PEF = \frac{Chamber\ Pressure - \ Cavity\ Pressure}{Chamber\ Pressure}$$

- Preliminary measurements of PEFs obtained from static spatially-uniform (i.e., constant) and spatially-varying (i.e., gradient) pressures are plotted in Figure 11. Each dot in Figure 1 represents the PEF in a chamber at a given moment in time; each cluster represents a specific pressure magnitude and spatial distribution. The PEFs were obtained using a mix of pressure magnitudes and distributions.

- PEFs from preliminary measurements as described above displayed an asymptotic trend towards a value of approximately 0.7, with slightly lower PEFs for the constant pressure case as compared to the gradient pressure case. Again, these are preliminary data demonstrating both the performance of the SPLA, and the range of PEF values that can be obtained under different experimental parameters. The data should be treated as research data only, not recommendations.
- Testing showed that the PEFs are a function of the background leakage in the test volume (illustrated in Figure 12), highlighting the need for benchmark testing to quantify this leakage before each test. This finding has been incorporated into the proposed test matrix.

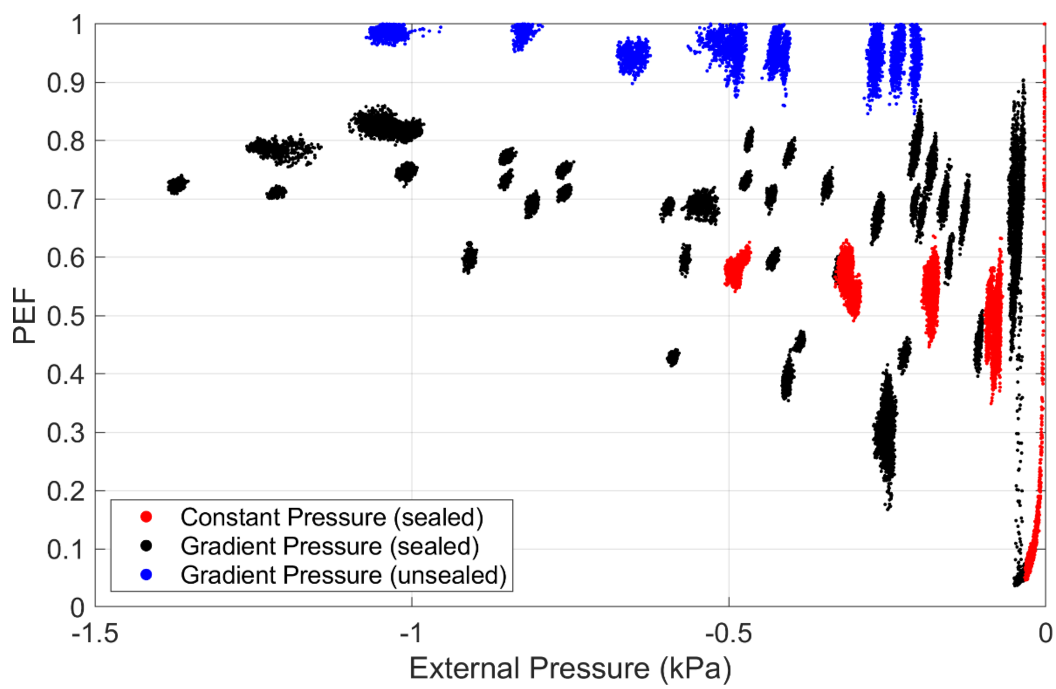
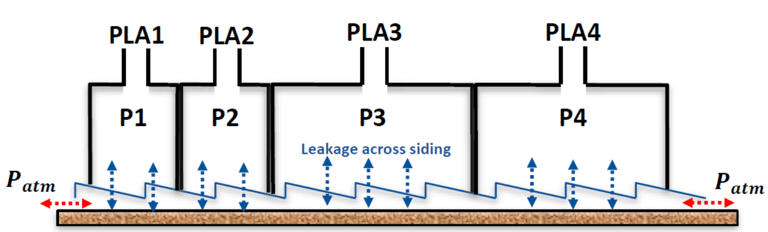


Figure 12. Preliminary measurements of PEFs obtained during preliminary tests. These values were obtained to observe the performance of the SPLA and instrumentation; they should be treated as research data only and do not suggest any final results or conclusions.



$$PEF = f\left(\frac{AreaLeakage_{atm}}{AreaLeakage_{siding}}\right)$$

Figure 13. Sketch of background leakage to the interior cavity pressure.

6 FINAL TESTING

- Testing of the six vinyl siding specimens is currently scheduled to start on July 6, 2020.
- The exact dates and invitations to the members of the advisory group will be confirmed and sent before the end of June when the walls have been constructed and instrumentation/software has been tested.
- External pressures in each chamber and the differential with respect to the inside the cavity under the panels will be recorded at a 50 m/s sampling rate.
- Each instantaneous value of differential pressure will be divided by the external chamber pressure at each time step.

$$PEF(t) = \frac{Chamber\ Pressure(t) - \ Cavity\ Pressure(t)}{Chamber\ Pressure(t)}$$

- Results will consist of a scatter plot of PEFs values at the different pressure differentials and test types described in the test matrix.
- Failure pressures will be recorded along with failures modes (when possible).
- Comparison will be made between the different combinations of spatially varying and temporally varying pressures to observe if there any similarities in trends of PEFs results or magnitudes.
- Suggestions of possible ways to replicate PEFs in simplified manners (i.e. static tests) will be given for consideration of the advisory group.

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APPENDIX A: MEMORANDUM OF FIRST MEETING

From: David O. Prevatt, Xinyang Wu

To: Advisory Group Members

Date: 8 February 2020

Project: PHASE II: Experimental Evaluation of Pressure Equalization Factors and Wind Resistance of Vinyl Siding Systems Using a Multi-Chamber Pressure Test Bed

Subject: Notes of Advisory Group Meeting Held on 6 February 2020

Attendees: *University of Florida:* David O Prevatt (DOP), Oscar La Fontaine (OL), Xinyang Wu (XW); *Auburn University:* David B Roueche (DBR); *Vinyl Siding Institute:* Matt Dobson (MD), Stan Hathorn (ST), Sara Krompholz (SK), Neil Sexton (NS); *IBHS:* Eric Stafford (ES); *Western University:* Greg Kopp (GK); **ABSENT:** Zach Priest (ZP) PRI

This provides notes of the above meeting. First meeting introducing the project goals, deliverables, review of progress with experimental setup. David O. Prevatt (DOP), David Roueche (DBR) and Oscar Lafontaine (OL) presented slides (click here for view).

1. Background updates of Phase I of project presented by DOP. DBR presented summary data and case study of previous studies of post Hurricane Irma and Hurricane Michael. Part of broader assessment, using cluster sampling techniques looking broadly at all cladding system types. Relatively high number of vinyl siding failures
    a. From building damage survey, 87 structures with vinyl siding cladding identified and damage ratios established.
    b. The complete dataset of 1,200 houses in Hurricane Irma, and 740 in Hurricane Michael. Reports available in Documents folder.
    c. MD: Suggest the Research Team explains total dataset numbers in their future reports (e.g. total number of houses, number of cladding types, explain damage ratio details etc.)
    d. DBR showed possible hypothesis of failures on found homes with vinyl siding cladding failure on building surfaces close to adjacent houses (i.e. wind speed up? Venturi effects?)
    e. GK points out observation of loose house wrap (Tyvek, underlayment) behind siding. Can this change allow interior pressure into gap and the pressure equalization effects assumed?
    f. MD mentions pattern of vinyl siding failure along soffit line. Information on fasteners are crucial to performance. Fastener length, spacing, fasteners missing. thinks the vinyl siding fasteners information is crucial, like length of fastener and quantity of fastener missing and penetration of fastener 1-1/4 in (min). Basically, some of the encountered failures may be due to installation issues instead of the actual vinyl siding capacity failure.
2. SH: In the slides 15, the Industry-accepted term is nail hem (both single and double nail hem possible)
3. GK: UWO chamber for the(Miller et al. 2017) study used hard exterior sides of pressure chambers (poly-sheet?), and flexible latex material used only for interior walls separating adjacent chambers. Vinyl siding completely enclosed (and not attached to exterior chamber walls.

    a. DOP: current test setup has vinyl siding sample (and wood wall) extending beyond the exterior chamber walls. UF's specimen then sealed using latex material to top side of vinyl.
4. DBR presented a protested text matrix (see ppt) including 2 repeats. Include ASTM D5206 and Pressure Equalization factors (PEF) test measurement on standard and high-wind vinyl siding systems.
    a. intermediate testing, developing pressure time histories from the Tokyo Polytechnic University (TPU) wind tunnel pressure database to represent Hurricane Michael orientation of wind direction, on side wall, leeward wall, cornering wind angles leeward wall (45 degree). he proposed two questions:
        i. Focus: what ultimately is an approach to considers spatial pressure variation, achievable in most standard test laboratories?
        ii. Can the test rig simulate pressures at failure or observed strengths from Hurricane Michael?
5. GK: For a leaky system requires considerable fan power to achieve failure. UWO experiments utilized up to 3 PLAs on a single pressure box to achieve air flow required at high pressures.
6. Discussion on various available grades of vinyl siding systems in use in Florida and elsewhere.
    a. Is there a difference between high wind versus builder grade?
    b. Is 0.04 in thickness a common lower wind grade?
    c. 0.05 in most strong product but hard to find
    d. 0.046 in is a solid product available widely, are these both double hems and single hems?
    e. What is the curl hem vinyl siding?
7. SH: Few single nail hem products meet current Florida FBC requirements. Curl hem and double hem vinyl siding is designed for high-wind rated. Note: current code includes product design requirements using PEFs of 0.5. Previously a PEF of 0.36 was used.
8. ES: According to FEMA/MAT team report for Hurricane Michael, most of vinyl siding installed in Florida were single nail hem, he didn't see any double hem vinyl-siding products.
9. UF will inform Advisory Group prior to testing dates in case others wish to witness tests in person.
10. UF to discuss with SH and MD on particular vinyl siding systems they used previously in IBHS tests as well as at University of Western Ontario and coordinate systems where possible.

APPENDIX B: MEMORANDUM OF SECOND MEETING

From: Oscar Lafontaine

To: Advisory Group Members

Date: 26 March 2020

Project: PHASE II: Experimental Evaluation of Pressure Equalization Factors and Wind Resistance of Vinyl Siding Systems Using a Multi-Chamber Pressure Test Bed

Subject: Notes of Advisory Group Meeting Held on 24 March 2020

Attendees: *University of Florida:* David O Prevatt (DOP), Oscar La Fontaine (OL), Xinyang Wu (XW); *Auburn University:* David B Roueche (DBR); *Vinyl Siding Institute:* Matt Dobson (MD), Stan Hathorn (ST), Sara Krompholz (SK), Neil Sexton (NS); *IBHS:* Eric Stafford (ES); Anne Cope (AC) *Western University:* Greg Kopp (GK); **ABSENT:** Zach Priest (ZP) PRI

This document provides brief notes of the above meeting. David O. Prevatt (DOP), David Roueche (DBR) and Oscar Lafontaine (OL) presented slides (click here for view) of the experimental work presented in the interim report including preliminary measurements

11. DOP presented a summary of the research focus, rationale for this experimental work, and how the Covid-19 situation could possibly affect our efforts.
12. DOP summarized the key points addressed during the first meeting:
    a. Meeting held in February 6, 2020
    b. 10 attendees
    c. Received feedback on experiment test setup, test matrix, etc.
13. DOP presented and explained the basic functions of the pressure loading actuators (PLAs) and how they are connected to the test bed to each pressure chamber.
14. OLB explained the latex procedure to seal the pressure chamber without restricting the vinyl siding panels deflections.
15. DOP proceeded to provide more insight about the test setup including:
    a. Chamber size
    b. Differential pressure transducers
    c. Specimen construction
16. DOP presented a preliminary data acquisition LabView software used to acquire preliminary measurements.
    a. The software allowed the manipulation of pressures within each chamber by manual control of the:
        i. Variable frequency drive voltage (VFD)
        ii. PLA valve control
    b. Signal of pressure readings from the pressure transducers are obtained via LabView for:
        i. Chamber pressures
        ii. Cavity pressures
17. DOP highlighted where the relevant literature review documents are accessible to the Advisory Group (Task C).
18. DBR presented the approach for preliminary testing performed at UF for gauging the performance characteristics of the test setup.
    a. Vinyl siding was tested with sealed and unsealed edges.
    b. Static pressure tests were performed both spatially-uniform and spatially-varying.

    c. Preliminary measurements of Pressure Equalization Factors (PEFs) were presented.
19. DBR explained the main takeaways from the testing:
    a. SPLA can generate a range of PEFs on vinyl siding specimens with spatially varying pressures.
    b. SPLA should be capable of performing destructive tests on vinyl siding panels.
    c. PEFs are conditioned upon the background leakage to the interior cavity.
20. DBR showed the proposed vinyl siding product types.
    a. MD and SH provided insight into what specific panels should be ordered and where to buy them.
    b. There was discussion of how to make sure that the panels installation was not the cause for any observed failures; thus, a Vinyl Siding Institute (VSI) certified installer will be hired to oversee the products installation.
    c. There was consensus by the Advisory Group and UF Team to not use the products name in any reports or document related to the project.
21. DBR explained the modified test matrix which includes three levels of static uniform, static gradient, dynamic sine waves, dynamic wind traces, and ASTM D5206 up to failure.
22. Matt Dobson expressed he had some concerns about some comments made at the Interim Report which he would share with team.
23. The interim report was accepted.

APPENDIX C: REVISED TEST MATRIX AND PRESSURE TRACE LIBRARY

From: David Roueche, Jinyi Wei
To: UF Team
Date: 19 March 2020
Project: FBC Vinyl Siding Phase II

Subject: Revised Test Matrix and Pressure Trace Library

Introduction

Vinyl siding specimens will be experimentally tested at the University of Florida using the Spatio-Temporal Loading Actuator (SPLA) to research pressure equalization factors in vinyl siding under various wind pressure loading scenarios. Previous correspondence with the UF team has indicated that three vinyl specimens will be constructed, each using a specific vinyl siding product (hereafter simply referred to as product) – (1) standard single hem vinyl siding, (2) curled hem vinyl siding, and (3) double-hem vinyl siding. The objective of this memorandum is to provide a suitable test matrix to ensure the desired research products are obtained through the testing. The test matrix will define the pressures that will be applied through each of the four pressure chambers to the vinyl siding specimen via the SPLA.

Constraints in Forming the Test Matrix

The following points provide constraints and objectives considered in developing the test matrix:

- Each product must be tested in accordance with ASTM D5206 *Test Method for Wind Load Resistance of Rigid Plastic Siding* to evaluate the maximum sustained static pressure and the ultimate (i.e., failure) pressure.
- Previous testing of pressure equalization effects in vinyl siding (e.g. Miller et al., 2017) have not explicitly evaluated to what degree the Pressure Equalization Factors (PEFs) are affected by changes in the maximum magnitude of the applied external pressures over a wide range. The consistency of the PEFs over a range of pressures approaching the failure pressure should be evaluated.
- It is desired to research the simplest test setup required to generate accurate PEFs. Therefore, PEFs resulting from both static and dynamic spatially-varying and uniform pressures should be obtained.

- Preliminary testing (February 18-19, 2020 at the University of Florida) demonstrated that air leakage from atmospheric to the gap between the vinyl siding and wood sheathing affects the obtained PEFs. The area of leak gaps from atmospheric pressure relative to the area of the through gaps (airflow paths across the vinyl siding) controls whether the gap pressure remains at atmospheric or is affected by the applied external pressure within the pressure chamber(s). Benchmarks are needed to quantify the extent of system leakage present in the test volume, with recognition that system leakage may change from one test to the next on the same specimen.
- Post-hurricane reconnaissance following Hurricanes Irma (2017) and Michael (2018) found some evidence that vinyl siding failures were more likely to occur on side walls under normal or cornering flows. These observations should be considered in developing the spatio-temporal pressure histories.

Proposed Library of Pressure Traces

Each specimen will undergo a series of static and dynamic, uniform and spatially varying pressure traces reflecting the constraints and objectives described above. Each trace will be produced in the form of a tab-delimited text file with pressures in kPa for each pressure chamber using a time step of 50 ms. Prior to each trace being run on a specimen, a benchmark trace will be run to document the system level leakage levels and ensure consistent system performance from run to run. The various pressure traces will be defined for three levels of pressure – Level 1, with a peak pressure magnitude (highest suction pressure at any time in any chamber) of 0.5 kPa, Level 2, peak pressure of 1.0 kPa, and Level 3, peak pressure of 1.5 kPa. Level 3 may not be feasible for spatially-temporally varying pressure traces due to limitations of the SPLA. The various pressure traces that are to be attempted at each Level are proposed below. The total run time of all testing for each specimen, assuming all traces can be performed, should be approximately 30 minutes, including benchmark traces. Actual test time will vary.

Benchmark Traces

The pressure trace for each of the four pressure chambers will linearly increase from 0 to 0.5 kPa, at a rate of 0.1 kPa per second, then maintain the 0.5 kPa pressure for 15 seconds, and finally return to 0 kPa at a rate of 0.1 kPa per second. The 0.5 kPa pressure will be used for Levels 1, 2 and 3.

Spatially Uniform Static Traces

The pressure traces will follow that of ASTM D5206, which consists of applying a uniform pressure difference across the specimen in increments of 5 lbf/ft2 (0.25 kPa), holding for 30 s before increasing the next 5 lbf/ft2 (0.25 kPa) until the specified pressure for the given level (e.g., 0.5 kPa for Level 1, 1.0 kPa for Level 2, 1.5 kPa for Level 3) is achieved.

Spatially Varying Static Traces

Spatially varying pressures will be applied such that pressures are held constant in each chamber, but at different magnitudes in each chamber. Possible spatially-varying static pressure patterns include (1) Peak Level pressure (e.g., 1.0 kPa) in Zone 1 with 75% of the peak in Zone 2, 50% in Zone 3 and 25% in Zone 4; and (2) Peak Level pressure in Zones 1 and 2 with 50% of the peak in Zones 3 and 4. Pressures will be held constant at each step for 30 seconds.

Spatially Varying Sine Wave Traces

Pressure sine waves will be traced in each pressure chamber with varying magnitudes, phase shifts, and angular frequencies (< 1 Hz). The highest magnitude pressures and angular frequencies will be in Zone 1, with decreasing pressures in Zone 2 and decreasing pressures and angular frequencies in Zones 3 and 4. Each spatially varying sine wave trace will have a duration of 1 minute.

Spatially-temporally Varying Wind Traces

A previous memo (Generating Pressure Time Histories from TTU WERFL Building Data, dated 2/22/2020, attached below) detailed the wind pressure traces that will be used from the Texas Tech University Wind Engineering Research Field Laboratory (WERFL). The only modification that will be made is to extend the dataset to include a leeward wall case to the original sidewall case for WERFL Run 2071 (Angle of Attack: 355°), and also include a leeward and sidewall case for WERFL Run 279 (Angle of Attack: 10°). Each wind trace will have a duration of 3 minutes, for a total of 12 minutes of wind traces with three intermediate benchmark traces at 20 seconds each, giving a total run time of approximately 13 minutes.

Memo_WERFL%20Pr
essure%20Time%20Hi

ASTM D5206

The pressure traces will follow that of ASTM D5206, which consists of applying a uniform pressure difference across the specimen in increments of 5 lbf/ft2 (0.25 kPa), holding for 30 s before increasing the next 5 lbf/ft2 (0.25 kPa) and continuing until failure of the specimen. Failure is defined as meeting any of the following criteria:

- Siding nail tab is torn or disengaged from fastener.
- Permanent buckling of siding.
- Fastener withdrawal from frame.
- Permanent disengagement of locks

Proposed Test Matrix

Level	Description	Trace ID
Level 1 – peak pressure magnitude = -0.5 kPa	Benchmark	SID-L1-B-1
	Uniform static tests	SID-L1-US-n*
	Benchmark	SID-L1-B-2
	Spatially-varying static tests	SID-L1-VS-n*
	Benchmark	SID-L1-B-3
	Spatially-varying sine wave tests	SID-L1-VSW-n*
	Benchmark	SID-L1-B-4
	Spatially-varying wind traces – Run2071 – side wall	SID-L1-SVW-2071S
	Benchmark	SID-L1-B-5
	Spatially-varying wind traces – Run2071 – leeward wall	SID-L1-SVW-2071L
	Benchmark	SID-L1-B-6
	Spatially-varying wind traces – Run279 – side wall	SID-L1-SVW-279S
	Benchmark	SID-L1-B-7
	Spatially-varying wind traces – Run279 – leeward wall	SID-L1-SVW-279L
Level 2 – peak pressure magnitude = -1.0 kPa	Benchmark	SID-L2-B-1
	Uniform static tests	SID-L2-US-n*
	Benchmark	SID-L2-B-2
	Spatially-varying static tests	SID-L2-VS-n*
	Benchmark	SID-L2-B-3
	Spatially-varying sine wave tests	SID-L2-VSW-n*
	Benchmark	SID-L2-B-4
	Spatially-varying wind traces – Run2071 – side wall	SID-L2-SVW-2071S
	Benchmark	SID-L2-B-5
	Spatially-varying wind traces – Run2071 – leeward wall	SID-L2-SVW-2071L
	Benchmark	SID-L2-B-6
	Spatially-varying wind traces – Run279 – side wall	SID-L2-SVW-279S
	Benchmark	SID-L2-B-7
	Spatially-varying wind traces – Run279 – leeward wall	SID-L2-SVW-279L
Level 3 – peak pressure magnitude = -1.5 kPa	Benchmark	SID-L3-B-1
	Uniform static tests	SID-L3-US-n*
	Benchmark	SID-L3-B-2
	Spatially-varying static tests	SID-L3-VS-n*
	Benchmark	SID-L3-B-3
	Spatially-varying sine wave tests	SID-L3-VSW-n*
	Benchmark	SID-L3-B-4
	Spatially-varying wind traces – Run2071 – side wall	SID-L3-SVW-2071S
	Benchmark	SID-L3-B-5
	Spatially-varying wind traces – Run2071 – leeward wall	SID-L3-SVW-2071L
	Benchmark	SID-L3-B-6
	Spatially-varying wind traces – Run279 – side wall	SID-L3-SVW-279S
	Benchmark	SID-L3-B-7
	Spatially-varying wind traces – Run279 – leeward wall	SID-L3-SVW-279L
	Benchmark	SID-D5206-B1
-	ASTM D5206	SID-D5206

Notes:
- SID indicates the specimen ID
- n* indicates a specific configuration within the trace family