Failed Fenestration: New Materials Require New Techniques

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ABSTRACT

The most troublesome and difficult problem when approaching the repair of an exterior wall system is the interface between the fenestration and the wall system. Typically, should there be leakage through the joinery of the fenestration, that leakage will seek evacuation through the wall cavity, unfortunately to the destruction of the existing sheathing or building components. Unless a continuous integration between the flashing at the sill and the water-resistive barrier is maintained, this leakage is not controllable, since it cannot be determined on which side of the water-resistive barrier this liquid water travels. Consequently, fenestrations are replaced on a regular basis, but the replacement installation is usually no better than the original installation, and relies totally on the integrity of the fenestration's joinery. In addition, the wall itself can leak, thus causing leakage on the perimeter of sealed window openings.

This presentation will highlight novel approaches to install fenestration in drainage walls and masonry barrier walls. Testing compared performance of traditional techniques versus new techniques that include coatings, waterproof sills, and waterproof receptors. The testing investigated performance of the walls independent of the windows.

The completed installations prevent failed window joinery from leaking into the wall, by directing all water to the exterior surface of the cladding. The receptor allows for future replacement of the window, should it either fail or need to be upgraded to new energy-efficient technologies not now known, without a destructive removal and replacement process. The new window will take only minutes to remove and be replaced.

INTRODUCTION

Fenestration has always played a prominent part in buildings. Fenestration, for the most part, consisted of windows that could pass light, had a reasonable amount of security, and assisted greatly in the overall comfort of the inner space.

Considerations such as the amount of air and water leakage initially were not important features. The design of the fenestration opening, usually in masonry, with its sloped sill, managed water by diverting it to the building exterior or absorbing it into the wall. These masonry materials had a very high storage capacity. Air infiltration through the fenestration was not an important consideration.

Conditioning of spaces was not sophisticated and when used, was in localized areas for comfort. There was no room interior environmental control; therefore the physics of the building reflected low expectations, keeping the inhabitant somewhat warm, somewhat dry, and somewhat comfortable.

Values changed in western cultures with the industrial revolution. Everything from technologies to materials were in flux. The concept of a comfortable indoor environment grew, making it necessary to greatly improve on the air- and water-tightness of buildings to achieve levels of comfort. Huge strides have been made in everything from central and channelled conditioning of spaces to the ability of fenestration manufacturers to develop products that were much tighter and leak-resistant. Further complicating this process is the fact that from 1900 to 2000, the population increased by 200 million, and the number of new windows per 100 population increased 5.5

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times: in 1900 new construction windows equalled 2 per 100 population, and in 2000 we had 11.1 new windows per 100 population (NAHB Research Center). It is complicated again by the many window configurations and shapes available today.

Changes in Interface of Fenestration and Building Envelope

This paper is focused on integration of fenestration into the building envelope. A hundred years ago, windows/fenestration were two-part assemblies, usually consisting of frame members which were built into the masonry openings or wood structure, and the sash members which came later and were installed into the frame members as a separate component. The window as we know it today is a rather new invention that has combined the frame and sash together as a single assembly. This paper will explore the failures of the installation methods for this new window unit, leading to destruction of either the structure's framing or delivering an unhealthy environment due to moisture to the interior, causing fungal growth. Where did we go wrong? What changed so drastically in the last hundred years that has made buildings so sensitive to moisture intrusion?

In the early 1970s, the United States/North America experienced its first major shortage of oil, which influenced conventional thinking on the costs of energy. As a result of that crisis, fuel consumption needed to be reduced. Not only would there have to be conservation, but the way we build would have to be scrutinized. New building materials and technologies were born that directly affected the integration of fenestration products.

One of the most noticeable was the rapid growth in the membrane industry, which started to offer rolls of water-resistive building wrap. In the past there had been no building membrane of any type, and if one was present, it was primarily made of asphaltic papers, usually used on roofs, that were installed shiplap fashion, but not sealed. This was also true for the interface around the fenestration, which at that time was never sealed to the membrane. In the 1950s through the 1980s, most fenestration in North America was aluminum and single-glazed with no thermal break, with little consideration given to installation into the building. Initially, most of the technical advances in windows were in the glazing infill, giving rise to such product as Twindow[1] (no longer available) and Thermopane[2] (no longer available). There was little consideration given to the integration of the window with a membrane and ultimately to the building, particularly in terms of moisture management through and around the fenestration.

1. Pittsburgh Plate Glass (PPG) sealed dual-pane glazing with air space
2. Libbey Owens Ford (LOF; no longer in business) sealed dual-pane glazing with air space

Fenestration Interfaces Identified as Problematic

Fenestration interfaces were identified early on as culprits for air and water infiltration and energy loss. A 1980 U.S. Dept. of Energy study (Weidt 1980) concluded that "the air leakage performance of the crack between the window unit and the wall has a significant effect on the air leakage performance of the entire window unit as installed." A 2002 study by RDH stated that 35 to 48 percent of newly installed windows were found to leak through the window unit itself, through joints between the window and the rough opening, or both. *This study concluded that 100 percent of installed residential windows examined after years in service were found to leak either through the window unit itself or at points of attachment to the building.* According to Home Energy Magazine, February 2000 issue, "Air infiltration at the joints between the window or door frames and the exterior wall, combined with those at the joint between the foundation wall and the exterior wall, account for about 20% of heat losses in houses with average workmanship. Improperly installed flashing and discontinuous insulation in these areas not only will seriously affect the thermal performance of the wall but also will increase the risk of condensation inside the wall, which will eventually deteriorate the insulation and reduce the wall's performance even further."

Energy Crises Give Rise to Changing Technologies, Building Defects, Codes and Standards

Additional energy crises occurred, resulting in rapidly changing technologies which produced building products that were much more water impermeable and airtight. These new products gave recognition of the dynamic relationship between the entire wall and its fenestration inserts.

The early seventies gave birth to the identification of building defects as we know them today. At the end of the 1970s, lawsuits started to emerge based on a variety of building defects, many of which were directly connected to leakage at interfaces and directly blamed on the performance of the window. In the late 1960s and early 1970s, AAMA[3] initiated programs of voluntary specifications for quality control and ratings to assist the specifier in identifying and comparing performance of fenestration products. However, the process does not require the testing of fenestration in walls as built. Thus, fenestration ratings are for standalone windows and do not attempt to identify the validity of the interface between fenestration and the building envelope or drainage plane or membranes. AAMA[4] currently offers a complete set of standard test protocols for fenestration, typically identified AAMA 101. These ratings are published and available from AAMA. Note that none of the ratings include performance of the fenestration in an as-built environment; i.e., AAMA-certi-

3. AAMA, at that time known as the American Aluminum Manufacturers Association
4. AAMA, now known as the American Architectural Manufacturers Association

fied products are not yet certified for the wall condition they are installed in.

Buildings built between 1970 and 1990 were particularly lacking in water management theory. Water management was poorly understood and seldom utilized. Buildings during this period often lacked attention to detail or identification of the responsibility of various portions of the process; e.g., whether house wrap or building paper should be used at all was still not enforced through the 1990s and only in the past few years has the use of such products become required by the building codes. When a membrane or housewrap was to be used, it was unclear at what phase of the construction that installation would take place.

From the early 1980s through the present, the U.S. Department of Energy[5] has developed programs that would thermally rate fenestration products and assign either U- or R-values. This would give the specifier an opportunity to match values between the wall and the fenestration, which had never been done before. It also gave the specifier an opportunity to value the efficiencies of the infill glazing with regard to solar and thermal capabilities. Through the efforts of the Department of Energy, a new organization known as the National Fenestration Rating Council (NFRC) was created to assist in this process. With the advent of NFRC, fenestration products could be rated for thermal efficiency; but as with air, water and structural testing, fenestration thermal ratings were based on testing that was always on the standalone fenestration product, uninstalled.

In the late 1980s the California Association of Window Manufacturers (CAWM)[6] recognized that there were no standards for the installation of fenestration products that would tie into the membrane (if used) and the fenestration products. By early 1990, CAWM had developed standards for the installation of both windows and doors, for limited product and wall types.

This initiative was recognized by the Department of Energy through NIBS/BETEC[7], who supported the development of a national ASTM fenestration installation standard, now known as E 2112 Standard Practice for Installation of Exterior Windows, Doors and Skylights. This standard, although rich in installation methods and information, is not a mandatory standard and does not require testing of the fenestration in the wall. The development of E 2112 has spawned activity in the flashing industry, which has brought self-adhered flashings to wide usage, which offer many advantages to the traditional mechanically attached flashings. Whereas the mechanically attached flashings are suitable to only deflect moisture away from the window-wall interface, self-adhered flashing act as an extension of the sealant joint to provide a more durable seal, as well as deflecting purpose.

New Materials—Self-Adhering Flashing:

Only recently has work been started to develop standards that can identify the robustness of self-adhered flashing[8]. Much work needs to be done to fully understand the adhesion properties and durability under various temperatures and humidities, and chemical compatibility with adjoining substrates of the self-adhered flashings, which we have only begun to address (Katsaros 2005). In addition, shingling methods of installing flashing can be difficult and often troublesome, particularly for the wide variety of wall configuration and exposures that are prevalent. Thus, a “one method fits all” installation approach is not practical. New efforts in ASTM E2112 are focusing on providing overriding Guiding Principles for general application, and then separate specific guidance pertaining to the actual system, such as concrete blocks, high wind/water exposure, and non-flanged window systems.

Inherent Window Problems

The inherent problems of windows themselves are of paramount importance. Are they manufactured to be as durable as the walls themselves? No. The fact is, according to marketing surveys conducted by AAMA, replacement window manufacturing is almost as voluminous as manufacture for new buildings. Other surveys show the service life of a window to be fifteen years or substantially less. Fenestration products are installed into residences that are anticipated to have a serviceable life of more than fifty years; therefore fenestration will be replaced at least twice in the life of a residential building. Windows inevitably develop joinery leakage from the constant thermal movement of the product and the wall, and the fatigue on the components such as sealants and weather-stripping through the UV, ozone and environmental chemical exposures. The window manufacturers do not know the durability or serviceable life of the various components that make up a window. Shouldn’t installation for fenestration anticipate this corner joinery problem and provide some method to drain it, rather than have it contaminate the interior of the building? Removal of failed fenestration requires some destruction of the surrounding wall, and often of the entire cladding and membrane system. Reintegration of the replacement product faces even more complication (and lack of available instructions) than the original (failed) installation.

Windows should not be installed permanently; the installation technique should encourage simple non-destructive replacement of fenestration, not unlike the changing of a water heater.

Complicating an already difficult situation is the occasional heavy weather event, such as hurricane Katrina. Current

5. Through the Lawrence Berkeley National Laboratories, Berkeley, CA
6. Fullerton, CA
7. National Institute of Building Sciences, Building Envelope Thermal Energy Council, Washington, DC
8. AAMA 711

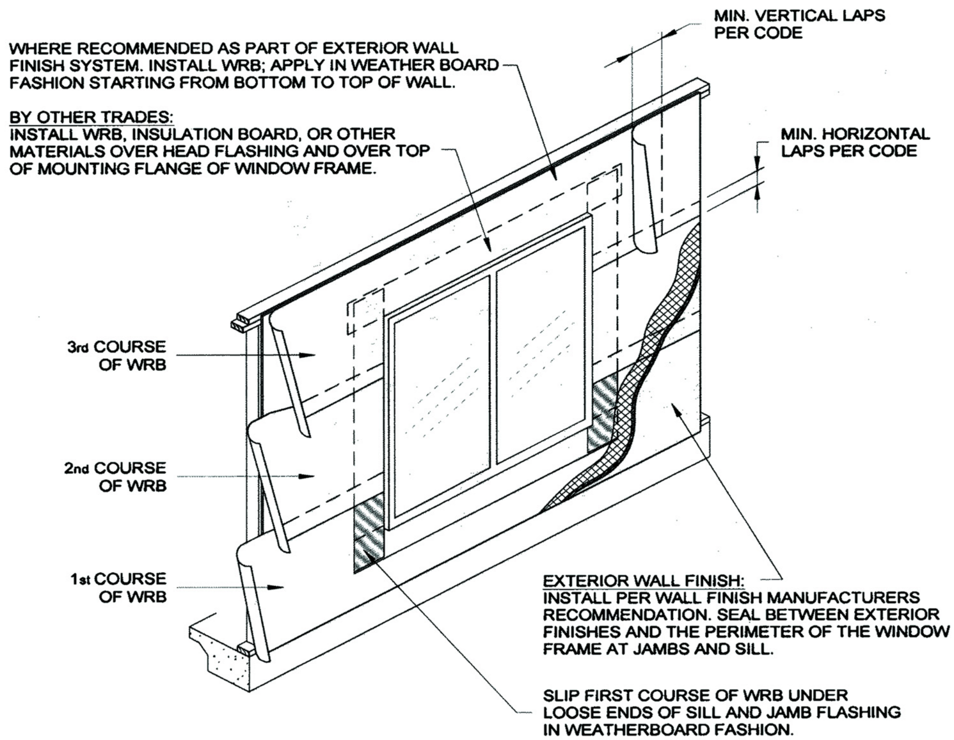

Figure 1 *Membrane/drainage system.*

typical installations are unable to withstand Hurricane Category One conditions (85 mph).

In summary of this introduction, problems to be solved to achieve a fenestration installation that is free from air and water leakage are:

- We have not developed a procedure that matches fenestration and its rankings to performance in the wall.
- We have no installation standards that can be relied upon to deliver an air- and water-performing interface at least equal to the performance of the window.
- We are using newly developed building products such sealants, coatings, membranes, and flashings, some of which we are uncertain as to their robustness (durability/serviceability) or compatibility with each other.
- Construction sequencing: Skilled labor, currently in short supply, is required to correctly interface the flashing, membrane, fenestration, sealants, and cladding to form a unitized envelope system. Coordination and identification of the responsibilities of all the trades installing materials involved in a fenestration opening are not standardized.
- The service life of a window is substantially shorter than that of the wall it is installed into, yet current installation practices install them permanently into the wall, requiring destructive removal and resulting in incorrect integration of the replacement product with the wall components.
- Today's new materials in yesterday's technology results in failure.

We now follow two problematic building situations with regard to fenestration, each of which has a modern solution. One looks at drainage wall construction and the other looks at barrier wall construction.

DRAINAGE WALLS

A drainage wall incorporates a water-impervious material under a cladding, such as a housewrap membrane. The drainage plane is designed to shed incidental water from the wall cavity and to deliver that incidental water to the exterior of the building. The interface between the window and the wall is critical to the system's ability to perform. See Figure 1[9].

This drainage wall installation is intended to join the fenestration product with the water-resistant membrane to become a single integrated envelope unit. When a pan system is employed under the fenestration to capture incidental water, that pan interrupts the completion of the seal across the bottom of the fenestration, thus causing an area of air infiltration, which requires additional attention to make an air seal.

It is recently required to use a water-resistive membrane over the exterior of sheathing in most areas of the United States. What needs to be clarified is whether the drainage

9. ASTM E 2112-01, Figure 19 Water-Resistive Barrier (WRB) Application (Methods A and B)

membrane is also an air barrier, and if so, how it affects what we do we with the through-wall cavity.

Twentieth century fenestration products are manufactured with their own built-in frame. We keep trying to figure out how to insert this complete window product into a building and integrate it into the building envelope. To accomplish this, we have created nailing fins, both integral and non-integral; brick molding; a variety of casings, moldings; flashings; sealant; and any number of techniques, all of which seem not be able to integrate the fenestration product properly with the wall and not leak. There are so many installation steps that the fenestration becomes literally buried in the wall and when it is time to replace the fenestration product, the task usually requires the removal of the cladding and destruction of any interface system employed to attempt to keep liquid water from reaching the interior.

Most of these current techniques should be abandoned. Should we go back in time and build frames into the wall and add sash later? No; because of today's scheduling and job sequencing, it would not be possible to build today's fenestration frames into the wall. But could there be a fixture that integrates on four sides of the opening with the water-resistive barrier, completely closes the cavity to weather infiltration, and also has the ability to integrate with vapor barriers and air barriers? Yes. This fixture could easily be a receptacle that can receive a fenestration product, thus isolating the fenestration in an area not integrated with the buildings water management system, but simply allowing it to function as a unit if and when incidental water leakage occurred that leakage would be captured by the fixture and simply drained to the exterior of the cladding. There is no good reason to bury a fenestration product in a wall as is currently the practice. Fenestration should be easy to replace without destruction of the existing wall and interfaces, with a difficulty factor equivalent to other known short lifetime products such as water heaters, roofs, etc.

TESTING OF DRAINAGE WALLS

In the 1980s the California Association of Window Manufacturers built a series of typical stucco-clad wooden walls which contained horizontal sliding glass windows. They were erected in Fresno, California at Architectural Testing, Inc.[10] These walls were built using all known instruction techniques from other organizations such as SMACNA[11] for flashing instructions and a California Lath and Plaster Institute. Note that at this time there were no instructions on fenestration installation available from any organization. Once the walls were erected and the windows were installed using several different techniques commonly used by window installers, the walls were tested for air and water infiltration by ASTM E 283 and E 331. The testing revealed that there was water penetration around the interfaces for some of the techniques that were employed. Further investigations showed that some of the flashing was reverse-shingled, even though an experienced plaster-and-lath contractor was hired to do the installation. Water also entered the interior through unsealed lapping of building paper and holes introduced by the lath installation. It became apparent that known technologies of installation were inadequate.

During the late 1990s AAMA, in coordination with the development of InstallationMasters™ fenestration installation training program, ran a series of membrane interface testing of walls containing windows, at ATI in York, PA. This series of tests was to verify the techniques that were being developed at the time by ASTM in E06.51.11, which became part of E 2112. During this series of tests, it became evident that workmanship was crucial to the success of any installation. In conclusion of testing conducted on drainage wall systems, it becomes apparent that workman's skill and the careful following of procedures is critical to a successful interface installation.

New Thinking

From lessons of the past we have determined that successful interface installation can only be achieved by careful attention to details which have been proven to work when installed by qualified, skilled craftsman familiar with these techniques. We have learned that new products such as self-adhered flashing can bring their own set of problems if installed with incompatible materials or against surfaces that are moist or dirty or beyond the safe temperature range of the adhesive. The question is, should we continue to develop these interface techniques, or should we abandon them and go back to the principle of building in a waterproof receptor into the wall, which could easily be integrated with the water-resistive membrane, contain the fenestration in both air and water leakage and simultaneously close the fenestration cavity and allow it to seal to vapor and air barriers where used on the interior.

The photographs in Figure 2 depict the testing of a prototype system which employes a 4-sided receptacle that is easily integrated with a waterproof membrane. In this case the claddings were part of an EIFS system; however, the same technology can be utilized for any cladding over a waterproof membrane. Figure 3 is an exploded view of a receptor installation into a wall. The photographs below were of testing of the complete wall assembly including the receptor and window, completed at ETC Laboratories in 2005, where the system was tested using ASTM E 283 for air, ASTM E 331 for water, and ASTM E 330 for structural.

The values tested were:

- ASTM E 330 Test Method for Evaluation of Structural Performance – The combined wall and fenestration products achieved a 45 psf positive and negative using a fenestration product that was rated at 25 psf.
- ASTM E 331 Test Method for Static Water Penetration - The combined wall and fenestration products achieved 12 psf for 15 minutes.

10. Headquartered in York, PA

11. Sheet Metal and Air Conditioning Contractors National Association, Chantilly, VA; Architectural Sheet Metal Manual

- ASTM E 289 Air Infiltration - Both combined wall/fenestration products measured 0.03 cfm per square foot (54 sq. ft. samples).

MASONRY BARRIER WALLS

Masonry barrier walls, though the most prevalent wall construction since early times, brings us a whole new set of problems today. Drainage walls, as mentioned earlier, are actually a rather new building technique by comparison.

The hurricane season of 2004, where Florida received four Cat 3+ hurricanes, brought an awareness of the effects of material changes that had been made with no consideration to compatibility to the rest of the system; changes in cementitious chemistries and the replacement of painted surfaces with pigmented stucco have changed the way walls react in heavy weather, especially being saturated over a long period. Some of these same changes would have had a different effect in a colder climate zone, where heating is the primary interior conditioning. This author conducted a study on masonry walls in Florida in 2005, after the recent set of storms in the southeast United States. At first glance it seemed that buildings that had been built several decades ago seemed to fare better against moisture intrusion than those being built today. Upon further investigation it became evident that the older buildings, simply stated, had been painted, usually with many layers of paint, which acted as a surface barrier to shed liquid water from the outside surface, and diverted exterior water away from the walls. This observation was also made by Dr. Joseph Lstiburek in his report to the Home Builders Association of Metro Orlando in conjunction with the Florida Home Builders Association (Lstiburek 2004).

Figure 2 *Testing of four-sided receptacle integrated with a waterproof membrane.*

In this author's survey of tracts of new homes in various price ranges located in many different locations on the west coast of Florida, although there was a plethora of problems in new home construction, window leakage prevailed as the largest problem.

In zeroing in on the older buildings' better performance, one could point to the usefulness of the paint; however, initial painting of new residences in Florida is not now common practice, but even if it were, the question is, what does it cost to paint your house every year in order to maintain a water resistive coating on the stucco? Isn't it easier and more cost effective to waterproof the block underneath the stucco – making

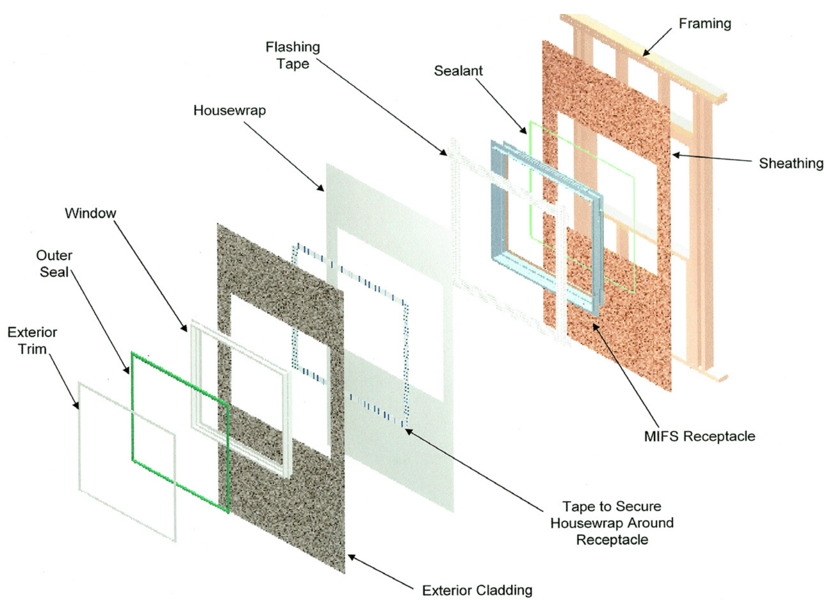

Figure 3 *Modular insert fenestration system.*

(a) (b) (c)

Figure 4 *CMU block, wood bucks, concrete sill.*

Table 1. Air/Water Testing on Unit B

Condition	Width	Height	Tare	Total	Net	Rate
Unit B	in.	in.	scfm	scfm	scfm	scfm/ft^2
With Window	38	54	28.41	38.5	10.09	0.708

the water management less dependent on the exterior surface, which gets all the exposure and wear?

In the southeast USA the lower level of a home is typically CMU block with no lath or any type of water-resistive membrane. The CMU is coated with a one-coat stucco system containing a color pigment that matches the color of the stucco on the upper floors. According to ASTM C 926, the thickness of the stucco should be at least 1/2-inch. However, when surveyed, most directly applied stucco finishes were found to be less than 1/2 inch, typically 3/8 inch or less.

This brings us to the fenestration installed on the bottom floor. See Figure 4, 4a through 4c. Fenestration which is installed into CMU block is placed into a masonry opening which contains a concrete sill (Figure 4a and 4c). The two sides and the top of the masonry opening are fitted with treated wood bucks (Figure 4a), where sealant has been placed on the underside of the treated wood bucks before attachment to the CMU wall (Figure 4b). Once the two jamb bucks are installed on top of the concrete sill, a frontal-flanged window is placed against the bucks and the concrete sill. Sealant has been placed against the interior of the frontal flange. Then the fenestration is placed into the buck-sill combination (Figure 4c). After this process has been completed, the one-coat stucco system is applied to the CMU and returned into the fenestration cavity, including coating the concrete sill. This installation, after the 4-storm 2004 season in Florida, was found to fail to keep liquid water from penetrating the wall.

MODELING OF MASONRY BARRIER WALL (CMU WITH STUCCO)

Modeling[12] was done of a CMU block wall as typically built in the southeast. The modeling was performed using the Miami climate zone, with various thicknesses of stucco, using WUFI 2D (two-dimensional). Modeling of this type of wall was extremely difficult, as it is complicated by the voids of the CMU, a variety of capillary sizes, and the porosities of various materials. Conclusion was that lime-based stucco acted in unison with CMU when directly applied. Both block and stucco absorbed liquid water and became fully saturated, drying as one to both the exterior and to the interior of the building. Modeling of this wall in Miami in the summertime demonstrated that this combination seldom dried out thoroughly.

TESTING OF MASONRY BARRIER WALLS

To observe paths of water leakage in the overall wall-window system, air tests[13] and water tests [14] were conducted[15] on mock-up walls that were constructed of CMU block with

12. Achilles Karagiozis, Ph.D., Senior Research Engineer, Hygrothermal Project Manager, Oak Ridge National Laboratories
13. ASTM E 283 Standard Test Method for Determining Rate of Air Leakage Through Exterior Windows, Curtain Walls, and Doors Under Specified Pressure Differences Across the Specimen
14. ASTM E 331 Standard Test Method for Water Penetration of Exterior Windows, Skylights, Doors, and Curtain Walls by Uniform Static Air Pressure Difference
15. ETC Laboratories, Rochester, NY, November 2006 - January 2007

Figure 5 *Interior view of saturated CMU.*

no stucco coat. Windows were installed per Florida building code. See Figure 5.

It became immediately evident that water easily penetrated the CMU wall through the CMU itself and under sealant joints and through mortar joints. See Figure 2. It was determined that sealant directly applied to CMU was totally ineffective in sealing joinery, as water simply transferred under the sealant surface, through the CMU, and into the interior.

A spray rack was placed on the exterior of the wall in accordance with ASTM E 331. The wetting pattern seen in Figure 5 shows 100 percent saturation of the CMU block on the interior. The pattern of wetting mimics the outline of the chamber that was placed on the interior. The test was stopped after 5 minutes of a usually 20-minute test because the water pouring through the CMU was uncontrolled. Cracks in the mortar and the concrete sill displayed water leakage within 5 seconds of the administration of the water on the exterior, and before any negative pressure was applied to the chamber.

The specimen was tested at DP 60 for water; the specimen had significant water infiltration, so testing was stopped after just one cycle.

It is unlikely that builders will start painting the exterior in an effort to seal the building. However, even a well sealed exterior stucco coating cannot hold out water through the inevitable cracks and leaks through seams in the stucco. This exterior surface, which is exposed to the harsh elements, cannot be depended on as the sole means to resist water penetration. New systems must be developed to deliver water management to the CMU wall before it receives the fenestration. When CMU is not coated or sealed, sealant, no matter what the quality or quantity, is useless; therefore all areas that are going to have sealant applied must have been previously coated with a waterproof coating.

Testing also revealed that the concrete sills typically used in Florida also leaked, both through inherent cracks in the product and at masonry joinery. This is especially true when two or more concrete sills are joined with mortar to fill longer expanses The concrete sill as currently utilized was inadequate, primarily because of its inability to keep liquid water from passing through cracks within the product. In job site inspections, mortar shrinkage and cracking were often observed as water pathways.

It was the conclusion of the author that the use of a concrete sill in mortar was an ineffective way to waterproof a masonry opening.

New Thinking

From the tests described above and the results seen in Figure 5, which investigated the various pathways of leakage and the weakness in the current system, a new and revised mock-up wall was built, which incorporated principles not currently utilized in the southeast United States.

- The CMU block wall was coated 9 inches around the exterior face of the fenestration opening and into the wall cavity, to the rear of the opening (Figure 6a). Two different brands of CMU wall sealer were utilized. One was a straight sealer that did not provide for the further application of stucco to the wall. The second was a sealer that contained a cemetitious mixture of Portland cement that could supply a base for adhesion of the stucco. Both products worked equally well in sealing the opening.
- The concrete sill was replaced with a new sill made from a polymer formulation and of a similar profile to the concrete sill. This new plastic sill incorporated a back dam and end (side) dams. In essence, the new plastic sill became a pan flashing and sill combination. This robust material is waterproof and crack-resistant, which eliminated the leakage paths observed with the concrete sill. With the inclusion of the end dams, the buck material was able to lap over and into the pan created by the new sill member.
- The bucks were installed per building codes; however, with the coating now applied to the inside of the CMU block opening, the sealant was able to bond between the buck to a sealed surface on the inside of the rough opening, thus eliminating a path of leakage. The purpose of this application was to stop liquid water from simply traveling under the sealant and through the capillaries of the CMU at the surface.
- All other conditions remained the same as in the first test.

The two above photo groupings, Figures 6 and 7, show the exterior of the wall, which has been coated 9 inches around the perimeter and into the cavity. Note the plastic sill and the preparation for the air and water tests.

Figure 8 shows the interior of the wall after undergoing both ASTM E 283 air test and E 331 water test. With the coatings and proper application of the sealer, along with the plastic sill, the air infiltration was 0.15 scfm, or none. The water test was conducted for 20 minutes at 9 pounds pressure. Note: no

(a) (b) (c)

Figure 6 *Sealers in openings, plastic.*

Table 2. Air/Water Testing on Unit A—Before Thermal Testing

Condition Unit A	Width in.	Height in.	Tare scfm	Total scfm	Net scfm	Rate scfm/ft^2
Without Window	38	53	31.93	32.08	0.15	0.011
With Window	38	53	31.93	33.77	1.84	0.132

water leakage occurred around the interior perimeter of the window, either through the lintel or under the sill.

With the window specimen completely sealed with plastic the specimen passed 24-minute water tests at DP 55. With the window installed in the in-situ condition, the specimen passed 24-minute water tests at DP 55 for 3 cycles and at DP 60 for 1 cycle.

DISCUSSION

For this series of tests, it is noteworthy that both the fenestration and walls were tested together as a unit. The values depict measurements including the interface and 9 inches surrounding the exterior face of the wall around the window and the wall cavity. Typically, window manufacturers would have tested their windows as standalone, and the wall and its surround would not have been tested. Therefore, the performance of the interface and surrounding wall would have remained unknown. ASTM's E 330 structural testing, E 331 water testing, and E 283 air testing are all current tests that window manufacturers use to qualify their windows for the AAMA rating system. In the future, the walls should be rated to at least the same ranking as the window. Window manufacturers should be encouraged to continue testing their products standalone, so that they may understand the nuances and physics of their products. To this author, this information is only useful to the manufacturer of the window. The specifier, builder, or developer should demand testing that proves an entire window/wall system. It would not be feasible to test every project, but it is feasible to test in CMU walls, stick-built wood framing in stucco, and other common wall types that contain claddings. The claddings should not be relied upon completely to prevent air infiltration or water leakage, as some claddings will leak air and water at a greater degree than others. The question is, can the wall as a system work well?

CONCLUSION

Modern materials with past installation techniques typically do not work. If you replace a surface barrier application such as paint with a pigmented stucco coating, somewhere the waterproofing capabilities of each should have been compared. If sealant of high quality and great quantity is utilized to seal various building components such as fenestrations, scuppers, and vents, the surfaces on both sides of the sealed joint need to be of a waterproof coating that allows the sealant to function as designed. It is utterly useless to put sealant on a porous surface such as stucco or CMU and expect an applied feature such as a window or vent to be watertight, when the water will simply go through the surrounding porous wall and bypass the sealant. Developers, architects, and fenestration manufacturers should join together to develop a series of as-built in-wall fenestration interface applications that can be rated. Testing revealed that when typical construction products such as cast concrete sills are replaced with modern polymer materials that have been specifically designed to shed water and integrate with the masonry opening, there was significant improvement in the performance of the overall wall-window interface. Further, when traditional shiplap flashing was replaced with a receptor system that could integrate to the water-resistive membrane and isolate the fenestration by acting as a 4-sided panning system, the water management of the walls was greatly improved. Further to this concept was the closing of the inner cavity and for the first

Figure 7 *Performing tare test on wall and chamber; spray rack.*

Figure 8 *Interior wall after testing.*

time, providing a surface that could be attached to on the interior for an air and vapor barrier.

New systems based on these concepts should be developed, as modern products emerge, especially with the influx of new materials that have entirely different material properties from the materials they are replacing. For example, vinyl wallpaper is not just wallpaper; it is an impervious air barrier. Claddings leak, whether there are small cracks in stucco or vinyl shiplap materials which have bowed on a warm day. Paint can be formulated so that the perm rate of the material can be identified. Further study is needed on selection criteria for high-perm and low-perm paints and where they should be used.

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