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Extreme Exposure Fenestration Installations—The Florida Challenge

ABSTRACT: Current standards for installation of fenestration units, such as ASTM E2112-07, "Standard Practice for Installation of Exterior Windows, Doors and Skylights" do not address regional considerations, or how the level of wind and rain exposure could influence installation methodology. In the coastal southeastern United States, where extreme wind-driven rain events occur with some regularity, more robust methods than those prescribed in ASTM E2112-07 are necessary. In Florida, single family houses are commonly constructed with surface barrier concrete masonry walls on the first story, and membrane-drainage, wood-frame walls on the second story. This "hybrid" construction is unique, or virtually so, to Florida. Finned windows of a particular design are made expressly for installation in cement masonry unit (CMU) walls as commonly found in Florida homes. The special considerations that relate to residential construction in Florida were of concern to an industrial consortium. The consortium thus formed an Installation Committee to develop methods for fenestration installation that would be applicable to the wall systems commonly found in the coastal Southeast, with consideration of the high wind-driven rain loads that accompany tropical storms. This paper addresses two general installation methods proposed by the Installation Committee, and presents test data for wall assemblies incorporating fenestration units installed using the methods.

KEYWORDS: construction, water management, flashing, sealants, extreme exposure, windows, buildings, durability, CMU, adhesives, Florida

Introduction

Moisture problems in buildings can originate from several sources, but in many buildings, water intrusion (often into walls) poses the greatest risk. The window-wall (w/w) interface is furthermore one of the most critical locations for water intrusion. In a recent study by RDH Building Engineering Limited [2], a wide variety of window types and assemblies were tested for leakage, with leakage via six potential leakage paths being monitored. Water leakage was found to occur to some extent via all six paths. However, leakage via the "through window to wall interface to adjacent wall assembly" path was prevalent for all the window types tested. Leakage via this path poses a high risk of consequential damage to the building. The causes for leakage via the "interface to adjacent assembly" path are many, but improper flashing installation and over-reliance on building sealants were noted in the study report [2] as consistently contributing to leakage via the path. The Durability by Design guideline [3] published by the Partnership of Advancing Technology in Housing (PATH) concurs with the RDH report [2]; the PATH Design guideline states: "most leakage problems are related to improper or insufficient flashing details or the absence of flashing."

Moisture management challenges occur with all types of wall systems and fenestration systems (windows and doors), and in all climates, but the potential for problematic leakage is greatest in regions that experience extreme wind-driven rain events, such as hurricanes and severe thunderstorms. In the coastal regions of the southeastern United States, problematic wall leakage from wind-driven rain is a common problem. The problem is not only due to the occurrence in the region of extreme wind-driven rain, but also because buildings in the region are designed to first maintain structural integrity during hurricanes. In designing with an emphasis on structural integrity (while remaining mindful of construction cost), water management principles have often been overlooked. For example, wide roof overhangs are effective for sheltering walls from wind-driven rain, but unless robustly constructed, are prone to removal from the

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FIG. 1—*Typical residential home construction in Florida.*

building by hurricane winds at which point they become airborne projectiles. As a consequence, wide roof overhangs are uncommon in the region. In addition, the first-story walls of residences in Florida are commonly constructed of Concrete Masonry Units (CMUs) with direct-applied stucco rendering. These walls resist termite attack, which can be an issue in the Florida climate. If the CMU cores are grouted and reinforced, the walls are furthermore appreciably resistant to projectile penetration during hurricanes. CMU walls with direct-applied stucco are, however, prone to problematic water intrusion. After the hurricane season of 2004, water intrusion in the affected areas of Florida was widely observed, particularly near fenestration (window and door) wall openings [4]. While a portion of this water intrusion was associated with rain driven at pressures well exceeding the design leakage pressure of the windows, which is generally 15 % of the structural design pressure, much of the water intrusion was identified as being due to faulty or poorly-designed installation methods. The report [4], prepared for the Home Builders Association of Metro Orlando and the Florida Building Commission, states: "Water-managed window and door installation methods (should) be developed and the Florida Building Code altered to require them."

The need for fenestration installation methods that resist leakage has been recognized by Florida building officials. As a result, an installation committee was formed by the Fenestration Manufacturers Association (FMA). The objective of the committee was to develop installation methods applicable to the types of walls commonly constructed in Florida, with particular emphasis on resisting leakage, or managing it, or both. This paper reports spray test results for prototype assemblies fabricated in accord with proposed installation methods that were developed by the installation committee. The prototype assemblies were of w/w interfaces. Two different types of wall systems were investigated.

Residential Wall Systems in Florida

A typical two-story residential building in Florida incorporates two different types of wall systems (Fig. 1). Second-story walls are usually of wood-frame construction, with wood-based sheathing covered with a water-resistive barrier (WRB). The second-story walls are thus membrane-drainage walls, as classified by ASTM E2112 [1]; they would be termed "drainage walls" by the terminology of ASTM E2266 [5]. In contrast, first story walls are typically of CMU construction with stucco applied directly to the block. The stucco is coated with water-proofing paint; the paint serves as the water barrier. There is no provision for drainage of water that breaches the outermost surface of the wall. This would include water intrusion associated with fenestration units.

Second-story wood-frame walls in Florida are not conceptually different than membrane-drainage wood-frame walls elsewhere in North America. Finned windows installed in these walls are of similar design as elsewhere in North America; they may have higher design pressure ratings, but are otherwise

FIG. 2—*Pre-cast concrete sill. The sill shown protrudes past the outer face of the block wall.*

similar. The conceptual difference between these walls and membrane-drainage wood-frame walls elsewhere in North America is the anticipated level of wind-blown rain to which they may be exposed.

First-story CMU walls in Florida pose unique challenges with regard to installation of fenestration units. Units made for installation in these walls are designed for installation in CMU walls; the design is not commonly found outside of the region. The fenestration units are flanged, but the flanges are not used for anchoring the unit. The units are commonly termed "frontal flange" units, indicating that the flanges are exposed in service, rather than being covered by trim or cladding.

Frontal flange units are anchored with screws through jamb and head members driven into pressure-treated 2 by 4 (38 by 89 mm) wood members. The wood members are in turn anchored into the CMUs with masonry anchors. The wood members form what is termed a buck. Inward/outward positioning of the window is determined by location of the outboard faces of the buck members; the top and side window flanges seat against the outboard faces of the buck members. The interfaces between the buck members and the CMU wall are potential leakage paths. The interfaces are essentially cracks, which are surface-filled with sealant. A pre-cast or site-poured concrete sill pan is found at the base of the window opening. The sill serves a structural purpose, tying together the CMUs at the bottom of the opening. The sill is also intended to serve a water management function, although this function is often not adequately achieved. The concrete sill incorporates a lip or ledge (back dam) against which the lower (bottom) flange of the window is intended to seat, a representative pre-cast concrete sill is shown in Fig. 2. Alignment and inward/outward positioning of the sill's ledge is important, as is subsequent alignment of members of the wood buck with the ledge in the sill. In residential construction practice, alignment is sometimes poor. To serve its water management function, the sill should shed water. In practice the concrete sill is often porous and permeable, allowing through-passage of water. Cracked sills, which are fairly common, will also allow water passage. Flaws at sill ends (casting flaws or faulty mortar joints) can also result in leakage. Examples of areas prone to water leakage with the concrete sill system are shown in Fig. 3. For the purpose of water management, it is desirable for the sill to protrude beyond the face of the CMU wall. More commonly, the concrete sill is flush with the outer surface of the CMU wall.

The Installation Committee, formed under the direction of the FMA, had the objective of developing effective installation methods for fenestration units in Florida. The committee has developed five installation practice documents, based on different window/door and wall configurations found in the southeastern United States. These are listed in Table 1. This paper reports on evaluation of wall assemblies constructed to be consistent with the first two documents listed in Table 1: (1) FMA/AAMA 100 for wood framed construction [6], and (2) FMA/AAMA 200 for frontal flanged windows in surface barrier CMU construction [7].

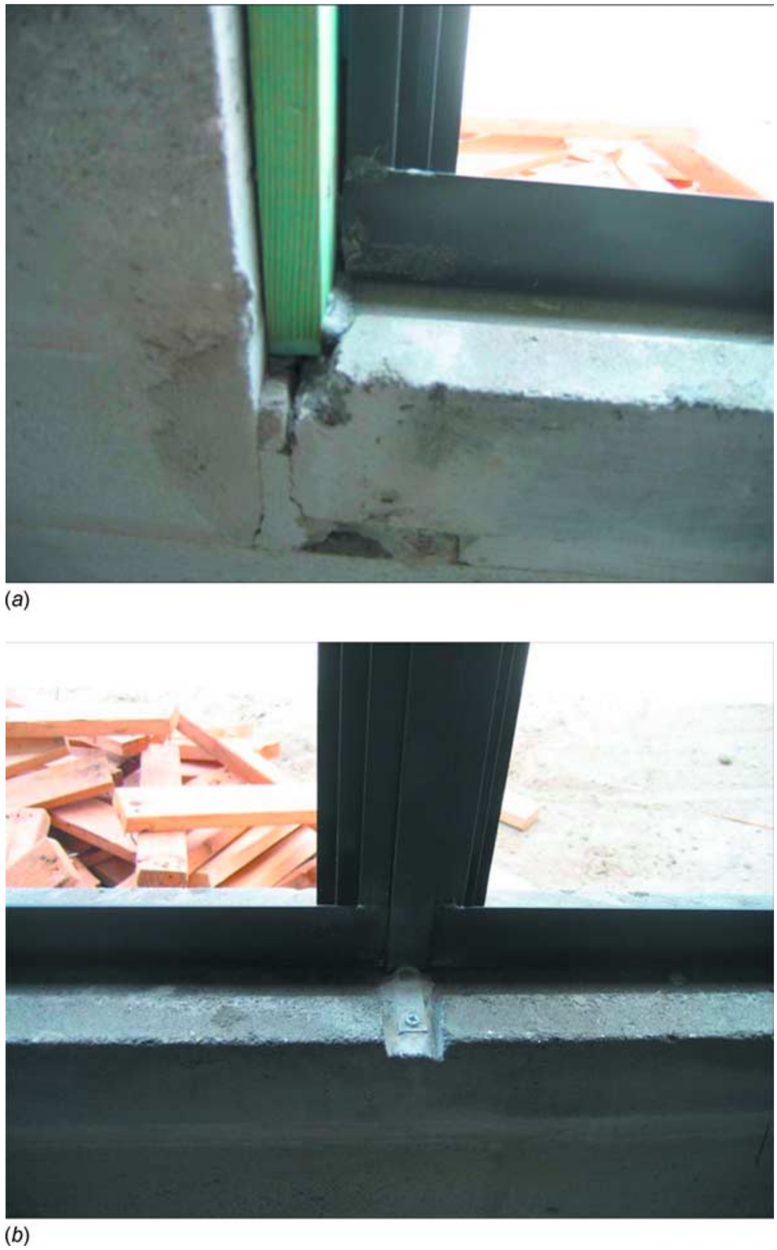


FIG. 3—*Common installation flaws. Cracks in joint between sill and rough opening, forced fitting of wood buck (a), and raised leg in sill back dam is cut out to fit anchoring hardware (b).*

Testing and Results

Installations Conforming with FMA/AAMA 100

The forward of FMA/AAMA 100 [6] states: "*This standard is specifically designed for installations subject to extreme wind/water climate exposure, particularly in the coastal southeast United States, and addresses buildings that will be at high risk for water intrusion. Thus, preventative measures shall be taken that are above normal installation practice.*"

FMA/AAMA 100 requires that the window rough opening be drainable through the use of sill pan flashing under the fenestration unit. In contrast, ASTM E2112-07 does not require the use of sill pans for installation of flanged windows in membrane-drainage walls, although it recognizes (recommends) use of sill pans. FMA/AAMA 100 also specifies that a perimeter air seal between the window frame and the rough opening be installed at or near the interior edge of the window frame. FMA/AAMA 100 includes details on specific installation steps for self-adhering flashing (100 mm/4 in. width) and mechanically attached flashing (230 mm/9 in. width), as well as pictorial illustration of the installation steps. The

TABLE 1—*FMA (AAMA/WDMA) Installation Committee documents as of 5/31/07.*

Document	Window System	Wall System	Status
FMA/AAMA 100	Flanged or Mounting Fins (Wood, Al, or Vinyl)	Wood Frame	Draft/AAMA Ballot complete, third ballot pending wall test results
FMA/AAMA 200	Frontal Flanged (Aluminum and Vinyl)	Surface Barrier CMU	Draft/AAMA Ballot complete, third ballot pending wall test results
FMA/WDMA 250	Nonfrontal flanged (Wood)	Surface Barrier CMU	Draft under development/awaiting WDMA ballot
FMA/AAMA 300	Sliding Glass Doors	Wood Frame	Draft under development
FMA/AAMA 400	Sliding Glass Doors	Surface Barrier CMU	Draft under development

procedural steps of FMA/AAMA 100 are generally consistent with the A1 method of ASTM E2112-07, for installation of flanged windows in membrane drainage walls; the procedural steps are not consistent with the A, or B, or B1 methods of ASTM E2112-07. This reflects common construction sequencing in the southeast region. Although other sequencing methods are not explicitly recognized, they are not prohibited by FMA/AAMA 100. It is also important to note that manufacturer's instructions take precedence over the explicit procedural instructions outlined in FMA/AAMA 100.

Section 1.2 of FMA/AAMA 100 states: "*Representative installation methods described in this document have been water tested up to a design pressure of* 575 Pascal (12 psf) *water test pressure, using the ASTM E331 water test, to simulate extreme exposure conditions*."

Two wall assemblies, each containing a flanged window installed in accord with FMA/AAMA 100, were fabricated in a laboratory and spray tested. A summary of the installation features is listed in Table 2. The window in each wall assembly was installed according to the detailed steps of Section 7 of FMA/AAMA 100 [6]. Illustration of the installation are included in Figs. 4–7, which show the cut in the water-resistive barrier, the sill pan flashing, the jamb and head flashings, and the interior air seal method, respectively. After windows were installed, the wall assemblies were left in the laboratory for 24 hours before spray testing.

There was no interior finish on the wall framing and no cavity insulation between studs; the wall framing and the back (interior) side of the wall sheathing was visible during testing. Spray testing was

TABLE 2—*FMA/AAMA 100 wall test installation details.*

	FMA/AAMA 100 Wall #1	FMA/AAMA 100 Wall #2
Water Resistive Barrier	Installed before window (A1 method) with full "I-cut"	Installed before window (A1 method) with modified "I-cut"
Sill Pan Flashing	150 mm (6 in.) wide extendable self-adhered flashing	150 mm (6 in.) wide extendable self-adhered flashing
Sealant under flange	Polyurethane hybrid sealant: continuous application under jambs and head of flange, discontinuous bead at sill (two 50 mm gaps near either end)	Polyurethane hybrid sealant: continuous application under jambs and head of flange, discontinuous bead at sill (two 50 mm gaps near either end)
Jamb and Head Flashing	100 mm (4 in.) wide self-adhered flashing (butyl adhesive based)	230 mm (9 in.) wide mechanically attached flashing
Interior Air/Water Seal	Backer rod with polyurethane hybrid sealant—later changed to pure polyurethane sealant at sill area after initial test	Polyurethane low expansion aerosol foam

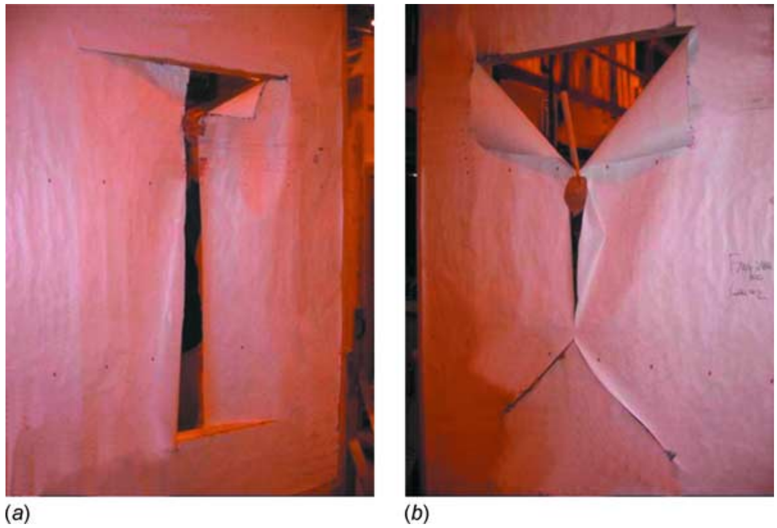


FIG. 4—*Cuts in water resistive barrier for FMA/AAMA 100 installations. Full I-cut used in Wall #1 (a) and modified-I cut used in Wall #2 (b).*

according to ASTM E331 [8], with the pressurized chamber sealed against the exterior side of the test assemblies. Spray testing was performed before and after thermal cycling consisting of fourteen 12-hour hot-cold cycles conducted in accord with ASTM E2264, Method A, Level 1 [9]. The test walls did not incorporate cladding systems; spray application was directly to the water resistive barrier, the flashing sheets, and the window unit. In most tests, water was applied at air pressure differentials of 145 Pascal (3.13 psf), 290 Pascal (6.2 psf), 440 Pascal (9.2 psf), 540 Pascal (11.29 psf), and 575 Pascal (12 psf). These pressures correspond with structural window pressure design ratings of approximately DP 20, 40, 60, 75, and 80 respectively, (per the 15 % of design pressure load rule of thumb for water test pressure). Water spray, at the rate of 3.4 L/m^2 min (5.0 U.S. gal./ft^2 min) at each differential air pressure was applied for 15 minutes, in accord with ASTM E331.

Results of FMA AAMA 100 Wall #1 Test—In the first round of testing of this wall assembly, water leakage was not observed until air pressure differential, reached 540 Pascal (11.29 psf), as shown in Fig. 8. At that 540 Pascal, leakage was observed between the sill pan and the sealant that served (along with backer rod) as the air seal (and the pan back dam) below the window unit's sill. It was noticed that the

FIG. 5—*Extendable sill flashing used in both Wall #1 and Wall #2 for FMA/AAMA 100 installations, with discontinuous bead of sealant at sill (can also be applied to back of the flange).*

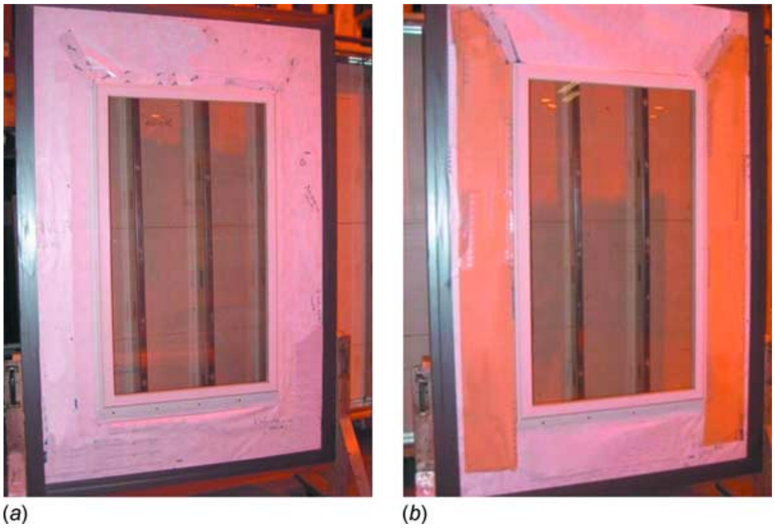


FIG. 6—*FMA/AAMA 100 completed installations, Wall #1 with 4 in. self-adhering flashing used at jambs and heads (a); Wall #2 with 9 in. mechanically attached flashing used at jambs and head (b).*

sealant had not fully cured; it was still wet/sticky to the touch. A spot or "patch" repair was made with additional sealant. The assembly was retested after seven days to allow the sealant to fully cure. During retesting the wall was taken directly to 440 Pascal (9.2 psf) pressure differential (the 145 and 290 Pa differential set-points were skipped). Within eleven minutes at 440 Pa, a leak was observed at the same area as before, and the leak was again between the pan flashing and the sealant. Upon inspection, two conclusions were drawn:

1. There was poor interfacial adhesion between the polyurethane hybrid sealant and the flashing topsheet—the sealant could be easily pulled away from the topsheet. This resulted in an insufficient bond to hold water back against the pressure differential (the back dam would leak at the higher differential pressures).
2. Since the leak occurred at the same location as the first test, it was also concluded that the repair "patch" was ineffective.

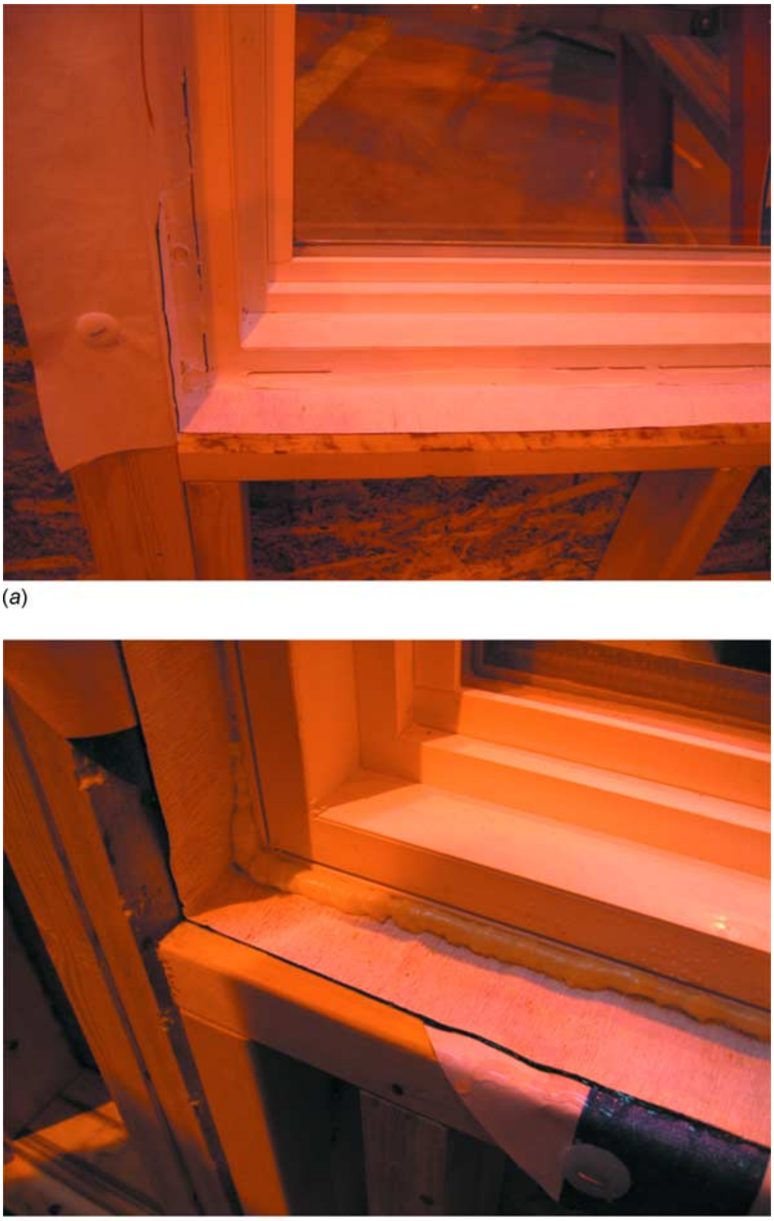
Given the conclusions drawn above, the polyurethane hybrid sealant was removed at the sill area of the installation and a short distance up the jambs and replaced with pure polyurethane sealant. It was known from previous experience that the topsheet of this flashing adhered effectively to pure polyurethane sealants.

Wall #1 was retested with the polyurethane sealant. No leakage was observed at 575 Pascal (12.0 psf) differential. The wall thus met the criterion specified in FMA/AAMA 100. The pressure differential was then increased to 720 Pascal (15 psf) to explore the limits of the installation; this pressure is beyond the FMA/AAMA criterion and above normal exposure for typical window and door installations. A small amount of leakage occurred at 720 Pa at the lower corner of the sill.

After thermal cycling (as described previously), the wall was retested with water application at 145, 290, 440, and 575 Pa differential. Dye tracer was applied at the final test pressure. Water containing the dye was applied with a hand-held sprayer around the entire perimeter of the w/w interface while pressure was still applied, but with the spray racks turned off. After several minutes of pressure application, the spray racks were reactivated to wash residual dye tracer from the exterior surface. The wall was then dismantled for forensic inspection. No water intrusion was noted behind the flashing or in the wall cavities, although some water penetration was evident under the sealant at the sill. It was found that the backer rod had been displaced during the sealant "repair" from the first phase, resulting in potential leakage paths from this action.

FMA/AAMA 100 Wall #2 Test Results—Test Wall #2 was tested in a similar manner as Wall #1. This wall differed from Wall #1 in that a polyurethane low expansion aerosol foam was used for the interior air seal (it also served as the sill pan back dam), and mechanically attached flashing was used for the jambs and head (the cut in the WRB was also different, as previously described in Table 1).

During its first round of testing, Test Wall #2 was subjected to pressure differentials of 290, 440, 540,



(a)

(b)

FIG. 7—*FMA/AAMA100 interior air/water seals: Wall #1 with backer rod and polyurethane hybrid sealant in (a); Wall #2 with low expansion polyurethane aerosol foam sealant in (b).*

and 720 Pascal (6.06, 9.20, 11.29, and 15 psf, respectively). No leakage was observed at 540 Pascal differential. A very small leak was observed at the lower right corner at 720 Pascal (15 psf). The installation was repaired at the location of the observed leak and then retested at 575 Pascal (12 psf); a leak was observed in the same location as before. As had been the case with Test Wall #1, it was concluded that a spot repair would not seal the leakage path. The foam at the sill area was thus completely removed and replaced with new material. The wall was again retested at 575 Pascal (12 psf) differential. No leakage was observed; the installation then met the FMA/AAMA 100 criterion.

The wall was then exposed to thermal cycling (according to ASTM E2264, Method A, Level 1), and the wall was retested with water application at 290, 440, 540, and 575 Pa differential. No leakage was observed at 575 Pascal (12 psf). Dye tracer was applied as described previously and the wall was dismantled for forensic inspection. The tracer dye indicated that no water intrusion had occurred behind the flashing or into wall cavities.

FMA/AAMA 100 Wall Test: Discussion of Results—As summarized in Table 3, both of the FMA/AAMA 100 Test Wall #1 and Test Wall #2 showed no leakage at 575 Pascal (12 psf) differential when

FIG. 8—*Water leak formed at 11.29 psf on FMA/AAMA 100 Wall #1 at interface between sealant and flashing, after 24 hour cure time.*

tested according to ASTM E331 (the criterion set forth in FMA/AAMA 100). The 100 mm (4 in.) self-adhered flashing system and the 230 mm (9 in.) mechanically attached flashing system can each qualify under this criterion, as can each of the methods evaluated for forming the interior air seal and sill pan back dam.

Key observations are summarized below:

1. The adhesive seal between the sill flashing topsheet and the sealant used for the interior air/water seal is important in meeting the FMA/AAMA 100 criterion.
2. Sealant/topsheet combinations that have a lesser seal (such as the initial test with Wall #1) are evidently capable of performing at lower differential pressures. In initial testing (before thermal cycling) the system with less-than-ideal seal did not leak at 440 Pascal (9.20 psf). This corresponds with wind impinging on the wall at approximately 55 mph (~90 km/h).
3. Once leaks formed in the backer rod and caulk method, the leaks could not be remedied by adding more of the same sealant. The sealant had to be fully removed and replaced (with a more effective sealant) in order for the installation to meet the criterion.
4. These installations did not utilize an upturned leg back dam, demonstrating that a continuous perimeter air/water seal at the interior interface between the window and wall cavity is able to serve as the “back dam” under high pressure loads up to 575 Pascal (12 psf). However, the small leakage observed at 720 Pa in test assemblies that were consistent with either of the methods could

TABLE 3—*Results of initial FMA/AAMA 100 water testing.*

FMA/AAMA 100 Wall Number	Initial ASTM E331 Water Test Results	ASTM E331 Results After Thermal Cycling (per ASTM E2264 Method A, L1)	Comments/Observations
1	Pass (no leakage) at 575 Pascal (12 psf)	No water penetration behind flashing. Some leakage at interior sealant—pan flashing interface	Adhesion between interior air/water seal and pan flashing is critical. Performance appears sensitive to mis-alignment of backer rod
2	Pass (no leakage) at 575 Pascal (12 psf)	No water penetration behind flashing. No leakage at interior seal up to 575 Pascal (12 psf)	Low expansion aerosol foam was effective as interior air/water seal provided it was not exposed to excessive pressure differential (in excess of 575 Pa)

have been managed with an upturned leg back dam.

It is important to note that performance of the jamb and head flashings cannot be fully concluded until the wall is disassembled and inspection made behind the flashings. It is worth noting that in these investigations disassembly and subsequent inspection was performed after the walls were thermally cycled and retested.

FMA/AAMA 200 Wall Test

The FMA/AAMA 200 standard practice addresses the unique window and wall configuration utilized in the southeast United States/Florida residential market, with a surface barrier concrete block construction. The FMA/AAMA 200 standard practice is specific to frontal flanged windows, which are typically made from aluminum.

As with the FMA/AAMA 100 standard practice noted in the previous section, the FMA/AAMA 200 standard practice specifies the same performance criterion—specifically an absence of leakage when tested according to ASTM E331 at 575 Pascal (12 psf) air pressure differential.

It is also important to note the following statement in the forward of the FMA/AAMA 200 standard practice: *The techniques demonstrated in this standard practice have been developed specifically to restrict liquid water from entering through the masonry opening and/or around the perimeter of the window frame. The major emphasis is focused on sealing the surrounding area of the window's masonry opening in such a manner as to restrict liquid water from penetrating the wall at the window opening [7]*. What this means is that the standard practice is only concerned with the surrounding area around the rough opening and not the entire wall system. Aligned with the test criterion set forth in Section 1.2, the following is noted: *Water resistance is demonstrated around the sealed portion of the rough opening and wall face only. This standard practice presumes that all other construction elements function to provide expected water resistance [7]*. Thus in FMA/AAMA 200, the focus is on the sealed area around the rough opening of the test assembly, rather than the entire block wall (although in the test assembly some area of block will be present).

Two assemblies, each incorporating an aluminum frontal flange window installed in a section of concrete block wall were fabricated. In each assembly, the window was installed in a manner consistent with FMA/AAMA 200 [7] and spray tested in accord with ASTM E331 [8]. In each assembly, the window was anchored to a pressure treated wood buck at the jambs and head of the rough opening, and polyurethane sealant was used to bed the frontal flange to the treated wood members that composed the buck. A discontinuous bead of sealant (also polyurethane) was applied at the sill of the window to allow for drainage. A fillet bead of sealant (also polyurethane) was installed between the wood buck members and the surrounding block wall. The interior perimeter of the window opening was sealed with backer rod and polyurethane sealant. It should be noted that the wall assemblies did not incorporate stucco rendering; this was conceptually similar to the wall assemblies constructed to be consistent with FMA/AAMA 100, (discussed previously), which did not incorporate cladding.

FMA/AAMA 200 Tests Results—All the blocks in the first of the two assemblies were sealed with a block sealer that is commonly used in the region. This included the rough opening return and the pre-cast concrete sill. The concrete sill in the assembly protruded beyond the face of the block wall. Figure 9 shows this assembly prior to spray testing.

The first testing of the assembly was performed during the fall of 2006. In that testing, leakage was observed between the concrete sill and the CMU wall below the sill without application of an air pressure differential (the only driving force being the momentum of the water droplets, imparted by the spray nozzles). A second application of sealer was made in January 2007. The assembly was then exposed to spray testing in February and March 2007.

In the first tests performed in early 2007, the window was masked with film. The masking covered the window flanges, including the sill flange. The only interface actually exposed to water spray was the joint between the wood buck and the concrete block wall. Pressure differentials of 145 Pascal (3.13 psf), 290 Pascal (6.2 psf), 440 Pascal (9.2 psf), and 540 Pascal (11.29 psf) were applied. At roughly 290 Pa differential, water seepage was noted at the interior lower corner of the concrete block, as shown in Fig. 10. Water leakage at the lower extremity of the wood buck was also noted (circled in Fig. 10). The test was continued to 1437 Pascal (30 psf) pressure before stopping. Additional leakage locations were not noted at

FIG. 9—*FMA/AAMA 200 setup for first test wall prior to wall testing in March 2007.*

FIG. 10—*Water seepage through concrete block in first FMA/AAMA 200 wall test near lower corner at interior, as well as the lower buck area, as highlighted by the circle.*

FIG. 11—*FMA/AAMA 200 water test—water puddle formed in lower corner with lower flange open.*

the higher pressure differentials.

The masking film was removed from the sill flange; this exposed the sill flange and the joint between the sill flange and the concrete sill. The wall was then retested. At 440 Pascal (9.2 psf), a pool of water was noted at the lower corner of the interior on the same side as the leak observed in earlier testing (Fig. 11). Spray testing was suspended and dye tracer was applied to the exterior surface of the assembly around the window perimeter. Dye application was by the same method, described previously, for assemblies conforming with FMA/AAMA 100.

The window was subsequently removed from the assembly. After window removal, it was noted that the lower portion of the wood buck on the left side facing the wall was very wet. It was evident that leakage had occurred at a mortar joint in the vicinity of the wood buck; the water that entered at this location traveled between the buck and the sealed concrete blocks and then penetrated the fillet sealant joint between the wood buck and the block wall. Figure 12 shows the area where the buck was soaked. Figure 13 shows the water path between the buck and the concrete wall, made evident by the blue dye tracer. The sill area of the window was dry, indicating that no water penetrated the open sill region under the flange.

The interface between the wood buck and the sealed concrete block wall had (as described previously) been subjected to a 1437 Pascal (30 psf) pressure differential. Leakage, as described previously, had been observed at pressure differentials below and substantially above the criterion level. The dye tracer had only been applied, however, after the assembly had been exposed to a test pressure well beyond the criterion

FIG. 12—*FMA/AAMA 200 wall after first test showing leakage at lower wood buck.*

FIG. 13—*FMA/AAMA 200 wall test indicating path of leakage with blue die entering at mortar joint between sealed concrete block and wood buck, penetrating the sealant.*

level, and a leakage path had been established.

A second assembly conforming with FMA/AAMA 200 was constructed. This assembly was tested in May 2007. In the second assembly, only 230 mm (9 in.) of the exterior perimeter face of the block was sealed (as directed in the AAMA/FMA 200 draft specification). Figure 14 shows the 230 mm (9 in.) coverage of the sealer, as well as the rough opening return and pre-cast sill. In this case, the pre-cast sill was flush sill with the block wall below the window. A flush sill is more common in actual field installations in Florida. The installation followed the detailed steps of FMA/AAMA 200.

Testing of this second assembly was conducted in two phases. First, water was applied only to the sealed area of the block, which is 230 mm around the exterior perimeter of the rough opening, in order to test the robustness of the sealed area and interface. Figure 15 shows the method used to mask the unsealed portion of the wall; the method used an acrylic sheet and sealant. In the second phase of testing, the test was repeated, with the mask removed (with the entire wall exposed, as shown in Fig. 16). The test results are summarized in Table 4.

As noted in Table 4, the masked assembly did not show leakage at 575 Pa (12 psf) pressure differential. This means that leakage through neither the window-wall (w/w) interface nor the perimeter area of sealed block occurred when air pressure differential was at the criterion level. Leakage was furthermore not observed through the interface via these pathways when the test pressure was increased to 720 Pascal (15 psf).

Some leakage was noted through the window glazing at the criterion pressure differential (575 Pa). This leakage collected at the interior of the pre-cast sill. The installation is not designed to manage this type of water intrusion. The system is designed to manage water that intrudes through or around the w/w interface or through window frame joinery, not water that intrudes through sash, between sash, or between the window sash and frame.

When the masking was removed and the entire CMU wall was exposed to water spray, water seepage to the interior occurred at the lowest pressure differential included in the test protocol (Table 4). Figure 17 shows the water penetration through the interior side of the unsealed area, but not the sealed area of the block. Unsealed portions of the CMU wall system were thus notably incapable of meeting the FMA/AAMA 200 criterion. Additional testing has shown that water seepage through block walls occurs readily in the absence of any air pressure differential. A "whole wall" approach to water management is thus justified. This, incidentally, was recognized in the report (dated January 2005) by Lstiburek [4]. It will be a key challenge for the FMA Installation Committee going forward.

FIG. 14—*Wall treatment for second FMA/AAMA 200 wall test, showing 230 mm (9 in.) sealant application around exterior perimeter and return of rough opening.*

Summary and Conclusions

The assemblies, which were constructed to be in accord with FMA/AAMA 100 and 200 installations, generally met the basic performance criterion set forth in the FMA/AAMA documents. The installation methods evaluated in this investigation incorporate a sill pan system, as recommended by but not required by ASTM E2112-07. They also rely on an air seal around the window perimeter at the interior edge of the window frame. At the window sill, this air seal also serves as a sill pan back dam. The following observations and findings were made:

1. The sill pan systems were found to be effective. Problematic water penetration between the pan and the window bottom flange (between which there was NOT a continuous seal) was not observed. The sill pan system is designed to manage water intrusion around the perimeter of the

TABLE 4—*Test results for the second assembly assembled in accord with FMA/AAMA 200.*

FMA/AAMA 200 Wall Test Descriptor	Initial ASTM E331 Water Test Results	Comments/Observations
Tested around sealed area of exterior perimeter only	Passed (no leakage observed) at 575 Pascal (12 psf)	Water leakage through window glazing was noted, but not around installation
Tested entire wall	Failed (seepage observed) at 145 pascal (3.13 psf)—14 minutes into test	Water seepage through block was observed in unsealed area

FIG. 15—*FMA/AAMA 200 wall test with unsealed area blocked by clear acrylic sheet and sealed.*

FIG. 16—*FMA/AAMA 200 wall test with full wall exposure, both sealed and unsealed areas (second phase).*

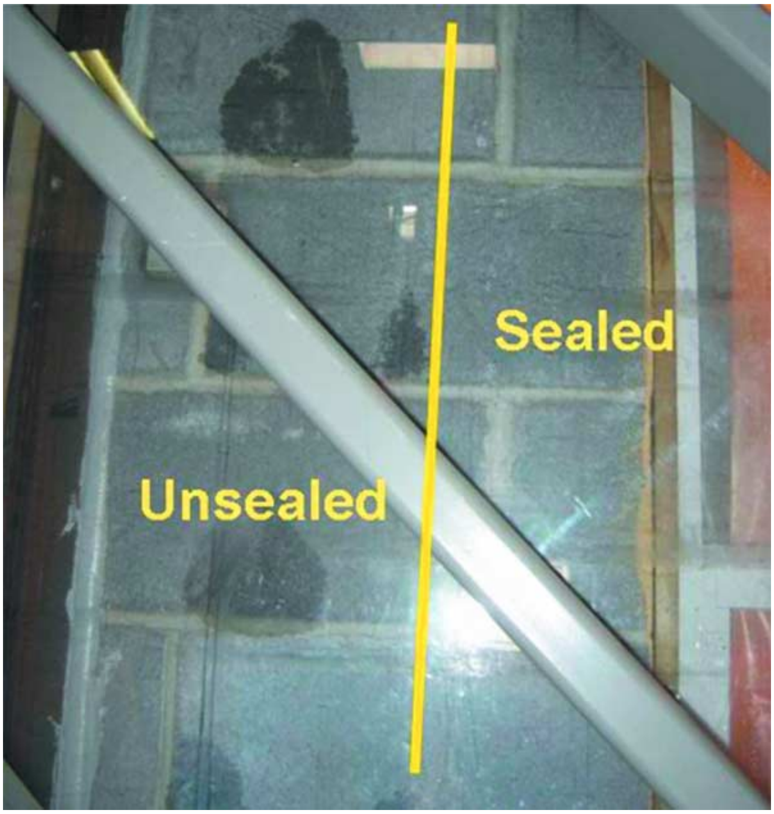


FIG. 17—*FMA/AAMA 200 second phase wall test results—water seepage through the internal portion of the block at unsealed area, but not at in the sealed area.*

window frame and at the interface with the window and wall. It is not designed to manage water that penetrates through the window glazing.

2. In formation of the air seal at the interior window perimeter, adhesion to the window frame and sill pan is critical. "Adhesive" as well as "chemical" compatibility between the sealant and interfacial materials is important. Leaks were observed in areas where adhesion was not sufficient.
3. The installation methodology detailed in FMA/AAMA 200 for frontal flange windows in a surface barrier concrete block wall system resulted in installations that did not leak at the criterion pressure. An effective seal however between the buck members (used to anchor the window unit) and the surrounding block wall was found to be important. In contrast to the leak resistance of installations that were in accord with FMA/AAMA 200, unsealed portions of the block wall exhibited seepage at the lowest differential pressure included in the test protocol. A "whole wall" approach to water management thus appears necessary.

These test results presented in this paper are preliminary. They are based on testing of assemblies fabricated in a laboratory setting. Tests of field installations are planned.

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