INTERIM REPORT
(Year 2)

Wind-Induced Loads on Roof Overhangs

Florida Department of Business and Professional Regulation

Florida Building Commission

And

Laboratory for Wind Engineering Research (LWER), Extreme Events Institute (EEI)

Florida International University (FIU)

Project PI: Ioannis Zisis, Associate Professor, CEE, Florida International University, USA

Project Co-PI: Ted Stathopoulos, Professor, BCEE, Concordia University, Canada

Graduate Student: Karim Mostafa, CEE, Florida International University, USA

Date: February 2022

Table of Contents

List of Figures

List of Tables

1. Introduction

An overhang is an unenclosed continuation of the roof surface. Particularly on low-rise residential applications, overhangs may be open or covered by a soffit and may be cantilevered or supported. Most of the foundational belief about overhangs seems to suggest that overhangs extend no more than 2ft, whereas, in Florida, overhangs are often much longer and are necessary for energy efficiency and livability in this semi-tropical climate. Overhangs in Florida can be cantilevered 6ft or more, or supported, as on a terrace or porch, for 10 to 12ft or more.

Low-rise buildings are greatly affected by extreme wind events. The risk of wind-induced failure is particularly increased on roofs and roof overhangs. Low-rise buildings are greatly affected by extreme wind events. The risk of wind-induced failure is particularly increased on roofs and roof overhangs. The latter are commonly used in residential and industrial buildings for weather protection against wind, snow, rain, and sun. Extended overhangs resemble a roof extension like a canopy or a patio cover that is attached to the main structure. Recent studies showed that canopies may experience lower wind loads compared to those specified for roof overhangs on ASCE 7 (Zisis and Stathopoulos 2010, Candelario et al. 2014, Zisis et al. 2017).

ASCE 7-16 (2017) provides methods for analysis of the loads on overhangs, both for main wind force resisting systems (MWFRS) and component and cladding (C&C) loads, but the commentary does not provide any information as to the maximum length of overhang for which this analysis is valid. In section 30.9, it states that the pressure on the bottom covering of the roof overhang is the external pressure coefficient on the adjacent wall surface. This particular assumption was adopted more recently in the ASCE 7-16 (2017). In earlier versions of the ASCE 7 (2010), the overhang pressures considered the net pressure applied on these elements from simultaneous contributions from both the top and bottom surfaces of the overhang. Moreover, this may be an adequate assumption for a 2ft overhang, but the pressure on the bottom surface of a 4ft or 6ft or 12ft overhang is not a simple one-to-one wall-to-overhang pressure equivalent. The research that was done for canopies (ASCE 7-16 section 30.11), suggests that this is not the case (Zisis and Stathopoulos 2010, Candelario et al. 2014, Zisis et al. 2017). Most importantly the research that led to the revised provisions of ASCE 7-16 did not consider any building model with roof overhangs.

In phase 1, large scale wind tunnel experiments were conducted at the Wall of Wind at Florida International University for two configurations of a residential building of hip roof with different overhang width (i.e. 2 ft and 6 ft) for a hip roof building with slope 4:12, eave height of 24 ft and horizontal dimensions of 40 ft by 50 ft (full scale). Peak local surface wind coefficients were measured for walls, soffits, and roofs with overhangs for both configuration cases. Moreover, area averaged pressure coefficients were measured for different combinations of taps and were compared to the GCp plots in ASCE7-16. In addition to local and area averaged pressure coefficients, correlation coefficients and regression analysis was considered to assess the correlation of soffit pressure coefficients to pressure coefficients of wall upper taps. The findings showed that the 2 ft overhang experienced higher suction coefficients at the edges compared to the 6 ft overhang. In addition, the results confirmed that, for both configurations, soffit pressure coefficients may be taken as the adjacent wall external pressure, as stated by ASCE7-16 for positive pressure only, while for negative pressure this assumption may not be valid. More details about the results and finding from phase 1 can be found in ‘phase 1 final report’ that is available online on floridabuilding.org (Zisis et al. 2021). In addition, data from phase 1 testing have been published online on Designsafe - Data Depot (Mostafa et al. 2022).

In this phase of testing, large scale wind tunnel tests will be carried out on six different models to clarify how the pressures on the wall relate to different overhang widths, and at what point does the wall pressure cease to affect the overhang and the more direct wind loads on the overhang control. This interim report is focusing on the plan of the physical testing, i.e. model design, test setup and test protocols.

2. Experimental setup and test protocol

This section comprises the proposed experimental test setup that will be conducted at the Wall of Wind (WOW) Experimental Facility at Florida International University (FIU) (Gan Chowdhury et al. 2016) in February 2022. The 12-fan WOW is the largest and most powerful university research facility of its kind and is capable of simulating a Category 5 hurricane – the highest rating on the Saffir-Simpson Hurricane Wind Scale. In 2015, the National Science Foundation (NSF) has designated the Wall of Wind as one of the nation's major "Experimental Facilities" (EF) under the Natural Hazards Engineering Research Infrastructure (NHERI) program as a distributed, multi-user national facility that provides the natural hazards research community with access to research infrastructure. The WOW EF is managed by FIU's Extreme Events Institute (EEI).

2.1. Model layouts and dimensions

Discussion were held with an informal advisory group of building code officials and truss manufacturing companies before phase 1 testing and before phase 2 testing as well. It was concluded that priority should be given to the most common layouts that exist in current residential construction market. Thus, a hip roof building layout was selected, with an eave height of 24ft and horizontal dimensions of 40ft by 50ft (full scale). The slope of the roofs are either 4:12 to continue on what have been tested on phase 1 testing, or slope 6:12 which is associated with phase 2 testing only. The building dimensions are the same between the models that were tested in phase 1 and that will be tested in phase 2, with the same scale of 1:10 for all the models. Configurations A has a roof with slope 4:12 and an inclined overhang with width of 4 ft, which is one of the most common lengths suggested by the truss manufacturing industry and covered underneath with a horizontal soffit. Configuration B, C and D have a roof slope of 6:12 with an inclined overhang width of 2 ft, 4 ft, and 6 ft respectively, and covered underneath with a horizontal soffit. The last two models (configuration E and F) have a roof slope of 6:12 and an open overhang (i.e. with no horizontal soffit) with inclined width of 2 ft and 4 ft, respectively. Drawings of the six configurations are shown in Figures 1 to 6 in model scale dimensions. Table 1 shows the scales for the different parameters in test setup and Table 2 shows the prototype and model dimensions.

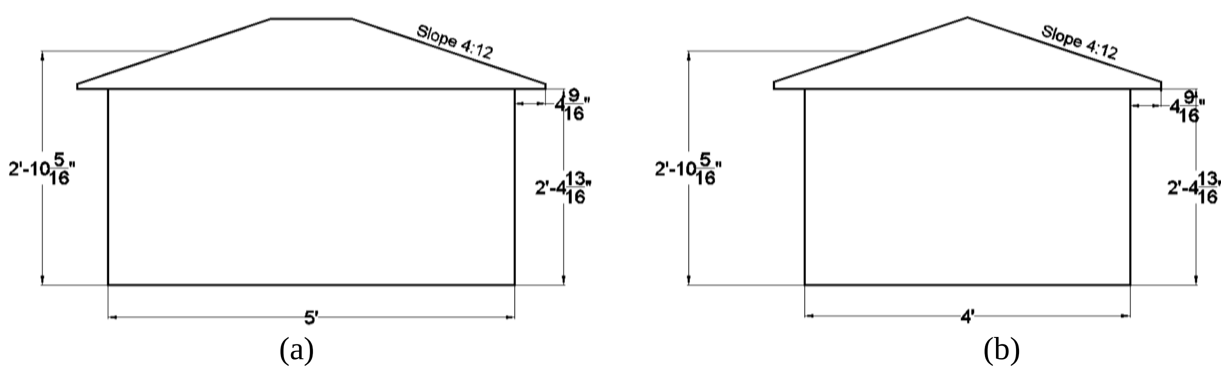
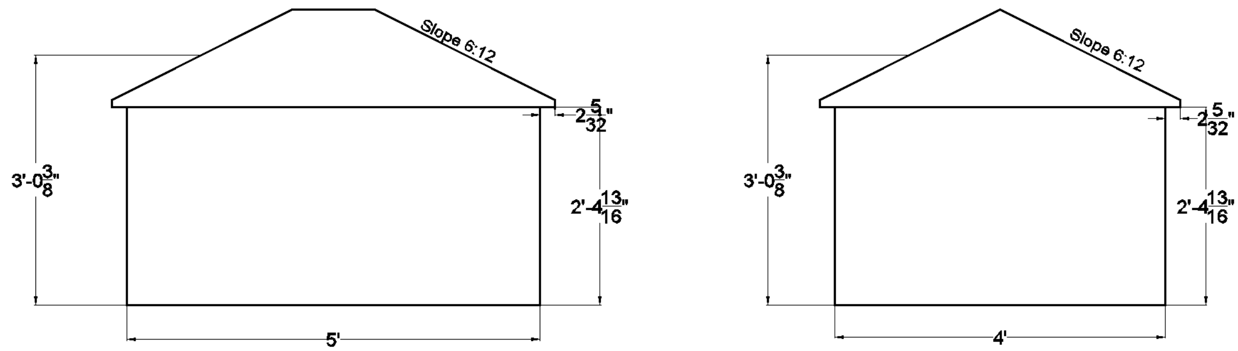
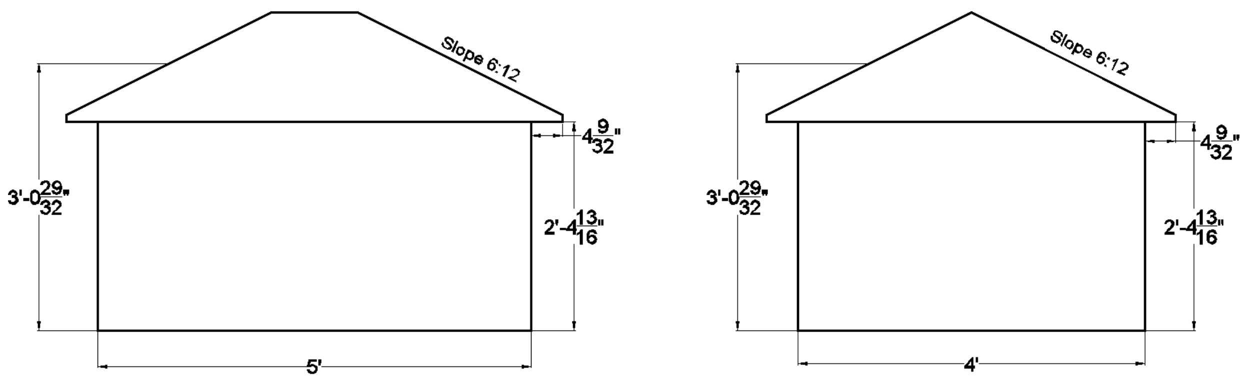


Figure 1 Configuration A model layout (a) Elevation View (b) Side View



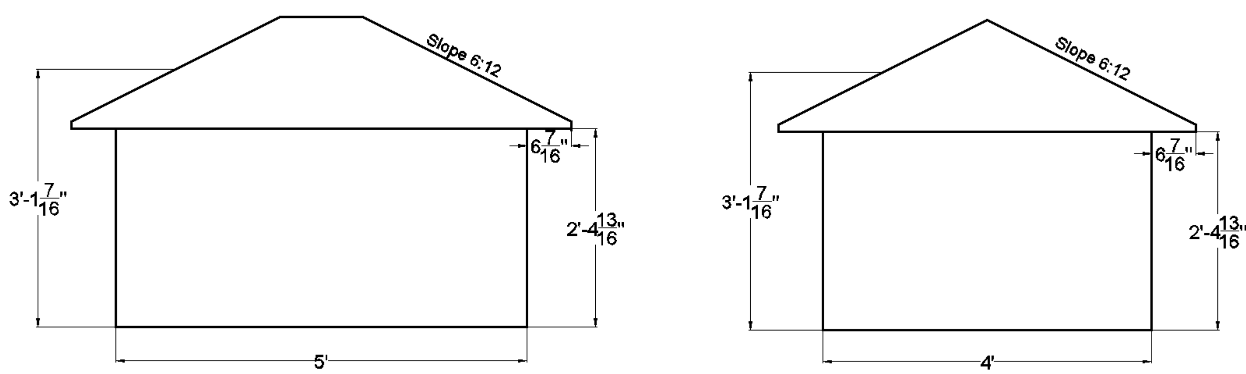
(a) (b)

Figure 2 Configuration B model layout (a) Elevation View (b) Side View



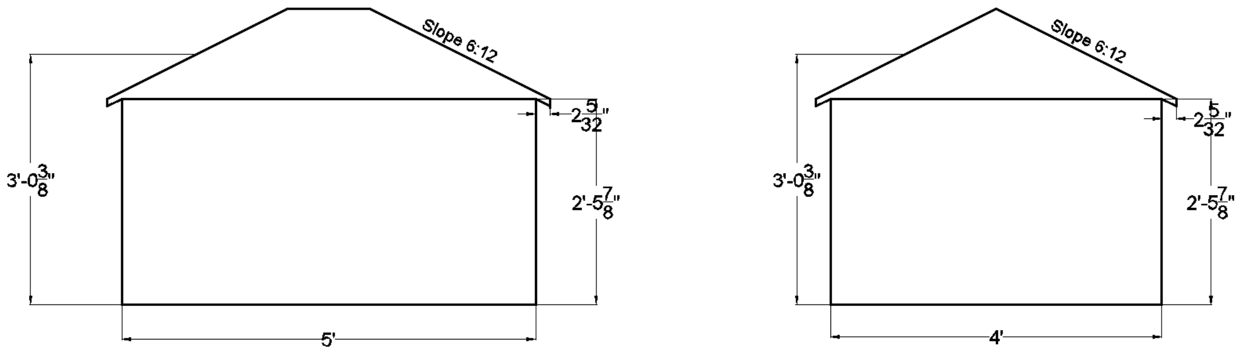
(a) (b)

Figure 3 Configuration C model layout (a) Elevation View (b) Side View



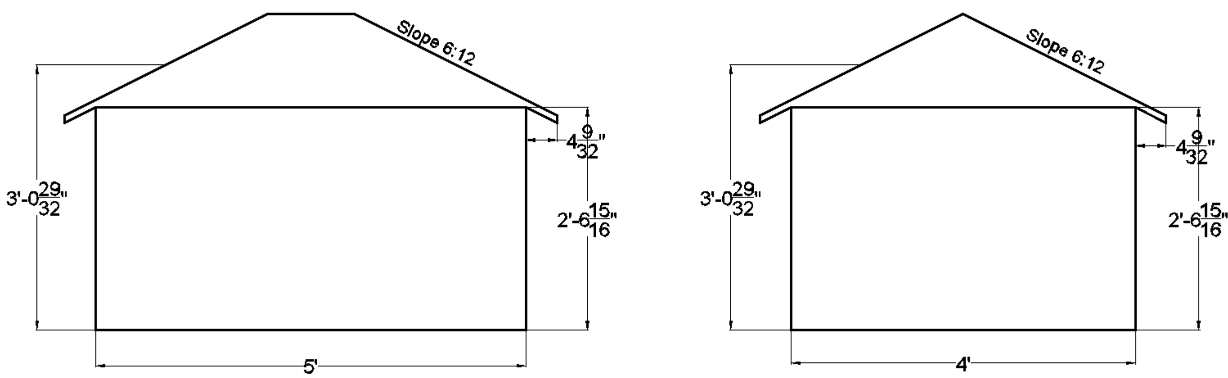
(a) (b)

Figure 4 Configuration D model layout (a) Elevation View (b) Side View



(a) (b)

Figure 5 Configuration E model layout (a) Elevation View (b) Side View



(a) (b)

Figure 6 Configuration F model layout (a) Elevation View (b) Side View

Froude number and Strouhal number were preserved and kept constant between the full scale (prototype) and the scaled model. Froud number is a dimensionless number defined as the ratio between the inertial force to the external field ($F = \frac{V}{\sqrt{gL}}$, where V is the flow velocity, g is the gravitational acceleration, L is the characteristic length). Since the gravitational acceleration is the same between the prototype and the model, the velocity scale is related to the square root of the length scale. Strouhal number is a dimensionless number describing the flow mechanism oscillation ($S = \frac{FL}{V}$ where F is the vortex shedding frequency, L is the characteristic length and V is the flow velocity). Thus, the frequency scale has been related to the velocity and length scale accordingly. The time scale was calculated as the reciprocal of the frequency scale which is the same as the ratio between the length scale to the velocity scale, see table 2.

Table 1 Testing parameters scale factors

Parameters	***Scale Factor***
Length	*1:10*
Velocity	*1:√10*
Frequency	*√10*
Time	*1:√10*

Table 2 Prototype and Model dimensions

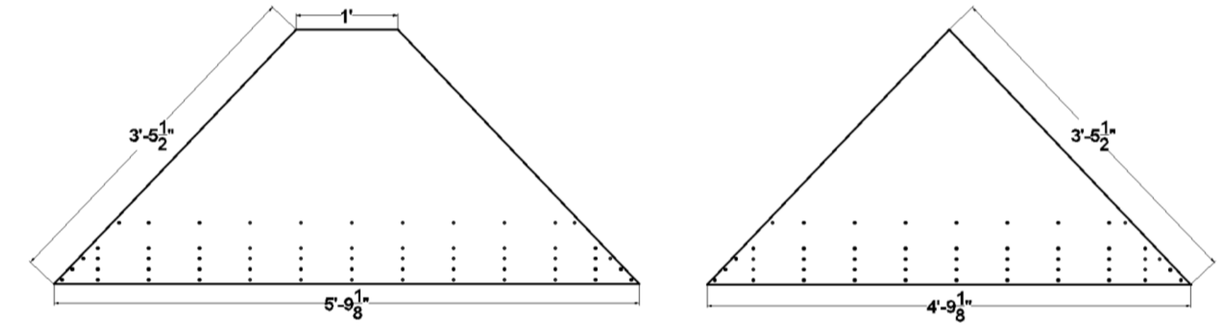
<table>
<tr><th rowspan="3">Configuration</th><th rowspan="3">Model</th><th rowspan="3">Roof Slope</th><th colspan="2">Building Dimensions</th><th rowspan="3">Scale</th><th colspan="2">Model Dimensions</th><th rowspan="2">Notes</th></tr>
<tr><th>L x W x h</th><th>Overhang</th><th>L x W x h</th><th>Inclined Overhang</th></tr>
<tr><th>(ft)</th><th>(ft)</th><th>(ft)</th><th>(in)</th><th></th></tr>
<tr><td>A</td><td rowspan="6">Hip Roof</td><td>4:12 (18.4°)</td><td rowspan="6">50 x 40 x 24</td><td>4</td><td>1:10</td><td rowspan="6">5 x 4 x 2.4</td><td>4.8</td><td rowspan="4">With soffit</td></tr>
<tr><td>B</td><td rowspan="5">6:12 (26.3°)</td><td>2</td><td>1:10</td><td>2.4</td></tr>
<tr><td>C</td><td>4</td><td></td><td>4.8</td></tr>
<tr><td>D</td><td>6</td><td></td><td>7.2</td></tr>
<tr><td>E</td><td>2</td><td></td><td>2.4</td><td rowspan="2">No soffit</td></tr>
<tr><td>F</td><td>4</td><td></td><td>4.8</td></tr>
</table>

2.2. Instrumentation and test protocol

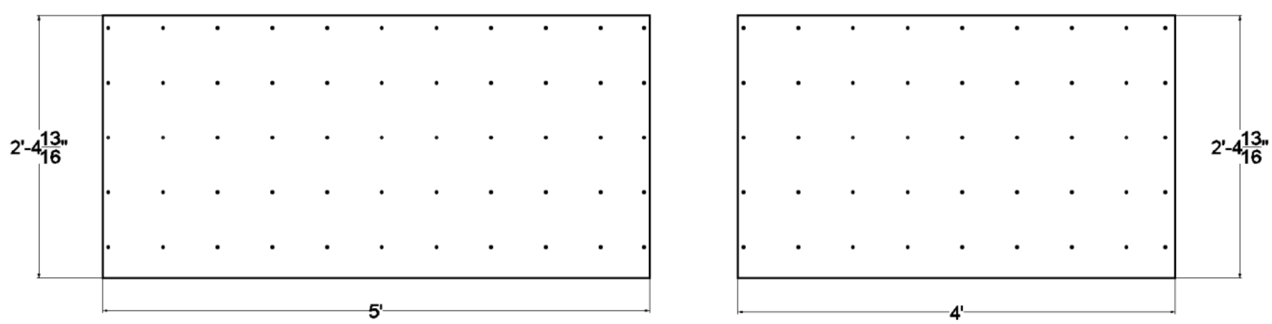
Pressure taps are added on the walls, the top surface of overhangs and the bottom surface of soffits, as well as on the roof area adjacent to overhangs to be placed within zone 3 and 2e as specified in ASCE 7-16 (ASCE 2017). Each model has a different number of pressure taps according to each model dimension (Table 3). The pressure taps will be connected to a sensitive pressure scanning system (Scanivalve ZOC33). The maximum pressure that could be measured by this module is 0.36 psi (51.84 psf). Pressure tap locations are shown in Figures 7 to 12. Figure 7b shows the walls for Model A, and these walls are the same for Models B, C and D. The test will be conducted for 40 wind directions for each model (i.e., 0° → 360° with increments of 10 degrees plus the four corners) with a target wind speed of 40 mph. The sampling time for each direction is 60 seconds and the sampling frequency is 520 (Hz). The six models will be tested for an open terrain exposure (i.e. category 'C' according to ASCE 7-16).

Table 3 Number of pressure taps in each model

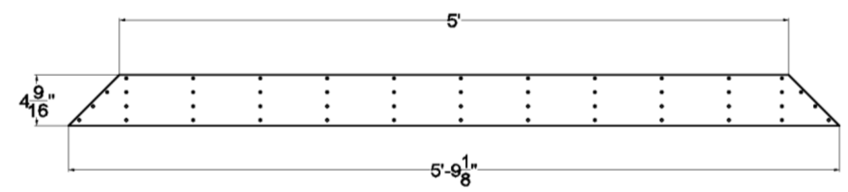
Configuration	Pressure taps on roofs	Pressure taps on soffits	Pressure taps on walls	Total Number of Pressure Taps
A	112	92	100	304
B	106	72	100	278
C	112	92	100	304
D	136	116	100	352
E	106	72	120	298
F	112	92	120	324



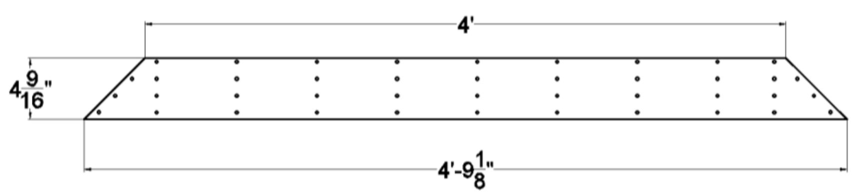
(a)



(b)

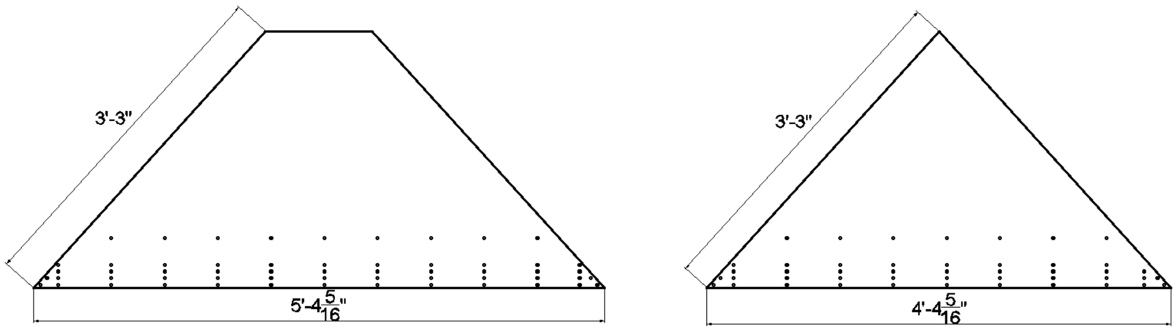


(c)

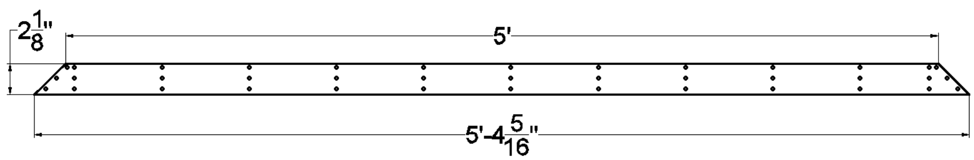


(d)

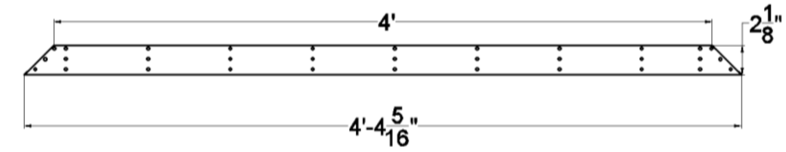
Figure 7 Pressure taps instrumentation on configuration A model (a) Roof (b) Longitudinal and Side Walls (c) Longitudinal overhang (d) Side overhang



(a)

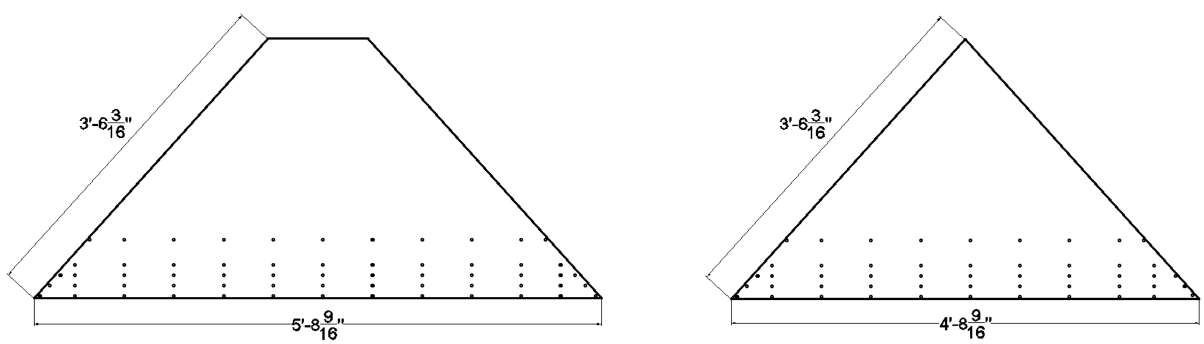


(b)

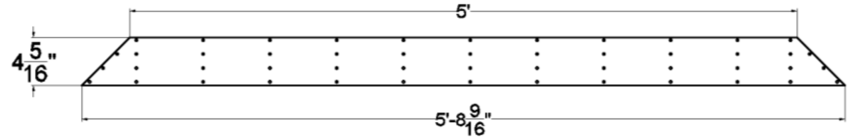


(c)

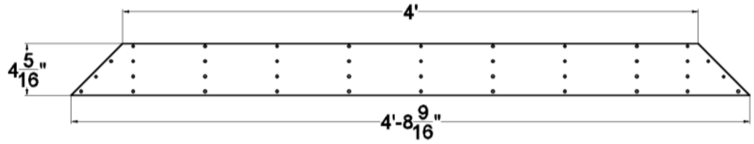
Figure 8 Pressure tap instrumentation on configuration B model (a) Roof (b) Longitudinal overhang (c) Side overhang



(a)

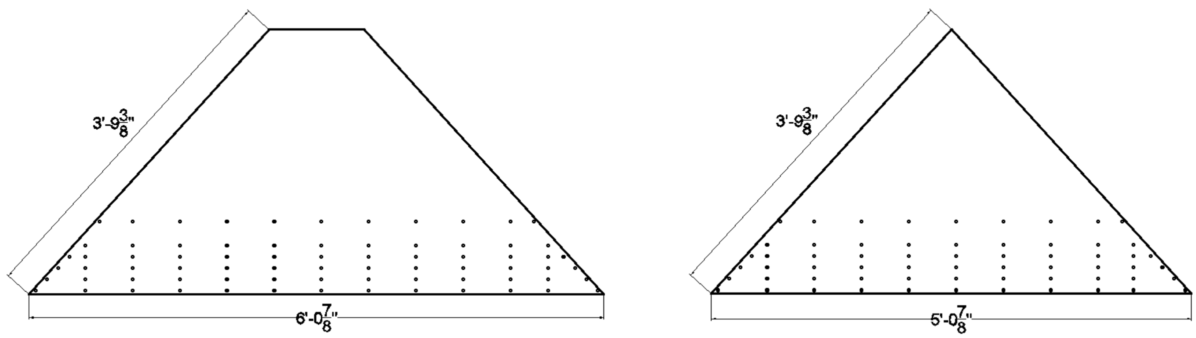


(b)

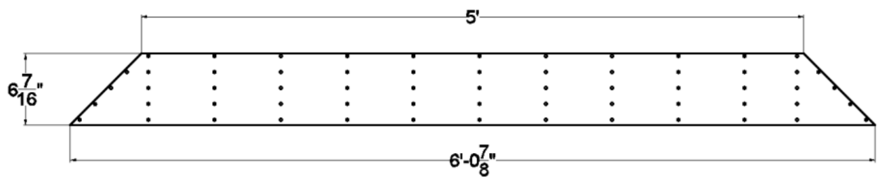


(c)

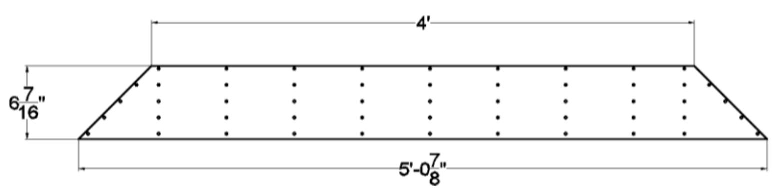
Figure 9 Pressure taps instrumentation on configuration C model (a) Roof (b) Longitudinal overhang (c) Side overhang



(a)



(b)



(c)

Figure 10 Pressure tap instrumentation on configuration D model (a) Roof (b) Longitudinal overhang (c) Side overhang

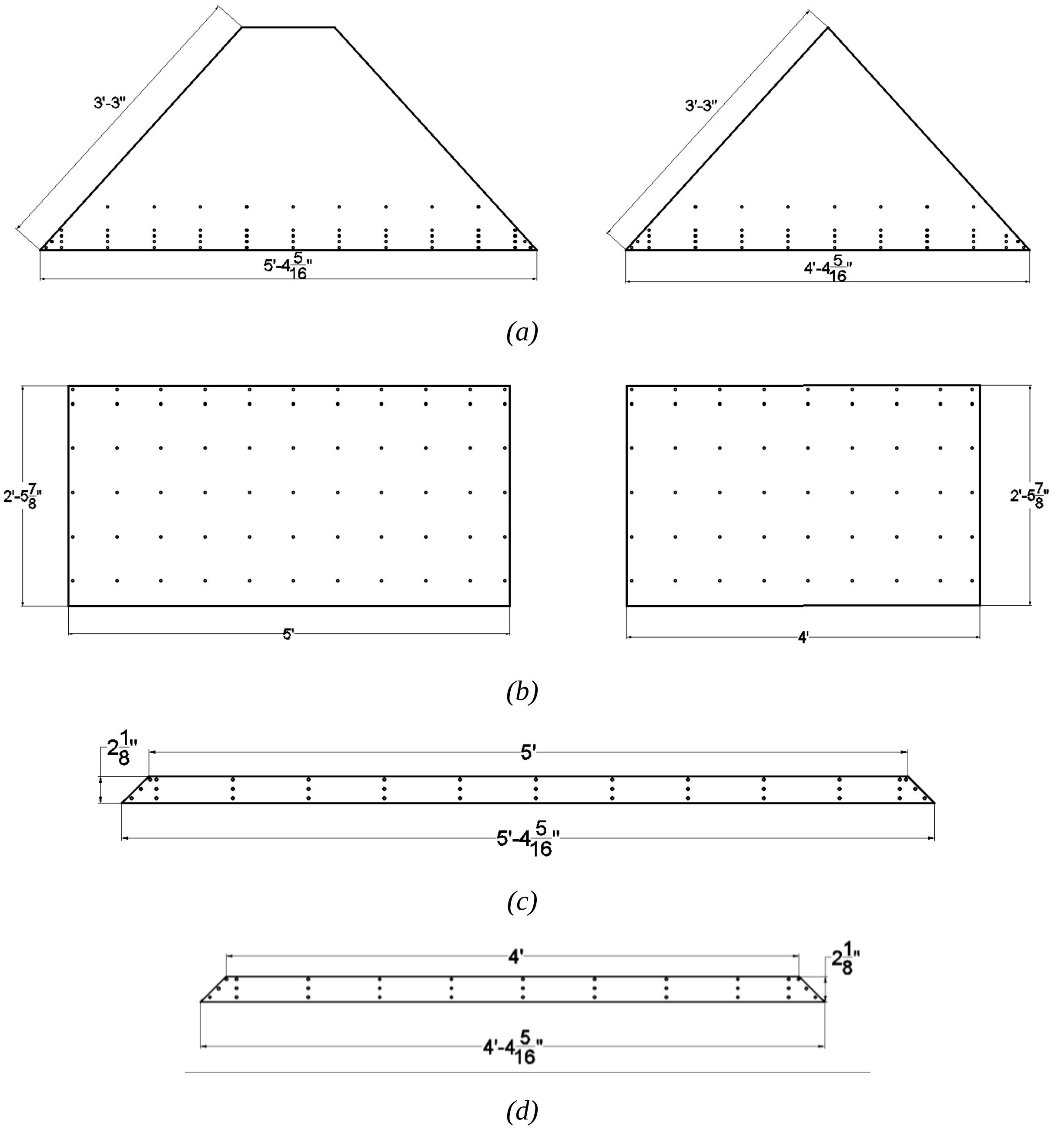
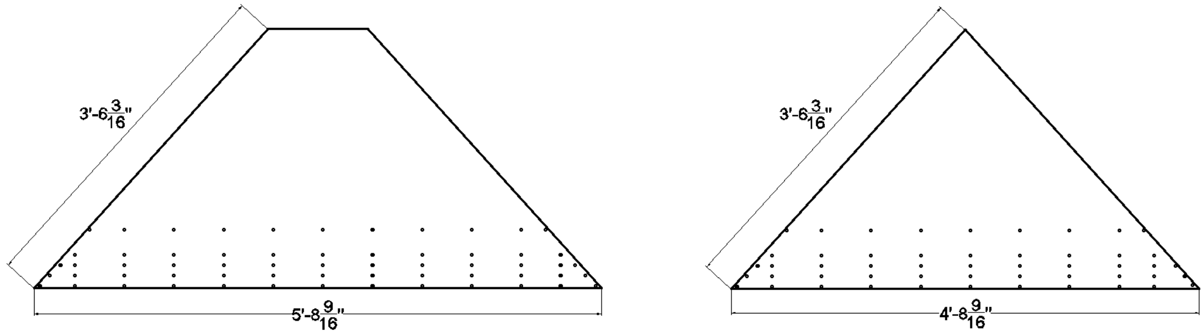
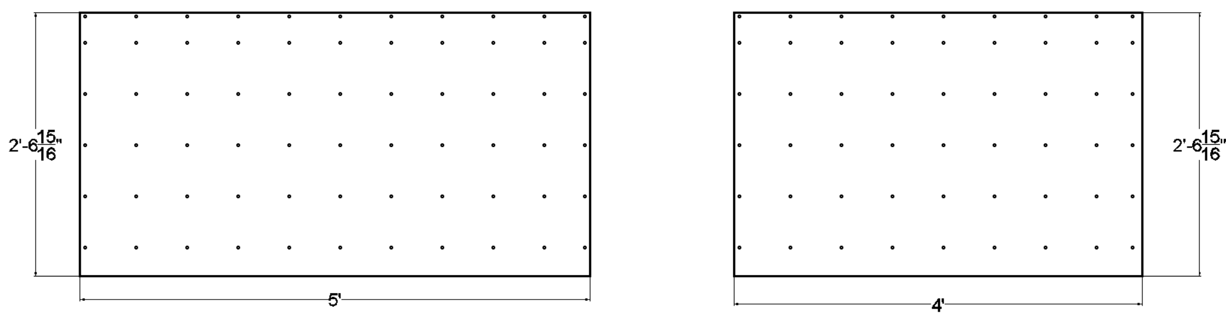


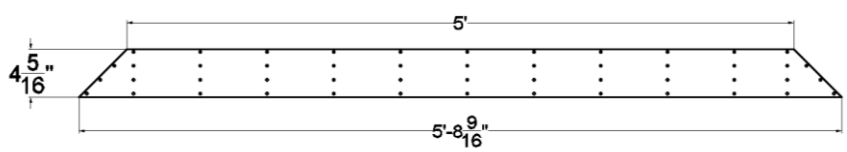
Figure 11 Pressure taps instrumentation on configuration E model (a) Roof (b) Longitudinal and Side Walls (c) Longitudinal overhang (d) Side overhang



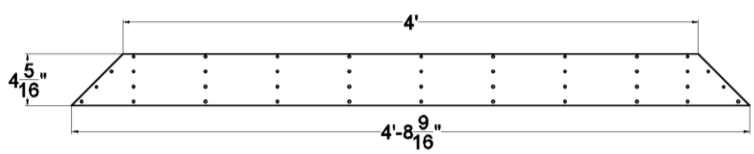
(a)



(b)



(c)



(d)

Figure 12 Pressure tap instrumentation on configuration F model (a) Roof (b) Longitudinal and Side Walls (c) Longitudinal overhang (d) Side overhang

3. Next Tasks and timeline

The proposed models will be tested by end of February 2022 in the WOW at FIU. After carrying out the experimental testing, data analysis process for the six models will be performed. This process shall include, but not limited to, peak pressure coefficients, contour plots, regression analysis, and correlation coefficients. The final report that include all the results and findings shall be ready for submission by June 1st, 2022.

References

ASCE. (2010). "*Minimum design loads for building and other structures*." American Society of Civil Engineers, ASCE/SEI 7-10, Reston, VA.

ASCE. (2017). "*Minimum Design Loads and Associated Criteria for Buildings and Other Structures*." American Society of Civil Engineers, ASCE/SEI 7-16, Reston, VA.

Candelario, J. D., Stathopoulos, T., and Zisis, I. (2014). "*Wind Loading on Attached Canopies: Codification Study*." Journal of Structural Engineering, 140(5), 04014007.

Gan Chowdhury, A., Zisis, I., Irwin, P., Bitsuamlak, G., Pinelli, J.-P, Hajra, B., and Moravej, M. (2017). "Large-Scale Experimentation Using the 12-Fan Wall of Wind to Assess and Mitigate Hurricane Wind and Rain Impacts on Buildings and Infrastructure Systems." *Journal of Structural Engineering*, Vol. 143, Issue 7.

https://www.floridabuilding.org/fbc/commission/FBC_0621/HRAC/HRAC-06-21/Wind-Induced_Loads_On_Roof_Overhangs_Final_Report.pdf

Mostafa, K. Zisis, I. Chen, D. (2022) "Large scale testing for roof overhangs aerodynamic pressure 572 distribution using the wall of wind experimental facility", in Wind induced loads on hip roof 573 overhangs of low-rise building. *DesignSafe-CI.* https://doi.org/10.17603/ds2-8nyb-dm44.

Zisis, I., and Stathopoulos, T. (2010). "Wind-Induced Pressures on Patio Covers." *Journal of Structural Engineering*, 136(9), 1172–1181.

Zisis, I., Raji, F. and Candelario, J. D. (2017). "Large scale wind tunnel tests of canopies attached to low-rise buildings." *ASCE Journal of Architectural Engineering*, Vol. 23 (1).