Neighborhood Configurations and their Effect on Single-family Home Hurricane Wind Dynamics

JASON R. CHANDLER
Florida International University

The following research[1] examined how different residential neighborhood configurations enhanced or damped hurricane force winds on single-family homes in Florida. This research was initiated principally by an absence of hurricane code requirements that takes into consideration the configurations of the immediate context of a single-family home. In large-scale buildings, engineers will test projects within their context to calculate wind loads. These projects are at a scale in size and in budget that merit this investigation and it is well established that the wind loading of tall buildings needs to be examined thoroughly. Single-family homes however may not be susceptible to the wind dynamics of tall buildings but they do exist in potentially varied contexts. This research examines the wind dynamics of typical single-family homes in contexts with differing densities and configurations.

In Florida, the building code requires architects, structural engineers and manufacturers of building products to meet stringent wind design criteria. The building code articulates the necessary minimum wind loads that a building and all the components of its exterior envelope must meet. The requirements of The Florida Building Code [2] and ASCE 7 [3] set quantitative wind load parameters for single-family homes by simply articulating that homes either exist in open fields or suburban contexts. As a result, design professionals are not required to take into account the actual configuration of surrounding buildings or vegetation in determining the wind loads on a single-family home. These codes assume a worst-case scenario for a home wherever it may exist. Yet context must affect wind dynamics. This study examines how three different neighborhood configurations affect wind loads on three different single-family houses.

The neighborhood configurations were selected from prevalent zoning types found in Dade County, Florida. The Dade County Zoning Code [4] sets forth the legal parameters for using a piece of land. It describes what activity what may be allowed, how large a structure may be built and where that structure may be located. All three of the zoning types selected for this examination allowed detached, single family homes. These zoning types encompass a full variety of building densities, house typologies and vegetation development.

Three different single-family houses were selected to represent a prevalent range of home configurations found in South Florida. The configuration of these homes where determined as part of work begun in a previous hurricane study[5]. These homes depict varying roof heights, roof configurations and plan layouts.

THE NEIGHBORHOODS

The first neighborhood type to be examined was the zero-lot-line configuration of the Dade County Zoning Code (Case 1).

Of the three neighborhood types selected this one allowed the greatest building density. Lots in this neighborhood are approximately four thousand square feet in size. The allowable building coverage for a house is fifty percent of the total lot size. The setbacks are as follows: twenty feet from the front property line, five feet from the rear property line, zero feet from the zero side and ten feet from the opposite interior side. The maximum

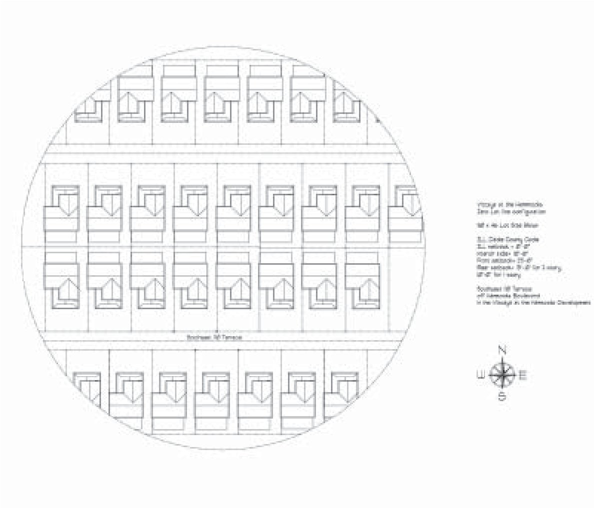

Figure 1

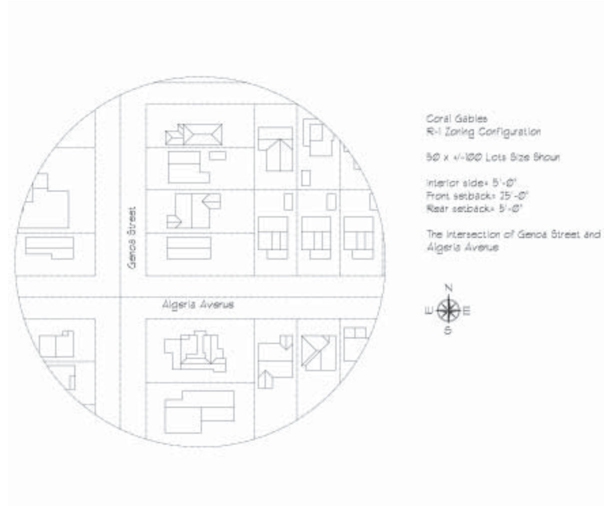

Figure 2

building height is thirty-five feet and two stories. The specific neighborhood selected of this zoning type is located along Southwest 110 Terrace in a planned unit development called the Hammocks by the Bay in Dade County, Florida. This particular development consisted of cookie-cutter homes of the same design repeated one right after the other. The uniformity of this development is unique along the neighborhoods examined.

The second neighborhood type to be examined was an "R" use district in Coral Gables, Dade County (Case 2).

This is the oldest neighborhood development of the three and has the greatest variety of house types and the most mature vegetation. Lots in this neighborhood are approximately five thousand square feet in size. The allowable building coverage is thirty-five percent of the total lot size. The setbacks are as follows: twenty-five feet from the front property line, five feet from the rear property line, and side setbacks totaling twenty percent of the lot width. The maximum building height is thirty-four feet and two and a half stories. The specific neighborhood selected of this zoning type is located at the intersection of Genoa Street and Algeria Avenue in Coral Gables, Florida. This neighborhood has mature trees of a variety of species. As a result, this study includes separate test simulating the tree masses found there. Metal mesh barriers were set up to simulate a permeable tree mass. The house types in this neighborhood are also quite diverse: there are one and two story homes, homes with attached and detached garages, and homes with flat roofs and sloped roofs.

The third neighborhood is also an "R" use district located in Dade County (Case 3).

This is the least dense neighborhood. Lots in this neighborhood are approximately nine thousand square feet in size. This neighborhood was selected for its cul-de-sac planning. While the two other neighborhoods were planned on orthogonal blocks, this neighborhood is planned around a series of serpentine dead-end roads with turn-a-rounds. Many of the sites are irregular shapes and have large amounts of left over land allowing the houses to be sited well with in their required setbacks. The allowable building coverage is thirty-five percent. The setbacks are as follows: twenty-five feet from the front property line, twenty-five feet from the rear property line, and side setbacks of ten percent of the lot width. This specific neighborhood is located along southwest 157 Avenue and 47 Street in Miami-Dade County.

THE HOMES

House One is the repeated model home found in the zero-lot-line neighborhood. This is a predominately two-story structure with one-story extensions. This home is approximately twenty-two hundred square feet in size. It has a two-car

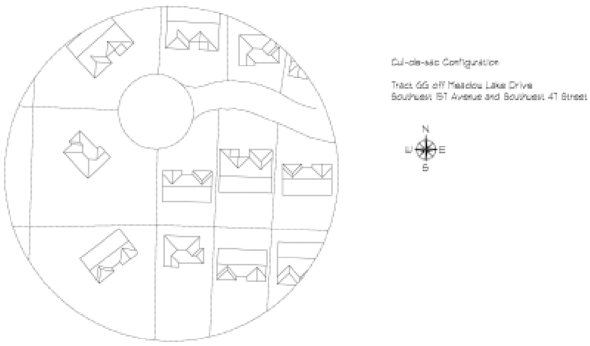

Figure 3

garage within the volume of the house and roof overhangs of one foot. This house has a roof composed of a second-story roof of two perpendicular gables and a first story roof with a front roof gable and a rear shed roof.

House Two is L-shaped. This seventeen hundred square foot, one story, single-family home was developed to represent a typical home in south Florida. All the program of this house fits under the roof. The “L” form was determined to provide the house with roof ridge and valley conditions. The two ends of this home provide the two most typical roof configurations: that of a hip roof and that of a gable end. As roof overhangs are quite prevalent in Florida homes for shade and rain run-off, this house has one-foot, three-foot and five-foot overhangs.

House Three, the breezeway house was selected as a more complex variation of house two. This home is split in two by a breezeway, an open covered space often found between the main structure of a house and its garage. This house is approximately nineteen hundred square feet and is comprised of a two-story and one story component. The two-story component represents the living area of the house while the one-story component represents the garage. This house has three-foot overhangs and hip roofs.

TESTING

One-quarter inch per square foot Plexiglas scale models of the homes and extruded polyurethane foam models of the neighborhoods were built and tested in a boundary layer wind tunnel. The Plexiglas home models were outfitted with numerous pressure taps located at critical points over the entirety of the roof.

The foam models of the three neighborhood configurations were built to fit on nine-foot wood disks. This disk size was the maximum size that would fit in the boundary layer wind tunnel. At one-quarter inch per foot these disks represent a circular area of approximately three and a third acres. Each Plexiglas model was placed at the center of these neighborhood disks.

The houses were tested individually within five different conditions, open country, open suburban, zero-lot-line neighborhood, Coral Gables neighborhood and cul-de-sac neighborhood. The open country test (Case 4) simulates a wind turbulence of nineteen percent, approximately the condition found if the house were located by itself in an open field. The open suburban test (Case 4) simulates a wind turbulence of twenty-five percent, approximately the condition found if the house were by itself near a suburban context.

Once tested, the maximum and minimum wind pressures at each tap location were recorded and incorporated in an overall pressure map. These pressure maps were then converted into pressure contour maps, which were then graphed on three-dimensional computer models for analysis and comparison.

All the data that is reviewed in this report concerns the reading of positive and negative pressure values on a roof surface. Negative roof pressures represent a pull or suction or uplift on the roof surface while positive roof pressures represent a push on the roof surface. After a review of the initial data, a set of pressure contours was established to organize the different negative and positive pressure tap values. These pressure coefficients on roof surfaces are based on three-second gusts at mean roof height. There are twelve contour values: 1. = above +1.00, 2.+.60 to +1.00, 3 = +.20 to +.60, 4. = -20 to +.20, 5. = -.60 to -.20, 6. = -.00 to -.60, 7. = -.40 to -1.00, 8. =-2.00 to -1.40, 9.= -2.60 to 2.00, 10.=-3.20 to -2.60, 11.= -3.80 to -3.20, 12= -4.40 to -3.80.
The following pressure maps for House One are

based on pressure coefficients from tables of maximum and minimum Pressure Coefficients. These pressure readings reflect local surface conditions for cladding and envelop items and are not necessarily for structural loads.

HOUSE MODEL ONE – THE ZERO-LOT-LINE HOUSE, NEGATIVE PRESSURE MAPS[6]

Case 1 Zero-Lot-Line Neighborhood

HOUSE MODEL ONE, NEGATIVE PRESSURE MAPS CONCLUSIONS

The zero-lot line map remains the standout from the group. It has the smallest areas of high negative pressure contours 9 through 11. These areas are restricted to one gable end. This gable on the second story is the most exposed of the three. The other two gable ends do not register the high negative pressures as the context acts to extrude the roof planes past the house not allowing the wind forces an opportunity to arise. The same condition occurs with the shed roof on the first floor. Low pressures distinguish this area as the context extrudes its geometry disallowing the wind a pocket to create uplift forces. The repetitive nature of the zero-lot-line neighborhood seems to protect the houses within the middle of the block. Exposed ends such as the front gables experience higher uplift pressures but not to the extent found in the four other conditions.

The Coral Gables test without trees exhibits contour patterns found in the cul-de-sac, open country and open suburban testes. It seems this comparatively large mass of the zero-lot-line house in this context leaves it unprotected from high uplift pressures. The map closest to this pressure configuration is the open country test. High uplift pressures occur at the gable ends while low uplift pressures occur at the middle of the roof plane.

When trees are introduced into the Coral Gables context there is a significant reduction in high uplift pressures. This map has no area of extreme negative pressure contour 11. Not only is this pressure contour absent, pressure contour areas 8 through 10 are greatly reduced. It seems that mature tree growth creates protection from high uplift pressure for houses that rise above a lower

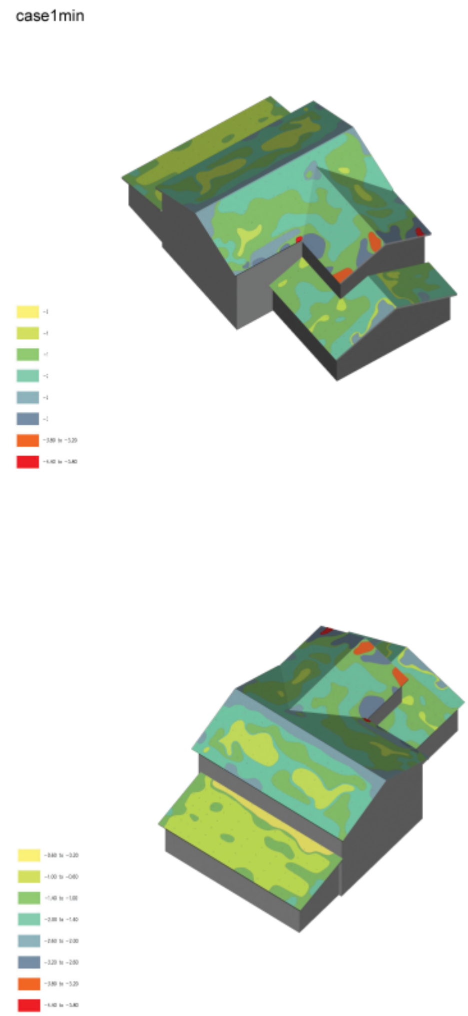

Figure 4

built context. While this map displays a significant reduction in uplift pressures it does not reduce uplift pressures at the order of magnitude the built environment of the zero-lot-line context does.

The cul-de-sac test displays a pressure contour map similar to the open country and open suburban test with one notable exception. Whereas the open country and open suburban maps have similar high pressures on their side gable ends, the cul-de-sac map has greater uplift pressures on its side gable nearest to the front gable. This variation can be attributed to the placement of the house in the cul-de-sac context. This side gable is exposed while the other side is near a context house. It seems this extra area and the angled position of the distant house creates a wedge of space that concentrates wind forces against this gable. This condition is the most volatile condition in the group and as a result, it has the greatest area of negative pressure contour 11.

HOUSE MODEL ONE – THE ZERO-LOT-LINE HOUSE, POSITIVE PRESSURE MAPS

Case 1 Zero-Lot-Line Neighborhood

HOUSE MODEL ONE POSITIVE PRESSURE MAPS CONCLUSIONS

With a series of small exceptions these maps tend to display quite similar pressure maps. All have a distinctive L-shaped high positive pressure contour 1 on the first-story front gable. They all have a linear high positive pressure contour 1 along the top of the first-story shed roof. On the second-story, all the maps have a high positive pressure contour along the lower edge of the side gable facing towards the front. At the ends of the highest peak of the house there is a consistent presence of low positive pressures in all the maps.

The zero-lot-line map and the Coral Gables map with trees both have large areas of low positive pressures at the highest roof peak. The two-story context of the zero-lot-line neighborhood and the mature trees tend to protect this house from extreme positive pressures.

The remaining maps have rather complex contour shapes on the second-story roof. The cul-de-sac map and the open country map display similar patchy pressure contours while the open suburban map has the least amount of low positive pressures. The shed roofs of theses maps are scarcely populated with low positive pressures. When compared to the open country map, the zero-lot-line neighborhood and the Coral Gables neighborhood with trees seem to protect the roofs from high positive pressures while the cul-de-sac neighborhood does not.

HOUSE MODEL TWO – THE L-SHAPED ONE-STORY HOUSE, NEGATIVE PRESSURE MAPS

HOUSE MODEL TWO NEGATIVE PRESSURE MAPS CONCLUSIONS

The pressure map with the greatest variation of this group is the map of case 1, the zero-lot-line neighborhood. While the other maps all have pressure contour 10 along the top of the hip roof this map does not. The extreme pressure contours are isolated in the zero-lot-line map and it is dominated by pressure contours 6 through 8. This can be directly related to the simple fact that

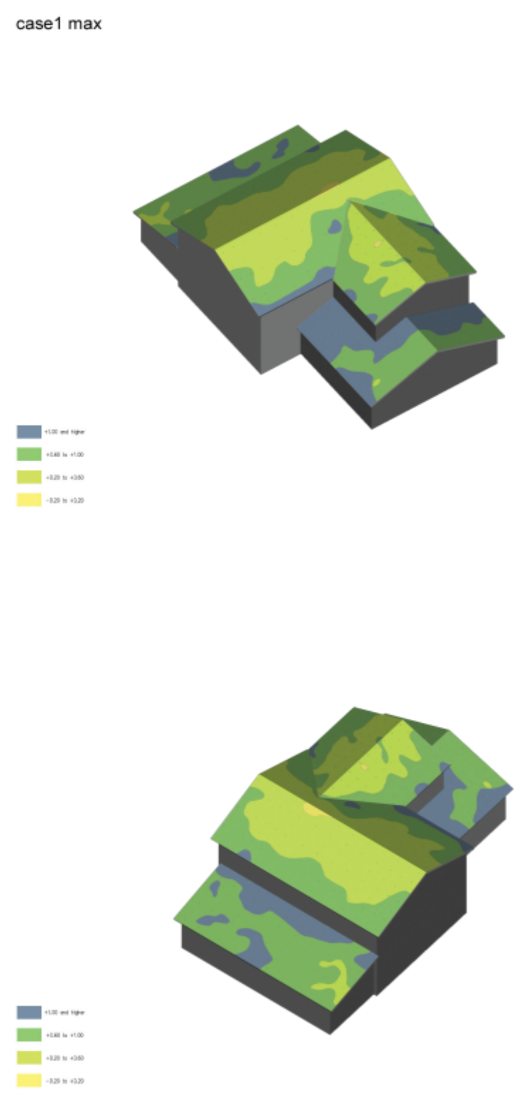

Figure 5

this one-story home is surrounded by two-story homes. The two-story context seems to block and protect the home from extreme uplift pressures.

Of the remaining four tests, the Coral Gables map is the only one with the low-pressure contour 6. Its pressure contours 6 through 8 brake up and isolate the higher suctions in a way not found in the other three tests. The Coral Gables neighborhood does have a mix of one and two-story houses that seem to be braking up the extreme uplift pressures.

The remaining three test conditions, case 4 open country, case 4 open suburban, and case 3 cul-de-sac neighborhood, all exhibit similar pressure contour configurations. Case 4 open suburban has the greatest areas of high uplift pressure.

HOUSE MODEL TWO – THE L-SHAPED ONE-STORY HOUSE, POSITIVE PRESSURE MAPS

HOUSE MODEL TWO POSITIVE PRESSURE MAPS CONCLUSIONS

Here again the zero-lot-line condition provides the greatest variation from the group. It is the only positive pressure map without any pressures below +20. In addition, this map displays the smallest pressure contour 3 and the largest amount of pressures above +1.00. In comparison to the open country map, the positives pressures found on the zero-lot-line map are dramatically greater. It seems that the second story context around this one story house has caused greater positive pressures on the roof.

The remaining three maps, the open suburban, the Coral Gables neighborhood and the cul-de-sac neighborhood maps are quite similar. They all display the same range of positive pressure and a similar layout of pressure contours.

HOUSE MODEL THREE – THE BREEZEWAY HOUSE, NEGATIVE PRESSURE MAPS

HOUSE MODEL THREE NEGATIVE PRESSURE MAPS CONCLUSIONS

The zero-lot-line neighborhood exhibits the lowest overall uplift pressures for this roof. It is distinguished by only four pressure contours (6 to 9) while the other tests exhibit five or six. The two-story context of the zero-lot-line neighborhood again seems to protect the house from high suctions. The second-story roof does have slightly higher suctions than the first but not at a significantly higher order of magnitude.

The Coral Gables neighborhood test also reveals that the context seems to be protecting the roof from higher uplift pressures but not to the extent the zero-lot-line neighborhood did. The higher uplift pressure contour 10 appears on this map on the second-story roof only. The first-story roof has the same number of pressure contours as the zero-lot-line map. Even though the Coral Gables context is made up of a mix of one and two-story homes it still manages to brake up stronger uplift pressures.

The cul-de-sac neighborhood test shares the same number of pressure contours as the open country and open suburban tests. It does however, have a significantly smaller high-pressure contour 11 area than these two. While the cul-de-sac neighborhood does not protect from high uplift pressure as the zero-lot-line and the Coral Gables neighborhood do; it does manage to reduce these pressures slightly.
The open country and open suburban tests reveal that the second floor roof is more susceptible to higher uplift pressures than the one-story roof. It exhibits a full range of pressure contours 6 to 11 while the one-story roof has a range of 6 to 10.

HOUSE MODEL THREE – THE BREEZEWAY HOUSE, POSITIVE PRESSURE MAPS

HOUSE MODEL THREE POSITIVE PRESSURE MAPS CONCLUSIONS

The zero-lot-line map continues to be the anomaly of the tests. It has to smallest area of high positive pressure contour 1. It has the most complex positive pressure contours. Whereas the contours in the four other maps tend to have clear distinct pressure areas, this map has contours slipping into one another creating erratic patches. In addition, while the other maps all have a distinct high-pressure area above the breezeway on the valley side; this map does not.

As stated before, the remaining positive pressure maps: the Coral Gables map, the cul-de-sac map, the open county map and the open suburban map all exhibit similar pressure contour dispositions with a distinct high pressure area above the breezeway. It seems the three-sided courtyard in front of the breezeway is concentrating the wind through the breezeway causing high pressure on the roof above. The leeward roof tends to have lower pressures with its edge catching some high pressures. The breezeway has caused the one-story section of this house to exhibit greater positive pressure area than the more exposed two-story section. Here, plan configuration not building height has been the more important factor in effecting wind forces on the roof.

OVERALL MAP CONCLUSIONS

NEGATIVE PRESSURE MAPS

For all three houses tested, the negative pressure maps showed that the densest configuration, the zero lot line house lowered uplift roof pressures. For house one and house two, the two-story context rose above to create a wind shelter protecting the lower roofs. The zero-lot-line house was situated amongst a context that extruded its form preventing the wind a chance to create high suction pressures at its edge.

The Coral Gables neighborhood also helped reduce extreme uplift pressures. The one-story house and the breezeway house were both at a scale that fit into this context. As a result, they seemed to be protected. The surrounding houses produced an irregular context, which broke up the wind flow. The larger zero-lot-line house did not benefit from this lower context. Only when trees were introduced did the uplift pressures for this house go down.

The cul-de-sac neighborhood consistently performed as the open country and open suburban contexts did. The houses of this context were so far apart from one another that wind forces behaved as if they were not there. Only the breezeway house depicted a slight reduction in uplift pressures. In the case of the zero-lot-line house, this context actually increased uplift pressures.

Context has played a role in reducing uplift (negative) pressures. The houses tested here were protected from high uplift pressures while situated in dense built up areas are dense vegetation. Left in the open, these houses were exposed to high uplift pressures.

POSITIVE PRESSURE MAPS

The positive pressure maps for all three homes yielded mixed results and produced no clear case for benefits for or against density.

When compared to the open country test, only the cul-de-sac neighborhood produced consistent results. The Coral Gables and zero-lot-line neighborhoods had mixed results for each of the three houses.

All the one-story portions of the three houses in the cul-de-sac neighborhood had an overall increase of positive pressure contours. The second-story roofs of the breezeway and zero-line-line house maps had both isolated positive and negative pressure variations but no significant variation from the open country test.

The zero-lot-line neighborhood increased positive roof pressures for the one-story house, the one-story portion of the zero-lot-line house and the upper portion of the breezeway house while it lowered positive pressures for the second-story portion of the zero-lot-line house and the one-story portion of the breezeway house.

The Coral Gables context also produced mixed results: it increased positive pressures for the one-story house and the zero-lot-line house while it maintained similar positive pressures for the breezeway house. The Coral Gables context with trees lowered positive pressures for the second-story portion of the zero-lot-line house and increased positive pressures for the one-story portion.

It seems the three neighborhood contexts generally increased the positive one-story roof pressures (except for the breezeway condition) while a there was some small decreases of the second-story positive roof pressures.

CONCLUSION

The results of this study do not produce compelling evidence that would merit an alteration of the existing building code. While the negative pressure maps reflected lowered uplift pressures due to denser suburban contexts, it does not seem that a significant amount of protection can be assumed. The current requirement[7] that houses that are located in Miami-Dade and Broward Counties need to be designed for open field conditions regardless of their context seems to be prudent.

FOOTNOTES

1. This research was completed for a grant entitled "Role of Impact Modifiers in Neighborhood Design" as part of the "Hurricane Loss Reduction for Housing in Florida" for the International Hurricane Center at Florida International University funded by the Florida Department of Community Affairs under Contract 04-RC-11-13-00-05-001 in 2004. Principle Investigator: Jason Chandler, Co-principle investigator: Jaime Canaves, Graduate Assistants: Carlos Escuti, Michael Figueredo, Robert Perez, George Torrente. All wind testing was done at the Wind Tunnel Laboratory of the Department of Civil Engineering at Clemson University under the direction of Dr. Timothy Reinhold with Graduate Assistant Scott Robinett.

2. Florida Building Code, Copyright, The State of Florida, 2001, First Printing, April 2001

3. Minimum Design Loads for Buildings and Other Structures Document Number: ASCE 7-02 American Society of Civil Engineers Reston, Virginia 20191-4400 01-Dec-2002 ISBN: 0784406243

4. Zoning, Metropolitan Dade County, Municipal Code Corporation, Tallahassee, Florida 1992, Updated May 25, 1995

5. This research was completed for a grant entitled "Investigation of Influence of Architectural Features on Wind Loads" as part of the "Hurricane Loss Reduction for Housing in Florida" for the International Hurricane Center at Florida International University funded by the Florida Department of Community Affairs under Contract 03-RC-11-13-00-05-012 in 2003. Principle Investigator: Jason Chandler, Co-principle investigator: Jaime Canaves, Graduate Assistants: Carlos Escuti, Josue Cruz, George Torrente. All wind testing was done at the Wind Tunnel Laboratory of the Department of Civil Engineering at Clemson University under the direction of Dr. Timothy Reinhold with Graduate Assistants Scott Robinett and John Lamb.

6. Only two pressure maps are illustrated here due to the limitation of allowable images per paper. Each was tested in five conditions for both negative and positive pressures. There are a total of ten pressure maps for each house.

7. 2004 Florida Test Protocols for High-Velocity Hurricane Zone, Florida Building Code, Copyright, The State of Florida, 2004

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