Interim Report:

Evaluation of Wind Resistance of Vinyl Siding and Soffit Systems, and Performance during the 2017 Hurricane Irma

Project #: P0103255

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Introduction

This literature review summarizes the current findings on the wind resistance of vinyl and aluminum soffits, vinyl siding, their performance during hurricanes, and design recommendations. Common or observed failure modes in soffit and siding systems were identified and recommendations to prevent them were stated. In the case of soffit systems, wind driven water intrusion and wind loads effects were identified from previous research while wind loads where the focus for vinyl siding.

In terms of performance, currently components and cladding of a building envelope are tested with static uniform pressure. These test methods do not represent how wind behaves in reality and pressure loading actuator (PLA) systems provide a method to apply spatio-temporal loads across building envelope components. The components, features, advantages and limitations of the PLA system are briefly presented in this literature review. Application of the PLA system is discussed by presenting previous research done on air-permeable cladding such as vinyl siding.

Three alternatives to set-up the experimental test are presented. The set-ups propose to use PLA systems to include the spatio-temporal variation of wind pressures. Failure modes from this experiment will be documented as well as failure pressures to compare them against observed failure mechanisms from previous hurricane damage surveys.

Soffit Panel Systems

1. Soffit Systems

Elements that enclose the underside of sloped or flat-roof overhang. Soffits are commonly made of fiber-cement panels, metal panels, stucco, vinyl panels or wood sheathing (FEMA 2008) .

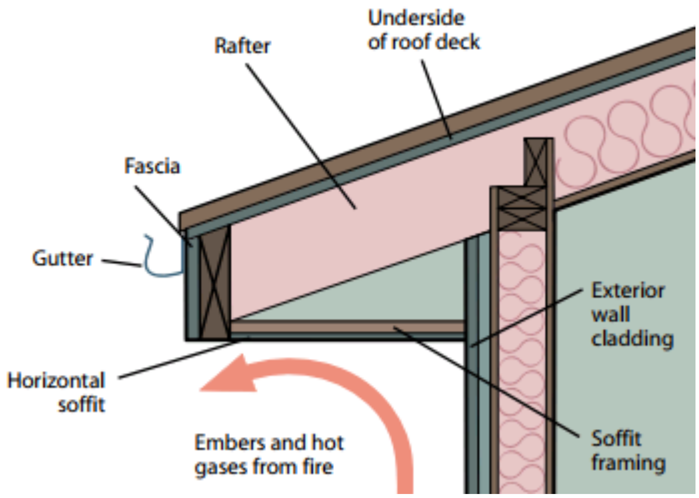


Figure 1. Enclosed Overhang with a Horizontal Soffit (FEMA 2008)

2. Design Requirements According to Florida Building Code 2017

The following steps summarize the design procedure for soffit systems according to the Florida Building Code 2017 (FEMA 2018)

- Determine the location and site-specific factors
    - Design wind speed
    - Exposure category
    - Mean roof height
- Find Zone 5 (soffit surfaces) pressures
- Modify wind pressure for specific wind zone
- Select the soffit system rated to resist Zone 5 pressures

3. Key issues

Following the building performance after hurricane Irma FEMA (2018) stated the following issues :

- Wind-damaged soffits allow wind-driven rain to enter the building envelopes
- The amount of water intrusion increases dramatically when the soffit material is missing
- Need for clarification of soffit installation criteria

4. Preliminary Investigation Of Wind-Driven Rain Intrusion Through Soffits

Reference

Masters, F. (2006). "PRELIMINARY INVESTIGATION OF WIND-DRIVEN RAIN INTRUSION THROUGH SOFFITS." project report to the Florida Department of Community Affairs Summer.

Experiment

Compare the performance of six soffit specimens subjected to wind-driven rain. The performance is measured as average percentage of freestream wind-driven rain that enters the soffit system (i.e. low average means better performance and viceverse) (Masters 2006).

Specimens

Specimen 1-Hidden vent soffit

Specimen 2-Perforated vinyl soffit

Specimen 3-Perforated aluminum soffit

Specimen 4-The perforated vinyl soffit in conjunction with an insect screen across the threshold of the attic and soffit space

Specimen 5- deflectors were added to the hidden vent soffits

Specimen 6-Baffled system

Figure 2. Specimens (Masters 2006)

Relevant Information

Unmodified soffit (specimen1~3)

- The perforated vinyl soffit (2.2% - 2.6% intrusion) outperformed the hidden vent and perforated aluminum soffits (4.2% - 8.3%).
- The perforated aluminum soffit (2.6% - 3.8%) outperformed the hidden vent soffit (4.2% - 8.3%).

Insect screen vinyl (specimen 4)

- Dry or wet initial condition make no difference
- Insect screen reduced intrusion 79% - 86% with values of average percentage of freestream wind-driven rain of (0.3% - 0.5%)

Deflector vent (specimen 5)

- Dry or wet initial condition didn't affect the performance of soffits.
- Deflectors reduced intrusion 69% - 79% with values of average percentage of freestream wind-driven rain of (1.3% - 1.8%)

Slot vent and Baffle system (specimen 6)

- Worst performer with 10.9% - 22.1% average percentage of freestream wind-driven rain

5. Structural and Wind-Driven Rain Resistance of Soffits (Final Report 2011/2012)

Reference

Fiscal Year 2011/2012 Scope of Work." <http://www.floridabuilding.org/fbc/commission/FBC_0812/HRAC/Task_5_Final_Report-Soffit.pdf>.

Experiment

The experiment consist in the application of several quasi-static and dynamic wind loading to soffit panles. In the first stage considers vinyl and aluminum soffit while the second stage considers stucco, fiber cement board and OSB soffit.

Observed Failure Modes Vinyl and Aluminum Soffits

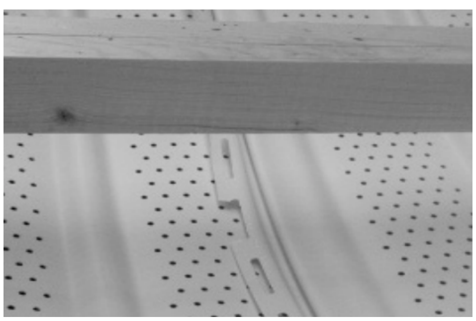
Panel Disengagement

- Dominant failure mode
- The aluminum sections failed in the middle from panel disengagement.
- The vinyl sections failed in the end from panel disengagement.

Nail Pullover

- Dominant failure mode
- Nail pullover of the J-channel can cause the panels to disengage
- The sequence of nail pullover and panel unlocking could not easily be distinguished visually

Torn Nail Slot



Non-dominant failure mode

Permanent Set

Non-dominant failure mode

Figure 3. Failure Modes (Masters and Kiesling 2011)

Relevant information from Vinyl and Aluminum Soffits

- Straight 305 mm (1 ft) overhang soffit for both vinyl and aluminum soffits that have J-channels are expected to fail at pressures that exceed design requirements in hurricane prone areas.
- Straight 610 mm overhang (2 ft) for both vinyl and aluminum soffit experienced lower values of failure pressures; many of the soffit product approval documents list the same failure pressure values as the Straight 305 mm (1 ft) case

- For the straight 610 mm overhang vinyl siding soffit, there was no statistical difference for failure pressures in the quasi-static and dynamic load cases. This may be attributed to the same dominant failure mode.
- Aluminum soffits failed at larger pressures from dynamic loading than quasi-static loading.
- Panel disengagement was the dominant failure mode followed by material yielding (nail pull-over) at the fastener. Fastener withdrawal does not appear to represent a problem
- Consistency was observed between the range of observed failure pressures caused by dynamic loading and field observations in single story homes during Hurricane Charley by Gurley and Masters (2011). These homes experienced failures at 50 m/s (110 mph) winds, corresponding to ~1.5 kPa threshold in suburban terrain exposure at the height of a one-story building.
- Corner sections were more susceptible to wind loads than straight sections. There is very little guidance in the public domain for installing corner sections. Standardized product approval testing protocols should be updated to evaluate the performance of corner sections.

Observed Failure Modes Stucco, Fiber Cement Board and OSB Soffits

Figure 4. Predominant Failure Mode (Masters and Kiesling 2011)

- The most common mode of failure was pullout of the soffit around the fasteners in the intermediate nailing member(as the picture show)
- This failure was seen in each of the 610 mm (2 ft) fiber cement board soffit during both loading.
- The middle fastener should receive nominally twice the load the edge fasteners receive due to the difference in tributary area.

Relevant information from Stucco, Fiber Cement Board and OSB Soffits

In contrast to the aluminum and vinyl soffit sections OSB, stucco and fiber cement board systems performed adequately under steady and time varying wind loads. Fiber cement board was an exception because it did not fail at 150% of the unfactored design pressure.

6. Component and Cladding Wind Loads for Soffits

Reference

Vickery, P. J. (2008). "Component and cladding wind loads for soffits." *Journal of structural engineering*, 134(5), 846-853.

Relevant Information

The experiment indicate that wall and soffit pressures are highly correlated. The high correlation of the soffit-wall loads suggest that the reduction in pressures with increased area for the soffits will be consistent with that which occurs along the walls. The results indicate a simple and accurate solution to the soffit loading deficiency in ASCE 7 (i.e. no guidance as to the wind load requirements for the design of soffits) is to prescribe that the component and cladding pressures. Both negative and positive for use in the design of soffits to be identical to the component and cladding loads used for the design of wall components (Vickery 2008).

Vinyl Siding

1. Vinyl Siding Systems

Vinyl siding is a durable form of plastic exterior wrapping for a home, used both for aesthetics and weatherproofing. Engineered primarily from polyvinyl chloride (PVC) resin.

- It improves the home's energy performance.
- It can reduce wall sheathing moisture content
- It can improve the aesthetic appeal of a home
- It can withstand winds of 110 mph(most products achieve much higher ratings)

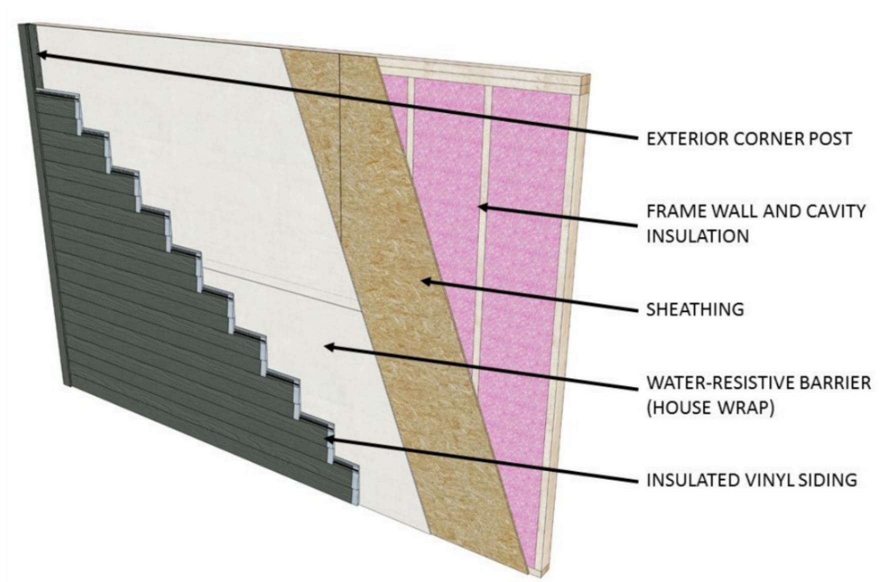


Figure 5. Multilayer wall system with vinyl siding cladding system (Building America Solution Center 2017)

2. Design Requirements According to Florida Building Code 2017

The following steps summarize the design considerations for vinyl siding according to the Florida Building Code (FBC).

- FBC 2017 refers to the 2011 ASTM D 3679, Standard Specification for Rigid (Vinyl Chloride) (PVC Siding); FBC 2014 refers to the 2009 ASTM D 3679 edition
- ASTM D 3679 allows for the reduction of load due to the net reduction of wind forces across cladding layers (pressure equalization)
- A pressure equalization factor of 0.36 is used in design pressure rating and a safety factor of 1.5

$$P_t = D_p \times PEF \times 1.5$$

Where:

P_t = test pressure

D_p = design pressure rating of vinyl siding

PEF = Pressure Equalization Factor, 0.36

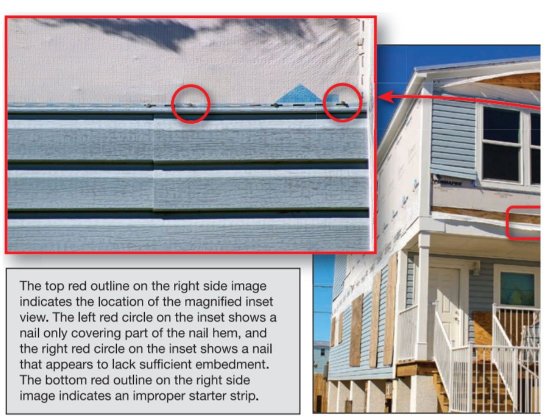
1.5 = Factor of Safety

Figure 6. Design pressure rating equation for vinyl siding (Fema 2018)

3. Key issues

- Mitigation Assessment Team found that most of the observed exterior wall covering damage was to vinyl siding. (Fema 2018)
- Vinyl siding failures at pressures it should have resisted based on design pressures, and design pressure rating. (Fema 2018)
- Frequently, loss of siding begins at the lowest course and proceeds up the wall. (FEMA 2010)
- The rating in many products do not make it easy to determine whether the product will be adequate for the coastal environment. (FEMA 2010)
- Recent full scale research performed by Cope et al. (2013), Morrison and Cope (2015) and Miller et al. (2017) recommend a PEF for vinyl siding closer to 0.8.
    - These results deem the 0.36 PEF of ASTM D 3679 an un-conservative value.

4. Observed failures in Hurricane Events



Failure of vinyl siding failure due to nail covering only part of the nail hem, and lack of nail embedment (Fema 2018)

Vinyl siding failure because to lack utility trim under the windows (Fema 2018)

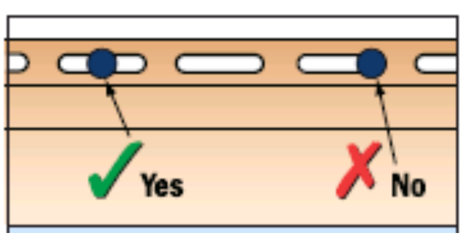
Unlatched vinyl siding panel susceptible to blow (FEMA 2005)

Extensive lost of vinyl siding and housewrap event though high wind panel was used (FEMA 2005)

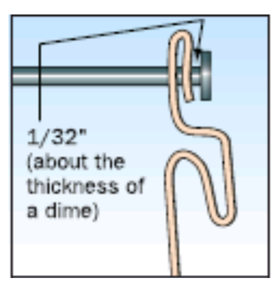
Figure 7. Failure of vinyl siding in hurricane events

5. Relevant Information

- Use an effective moisture barrier (i.e. housewrap or building paper))to avoid wind-driven rain penetration into wall cavities
- Stainless steel fasteners are recommended for buildings within 3,000 feet of the ocean line.
- When applying new siding over existing siding, use shims or install a solid backing to create a uniform, flat surface on which to apply the siding, and avoid creating gaps or projections that could catch the wind.
- Nails should be positioned in the center of the nailing slot (Figure 8a). To allow for thermal movement of the siding, do not drive the head of the nail tight against the nail hem (unless the hem has been specifically designed for this). Leave approximately 1/32 inch (which is about the thickness of a dime) clearance between the fastener head and the siding panel (Figure 8b).



(a)



(b)

Figure 8. Nail location

- Drive nails straight and level to avoid distortion and buckling in the panel.
- Do not caulk the panels where they meet the receiver of inside corners, outside corners, or J-trim. Do not caulk the overlap joints.
- Do not face-nail or staple through the siding.
- Use aluminum, galvanized steel, or other corrosion-resistant nails when installing vinyl siding.
- Nail heads should be 5/16 inch minimum in diameter. Shank should be 1/8 inch in diameter.
- Adjacent panels shall overlap properly, about half the length of the notch at the end of the panel, or approximately 1 inch. Overlap should not be cupped or gapped, which is caused by pulling up or pushing down on the siding while nailing. Reinstall any panels that have this problem.
- Use utility trim under windows or anywhere the top nail hem needs to be cut from siding to fit around an obstacle. Be sure to punch snap-locks into the siding to lock into the utility trim. Do not overlap siding panels directly beneath a window
- At gable end walls, it is recommended that vinyl siding be installed over approved sheathing capable of independently resisting the full design wind pressures

Experimental Research

1. Detailed Misconceptions "Three Little Pigs" Project: Hurricane Risk Mitigation by Integrated Wind Tunnel and Full-Scale Laboratory Tests

Kopp et al. (2010) developed a new testing methodology to apply realistic wind loads on homes, and other light frame structures during severe wind storms to mitigate previously observed damage. This methodology consists of utilizing pressure loading actuators (PLA) which are able to apply spatial and time varying wind loads. The PLA system was able to replicate the desired target pressure with 0.95 correlation compared to IBHS full scale results.

1.1 Reference

Kopp, G. A., Morrison Murray, J., Gavanski, E., Henderson David, J., and Hong Han, 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.

1.2 Objectives

To develop a more realistic testing method considering temporal and spatial variations that allows to calibrate a simplified test to full scale. In addition, the development principles for the incorporation of material variability in computational models.

1.3 Loading conditions

- External Pressure Gradient
- Compared with uniform, time varying external pressure
- Compared with full scale loading results

1.4 Equipment (PLA System)

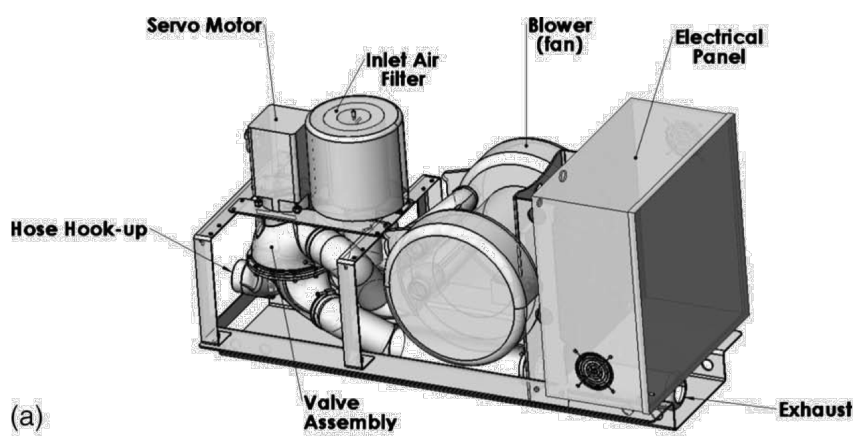


Figure 9. Pressure loading actuator system (PLA) (Kopp et al. 2010)

- Blower Fan
- Rotating Disk inside the valve
- Servomotor to regulate pressure
- Pressure transducer to monitor pressure inside bags connected to each PLA
- PLA updates 100 times/sec
- Maximum frequency 10hz
- Maximum pressure 23kPa Minimum pressure -20kPa   Q=0.24 m3/sec

1.5 Relevant Information

- The relationships between the pressure and velocity is as clearly defined
- Temporal effects of real storms, with all the load cycling and duration effects, can be simulated, including changes in wind speed and direction
- The PLA approach replicates only the pressure field, so in situations where the flow field is equally important, PLA's cannot be used
- Airbags:
    - For very flexible cladding elements, like vinyl siding, the requirement of mechanical attachment means that only uniform pressures can be applied using a single air box which surrounds a relatively large test sample. Therefore, while time varying loads can be used, any spatial effects cannot be identified.
    - Maximum allowable displacements are imposed by the depth of the airbags
    - Very small elements cannot be tested, such as fascia, due to limitations on the minimum airbag size.

2. Experimental Assessment of Wind Loads on Vinyl Wall Siding

Moravej et al. (2016) conducted a full-scale test on a vinyl siding wall to study pressure equalization effects as a function of pressure tap location and combinations. The experiment wants to test the hypothesis that it may be under conservative to design vinyl siding cladding based on pressure equalization values from averaging net pressure coefficients over entire wall areas. This study was conducted at the WOW experimental facility in Florida International University for various wind directions. Using a 2.43 m by 2.74 m and eave height 2.34 m building model, wind pressures were measured in the exterior, interior cavity surfaces of the vinyl siding cladding. Interior pressures of the building model was also determined for pressure equalization factors. The area in which the pressure coefficients are averaged was varied in order to compare effects of pressure equalization in the entire wall system and how much equalization occurs at local connection areas.

2.1 Reference

Moravej, M., Zisis, I., Gan Chowdhury, A., Irwin, P., and Hajra, B. (2016). "Experimental Assesement of Wind Loads on Vinyl Wall Siding." Frontiers in Built Environment, 2(35).

2.2 Objectives

To prove that the area over which pressure equalization factor (PEF) is calculated affects its value. If the entire wall area is considered PEF value tends to be lower than considering localized areas (smaller areas) resulting in under-estimation of design wind loads.

2.3 Loading Condition

Wall of Wind (WOW) wind tunnel load at Florida International University

- Sampling rate of 512 s-1 using a Scanivalve ZOC 33

2.4 Experimental Setup (building model)

- The wood frame building was sheathed by a layer of plywood and was then covered by the vinyl siding.
- The vinyl siding consisted of several individual panels that were connected to the building wall sheathing using nails (using spacing of 23 cm or 9″).
- 49 pressure taps on the exterior surface of the vinyl siding.
- 49 pressure taps on the exterior surface of the plywood layer for cavity pressure.
- 4 pressure taps on the interior surface of the plywood layer.

2.5 Pressure measurements

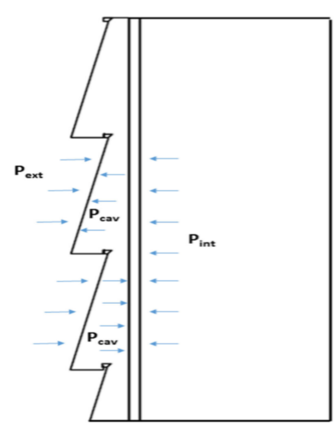


Figure 10. Schematic of the wall section and the location of pressure measurements (Moravej et al. 2016)

- Exterior taps on the vinyl siding to measure external pressures.
- Pressure taps on the exterior face of the plywood sheathing to measure pressures in the cavity.
- Internal taps inside the building model to measure building internal pressure

2.6 Results

- The study found that positive pressures produces a near zero net pressure on the vinyl siding due to the pressure equalization. The sheathing takes most of the pressure in this case. In suction, between 70° and 90°, the net pressure coefficient was in the range of approximately 0.25- 0.35 and closer to zero for the other wind directions.
- The study found that PEFs for suction zones vary from 78% to 106% for individualized pressure tap areas and from 52% to 78% for case combinations of pressure taps. In pressure zones, PEFs varied from 39% to 110% for individualized pressure taps areas and from 13% to 74% for cases of pressure taps combinations. This proves that the area considered to average pressure coefficients and calculate pressure coefficients has a definite effect on the observed reduction of load.

2.7 Relevant Information

- Net wind pressure across vinyl siding is minimal when pressures are averaged over a large area of the wall.
- The current results suggest that the net load on vinyl wall siding for 1 m^2 tributary area can be obtained by applying PEFs of 0.75 to the net design "suction" and 0.40 to the net design "pressure" loading, across the whole wall assembly.
- For smaller tributary areas (0.2 m^2), the PEF should be about 0.85 suction to help prevent local failure of connections that could lead to cascading failure.

3. Multichamber, Pressure- Based Test Methods to Determine Wind Loads on Air-Permeable, Multilayer Cladding Systems

Miller et al. (2017) studied if it was feasible to determine realistic wind loads on multi-layer vinyl siding wall systems using a multichamber airbox/pressure chamber approach. The experiment wants to test the hypothesis that by creating an external pressure gradient, sealed airbox systems pressure equalization factors (PEF) should agree with PEFs in full scale testing. The study was conducted at the University of Western Ontario. Five pressure traces were applied to a 12 ft. long by 8 ft. high multilayer wall system. External and internal cavity pressures were measured in order to calculate PEF. PEFs form multichamber test approach were compared to IBHS full scale testing on the same vinyl siding multilayer wall systems.

3.1 Reference

Miller, C. S., Kopp, G. A., Morrison, M. J., Kemp, G., and Drought, N. (2017). "A Multichamber, Pressure- Based Test Method to Determine Wind Loads on Air-Permeable, Multilayer Cladding Systems." Frontiers in Built Environment, 3, 7.

3.2 Objectives

To determine if multichamber airbox testing is feasible for assessing wind loads on air-permeable, multilayer cladding systems. If an external pressure gradient is created for the multilayer wall system by using different airbox chambers, similar pressure equalization factors (PEF) should be observed than those obtained in IBHS full scale testing.

3.3 Loading Conditions

- Pressure loading actuators in multiple chambers creating external pressure gradient at the University of Western Ontario
    - Able to capture pressure fluctuations up to 10 Hz
    - Peak pressures of 23 kPa and -20 kPa
    - Controlled by Proportional-Integral-Derivate system (PID) capable of following target pressure; system corrected in 1/10 of a second a pressure trace deviation in this experiment
- Compared with uniform, time varying external pressure
- Compared with full scale loading results

3.4 Experimental Setup

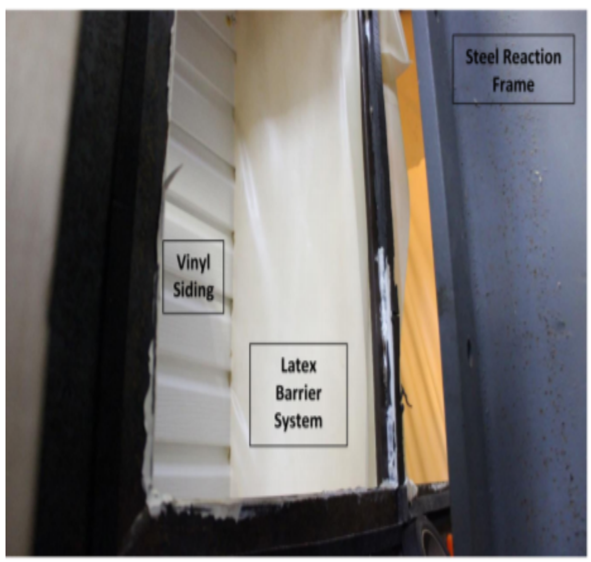


Figure 11. Latex barrier system which creates separate airboxes which are attached to the vinyl siding specimen and steel reaction frame (Miller et al. 2017)

- Walls of 12 foot long by 8 ft high with 2 by 4's studs
- ¾" plywood sheathing with polyurethane sheet to seal the pressure chamber
- Housewrap over plywood to replicate typical construction practice
- Pressure taps installed at same locations of IBHS walls
- 12 feet vinyl siding installed using appropriate nails at 16" intervals along the wall

- Test wall installed in rigid-sided chamber (same as used by (Gavanski and Kopp 2011(b))
- Five pressure chambers created using latex barrier system and each chamber had a different pressure trace from IBHS full scale testing creating the external gradient

3.5 Relevant Information

- Concept of creating multichamber, pressure-based, testing apparatus to obtain accurate wind loads on air-permeable cladding worked.
- Accomplished by:
    - Application of multiple, discreet, time-varying loads across a test specimen
    - Development of linearized five-port, flow reversing valve
    - Adaptive Proportional-Integral-Derivate system (PID) as a control strategy
- Multichamber pressure loading together with external pressure data obtained from the IBHS wind tunnel matched the cavity pressures and PEF's from the IBHS full scale test on vinyl siding.
- Results confirm PEF used in ASTM D3679-13 is unconservative.
- Static, multichamber test may be feasible for a test standard eliminating the complexity of using PLA system. These PEF varied by 5% from the results obtained in the multichamber using the pressure-time history.

Experimental Setup

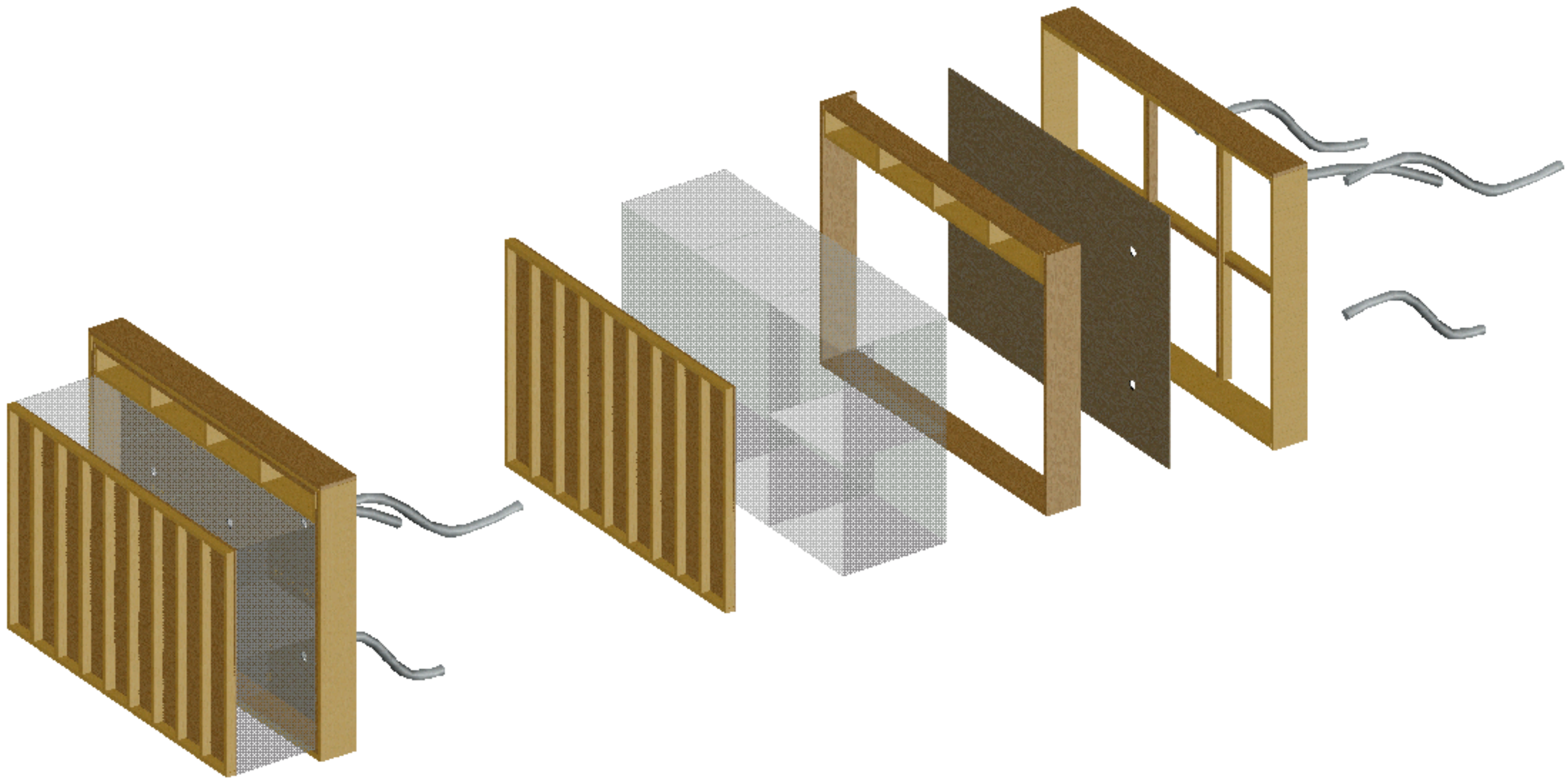


Figure 12. Option A- View 1

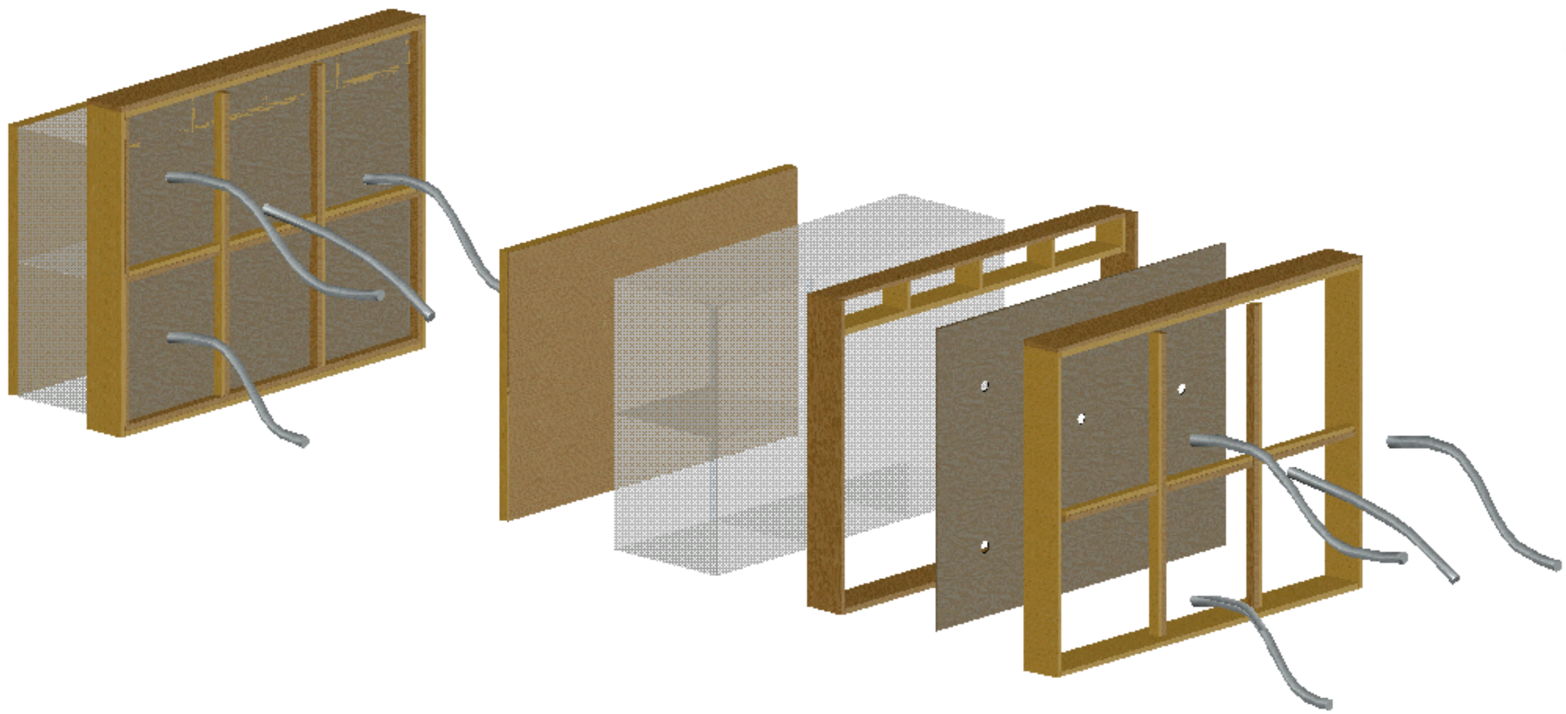


Figure 13. Option A- View 2

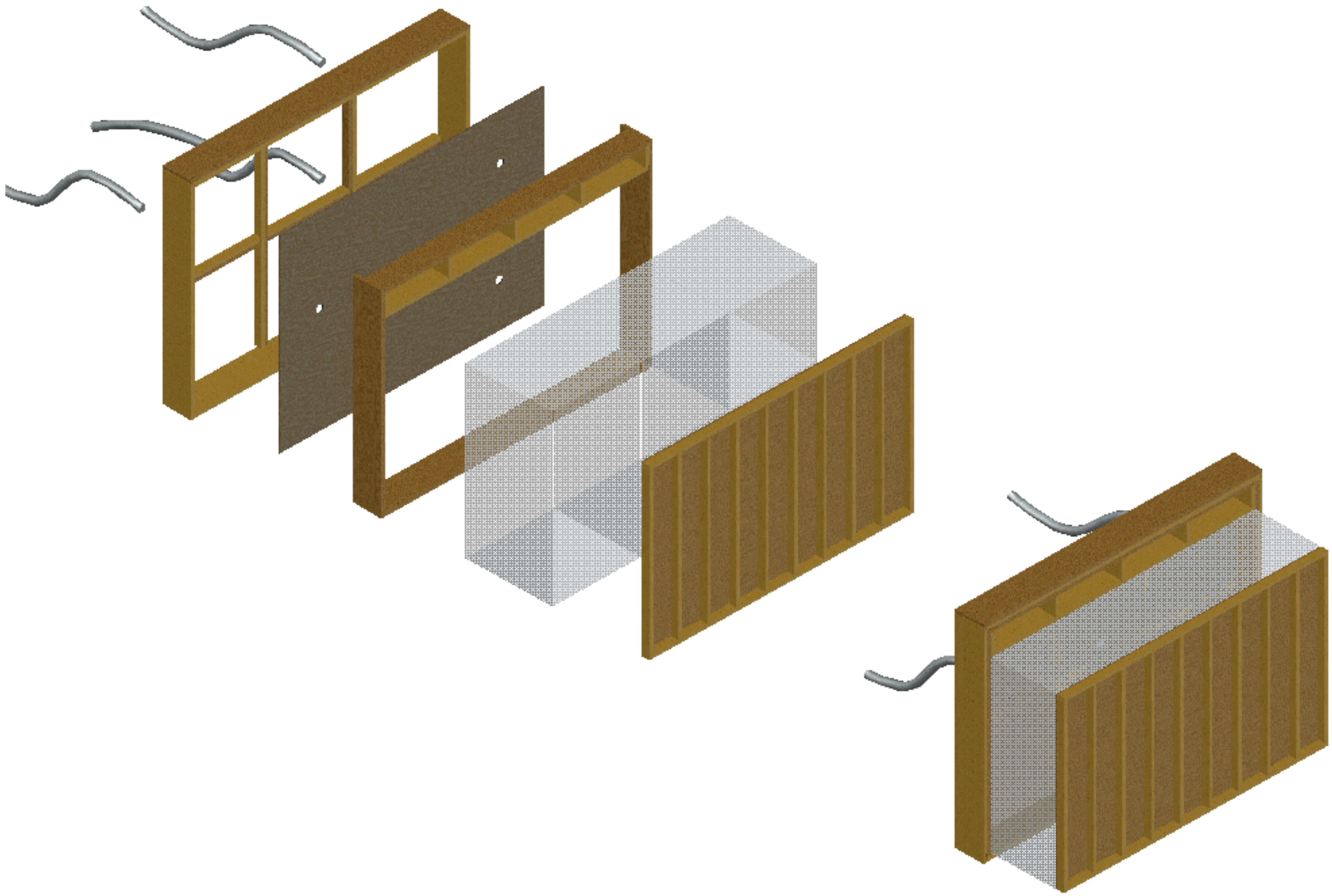


Figure 14. Option A- View 3

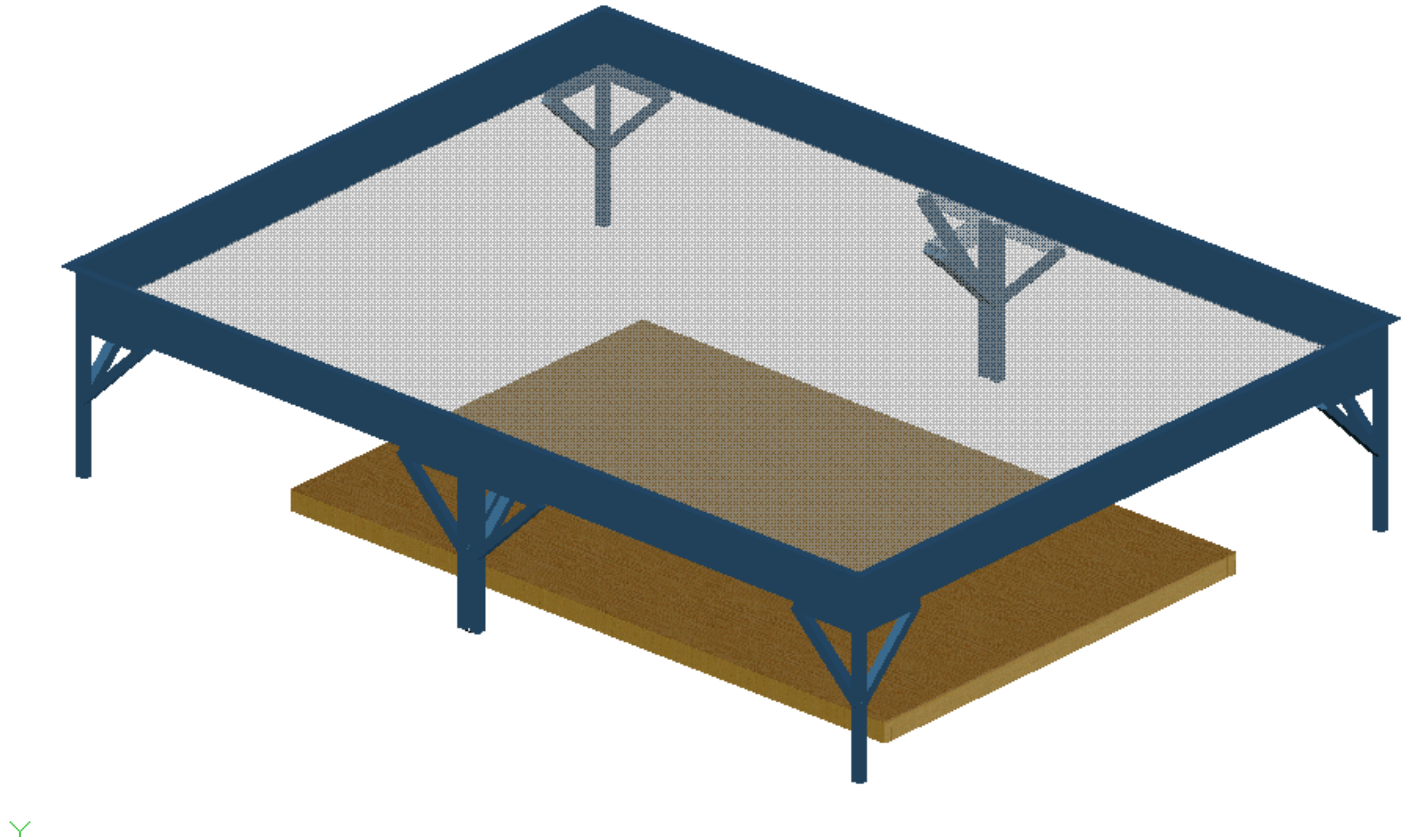


Figure 15. Option B

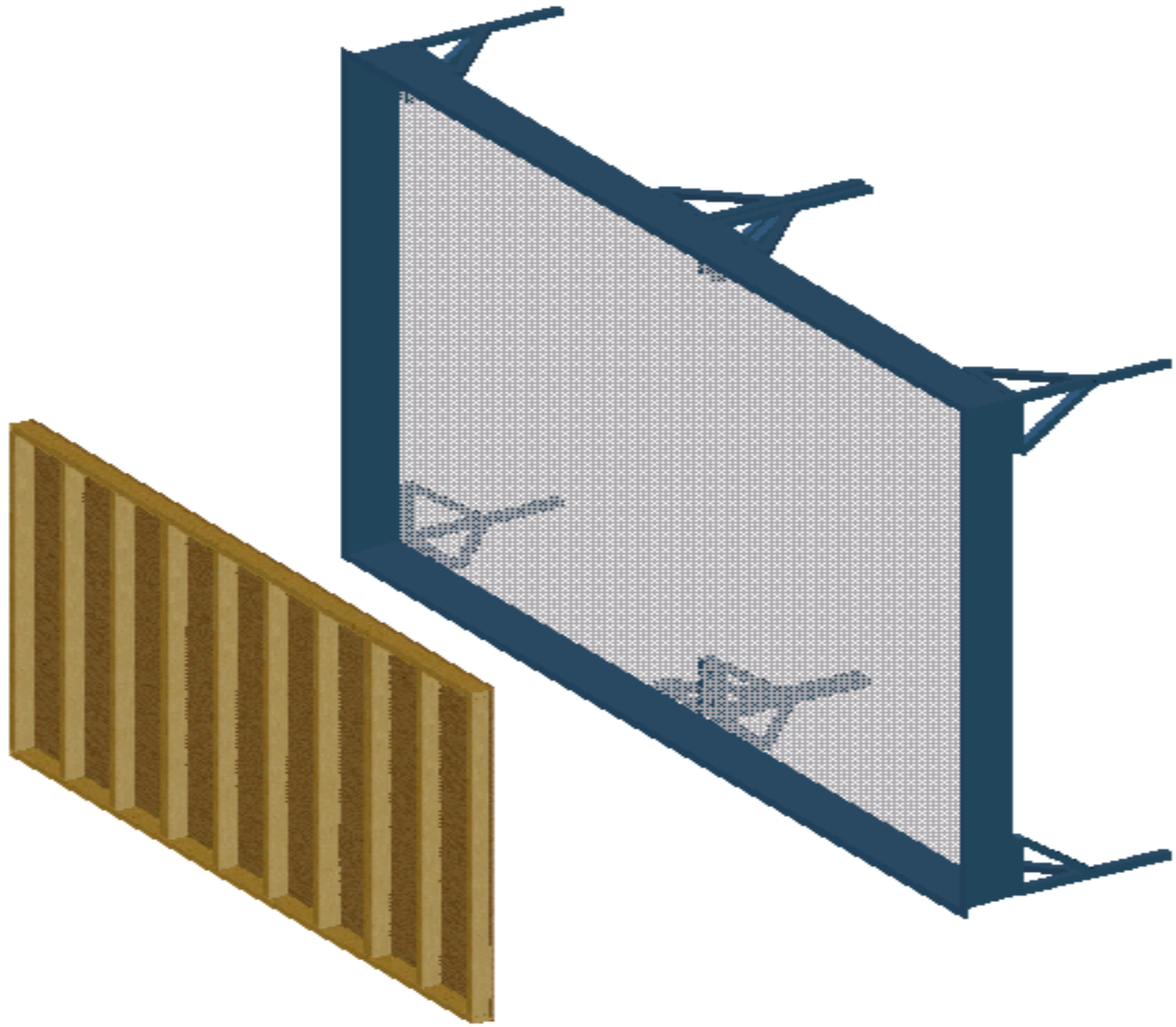


Figure 16. Option C

Investigation of Vinyl Siding and Soffit Failures in Hurricane Irma and Michael

The original damage database collected in Florida by the PI following Hurricane Irma identified 171 homes with vinyl siding, but questions were raised as to the accuracy of the vinyl siding damage dataset (e.g., some cladding types appeared to have been misidentified during the quality control process), and the precision of the database, since damage was only quantified for the structure as a whole without regard for mixed cladding types.

Further, the overall cladding damage ratios did not inform the distribution of damage about the building, which is important to properly characterizing the flow regime under which the failures occurred in relation to the dominant wind directions. Finally, the original damage database did not consistently identify soffit materials or failures. The objective of the current work is to develop a protocol for more accurately and precisely quantifying the nature and distribution of damage to wall cladding systems, and apply it first to the existing Hurricane Irma damage database, and second to the Hurricane Michael damage database that was newly collected in 2018.

Progress in this objective of the original scope of work is summarized as follows:

- A review of the existing database for Hurricane Irma has so far confirmed the presence of vinyl siding in 25 homes and has quantified vinyl siding damage by wall and story level in these homes to identify suitable case studies for development of the full vinyl siding assessment protocol.
- A new protocol has been developed that quantifies the existence and performance of vinyl siding systems in a discrete grid for each wall surface of each story of the building. A graphical user interface has been developed in Matlab for subdividing each wall surface of each building into a discrete grid (**Figure 17**), from which the data regarding wall cladding material type and damage level are visually defined. The process has been demonstrated for several case studies, and is now being implemented for the full dataset in Hurricane Irma. The same protocol will be extended to Hurricane Michael once buildings with sufficient use of vinyl siding have been confirmed.

Figure 17. Vinyl siding use and damage levels will be quantified using discrete grids for each wall surface on each story to precisely identify patterns in the locations of failures.

REFERENCES

Building America Solution Center (2017). "Vinyl Siding with Integrated Rigid Foam for Existing Walls."U.S.DEPARTMENT OF ENERGY.

Cope, A. D., Crandell, J. H., Johnston, D., Kochkin, V., Liu, Z., Stevig, L., and Reinhold, T. A. (2013). "Wind Loads on Components of Multi-Layer Wall Systems with Air- Permeable Exterior Cladding." 2013 American Society of Civil Engineers, **https://doi.org/10.1061/9780784412626.022**.

FEMA (2005). "Hurricane Ivan in Alabama and Florida."

FEMA (2008). "Eaves, Overhangs,
and Soffits." *Technical Fact Sheet*.

FEMA (2010). "Siding Installation in High- Wind Regions." *Technical Note*.

Fema (2018). "Hurricane Irma in Florida."

FEMA (2018). "Soffit Installation in Florida." *Technical Fact Sheet*.

Gavanski, E., and Kopp, G. (2011(b)). "Examination of load resistance in window glass design." *J. Struct. Eng*, 138.

Kopp, G. A., Morrison Murray, J., Gavanski, E., Henderson David, J., and Hong Han, 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.

Masters, F. (2006). "PRELIMINARY INVESTIGATION OF WIND-DRIVEN RAIN INTRUSION THROUGH SOFFITS." *project report to the Florida Department of Community Affairs Summer*.

Masters, F. J., and Kiesling, A. A. K. (2011). "Task 5 Final Report (Structural and Wind-Driven Rain Resistance of Soffits)
Fiscal Year 2011/2012 Scope of Work."
<http://www.floridabuilding.org/fbc/commission/FBC_0812/HRAC/Task_5_Final_Report-Soffit.pdf>.

Miller, C. S., Kopp, G. A., Morrison, M. J., Kemp, G., and Drought, N. (2017). "A Multichamber, Pressure- Based Test Method to Determine Wind Loads on Air- Permeable, Multilayer Cladding Systems." *Frontiers in Built Environment*, 3, 7.

Moravej, M., Zisis, I., Gan Chowdhury, A., Irwin, P., and Hajra, B. (2016). "Experimental Assesment of Wind Loads on Vinyl Wall Siding." *Frontiers in Built Environment*, 2(35).

Morrison, M. J., and Cope, A. D. (2015). "Wind Performance and Evaluation Methods of Multi-Layered Wall Assemblies." *American Society of Civil Engineers*.

Vickery, P. J. (2008). "Component and cladding wind loads for soffits." *Journal of structural engineering*, 134(5), 846-853.