Performance of the Acrylife Roof Vent

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Project Overview

Experiments to evaluate the performance of Acrylife roof vents were conducted at the IBHS Research Center on March 24, 2012. The test program included visual observations, video of the roof membrane response, measurements of pressures in the vents (conducted by others), and measurements of pressures at numerous locations under the roof membrane. All tests were conducted using a 30-foot wide by 40-foot long flat roof building with a roof height of 13-feet. This building footprint is the largest that can be tested at the IBHS research center because of blockage considerations. It should be pointed out that this building footprint is significantly smaller than that of buildings where this technology has been deployed. Tests were conducted using a 15-minute segment of an open country flow simulation. Time series of winds for this flow simulation were created with different amplitudes so that it was possible to conduct the tests with different levels of mean, maximum one minute and maximum 3-second peak gust wind speeds. The flow time history and control functions for the wind simulation had been previously used to validate the facility by reproducing wind pressures on a replica of a full-scale building used in field studies conducted at Texas Tech University. The use of 15-minute wind records that included a simulation of the variation in mean wind speed with height and simulation of the gust structure of natural winds over open terrain ensured that the roof system and vents were subjected to realistic wind conditions where the flow over the roof is turbulent and edge and corner vortices that affect the surface pressures and system performance are faithfully reproduced.

Pressures were measured under the roof membrane using pressure taps installed on the left windward quadrant of the roof when the narrow face of the test building faced the fans. These tap locations had been developed as part of IBHS testing of roof top equipment. The Acrylife testing used that same structure as its base building. Initial tests without the membrane installed provided baseline data on pressures magnitudes and distributions on the roof surface and represent the pressures that are expected to have occurred on the top surface of the roof membrane once it was installed.

Tests were conducted with up to two roof vents, a couple of different wall / parapet vent designs. One of the roof vents was located at the center of the roof and it was surrounded by pre-installed pressure taps on the plywood deck under the roof membrane as well as a pressure tap located directly under the vent location. The position of the second roof vent was changed as a result of exploratory tests that used smoke to help map out the flow separation regions and to define the extent of edge and corner vortices that affect the flow over and peak uplift suctions near the corners of the roof. In addition, a removable parapet was used in some tests and some concepts for parapet mounted vents were evaluated. A limited number of tests were performed to evaluate roof vent performance when the membrane was cut at locations near the vents. IBHS staff visually monitored the performance of the roof membrane and recorded video of the roof cover performance. IBHS also recorded wind speed data from a reference anemometer located at an elevation of 16-feet and pressures at each of the roof pressure taps. Other parties measured pressures in the vents.

Visual Assessment of System Performance

In initial tests the roof membrane was not sucked down by the vents and in fact the vertical movement of the roof membrane increased as the tests progressed. Air leakage through the roof deck was suspected as the major factor leading to this poor performance. Consequently, the membrane was cut about three feet in from the roof edge and peeled back to allow access to the roof deck. The sealing of the center portion of the deck was improved. Then, rather than completely remove the membrane to gain access to the edge of the roof, where leakage was also suspected, the three foot edge was sealed down to the wood roof deck. The cut membrane was then welded along the cut perimeter to the portion of the membrane glued down to the roof deck, sealing the interior of the membrane from the perimeter of the roof.

While the re-sealed roof membrane performed better, it still did not represent the performance observed in actual field installations. The lack of performance was investigated using smoke flow visualization techniques. The smoke flow visualization showed that both vents in the original configuration were located within flow separation zones or near the point where flow was just starting to reattach to the roof. Consequently, both vents were subjected to reversing flow conditions and did not experience a strong flow through the gap between the half spheres of the vent apparatus. In subsequent tests, the vent at the center of the roof was retained and the one in the upwind corner was relocated to the rear downwind quadrant of the roof. When these modifications were completed, the vents did pull the roof membrane down against the deck and that effect was visually confirmed even when several cuts were introduced in the membrane. Attempts to improve system performance near the roof corners through the use of wall and parapet mounted vents were not effective in reducing the visible movement of the roof membrane near the roof edges or roof corner. The tests conducted near the end of the day when the roof deck was well sealed and a vent was located near the back corner of the building produced the best visual performance of the roof membrane. In this case, the membrane was pulled down tightly against the roof deck throughout most of the middle portion of the roof. A slight flutter of the roof membrane was observed near the windward edges of the roof; but, it did not increase during the test and the membrane did not balloon up near the edges. Maximum 3-second gust wind speeds of 101 mph at an elevation of 10 meters (33 ft) in open terrain were achieved during the tests without causing any damage to the vents or the membrane.

Once a successful test configuration was created where the roof vents performed well, a series of tests were conducted with cuts introduced into the membrane to represent damage that might occur from debris tumbling across the roof. No degradation in performance was observed for cuts up to a foot or more in length. However, as the cuts were extended, the edges of the cut membrane began to cup upward and air infiltration rates exceeded the capacity of the vents to extract air from beneath the membrane. When this happened, the membrane began to lift and flutter.

Pressure Measurement Results

Numerous experimental configurations were investigated throughout the day of testing. Table 1 summarizes all the configurations where pressure data was acquired. However, since much of the testing involved configurations that did not perform well as various issues were investigated and solved, only selected results are presented in this report. Accompanying figures provide contour plots of non-dimensional pressure coefficients where red is zero (no suction) and blue represents areas of the highest suction. All figures are plotted with the same scale and show results for similar wind speeds. During these tests the 15-min mean wind speed was between 40-45 mph.

Table 1. Descriptions of tests where data was collected from the pressure transducers

Name	Membrane Installed	Wind Angle(s) (degrees)	Parapet	Roof Vent(s) Active	Parapet Vents Active	Following Re-sealing procedure at the edge of the membrane
Test #1	No	0, 15, 30, 45, 60, 75, 90	No	N/A	N/A	N/A
Test #2	No	0, 15, 30, 45, 60, 75, 90	Yes	N/A	N/A	N/A
Test #3	Yes	0, 15, 45	No	Yes	No	No
Test #4	Yes	0, 45	Yes	Yes	No	No
Test #5	Yes	0, 45	No	Yes	Yes	Yes
Test #6	Yes	0	No	No	No	Yes
Test #7	Yes	45	No	Yes	Yes	Yes-Membrane intentionally cut, in two locations, with cuts of different lengths

Figure 1 presents mean surface pressures on the roof deck for test #1 (left) and test #3 (right) at a wind angle of 0 degrees, as indicated by the arrow in the figure. The active vent location in Figure 1 (right) for test #3 is indicated by the black circle at location (X=15', Y=19.58'). The pattern of surface pressures for test #1 and test #3 are similar although the surface pressures of test #1 have a larger magnitude (greater suction) than those in-between the membrane and the roof deck of test #3. In proximity to the roof vent there does not appear to be any change in the pattern of the surface pressures for test #3. Test #3 suffered from air leaks and it was clear that whatever beneficial effects the vents might have provided were overwhelmed by the air infiltration into the cavity under the membrane.

Figure 2 shows the mean surface pressures between the membrane and the roof deck following the re-sealing procedure. Figure 2 (left) shows the results for test #6 where no roof vents were active, while Figure 2 (right) presents the results from test #5 where 2 roof vents and 2 parapet vents were active, as indicated by the black circles on the figure. Due to the sealing of a portion of the roof membrane to the roof deck the results from the first 3 rows of pressure taps from each wall should be ignored. Figure 2 indicates that there is little difference between the mean surface pressures with and without the roof vents active, although no data is available in proximity to the roof vent closest to the leeward wall. Overall, from examining Figures 1 and 2 there appears to be little effect of both the roof and parapet vents on the pressures between the roof membrane and roof deck at a wind angle of 0 degrees.

Figure 3 presents present the mean surface pressure results from test #1 (left) and test #5 (right) at a wind angle of 45 degrees. Similar to Figure 2 the surface pressures near the edges of the building in Figure 3 (right) are erroneous due the sealing of the membrane to the roof deck. As a result it is difficult to determine if the mean surface pressures with and without the membrane follow the same general pattern as they did at a wind angle of 0 degrees (Figure 1), although it is very likely that they do. However, what is notable is that the pattern of the surface pressures in close proximity to the roof vent in the center of the roof (X~15 ft, Y~20 ft) appears to be affected by the presence of the roof vent. However, the area affected appears to be small since the only deck surface pressures showing any effects are located in a 2.5 ft radius from the center of the roof vent. Moreover, this effect is localized to a region of the roof that has relative low wind loads compared to the high wind loading present along the edges of the roof. Since no effect at all was observed at a wind angle of 0 degrees it appears that the placement of the vent is critical and varies based on wind angle. Based on data currently available, the sensitivity of results to the vents location coupled with the limited area of influence of the vent indicate that widespread mitigation of the wind load on the roof membrane particularly in the highest loaded edge regions of the roof may not be feasible.

It should be noted that pressures presented in the report are time averaged quantities. Due to the fact that the wind loads on the roof vary significantly in both space and time and since pressures on the exterior surface of the membrane (Figures 1 (left) and 3 (left)) and between the membrane and the roof deck were not obtained simultaneously, the correlation between the pressures above and below the membrane cannot be determined. Consequently, the net loads applied to the membrane cannot be determined from the current test results, as the pressures both above and below the membrane may not be correlated (i.e. a high suction on the exterior of the membrane may coincide with a low suction between the membrane and the roof).

Breaches in the Membrane (Cuts)

In addition to the intact membrane experiments discussed above, 4 tests were conducted with intentional cut(s) in the membrane. Table 2 lists the location and length of each cut configuration. All tests were conducted at a wind angle of 45 degrees for a duration of 180 seconds. The resulting surface pressures between the roof deck and the roof membrane are shown in Figure 4, with each cut configuration being denoted by the letter provided in column 1 of Table 2. The purple lines in Figure 4 represent both the length and location of each of the cut(s) in the membrane. As previously discussed the current experimental setup did not have surface pressure measurements near the leeward vent in close proximity to the Cut1. For cut case A there appears to be no change in the surface pressure measurements as compared to the no cut case (Figure 3 right). This is not surprising due to the small length of the cut and its distance from any surface pressure measurements. However, a small change in the mean pressures around the roof vent in the center of the roof can be observed between cut case A and cut case C, while the surface pressures away from the vent continue to be very similar. Finally, during cut case D the local effect of the vent can no longer be observed in the surface pressures.

Table 2. List of Cuts made in the membrane

Cut case	Location of Cut 1	Length of Cut 1	Location of Cut 2	Length of Cut 2
A	Start: X=27.5', Y=2.5', in 'Y' direction	6"	N/A	No Cut
B	Start: X=27.5', Y=2.5', in 'Y' direction	12"	N/A	No Cut
C	Start: X=27.5', Y=2.5', in 'Y' direction	18"	Start: X=12', Y=23.25' 'Y' direction	12"
D	Start: X=27.5', Y=2.5', in 'Y' direction	24"	Start: X=12', Y=23.25' 'Y' direction	24"

Video Documentation of Performance

As part of the reporting process numerous videos clips from several tests have been provided based on the meeting of August 2, 2012. Table 3 presents information for each of these video clips along with the UTC timestamp at the start of each of these videos. The UTC timestamps provided are relative to our own internal time clock at IBHS. It appears that this time clock was offset compared with the true UTC times during the tests of March 24, 2012. However, all timestamps provided are shifted by the same amount, and are approximately 3 hour and 23 minutes ahead of the true UTC time. Table 3 provides the information for the video clips provided.

Table 3. List of video clips provided

Clip filename	Test # /Name	Wind Angle	UTC timestamp at start of the test (uncorrected)	Maximum 3-second gust wind speed at 10m (mph)
212.mov	Test #2	Unknown	00:04:30;13 (March 23, 2012)	69
213.mov	Test #3	0	16:08:48;02	69
213-2.mov	Test #3	0	16:16:54:44	69
214.mov	Test #3	0	16:20:02;24	69
215.mov	Test #3	15	16:44:58;34	69
216.mov	Test #3	45	17:05:29;58	69
217.mov	Test #3	0	17:17:34;54	69
218.mov	Test #4 (With parapet vents)	0	20:05:18;45	69
222.mov	Test #5	45	03:39:16:53	101
227.mov	Cut case A	45	05:36:23;45	88
228.mov	Cut case B	45	05:43:31;33	88
229.mov	Cut case C	45	05:49:54;12	88
230.mov	Cut case D	45	05:56:51;30	88

Conclusions

Observations of roof membrane performance indicate that the vents work best when they are far enough away from the roof edges and corners to be in an area where the flow is re-attached to the roof. The vents did not perform well when they were located in the flow separation region near the edges and corners of the building. In addition, when the roof deck was not well sealed air infiltration easily overcame the amount of air that could be extracted by the vents. This indicates that there are limits to the utility of the vents depending on the amount of air infiltration through the roof deck or around the edges of the roof. This suggests that the vents are best suited for restraining the membrane towards the middle of the roof on buildings with well sealed roof decks and significantly larger roof areas than the one tested at the IBHS Research Center.

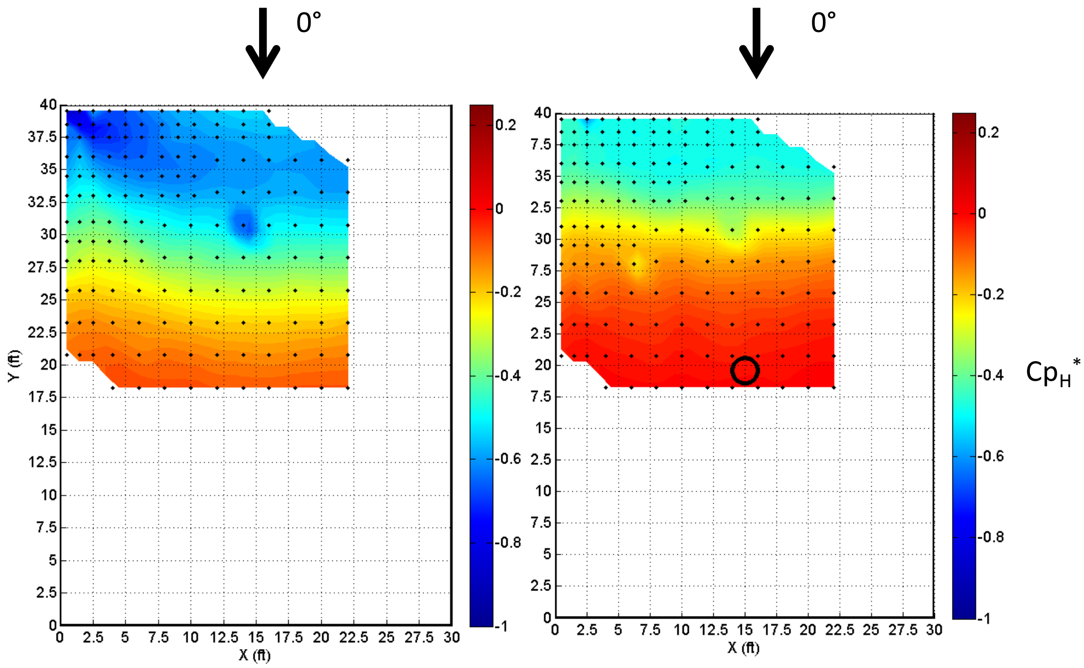
The tests did show that the vents could withstand strong winds without damage to themselves or the roof membrane. The maximum equivalent open country 3-second gust wind speeds at 10 meters achieved in the tests was 101 mph. Tests conducted with a configuration of vents that demonstrated the ability to pull down the membrane also showed good performance when there were reasonably small cuts in the membrane near the vents.

Measurements of pressures between the top surface of the roof deck and the roof membrane did not clearly support the observed roof membrane performance for the most successful configuration. Clearly the vent farthest away from the roof edge performed the best. However, there were no pressure taps in this area of the roof because the original test plan anticipated better performance of the vents in the windward quadrant than were actually experienced. The only vent location where it was possible to measure some benefit in reducing pressures in the cavity between the roof deck and the membrane was at the center of the roof and then only for a wind direction of 45 degrees. It is also not clear how well the mesh inserted under the roof membrane to promote air movement to the vents actually worked to distribute negative pressures from the vents to various locations under the membrane.

Based on the current test data, the influence of the roof vent was only observed for a 2.5 ft radius from the center of the vent. Visually, the benefit appeared to be much greater. Given the small area of influence observed in the pressure data, the sensitivity of results to the placement of the vent on the roof, and the small roof plan area possible in the IBHS test facility no definitive conclusions or detailed discussion of the data, in regards to vent performance is really possible. Key aspects that should be addressed in any future work include:

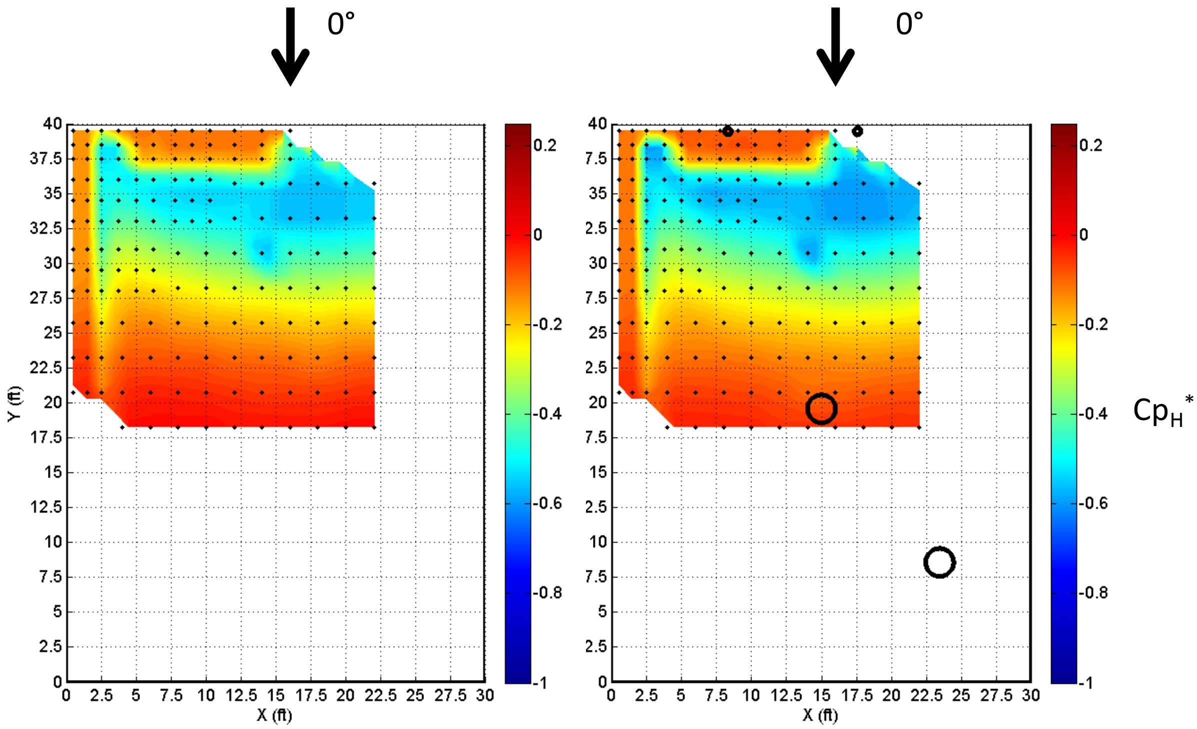
1. The ability to accurately measure pressures between the membrane and the roof deck both when no vents are present and when they are present.
2. To resolve the net forces on the membrane, the pressures on both sides of the membrane must be measured simultaneously.
3. Tests need to be conducted for vents on a larger roof plan area than is possible at the IBHS research center. One way to do this would be to conduct tests at a 1:5 scale.

The current results suggest a more extensive and rigorous experimental test program would be required in order to fully determine the benefits and limitations of the Acrylife Roof vent(s) under high wind conditions.



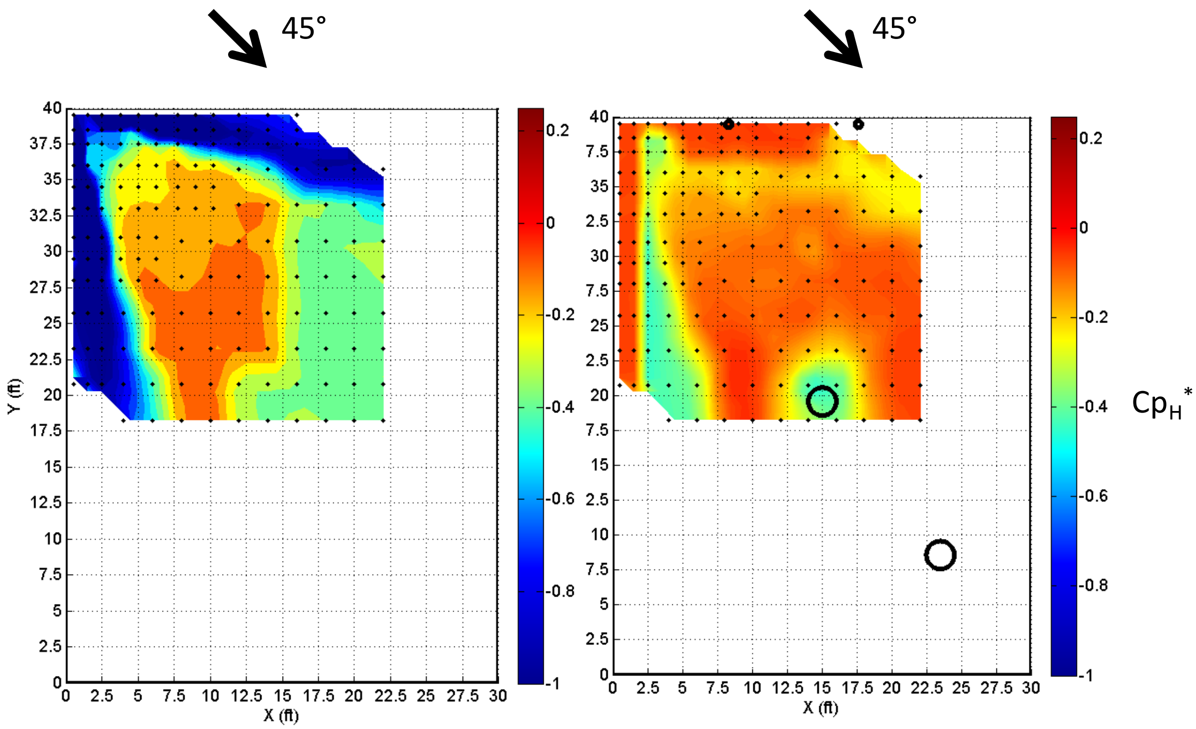
*Pressure coefficients referenced to a 900 second roof height wind speed.
As presented these coefficients cannot be compared directly to ASCE7

Figure 1 Surface pressures on the roof deck of the building at 0 degrees (left) test #1 with no membrane (right) test #3 with the membrane and 1 active roof vent as shown by the black circle. The colors in both left and right figures are presented in the same scale.



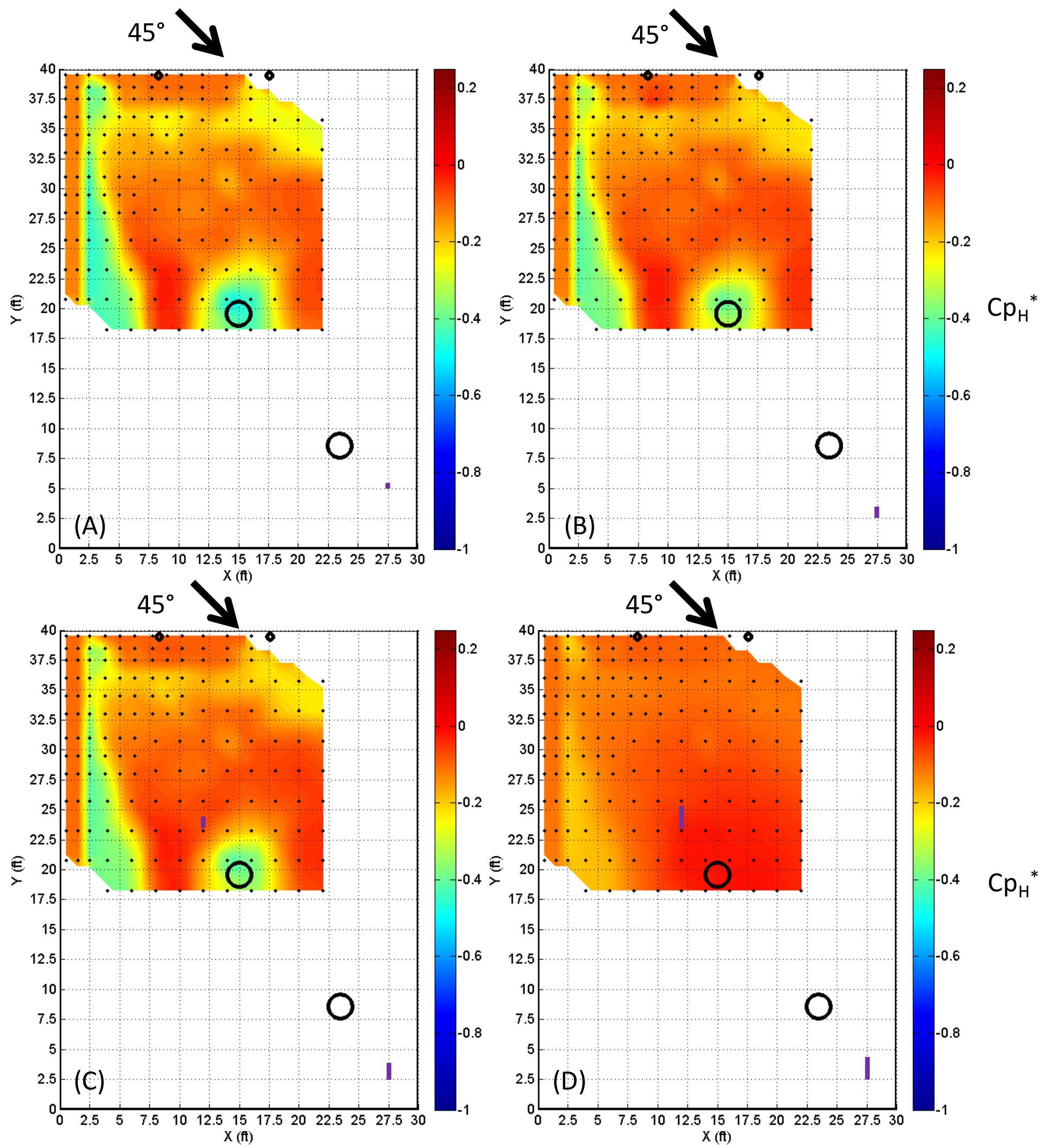
*Pressure coefficients referenced to a 900 second roof height wind speed.
As presented these coefficients cannot be compared directly to ASCE7

Figure 2 Surface pressure contours between the membrane and the roof deck following the resealing procedure at a wind angle of 0 degrees (left) no roof or parapet vents active (right) 2 roof vents and 2 parapet vents are active



*Pressure coefficients referenced to a 900 second roof height wind speed.
As presented these coefficients cannot be compared directly to ASCE7

Figure 3 Surface pressures on the roof deck of the building at 45 degrees (left) test #1 with no membrane (right) test #5 with the re-sealed membrane with 2 active roof vents and 2 active parapet vents as shown by the black circles. The colors in both left and right figures are presented in the same scale.



*Pressure coefficients referenced to a 900 second roof height wind speed.
As presented these coefficients cannot be compared directly to ASCE7

Figure 4 Surface Pressures on the roof deck of the building at 45 degrees. The purple lines denote the approximate location(s) of the cuts to the membrane for each case. (A) First cut in the Membrane, (B) Second cut in the membrane, (C) Third cut in the membrane, (D) Fourth cut in the membrane