



Standard Guide for Evaluating Water Leakage of Building Walls¹

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1. Scope

1.1 This guide describes methods for determining and evaluating causes of water leakage of exterior walls. For this purpose, water penetration is considered leakage, and therefore problematic, if it exceeds the planned resistance or temporary retention and drainage capacity of the wall, is causing or is likely to cause premature deterioration of a building or its contents, or is adversely affecting the performance of other components. A wall is considered a system including its exterior and interior finishes, fenestration, structural components, and components for maintaining the building interior environment.

1.2 Investigative techniques discussed may be intrusive, disruptive, or destructive. It is the responsibility of the investigator to establish the limitations of use, to anticipate and advise of the destructive nature of some procedures, and to plan for patching and selective reconstruction as necessary.

1.3 *This practice does not purport to address all of the safety concerns, if any, associated with its use. Establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use. Awareness of safety and familiarity with safe procedures are particularly important for above-ground operations on the exterior of a building and destructive investigative procedures which typically are associated with the work described in this guide.*

2. Referenced Documents

2.1 ASTM Standards:²

C1601 Test Method for Field Determination of Water Penetration of Masonry Wall Surfaces

C1715 Test Method for Evaluation of Water Leakage Performance of Masonry Wall Drainage Systems

E331 Test Method for Water Penetration of Exterior Windows, Skylights, Doors, and Curtain Walls by Uniform Static Air Pressure Difference

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² For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

E547 Test Method for Water Penetration of Exterior Windows, Skylights, Doors, and Curtain Walls by Cyclic Static Air Pressure Difference

E631 Terminology of Building Constructions

E860 Practice for Examining And Preparing Items That Are Or May Become Involved In Criminal or Civil Litigation

E1105 Test Method for Field Determination of Water Penetration of Installed Exterior Windows, Skylights, Doors, and Curtain Walls, by Uniform or Cyclic Static Air Pressure Difference

E1188 Practice for Collection and Preservation of Information and Physical Items by a Technical Investigator

2.2 AAMA Standards:³

AAMA 501.2 Quality Assurance and Diagnostic Water Leakage Field Check of Installed Storefronts, Curtain Walls and Sloped Glazing Systems

AAMA 511 Voluntary Guideline for Forensic Water Penetration Testing of Fenestration Products, Article 4.2.1.3.1 Optional Sill Dam Test (This test method previously appeared in AAMA 502.)

3. Terminology

3.1 *Definitions*—Refer to Terminology E631.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *incidental water*—unplanned water infiltration that penetrates beyond the primary barrier and the flashing or secondary barrier system, of such limited volume that it can escape or evaporate without causing adverse consequences.

3.2.2 *water absorption*—a process in which a material takes in water through its pores and interstices and retains it wholly without transmission.

3.2.3 *water infiltration*—a process in which water passes through a material or between materials in a system and reaches a space that is not directly or intentionally exposed to the water source.

3.2.4 *water leakage*—water that is uncontrolled; exceeds the resistance, retention, or discharge capacity of the system; or causes subsequent damage or premature deterioration.

3.2.5 *water penetration*—a process in which water gains access into a material or system by passing through the surface exposed to the water source.

³ Available from American Architectural Manufacturers Association (AAMA), 1827 Walden Office Square, Suite 550, Schaumburg, IL 60173-4268, <http://www.aamanet.org>.

3.2.6 *water permeation*—a process in which water enters, flows, and spreads within and discharges from a material.

4. Significance and Use

4.1 This guide is intended to provide building professionals with a comprehensive methodology for evaluating water leakage through walls. It addresses the performance expectations and service history of a wall, the various components of a wall, and the interaction between these components and adjacent construction. It is not intended as a construction quality control procedure, nor as a preconstruction qualification procedure. It is intended for evaluating buildings that exhibit water leakage.

4.1.1 *Qualifications*—This guide requires the evaluator to possess a knowledge of basic physics and of construction and wall design principles and practices.

4.1.2 *Application*—The sequential activities described herein are intended to produce a complete and comprehensive evaluation program, but all activities may not be applicable or necessary for a particular evaluation program. It is the responsibility of the professional using this guide to determine the activities and sequence necessary to properly perform an appropriate leakage evaluation for a specific building.

4.1.3 *Preliminary Assessment*—A preliminary assessment may indicate that water leakage problems are limited to a specific element or portion of a wall. The preliminary assessment may also indicate that the wall is not the source of a leak even though it is perceived as such by the building occupant. The presence of water might result from a roofing problem, a condensation problem, a plumbing problem, operable windows or doors left opened or unlatched or some other condition not directly related to water leakage through the building wall and is outside the scope of this guide. The evaluation of causes may likewise be limited in scope, and the procedures recommended herein abridged according to the professional judgement of the evaluator. A statement stipulating the limits of the investigation should be included in the report.

4.1.4 *Expectations*—Expectations about the overall effectiveness of an evaluation program must be reasonable and in proportion to a defined scope of work and the effort and resources applied to the task. The objective is to be as comprehensive as possible within a defined scope of work. The methodology in this guide is intended to address intrinsic leakage behavior properties of a wall system, leading to conclusions that generally apply to similar locations on the building. Since every possible location is not included in an evaluation program, it is probable that every leak source will not be identified. Leakage sources that are localized and unique may remain and may require additional localized evaluation effort. The potential results and benefits of the evaluation program should not be over-represented.

4.2 This guide is not intended as a design guide or as a guide specification. Reference is made to design features of a wall only for the purpose of identifying items of interest for consideration in the evaluation process.

4.3 This guide does not address leakage through roofs, leakage below grade, or water that accumulates due to water vapor migration and condensation. It is not intended for use with structures designed to retain water, such as pools and fountains.

SYSTEMATIC APPROACH TO AN EVALUATION

5. Overview

5.1 The methodology presented in this guide is a systematic approach to evaluating wall leaks and is applicable to any wall system or material. It differs from other approaches that are material specific or component specific and which are basically adaptations of quality control procedures. The sequence of activities is intended to lead to an accumulation of information in an orderly and efficient manner, so that each step enhances and supplements the information gathered in the preceding step.

5.1.1 *Sequence of Activities*—The recommended sequence of activities, discussed in individual sections below, are:

- 5.1.1.1 Review of project documents.
- 5.1.1.2 Evaluation of design concept.
- 5.1.1.3 Determination of service history.
- 5.1.1.4 Inspection.
- 5.1.1.5 Investigative testing.
- 5.1.1.6 Analysis.
- 5.1.1.7 Report preparation.

5.1.2 The first four recommended activities, and their descriptions in the body of the guide, are: *6. Review of Project Documents*; *7. Evaluation of Design Concept*; *8. Determination of Service History*; and *9. Inspection*. These activities intentionally precede *10. Investigative Testing* because they facilitate a rational determination of the spectrum of conditions, and are the basis for a rational selection of investigative test locations and procedures.

5.2 The protocol in this guide is not based on conventional hypothesis testing and quantitative random sampling.⁴ The starting premise for the application of this guide is that the building is suspected or known to leak. The objective of this guide is qualitative, purposeful, and intended to address the question of why, how and to what extent a building leaks. A statement stipulating the limits of the investigation and the starting premise of the investigative program should be included in the report.

5.3 *Scope of Investigation*—It is not assumed or expected that all locations with similar design, construction and service characteristics will be currently performing in precisely the same manner. Likewise, it is not necessary to establish such in order to reach technically valid conclusions about why and how a building leaks. The evaluation of water leakage of building walls is a cognitive process in which technically valid conclusions are reached by the application of knowledge, experience and a rational methodology to determine the following:

- 5.3.1 The intrinsic properties of the wall.
- 5.3.2 The cause(s) and mechanism(s) of leakage.
- 5.3.3 The applicability of findings to similar un-inspected or un-tested locations on the building.
- 5.3.4 And, if within the scope of the evaluation, to acquire and report sufficient information to permit an assessment,

⁴ Houghton, L.L., and Murphy, C.R., “Qualitative Sampling of the Building Envelope for Water Leakage,” *Journal of ASTM International*, Vol 4, No. 9, paper ID JAI100815, 2007.

within a reasonable degree of scientific certainty, of the likelihood of additional water leakage to occur arising from the conditions identified and the conclusions reached as a result of the evaluation.

5.4 Sampling—The recommended sampling method for the application of this guide is to consider the spectrum of wall conditions from apparently performing to apparently non-performing areas, and from un-deteriorated or un-damaged areas to deteriorated or damaged areas. It is also important to distinguish between varying conditions which may result from prior modifications or attempted repairs, and to determine the extent of sampling necessary to address and evaluate these variations in conditions.

5.5 Analysis and Interpretation—The information systematically gathered during a leakage evaluation is analyzed as it is acquired. The sequential activities described in this guide are not intended to imply that analysis and interpretation of the information occurs only at the completion of all activities.

6. Review of Project Documents

6.1 Ideally, project documents including wall component shop drawings will be available and accessible for review. The discussion in this section assumes that a project was organized on a conventional Owner/Architect/Contractor model. Building projects can be delivered in a variety of ways, and the actual method used will dictate the appropriate organization of the project documents. Regardless of how a project is organized and administered, the information discussed below should be available for review somewhere in the project documents.

6.1.1 Design, Bidding, and Contract Documents—These documents include architectural and engineering drawings and specifications and may also include calculations, wind tunnel reports, correspondence, meeting minutes, addenda, substitution proposals, product literature, test reports, etc. They contain the information necessary to understand the performance criteria, the design intent, the required materials, and relationships among wall components.

6.1.1.1 Documents may be revised or supplemented over the course of construction. Revisions to drawings are typically recorded by number and date with a cross reference to other accompanying documents. Reviewing all revisions and issuances of the documents, and understanding the differences between them and the reason for the differences, is part of a comprehensive evaluation.

6.1.1.2 Documents with the most recent issue date and the highest revision number establish the requirements for the project. Ideally, a set of documents marked “as-built” or “record set” intended to show the actual construction will be available.

6.2 Referenced Codes and Standards—Project documents usually contain references to regulatory codes and industry standards. Standards and referenced codes often contain default or minimum criteria that might have been relied upon to establish the performance criteria for the wall. Conflicting requirements between referenced standards and codes, and those explicitly stated in the project documents, should not be assumed to be a cause of leakage without further investigation.

6.2.1 Regulatory codes and industry standards change over time. The version of regulatory codes and industry standards examined as part of the review of project documents should be those listed with dates in the project documents, or if not listed with dates, those in effect when the building permit was issued. Understanding the history and background of referenced codes and standards is part of a comprehensive evaluation.

6.3 Submittals—Additional documents are generated after the award of contracts and are submitted to the design professional for review and inclusion in the project record. The submittals usually apply to a specific material, component, assembly, or installation method; and the information contained will augment the project documents. There are often a number of revisions to submittals prior to final approval. The standard for the project is set by the submittals approved by the design professional. Submittals include some or all of the following: shop drawings, test reports, product literature, manufacturers’ recommendations, installation and maintenance guidelines, warranties, etc.

6.3.1 Test reports provided by manufacturers and suppliers should have been performed by an independent laboratory or witnessed by an independent agency. Review the test dates and the description of what was tested to determine if and how the information actually applies to the project.

6.3.2 Manufacturers’ and suppliers’ information, and the exclusionary language in warranties, may suggest circumstances under which a component may not function properly. Project conditions should be evaluated to determine if an appropriate product selection was made.

6.3.3 Submittals should be reviewed for maintenance recommendations and guidelines.

6.4 Pre-Qualification and Mock-Up Reports—Compliance with project requirements may have been demonstrated by a mock-up test. Mock-ups of complex wall systems rarely pass all tests on the first attempt. The mock-up report should contain a clear and complete description of changes necessary to pass the test. Project documents should incorporate these changes, and they should be reflected in the actual construction. Failure to incorporate these changes should be considered as a possible cause of water leakage.

6.5 Additional Construction Documents—Additional construction documents that record changes, decisions, and activities during the construction phase may include bulletins, requests of information (RFI), clarifications, change orders, directives, progress photos, inspection and quality assurance reports, test reports, meeting minutes, and correspondence. The information in these documents may augment, modify, or supersede the design documents.

6.6 Local Practices—Knowledge of local and historical practices will permit a more thorough assessment of the project design and construction. The actual construction may be influenced in an undocumented manner by local practices.

6.7 Missing Documents—Project documents may be unavailable or have missing parts. This unfortunate situation will require the determination of existing and as-built conditions. Rather than verifying the information in the project documents, the information may need to be generated from observations and measurements of the building.

7. Evaluation of Design Concept

7.1 *Performance Criteria*—Review of the project documents should reveal what, if any, water resistance performance requirements were specified for the wall. The required water infiltration resistance for manufactured wall components such as windows and curtain walls, expressed as a differential test pressure across the wall to simulate the action of wind-driven rain, is usually stated explicitly in the contract documents. Alternatively, the required resistance may have been implied through references to industry standards or local codes.

7.2 *Efficacy of the Design*—The wall design must be consistent with the performance criteria so that the desired performance can actually be achieved. The design must include properly selected components. The details must provide for the interfacing and integration of components so that each one can perform individually and so that the components can perform collectively as a system. The details must also address issues such as construction tolerances, material compatibilities, volume changes, and movements. A careful evaluation of the efficacy of the design relative to the performance criteria will indicate inconsistencies that may contribute to leakage.

7.2.1 The failure of a single wall component to perform at the specified level does not automatically mean that it was the cause of leakage, particularly if the performance requirements for the component were unnecessarily severe relative to other components. In evaluating the overall wall, it must not be assumed that the cause of leakage is a single component simply because it does not satisfy a performance requirement in the project documents.

7.3 *Exposure*—The performance criteria in the project documents will generally differ from actual exposure conditions. Based on an analysis of local weather conditions, and the location and geometry of the building, identify the actual weather conditions during periods of leakage. These conditions can be correlated with the service history, described in the next section, to help establish a protocol for the evaluation process.

8. Determination of Service History

8.1 Gathering information on the service history related to leakage problems serves several purposes. First, patterns in the observed leakage and visible damage can provide an indication of the cause(s) and where to focus an investigation. Second, and more importantly, the information provides a checklist against which failure theories and conclusions can be evaluated. A comprehensive diagnostic program should result in an explanation for most if not all aspects of the observed leaks and damage.

8.1.1 *Document Physical Symptoms of Leaks:*

8.1.1.1 Make a detailed visual inspection of both the exterior and interior wall surfaces. Locations that should be checked for indications of leakage include but are not limited to:

- (1) Intersection of walls with floors and ceilings.
- (2) Window, door, vent, and louver openings; particularly at corners and mullioned joints between units.
- (3) Handrail connections.
- (4) Intersection of walls with exterior balconies. Balcony features that can contribute to leakage problems are little or no slope away from the wall, absence of a curb under the wall and door, little or no slope to drain grates or scuppers, or handrail base which obstructs drainage.
- (5) Utility and building services penetrations.
- (6) Below setbacks, where an exterior wall on one floor is above an interior space of the floor below.
- (7) Intersection of an exterior wall and a roof plane.

8.1.1.2 Note all indications of past and existing water damage including, but not limited to, the following:

- (1) Wet, damp, or water-saturated surfaces.
- (2) Color differences caused by organic growth, staining, or corrosion.
- (3) Surface deposits associated with recrystallization of dissolved materials from within the walls. In masonry construction this is commonly called efflorescence, but it can also occur in other wall types.
- (4) Staining indicating the flow or accumulation of water.
- (5) Areas repaired or patched due to prior leakage.
- (6) Blistering surface finishes that can indicate subsurface wetting.

8.2 *Interviews*—Interview occupants, maintenance personnel, subcontractors, tradesmen, or other first-hand observers. Obtain information that will help correlate leakage with building features and other events, such as:

- 8.2.1 The apparent origination point of a leak.
- 8.2.2 The exterior environmental conditions under which the leak occurs.
- 8.2.3 The frequency of occurrence. Is the leak a one-time occurrence under exceptional or extreme conditions, or is it a recurring problem? When was the leak first observed?
- 8.2.4 For leaks that occur during rains, ascertain if a leak:
 - 8.2.4.1 Occurs immediately after the onset of rain or after a period of time.
 - 8.2.4.2 Stops immediately when the rain stops or continues for a period of time after the rain ends.
 - 8.2.4.3 Occurs during every rain regardless of severity.
 - 8.2.4.4 Occurs during every, rain regardless of wind direction, or only with wind from a certain directions.

8.2.5 Whether the leak occurs during or immediately after cold weather, with or without accompanying rain. If a leak occurs during cold weather without accompanying rain, it might be due to condensation rather than rain infiltration.

8.2.6 The interior environmental conditions and the building operating conditions under which the leak occurs. Weekend and evening operating conditions may differ from weekday business hour conditions.

8.2.7 Whether the leak appears to be related only to a particular feature or detail.

8.2.8 The performance of the building piping system, including water supply and drainage, heating and air conditioning supply and return, and roof drains. Leaks from the piping system might be misinterpreted as wall leakage.

8.3 *Maintenance and Repair Records*—Buildings with chronic leakage problems are often subjected to several attempts at remediation before a comprehensive evaluation is made. An effort should be made to understand the earlier attempts at repairs because: (1) they may indicate a pattern of leakage; (2) although well-intended, repairs may be causing or contributing to current leakage; and (3) it will be necessary to distinguish between original construction and attempted repairs during the inspection and testing phases of a systematic evaluation. Where appropriate and possible:

8.3.1 Review the original project close-out comments or “punch list” if available. Water infiltration problems often occur early in a building’s life, and stop-gap repairs might have been made in an effort to close out the project.

8.3.2 Review purchase orders or contracts, or both, for building maintenance and repair. Consider roofing, caulking and sealants, painting, waterproofing, removing efflorescence or staining, and other activities that may relate to water leakage problems.

8.3.3 Review maintenance work orders that deal repeatedly with the same leakage problem.

8.3.4 Evaluate the success of previous repair attempts.

8.3.5 Compare original details to actual conditions observed to determine deviations from original construction intent or undocumented repair attempts.

8.3.6 Identify repairs that inadvertently seal weep holes or other openings and paths which are intended to dissipate or weep entrapped water. These might have been sealed in an attempt to stop leaks.

8.3.7 *Interpretation*—Information gathered while determining the service history of a building must be interpreted by the evaluator. The information is usually gathered from occupants or personnel who are not trained or experienced in leakage evaluations. While their observations may be useful and important, the actual presence or absence of a leak and their interpretation of the observations must be considered by the evaluator. For example, water dripping from a window head might have been interpreted and reported by occupants as a window leak when in fact the infiltration occurred elsewhere in the wall. Evidence of leakage might be observed by the evaluator at locations where an occupant has not observed or reported a leak.

8.3.8 Evaluate the effect of attempted repairs on the original design intent. Common but often ineffective repairs made to

leaking walls include the application of additional sealant and coating of exterior surfaces with clear water repellents or elastomeric coatings. Inappropriate use of these procedures can cause additional problems, for example:

8.3.8.1 Sealant installed at weep holes and other drainage paths can entrap water within the wall assembly. The application of additional sealant should not be made prior to evaluation of the total wall assembly except to correct obvious omissions.

8.3.8.2 Water repellents can affect the performances of future repairs, such as the adhesion of sealants or the bond of repointing mortar. These materials can also reduce the water vapor transmission rate of a wall assembly.

8.3.8.3 Low permeance coatings will reduce the water vapor transmission rate of the wall assembly and can increase the time required for water-saturated walls to dry. The application of these materials can increase the amount of entrapped water if any other uncorrected deficiencies exist.

8.4 *Determine Extent of Leakage*—Use the information gained above to determine the extent of leakage.

8.4.1 Attempt to correlate historical leak occurrences with particular building features and details.

8.4.2 A graphical analysis is useful for correlation studies. Leak occurrences can be superimposed on building drawings to help reveal patterns that might be traceable to potential leak sources.

8.4.3 Consider wall components that might act as conduits or channels for infiltrated water, such as furring strips, board joints, shelf angles, etc. They can cause interior manifestations of a leak to occur at a distance from the exterior points of entry.

8.5 *Weather Records for the Vicinity*

8.5.1 Detailed weather data for a specific time period, typically recorded at major airports, can be obtained from the National Weather Service. The data of particular interest for a leakage evaluation are: precipitation rate, wind speed during precipitation, wind direction, and relative humidity.

8.5.2 Unusual events and severe leakage occurrences should be correlated and may require additional weather data for specific times.

8.6 *Correlations*—Correlate leak occurrence with other factors such as temperature, wind direction and speed, season of year, and building operations.

8.6.1 *Temperature*—Ambient air temperature and wall surface temperature can effect water leakage. Building joints and material cracks are most likely at their widest when ambient temperatures are low and at their narrowest when surface temperatures are high.

8.6.2 *Wind Direction and Speed*—A primary driving force for water leakage of walls is wind-driven rain. The severity and location of leakage can often be correlated to the direction and speed of the wind.

8.6.3 *Season of Year*—Some buildings in northern climates only leak during the winter months. The accumulation of ice and snow on horizontal surfaces can feed water into a wall assembly during clear cold sunny days even when the outside temperature stays below freezing.

8.6.4 *Building Operations*—Although most building HVAC systems operate at a positive pressure, parts of the building

could be subjected to negative interior pressures when exposed to certain wind conditions. Negative interior pressure might also result from the “stack effect” due to the difference between interior and exterior temperatures. Portions of a wall might also communicate with return air plenums that are operated at a negative pressure. Negative interior pressure can allow water to enter walls through small openings that might otherwise resist leakage. Building operating pressures are usually very small compared to the effect of wind and are rarely the sole cause of leakage in occupied spaces. However, in the vicinity of louvers and equipment spaces, mechanically induced pressures can be significant.

9. Inspection

9.1 Inspections complement and extend the information gathered from the review of project documents and the service history. The major objectives of an inspection program are: to determine as-built conditions, to determine the current condition of the wall including visible and concealed water damage and apparent water paths, and to formulate initial hypotheses about cause.

9.2 *Determine As-Built Conditions*—The various components of the wall system, including the structural support system, utilities within the wall, thermal and condensation control systems, and the finishes, should all work together to provide the desired wall performance. Project drawings rarely depict the relationship between all of these components of a wall completely and accurately. The inspection process should result in a clear understanding of the relationship between all the parts of a wall system.

9.2.1 *Presentation*—Composite large-scale drawings are helpful in gathering and recording information about as-built conditions. A composite drawing can begin with the best available information from the project documents, including pertinent information from the architectural, structural, mechanical and electrical drawings, and specifications, as well as the structural and wall component shop drawings. The investigator must correlate information from these sources based on some reference such as the column centerlines or face-of-wall dimensions. The composite drawing can serve as a form for recording actual field conditions. Differences between information in the project documents and the as-built conditions should be anticipated, and discovery of differences does not necessarily mean that a leak source has been identified. The purpose of accurately determining the as-built condition is to provide a rational basis for further inspection, testing, and remedial recommendations.

9.3 *Determine Current Conditions*—The physical condition of wall components, and visible and concealed evidence of water infiltration, should be documented during the inspection process. This information is later correlated with information from the service history of the wall in formulating a hypothesis on the cause(s) of leakage. Examples of information that should be documented include:

9.3.1 Placement, condition, and resilience of sealants and gaskets.

9.3.2 Functional aspects of drainage systems, such as end dams, weeps, lap and splice configurations, placement of the flashing relative to other components, and obstructions.

9.3.3 Interfaces between wall components. Critical interfaces include the integration of walls and windows, locations where wall materials or support conditions change, and where prefabricated units of the wall are joined.

9.3.4 Interface with other building components, such as copings, penetrations by mechanical equipment or structural supports, and foundations.

9.3.5 Wall attachments and appurtenances such as signs and canopies, balconies, and handrails.

9.3.6 Location and size of drip grooves or drip edges at the underside of horizontal surfaces.

9.3.7 Other possible mechanisms for water entry into a wall or migration within a wall, such as capillary action or air movements causing percolation.

9.3.8 Material conditions, including symptoms of deterioration, freeze-thaw damage, prolonged saturation, delaminations, adhesive or cohesive material failures, efflorescence, and water-related damage to finishes.

9.3.9 Indications of wear and tear, maintenance, attempted repairs, damage from non-weather-related causes such as impacts, unaccommodated volume changes, or structural movements.

9.3.10 General assessment of workmanship and compliance with specified installation and execution as it affects water penetration.

9.4 *Determine Water Paths*—Inspections produce information on water paths resulting from the service conditions of the building. The significance of water paths that are induced during testing can not be properly evaluated without information about water paths from service conditions.

9.5 *Planning*—Inspections conducted in a planned and orderly fashion are the most efficient and effective way to produce useful results. Planning is also necessary when concurrent sampling and testing are incorporated in the inspection program. The inspection plan should address the following issues:

9.5.1 *Scope*—Both typical and atypical conditions should be included. It is particularly important to include the terminations and interfaces of the components being inspected, such as corners, ends, tops, bottoms, joints, transitions to other materials, or changes in geometry. The inspection should also include both non-performing and properly performing locations, if any exist. The differences between non-performing and properly performing locations can provide useful information about the cause(s) of leaks. The objective of the inspection program is to acquire information about the intrinsic properties of the wall system so that conclusions reached are applicable to all similar locations in the wall. A sufficient number of inspection locations must be selected to accomplish this objective. If constraints on the inspection program preclude a sufficient number of locations, the results should be so qualified.

9.5.2 *Selection*—It is normally not necessary to inspect an entire building facade except in special situations such as where safety is an issue. The selection of inspection areas is based primarily on the service history, review of project documents and accessibility. The scope of the inspection should encompass the spectrum of relevant current conditions.

It may also be relevant to distinguish between areas where prior modifications or attempted repairs were made and areas which are original construction, and to determine the extent of inspection necessary for these conditions. Limitations of resources will often require the selection of inspection areas from seemingly equal choices. A preliminary inspection using rapid methods of limited detail can help in the rational selection of areas where more detailed methods are warranted.

9.5.3 Access—Both interior and exterior access for close-up inspection should be pre-arranged with the building owner. Interior access may require temporarily moving furniture, removing interior finish materials, or relocating or suspending the use of a space, and might have a significant temporary impact on use of the space. Exterior access will probably require the assistance of a contractor to erect scaffolding and walkway protection, provide a boom truck or rig a swing stage. Possible damage to the building resulting from the access equipment should also be considered, and either avoided or corrected.

9.5.4 Organizing Information—A comprehensive inspection will generate a large amount of data. Determining how the information will be recorded and organized is part of the planning process. Building drawings can be made beforehand and used to record observations, thereby making the location of the information self-evident. Symbols and shorthand notations can be developed and tabulated beforehand. It is sometimes useful to establish a numbering system based on column lines, swing stage drops, floor number, wall component within a typical module, etc., rather than repeating lengthy location identifications using words.

9.6 Methods—Inspection methods range from rapid visual inspections using binoculars or a telescope, to close-up observations and inspection openings. The evaluator determines the scope and number of inspection locations, the inspection methods utilized, and the sequence of inspection activities to provide the information required. Rapid methods are particularly useful for preliminary inspections and to narrow the scope of more detailed inspections. A comprehensive inspection program will include some method for observing or evaluating concealed conditions, such as inspection openings, borescope probes, moisture meters and detectors, mechanical penetrators, or infrared thermography scans.

9.6.1 Inspection openings involve the progressive removal of wall materials to reveal underlying, concealed conditions. Each layer may be changed or destroyed during the process, so it is desirable for the investigator to be present during the operation and to document each step. Possible safety issues such as the presence of asbestos, lead paint, and toxins must be considered and the necessary precautions taken.

9.6.2 An inspection mirror with an adjustable head and a flashlight, are useful tools for viewing concealed conditions through confined openings in much the same way that a dentist uses a mirror.

9.6.3 A fiber-optic borescope makes it possible to observe and photograph concealed conditions while making only a small diameter hole in the outer layers of a wall. It is most useful where there is an empty cavity space in the wall so the

light from the scope can disperse and the field of view can be targeted to items of interest.

9.6.4 Moisture detectors of the capacitance/impedance type and moisture meters of the resistance type make it possible to estimate the moisture content of concealed wall materials. High moisture content can indicate proximity to a water entry point or location along a water migration path. Plotting the measured relative moisture content on a grid superimposed on a building drawing can provide a diagram of wetted area resulting from leak. Care must be taken in interpreting the absolute values of readings reported by these instruments, since calibration and operating technique can affect the readings.

9.6.5 Mechanical penetrators provide an indication of the extent of deterioration caused by prolonged exposure to water by the way some materials, such as wood or gypsum board products, resist penetration by a sharp object. The tactile resistance to penetration decreases as deterioration of these materials increase. Any sharp object, such as a awl, ice pick, or nail can be used. Some commercially available devices have a calibrated spring that produces a consistent force at the tip of the penetrator.

9.6.6 Infrared thermography produces an image that, with proper interpretation, can indicate conditions such as air movements through a wall, concealed water within the wall, and saturated wall materials. Infrared thermography is a specialized technology and should be performed and interpreted with the assistance of a specialist knowledgeable in the technology.

9.7 Documentation—Inspection findings should be recorded in writing, with clarifying sketches where appropriate. The documentation should be supplemented graphically with photographs, video, or dictated notes, but these should not normally be relied upon as the sole record of the inspection process because of the risk of accidental erasure, undetected camera or recorder malfunctions or processing accidents.

9.7.1 Written documentation should be complete enough for the evaluation process to be repeated, as well as for the information gathered to be interpreted in determining the cause(s) of leaks. In addition to carefully recording observations, the following should be considered in making the written documentation:

9.7.1.1 The location of the observation should be clearly defined. References to column lines and floors can be used.

9.7.1.2 Preliminary opinions formed and interpretations made during the inspection should be recorded separately from the inspection notes and be distinct from observations of fact and measurements.

9.7.1.3 Keys for codified shorthand notations and symbols should be given. Undefined cryptic shorthand should be avoided.

9.7.1.4 If the procedure used is not self-evident, it should be described in detail.

9.7.1.5 The sequence of the inspection process should be clear from the written documentation.

9.7.1.6 The date, time, and name of the person(s) making the observation, should be recorded for each data sheet.

9.7.2 Supplementary photographs and video are useful for informing others of the inspection procedures and observations and provide an opportunity to reconsider or check findings at a later date. In making photographs or video recordings, the following should be considered:

9.7.2.1 It should be possible to orient the pictures. This may require a progression of photos from wide to narrow view or zooming from wide to narrow view with a video camera. Including something of known size in a photograph will help viewers determine the size of the object of interest. For example, a person or a piece of equipment such as a pocket knife can be used. For a more accurate reference, a ruler or an extended length of a carpenter's tape can be included in the picture.

9.7.2.2 The location of a picture should be identified. Labels in the picture, or markings directly on the wall, are useful for this purpose.

9.7.2.3 If the object of interest in a photograph is a crack or a split, it is helpful to add a pointer to focus attention or to insert a tool in the crack. Cracks with low contrast do not photograph well, and enhancing the path of a crack by drawing a line next to it in a contrasting color can also be helpful. It is also sometimes helpful to intentionally cast a shadow over a small or faint object of interest to reduce the overall contrast of a photograph.

9.7.2.4 Automatically recording a sequential number or the time and date on the film, or including the time and date in the photo label, may be helpful in organizing the pictures.

10. Investigative Testing

10.1 Testing can be an integral part of the evaluation process and should be thought of as a means to verify and extend hypotheses arrived at during the document review and inspection phases of the program using controlled and reproducible procedures. Implementing testing before completing the preceding steps in a systematic approach may significantly limit the potential benefits of the test, and more importantly, can lead to incorrect conclusions. At the very least, skipping the preceding steps will reduce the efficiency and effectiveness of on-site testing efforts. Some leakage problems can be diagnosed and corrected with little or no testing.

10.1.1 Objectives:

10.1.1.1 *Recreate Leaks*—The primary purpose of investigative testing is to recreate leaks that are known to occur. Investigative testing is not intended to demonstrate code compliance or compliance with project documents unless such deviations are actually related to the leakage problem.

10.1.1.2 *Trace Internal Path of the Leak*—Leakage paths within a wall are difficult to trace during a rain. Testing provides the opportunity to recreate the leakage and water migration paths under controlled and reproducible conditions. The paths observed during testing should be compared to evidence of water paths during actual leaks by assessing existing concealed staining, damage, and residue accumulation.

10.1.1.3 *Correlate Test Results with Observed Damage*—The test procedure should reproduce the observed in-service leakage behavior. Creating new leaks during a test may be

useful information, but it is not a valid assessment of the existing leakage problem.

10.1.1.4 *Verify Hypothesis*—The controlled conditions during a test are an opportunity to verify hypotheses about the cause of leakage. If a theory on the cause of a leak cannot be demonstrated by a reasonable and appropriate test, the theory is questionable. Remedial recommendations should not be based on unverified theories.

10.2 Planning:

10.2.1 *Service History*—The service history of the building and the environmental exposure history of the site must be considered in planning a testing program. To the extent practical, the selected test method should simulate the actual conditions under which leakage has been observed.

10.2.2 Investigative testing is a diagnostic procedure, not a quality assurance procedure. A distinction must be made between leak causation and compliance with design criteria. Focusing on the design criteria may interfere with the diagnostic objectives of testing. Testing at an environmental exposure level that the building has never experienced and has little likelihood of experiencing may lead to incorrect conclusions.

10.2.3 For diagnostic purposes, a wall should be tested in its current as-found condition if the cause of the current leaks is to be determined. Upgrading components of a wall to their original construction condition, or to their original design intent, so that they can “pass the test” and be exonerated prevents the acquisition of important information about current behavior. If original construction conditions or compliance with the original design intent are of interest, those tests can be performed separately after the diagnostic tests.

10.2.4 Previous remedial measures and modifications must be accounted for in the test plan. It may be desirable to undo modifications prior to or during testing to limit confusion, particularly if the modifications can be readily identified and have proven to be ineffective.

10.2.5 Both technical and non-technical constraints can affect the choice of a test method. Testing costs can vary significantly depending on the methods utilized. The evaluation budget and the agreed scope of work can be an important consideration. An owner may establish limitations on access due to cost, safety, security, or operational requirements and may require that disruption of normal building operations be limited.

10.2.6 If repeated modifications and retesting are anticipated, particularly for isolation protocols using selective masking or for the development of repairs, the selected test method must accommodate repeated access to the interior and exterior of the wall without compromising the reproducibility of the test. The selected test method should not require complete disassembly of the test setup for each cycle of access. Gasketed access doors and hatches, and adequate working space within a test chamber, can make repeated removal of the chamber unnecessary.

10.2.7 Diagnostic testing methods can be adapted from standard test methods such as Test Methods **E331**, **C1601**, and **E547** to meet specific objectives for a particular building and do not necessarily conform in every way to standard test

methods. Diagnostic testing can also be adapted from in-service quality assurance testing procedures such as Test Method [E1105](#) or diagnostic test procedures such as Test Method [C1715](#), [AAMA 501.2](#), and [AAMA 511](#). Therefore, agreement on testing methods and interpretation of results should be reached between the interested parties before testing begins. Items that should be addressed by the interested parties include:

10.2.7.1 Test criteria, methods, frequency, and location.

10.2.7.2 Participation of interested parties and opportunity for close-up examination of test location and test set up.

10.2.7.3 Innermost acceptable migration of water.

10.2.7.4 Documentation.

10.2.7.5 Effects of age and use/abuse.

10.2.8 *Testing Duration*—Judgement is needed in determining the duration of water testing, recognizing that the ultimate objective of diagnostic testing is to recreate existing leakage behavior that occurs under in-service conditions. Factors that may influence the test duration required to recreate leakage paths include wall construction details, the potential length of internal leakage paths, the absorption properties of exposed and concealed materials, and internal storage capacity. For example, water may leak more readily and more immediately through a glass and metal curtain wall system than through a thick, multi-wythe masonry wall. Testing durations specified for new construction quality control testing may not be sufficient for a leakage diagnosis if in-service leaks indicated by the service history cannot be recreated within that time. The investigator must analyze the building service history to establish a useful and realistic test duration.

10.3 *Methods and Equipment*—Testing under controlled and reproducible conditions to recreate leaks can be divided into two broad categories: (1) methods that simulate surface flow; and (2) methods that simulate wind-driven rain.

10.3.1 *Simulating Surface Flow*—Water flows down the face of a wall by gravity. This flow is capable of causing leaks under some circumstances even without wind-induced differential pressure. Surface flow can be simulated by wetting a wall area with a matrix of uniformly spaced spray nozzles that deposit a full film of water. The customary spray rate is between 4 and 10 gallons per square foot per hour, nominally averaging 5 gallons per square foot per hour, and is intended to deliver a continuous water film to the test area, rather than to simulate a particular rain event. Tests to simulate surface flow alone, without differential pressure, are a useful first test. Other methods of depositing a surface film of water for diagnosing leaks include soaker hoses or a trickle of water from an ordinary hose. Soaker hoses or a trickle of water have been particularly useful in diagnosing problems with drip edges and small overhangs.

10.3.2 *Simulating Wind-Driven Rain*—Wind-driven rain produces leaks because of the kinetic energy of the rain drops and the differential pressure caused by the wind. Under some wind conditions, rain water deposited on the face of a building may actually flow upward. Capillary action and absorption may also be operative.

10.3.2.1 The effect of differential air pressure on the leakage mechanism can be simulated with the use of a chamber capable

of being pressurized. The chamber is sealed to the wall test area, and a positive pressure is created by blowers if the chamber is on the exterior or a negative (vacuum) pressure is created if it is on the interior. A matrix of spray nozzles is used to deposit a uniform flow of water onto the exterior surface. The flow rate is customarily between 4 and 10 gallons per square foot per hour with a target average of 5 gallons per square foot per hour. Standard methods using differential pressure are Test Method [E1105](#), [AAMA 501.2](#), and [AAMA 511](#), each of which include calibration requirements for the water spray rack. The required pressure is differential, meaning the difference in pressure between the exterior and interior faces. The pressure measuring device, such as a manometer, should therefore be referenced in a similar manner to limit the effects of wind fluctuations or building operations during the test. The simple act of opening an interior door can have a significant effect on the actual differential pressure across the test area that a manometer will not register correctly unless the reference side of the manometer is properly located. If it is not practical to reference the manometer in a straightforward manner and there is concern that the manometer might not accurately measure the effective differential pressure across the test area, alternative methods may be used. For example, if exterior wind fluctuations are not significant, discrete measurements across the building facade in areas remote from the test area but otherwise judged to have equivalent exposure to the test area may be used to estimate the ambient conditions.

10.3.2.2 The effect of kinetic energy can be simulated by spray testing with a calibrated nozzle operating at a prescribed pressure at a specific distance from the test surface and moved at a specified sweep rate as described in [AAMA 501.2](#). This method is intended primarily for wall systems with non-operating joints, but it has also proven useful for other diagnostic purposes.

10.3.2.3 A hydrostatic head can be used to simulate differential pressure. A confined test area can be flooded, and the height of the water head correlated to a static differential pressure. Sill sections are often tested in this manner after the weeps are temporarily blocked, as described in [AAMA 501.2](#). Vertical surfaces can also be tested this way if a small trough is fabricated from wax, putty, or tape and adhered to the surface. Troughs are useful for localized testing of joints, cracks, gaskets, etc.

10.3.2.4 Spray testing using a calibrated nozzle, and flood testing, may not simulate all of the effects of differential pressure or the ability of air moving through cracks or openings to transport water by percolation.

10.3.3 Testing of isolated areas usually begins at the bottom of the test area and progresses vertically to the top as selective masking is removed or as selective testing with a calibrated nozzle advances. Starting at the bottom helps eliminate ambiguity about the origin of a leak that might result from water running vertically down the surface of the test area.

10.4 *Tracing Leaks*—Once testing reproduces an in-service leak, the entry point and the path followed by the water within and through the wall must be traced. A single entry point may lead to several concealed water paths or several entry points may merge together internally. Every contributory source to

each water path must be identified if a complete diagnosis and repair is to be developed. Tools that are useful for tracing leaks include:

- 10.4.1 Flashlight and mirror.
- 10.4.2 Optical Borescope.
- 10.4.3 Infrared thermography.
- 10.4.4 Paper strips or other absorbent materials that can be used to probe concealed spaces for indications of water.
- 10.4.5 Smoke pencil that can be used to expose air paths leading to water percolation.
- 10.4.6 Moisture meters.

10.5 *Isolation*—Effective diagnostic testing should result in the identification of entry points, not just a “pass or fail” result. Selective masking of the exterior is useful for controlling the components exposed to the test water source. If a leak is induced, only those components exposed to the water source need to be considered in identifying the entry points. Selective masking can then be progressively removed and the wall retested, exposing more and more of the wall to the test water source until the entire area of interest is exposed.

10.5.1 It may also be useful to temporarily repair a water entry source during a progressive testing program to eliminate it from further consideration during the test. Thorough record keeping and clearly identifiable temporary repairs are necessary if this technique is used.

10.5.2 Materials that are useful for selective masking and temporary selective repairs include duct tape, 6 mil clear plastic sheeting, wax, and silicone sealants. Drying with a heat gun or hair dryer, or wiping with alcohol, or priming with a spray adhesive may be necessary before attempting to adhere selective masking materials to wet surfaces. Sealants must be allowed to at least skin over or they can be washed away by further testing.

11. Analysis

11.1 The objectives of an evaluation program are broader than the objectives of a standard test. A test may have a pass/fail criteria for the result of a standardized test that is completely described by reference to its name and the relevant test standard. An evaluation is conducted in response to a problem situation and a non-performing wall and may involve several techniques and procedures specifically adapted and applied in a systematic manner to diagnose a specific problem.

11.2 The information systematically accumulated in a leakage evaluation is analyzed as it is acquired. The information may motivate a change in approach or focus for subsequent steps in the evaluation process.

11.3 The evaluator is expected to establish a cause and effect relationship between wall characteristics and observed leakage. This requires an appropriate selection of activities and a logical analysis and interpretation of the acquired information. The analysis will address issues such as:

- 11.3.1 Reduction of quantitative data and interpretation of qualitative data.
- 11.3.2 Resolution of conflicting data and observations.

11.3.3 Patterns and commonalities in the data and observations.

11.3.4 Identification and explanation of anomalies.

11.3.5 Correlation with known wall performance.

11.3.6 Significance of an observation or measurement and its relevance to the behavior of the entire facade.

11.3.7 Corroboration between various procedures used.

11.3.8 Limitations of the scope and constraints on the execution of the evaluation program that necessitate caveats or qualifiers for the application of the findings.

11.4 The conclusions and findings from an evaluation must be rationally based on the activities and procedures undertaken and the information acquired, if they are to be considered legitimate and substantiated.

11.5 The record should be sufficiently complete so that any interested party can duplicate the evaluation program and acquire similar information. Notes on the analysis and interpretation of the acquired information should be clear and complete enough to be understood by any other building professional skilled in leakage evaluation. Practices **E860** and **E1188** provide guidance on the collection, preservation, and evaluation of information, and are particularly relevant in situations which are or may become involved in litigation.

12. Report Preparation

12.1 Prepare a report describing the conditions under which the evaluation was conducted, the methodology used, the observations and measurements made, and the findings and conclusions. The report should be comprehensive so that it will serve as a permanent addition to the project record. Reports issued by the investigator should be prepared on paper with a letterhead, logo, or some other feature that will make it distinguishable from copies.

12.2 Use a writing style appropriate to the intended reader of the report, and also anticipate that the report may be reviewed by other building professionals.

12.3 *Organization of Report:*

12.3.1 Generally, a report of the evaluation should contain the following sections in the sequence listed:

12.3.1.1 Title page with mandatory information.

12.3.1.2 Executive summary.

12.3.1.3 Statement of objective or scope.

12.3.1.4 Description of evaluation process, with rationale for selection.

12.3.1.5 Analysis of acquired information.

12.3.1.6 Identification of cause(s) of leakage.

12.3.1.7 Distribution list.

12.3.2 Not all of the above headings may be required. Other more appropriate headings may be used, if they better describe the content and scope of work.

12.3.3 When the expected readership includes both construction professionals and laymen, a summary of background information, methodology, and findings in non-technical language may be useful.

12.4 *Title Page with Mandatory Information:*

12.4.1 *Title*—brief but definitive, including identification of the building.

12.4.2 *Author*—first name and surname, and any professional registration, included in a by-line for positive identification. This information may also be presented on a signature page at the end of the report.

12.4.3 *Date(s)* of evaluation and tests and date of report.

12.4.4 *Evaluating Agency* with mailing address.

12.4.5 *Sponsoring Agency* with mailing address.

12.5 *Executive Summary*—Provide a concise statement of the investigation findings and recommendations, for use by a reader who does not have the time or construction background to utilize the detailed information in the body of the report.

12.6 *Statement of Objective or Scope*—State the reason(s) for undertaking the evaluation and the scope of the evaluation, including limitations.

12.7 *Description of the Evaluation Process*—Describe the methodology used in the evaluation process. Where appropriate, put the steps in the evaluation process in context by giving a rationale that associates the steps with the objectives.

12.7.1 *Sources of Information*—List or describe the project documents, product literature, standards, reports by others, etc., reviewed in the course of the evaluation. Information generated by others that was relied upon in the evaluation should be clearly identified.

12.7.2 *Performance Criteria*—List specific performance criteria relevant to the evaluation, including wind loading, structural loading, deflection limits, temperature ranges. Any differences between the performance criteria used in the original design of the wall and criteria used for the evaluation must be clearly identified.

12.7.3 *Description of Design Intent*—Describe the specific methods, components, systems, etc. intended to resist water leakage. Identify items critical to performance of the wall system with respect to water leakage, such as method(s) to

accommodate volumetric changes and structural movements, material compatibility, pressurization, drainage, etc.

12.7.4 *Description of the Wall Components or System(s)*—Describe materials, primary components, dimensions, and include sketches or photographs, or both, as necessary. Describe the physical condition of the wall assembly, including damage, deterioration, normal wear, prior repair attempts.

12.7.5 *Service History*—Describe the known performance record of the wall system, including the physical symptoms of water leakage, progression of leakage behavior, maintenance and repair history, extent and locations of leakage, correlation of leaks with wind direction, building operations, season, etc.

12.7.6 *Inspection*—Describe methods used in inspection of the wall system, including access, equipment, and documentation.

12.7.7 *Testing*—Describe the tests performed, including access, equipment, sequence, and modification made to the test area. Include reference to industry standards for test methods and identify adaptation and modifications made to the standard test methods.

12.7.8 *Conformance with Design Intent*—Describe any observed variations in the as-built wall assembly from the design, including any apparent modifications or prior repairs to the wall. The discussion can be qualified and limited to differences that are relevant to the causes of leakage.

12.8 *Analysis of Acquired Information*—Describe the analysis of observations and measurements in a manner appropriate to the scope of the report.

12.9 *Identify Cause(s) of Leakage*—List or describe those elements or components of the system that contribute to the leakage. Describe the point(s) of water entry and the internal path(s) of the leakage. Describe the cause-and-effect relationship between wall characteristics and observed leakage.

13. Keywords

13.1 evaluation; inspection; testing; water leakage

ANNEX

(Mandatory Information)

A1. BACKGROUND

A1.1 Consequences of Leaks

A1.1.1 Water leakage in exterior walls of buildings has a broad range of possible effects. Water that penetrates through a wall assembly can result in wetting of interior finish materials, including interior sills, wall finishes, drywall, insulation, and floor and ceiling finishes. Intermittent or prolonged contact with water can cause component damage, including corrosion of connection materials and embedded reinforcing, wetting, and loss of “R” value in insulating materials, mildew and bacterial growth, peeling of paints, efflorescence in masonry and mortars, deterioration of concealed sealants, and damage to perimeter seals in insulating glass units, among other effects. Water leakage within a wall system is sometimes not observed

on the interior surfaces, but remains hidden within the wall, ceiling, or floor systems, or combination thereof. Trapped and concealed water can contribute to significant deterioration. Water leakage can also contribute to freeze/thaw damage of a wall system.

A1.2 Performance Criteria

A1.2.1 Performance requirements of exterior wall assemblies and fenestration are established by the project contract documents and the building codes. Criteria relating to structural integrity are typically mandated by the building code, which will control thickness or types of glass, or both, required strength and stiffness of framing members and connections.

Geographic location is considered in establishing performance criteria for design wind pressures, hurricanes, seismic movements, thermal performance, and condensation resistance. Occupancy type will establish the relative importance of the various performance aspects of the system. Criteria for air infiltration and water penetration should be established by the specifier, with a clear understanding of these considerations. The air infiltration and water penetration criteria are typically demonstrated by testing of prototype units or project mock-ups under laboratory test conditions and may be verified as part of a quality assurance program during construction.

A1.3 Maintenance

A1.3.1 Performance criteria for new construction are specified as a means of establishing the relative quality of the assemblies and their expected performance characteristics. The long term performance of installed systems will require a program of regular maintenance of various components of the system, consistent with their specific material characteristics. The long-term performance of exterior seals, sealants, and water-proofing membranes require particular attention.

A1.4 Sources of Water

A1.4.1 Water leakage through exterior wall assemblies can come from several possible sources. Rain on the exterior surface of a wall may lead to some degree of penetration, due to the effects of gravity, surface tension, kinetic energy, or capillary action. Wind-driven rain, which wets an assembly under a pressure differential, can force water through small openings, seams, and cracks in the assemblies or over the top of barriers with insufficient height. Air moving through openings in an assembly can transport water by percolation.

A1.4.2 Penetration of wall assemblies can occur at discontinuities between materials such as at mortar joints, cracked or damaged materials, gaps in sealants, window joinery, gasketed or weatherstripped operable joints, splices, butt joints, expansion joints, or due to failed or omitted flashing, missing or damaged end dams, or blocked or improperly executed weeps.

A1.4.3 Permeation of the wall materials is the process of water passing through a component such as a porous brick or concrete block. Permeation of walls incorporating porous materials should be anticipated in the design and the wall detailed accordingly. Excessive or unanticipated permeation of wall materials can be a symptom of material deficiencies or misapplication.

A1.4.4 The direction of water movement on the wall surface is determined by the combined effects of gravity, surface tension, and wind velocity. The effects of wind velocity can be greater than the effects of gravity, resulting in regions of the wall where wind-driven rain actually flows upwards or sideways.

A1.4.5 Surface tension can cause water to cling to and migrate along horizontal surfaces, thereby wetting areas not directly exposed to rain or in the path of water flowing down the face of a building. Drip grooves at the edge of horizontal overhangs are intended to interrupt the effects of surface tension.

A1.4.6 Water can penetrate a wall by being transported along a stream of moving air. It will percolate across barriers or

through cracks and holes. Control of penetrating water usually also requires considering the control of air movement.

A1.4.7 Interfaces between vertical and horizontal surfaces are often subjected to large amounts of water due to sheeting action along the vertical surfaces. Areas where water accumulates in large amounts on the horizontal surfaces are particularly vulnerable to eventual water penetration. The proper design and functioning of interface joinery, sealants, and closures between vertical and horizontal elements are essential to the performance of the system.

A1.4.8 Water retained within cavities or absorbed by material components of wall systems can cause significant damage if it freezes. Snow and ice can block drainage systems designed to accommodate water, thereby preventing these systems from functioning properly. The service history and conditions under which leakage occurs are particularly important in evaluating leaks of this type because they might not be recreated during diagnostic testing.

A1.5 Methods of Resisting Leaks

A1.5.1 The intended behavior of a wall system is determined by the principles of physics applied in its design. Evaluating wall leakage requires an understanding of the design of the wall system, the materials used, and the conditions of exposure.

A1.5.2 The “first line of defense” against water penetration is the exterior exposed surfaces of the wall system. In order for leakage to occur, water must first penetrate the outer surfaces. The ability of a wall to resist leakage may or may not be totally dependent on the “first line of defense.”

A1.5.3 The design of a wall system can be described in two broad categories: barrier walls and water managed walls. A wall system may have characteristics of both a barrier and a drainage wall in various combinations. Every wall must have an identifiable mechanism to resist leakage, whether it is a distinct barrier material whose only function is to resist the movement of water toward the interior, or a combination of several wall elements intended to function together to provide leakage resistance. The anticipated volume of rain penetration, the method of controlling rain that penetrates, the location of a barrier within the wall assembly, the interaction of the wall components, the materials used, and the exposure of the barrier to environmental wind pressure and rain, determine how a wall is intended to function and how it is categorized. Terms and definitions describing the mechanics of a wall system are currently evolving and are being influenced by new wall concepts and a better understanding of existing wall concepts. The discussion below is presented for information only and does not necessarily represent consensus definitions at this time.

A1.5.3.1 *Barrier Walls*—The mechanism intended to prevent leakage in this type of wall is blocking or interrupting the movement of water to the interior.

(1) *Mass Barrier*—The thickness and properties of wall materials are relied upon to provide a barrier. The wall mass itself may absorb water, but permeation to the interior is prevented by sufficient thickness and absorption capacity, or a

layer with low permeability within the wall. Examples: solid multi-wythe masonry and stone walls; masonry walls with filled collar joints.

(2) *Face-Sealed Barrier*—The exterior surfaces are relied upon as the only barrier. All joints and interfaces must be sealed to provide a continuous exterior barrier, and the absorption properties of the materials must also be controlled. The materials within the wall assembly must be able to sustain occasional short-term wetting as might occur between maintenance cycles of the exterior seals or from unintended incidental water infiltration. The system can also incorporate a secondary water resistant system in selected areas where incidental infiltration is anticipated. Examples: precast concrete panels; some prefabricated metal or stone panels; adhered EIFS systems.

A1.5.4 Water Managed Walls—The mechanism intended to prevent leakage in this type of wall is the control and discharge of anticipated and accepted amounts of water that penetrates the exterior surfaces.

(1) *Drainage Walls*—Penetrating water is intended to reach a cavity incorporated within the wall and then to flow towards a flashing or drainage system, where it is discharged to the exterior. Water within the cavity is intended to flow freely and not be retained. Therefore, the cavity must be wide enough so that surface tension does not cause water retention and must be relatively free of obstructions and construction debris. If water can cross to the interior side of the cavity at intended bridging such as structural anchors and ties, or at unintended bridging such as mortar projections or stucco keys, then the interior side of the cavity must resist water penetration by incorporating a membrane, parging, or some other means. Examples: masonry cavity walls; brick veneer and metal stud walls.

(2) *Collection and Retention Walls*—Water leak problems and damage are controlled by systematic collection of water that penetrates the exterior surfaces of the wall. Such systems provide means to accommodate minor amounts of water penetration and provide short term retention of collected water by means of cavity dams and reservoirs. Discharge of collected water can be accomplished by providing mechanisms to redirect the collected and retained water to the exterior via weep drains. In some systems, evaporation is used as a means of discharge of collected water, but this method requires that the materials used in the collection and drainage system can sustain prolonged wetting while evaporation takes place. The vapor transmission rate of all materials on the exterior side of the collection and retention system must be considered so that evaporation can occur rapidly. The volume of water collected must be controlled and not exceed the capacity of the collection

and retention systems. Discharge of collected water to the exterior must be rapid enough to avoid dangerous mold growth. Examples: glass and aluminum curtain wall systems; stucco; siding systems.

A1.5.5 Rain Screen Walls and Pressure Equalization—The concept of a rain screen and pressure equalization can be used to reduce the air pressure differentials across the exterior surface of a wall, thereby reducing the volume of wind-driven water that must be resisted, drained, or retained. Special wall characteristics and details must be incorporated in the wall design for pressure equalization to be realized. Of particular importance is maintaining an air barrier behind the exposed surface of the wall and adequately ventilating the exterior surface. This allows the space behind the exposed surface to rapidly change pressurized in response to the imposed pressure from the wind. In theory, perfect equalization would result in no differential pressure across the exposed surface but in reality a wall can not achieve or be intended to achieve perfect equalization. Air leaks at this barrier will reduce the effectiveness of pressure equalization and can cause water leakage.

A1.6 Sources of Additional Information

A1.6.1 ASTM Special Technical Publications—Proceedings of symposia sponsored by ASTM on water leakage problems and solutions:

STP 1107 *Water in Exterior Building Walls—Problems and Solutions*, Thomas A. Schwartz, ed., 1991.

STP 1314 *Water Leakage Through Building Facades*, Robert J. Kudder and Jeffrey L. Erdly, ed., 1998.

STP 1352 *Water Problems in Building Exterior Walls: Evaluation, Prevention and Repair*, Jon M. Boyd and Michael J. Scheffler, ed., 1999.

STP 1422 *Performance of Exterior Building Walls*, Paul G. Johnson, ed., 2003.

STP 1484 *Interface and Durability of the Window-Wall Interface*, ed. Barry G. Hartman, Carl R. Wagus and Theresa A. Weston, 2006.

STP 1493 *Repair, Retrofit, and Inspection of Building Exterior Wall Systems*, ed. Paul G. Johnson and Jon M. Boyd, 2009.

A1.6.2 Books:

Lstiburek, Joseph, and Carmody, John, *Moisture Control Handbook*, Van Nostrand Reinhold, New York, 1993.

Trechsel, Heinz R., *Moisture Control in Buildings*, American Society for Testing and Materials, ASTM Manual Series MNL 18, West Conshohocken, PA, 1994.

Kubal, Michael T., *Waterproofing the Building Envelope*, McGraw-Hill, New York.

APPENDIXES
(Nonmandatory Information)
X1. SEALANTS

NOTE X1.1—The appendices attached to this guide contain non-mandatory information on the evaluation process applicable to several common wall systems. They briefly present considerations that task group members have found to be useful in leakage evaluations and are intended to supplement the general methodology described in the body of the guide and to assist users by sharing information and experience. The appendices cannot present all possible issues that may be relevant to a specific building with a specific wall configuration and combination of components or to a specific evaluation program. The task group does not intend to imply anything negative by inclusion of a system in the appendices, nor anything positive by omission of a system. The Referenced Documents and the publications listed in Sources of Additional Information can be consulted for more comprehensive information.

Sealants are often a critical component of a wall system, and the performance and durability of the sealants can affect the performance of the overall wall system. **Appendix X1** on Sealants should therefore be considered when evaluating any wall system containing sealants.

X1.1 Scope

X1.1.1 Appendix X1 provides specific investigation and evaluation practices for water leakage resulting from the failure of sealant used in exterior weather-seal joints. Critical issues and details to obtain water-tight sealant joints capable of withstanding cyclical movement and exposure to the environment are defined. Methods of inspection to assess weather-seal joint sealant integrity are also addressed.

X1.1.2 Sealants within the scope of **Appendix X1** are high performance, elastomeric materials used to provide the primary exposed seal at expansion joints, control joints, and joints where individual wall components adjoin. Sealants used within sub-assemblies are not specifically addressed, although the general criteria for their performance is similar to those outlined for primary weather-seal joints.

X1.2 Referenced Documents

X1.2.1 SWRI Standards:⁵

“Sealants: The Professionals’ Guide,” 1995.

X1.3 Method of Water Penetration Resistance

X1.3.1 Sealants resist water penetration by maintaining a watertight seal over or across a joint between components. The primary failure mechanisms affecting sealants are:

X1.3.2 Adhesive Failure—failure of the bond between the sealant and the substrate surface.

X1.3.3 Cohesive Failure—failure characterized by rupture within the sealant.

X1.3.4 Chemical Breakdown and Reversion—an adverse combination of temperature, ultra-violet exposure, and humidity conditions can cause a chemical change in some polyurethane sealants formulations, resulting in a gummy consistency, and loss of resilient elastomeric properties, adhesion, and strength.

⁵ Available from the Sealant Waterproofing and Restoration Institute (SWRI), 400 Admiral Blvd Kansas City, MO 64106, <http://www.swrionline.org>.

X1.4 Critical Material Properties

X1.4.1 Sealant materials must provide adequate elasticity, strength, and adhesion to accommodate joint movements. They must also be resistant to weathering and deterioration from ultraviolet light, ozone, and pollutants. The performance characteristics of the material selected must accommodate anticipated movement and environmental exposure of the sealant joint.

X1.5 Critical Details

X1.5.1 Joint Design—Sealants’ performance within joints is rated as the allowable movement expressed as a plus and minus percentage of the effective joint width. High performance sealants provide between 25 % to 50 % movement capability. Additional factors that influence joint design include:

X1.5.1.1 Joint Sizing—A joint’s width must be sized to accommodate the type and amount of movement for each material in contact with the sealant. Sizing must also anticipate fabrication and erection tolerances, the strength of the substrate and the temperature of the assembly when sealants are installed.

X1.5.1.2 Joint Spacing—The distance between joints must be based on anticipated movements and the relief required by the substrate materials. Often, joint locations are based on specific component sizes or column bay spacing, or both, not computed movement.

X1.5.2 Sealant Backing—Sealant backing controls the depth of sealant, prevents three-sided adhesion of the sealant, permits wetting of the joint surfaces and consolidation of the body of the sealant when it is tooled and promotes good contact with the joint surfaces. Some types of sealant backing can also provide temporary weather protection when conditions are unsuitable for immediate sealant application.

X1.5.2.1 Three-sided adhesion of sealant reduces its ability to accommodate movement, causing excessive sealant stress and failure.

X1.5.2.2 Common sealant backings include:

(1) Compressible open-cell foam, closed-cell foam, or hybrid combinations of open-cell foam core with a closed-cell sheath. The backing typically has a rod shape that is compressed while inserted into a joint so that it can retain its position at the required depth during tooling. Open-cell backing rods can permit water migration and retention and are most often used in horizontal joints. Closed-cell backing rods can release gas if the skin is punctured during installation, causing bubbles in uncured sealant.

(2) Bond break tape or release tape is a self-adhesive material such as polyethylene or Teflon to which most sealants do not adhere. Tapes are used in shallow joints that do not have sufficient space for compressible backing rod and for other specialized joint applications.

X1.5.3 *Substrate*—The substrate is the surface that the sealant adheres to. The substrate must be structurally sound and properly prepared to receive the sealant. Common substrate problems include:

- X1.5.3.1 Presence of moisture, frost, or ice.
- X1.5.3.2 Chemical or moisture contamination.
- X1.5.3.3 Improper cleaning during surface preparation.
- X1.5.3.4 Porosity.
- X1.5.3.5 Cracking.
- X1.5.3.6 Weathering.
- X1.5.3.7 Inadequate surface area, such as attempting to adhere sealant to the edge of a thin metal extrusions.
- X1.5.3.8 Substrates that are softened by exposure to moisture, such as EIFS finish coat.

X1.5.3.9 Uneven surfaces, such as exposed aggregate panels where the joint interface includes aggregate protruding from the matrix.

X1.5.4 *Primers*—Primers improve the adhesion of a sealant to a substrate. Some sealants require primers on all substrates; others require primer for specific substrates or none at all. Absence of a required primer can contribute to premature sealant adhesion failure.

X1.5.5 *Joint Seal Geometry*—Sealant joints require specific ratios between joint width and depth. Non-typical joint configurations can be successfully sealed; however, they require careful design and forethought prior to sealant application.

X1.6 Workmanship

X1.6.1 *Joint Preparation*—Joint preparation is critical for the proper application and performance of sealants. The following conditions are necessary for optimal sealant performance:

- X1.6.1.1 The joint interfaces are free of any contaminants and are structurally sound.
- X1.6.1.2 The substrate strength is sufficient to sustain the force generated by the sealant intension without failure.
- X1.6.1.3 Required primer(s) have been installed.
- X1.6.1.4 Sealant backers are in place, providing for a proper width to depth ratio.
- X1.6.1.5 The joint backing (interior joint face or rear of joint) provides an effective bond breaker.
- X1.6.1.6 Substrate temperatures are within the sealant manufacturers' recommendations and are free of moisture and frost.

X1.6.2 *Sealant Installation*—Proper installation includes the following basic techniques.

X1.6.2.1 Multi-component sealants must be mixed and installed in accordance with the manufacturer's written instructions.

X1.6.2.2 The uncured sealant is installed in the joint with a gun-type applicator. These guns may be bulk or cartridge type and may be either hand or power actuated.

X1.6.2.3 The gun tip should be sized to allow placing the fluid sealant within the joint and used in a manner causing the material to flow ahead of the tip. This assists the sealant to fill the joint cavity and wet the joint interfaces prior to tooling.

X1.6.2.4 The uncured sealant is properly tooled. Tooling compacts the sealant into the joint, forcing the sealant against the joint faces. This ensures that there are no voids in the

sealant. Tooling also provides a slightly concave joint surface that improves the sealant configuration and achieves a visually satisfactory finish. Solutions should not be used to facilitate tooling unless approved by the sealant manufacturer.

X1.7 Inspection

X1.7.1 *Visual Inspection*—Visual inspection is the primary means of evaluating exterior sealant joints. Sealant inspection on buildings over one story generally requires the use of a lift or swing stage scaffolding, or both. Ground level inspection using binoculars, combined with interior inspection of water infiltration points, may be used to assess locations that require close-up exterior sealant inspections. Sealants must be carefully inspected for adhesive and cohesive failure and for sealant condition.

X1.7.2 *Adhesive Failure*—This may not be easily identified using only close-up visual inspection. A blunt tool pressed against the sealant bead may be required to expose some adhesive failures. Causes of sealant adhesion failure commonly include the following:

- X1.7.2.1 Chemical or moisture contaminated substrate.
- X1.7.2.2 Improper substrate preparation, cleaning, or priming.
- X1.7.2.3 Porosity, cracking, or weathering of the substrate.
- X1.7.2.4 Inadequate surface area for bonding, such as adhesion to the thin "raw" end of an extruded metal section.
- X1.7.2.5 Inappropriate surface area for bonding, such as adhesion to exposed aggregate panels where sealant cannot be tooled to achieve intimate contact with the irregular surface.
- X1.7.2.6 Improper joint geometry, such as three-sided adhesion, a fillet configuration in a moving joint, or an improper width-to-thickness ratio.
- X1.7.2.7 Improper tooling techniques or poor joint filling.
- X1.7.2.8 Insufficient effective joint width to accommodate the movement.
- X1.7.2.9 Detrimental movement during sealant cure.
- X1.7.2.10 Inadequate strength of the substrate. Adhesion failures of this type are due to material failure within the substrate rather than the sealant. Substrate material will remain embedded in the sealant at the failure surface.
- X1.7.2.11 Use of sealant materials that have exceeded their shelf life, pot life, or which have been improperly stored, mixed, and handled.

X1.7.3 *Cohesive Failure*—Common causes of sealant cohesive failure may include one or more of the following.

- X1.7.3.1 Heat aging deterioration.
- X1.7.3.2 Ultra-violet light degradation.
- X1.7.3.3 Continuous exposure of sealants to moisture due to a saturated substrate, water retention in the sealant backing or a ponding condition.
- X1.7.3.4 Strain-induced cracking.
- X1.7.3.5 Improper mixing of multi-component sealants.
- X1.7.3.6 Insufficient effective joint width to accommodate the movement.
- X1.7.3.7 Detrimental movement during sealant cure.
- X1.7.3.8 Use of materials that have exceeded their shelf life or pot life or which have been improperly stored, mixed, and handled.
- X1.7.3.9 Inadequate sealant thickness.

X1.8 Testing

X1.8.1 *Field Adhesion Test*—A simple field adhesion test is available as described by SWRI. The hand pull test procedure for a vertically-oriented joint is:

X1.8.1.1 Make a knife cut horizontally from one side of the joint to the other.

X1.8.1.2 Make two vertical cuts approximately two in. long at the sides of the joint, meeting the horizontal cut at the top of the two-in. cuts.

X1.8.1.3 Grasp the two-in. piece of sealant firmly between the fingers and pull down at a ninety-degree or more angle. Try to pull the uncut sealant out of the joint.

X1.8.1.4 If the adhesion is proper, the sealant should tear cohesively in itself before adhesively releasing from the substrate.

X1.8.1.5 The percentage of extension prior to adhesive failure should be observed and documented.

X1.8.1.6 Specific sealant material manufacturers may recommend variations regarding this general test.

X1.8.2 *Joint Movement*—The actual movement to which a joint is subjected can be measured. Accurate movement measurement of joints may require monitoring for a period sufficient to permit the components to respond to the anticipated temperature extremes. A continuous record of joint movement can be obtained with linear transducers and a data-logger or a data acquisition system. Simpler scratch and target gages are also commercially available for these measurements. The following is a simple method of joint movement measurement:

X1.8.2.1 On one side of the joint, attach a base that holds a scribe, capable of scratching a painted surface, over the joint.

X1.8.2.2 On the opposite side of the joint, beneath the scribe point, attach a painted plate.

X1.8.2.3 The scribe should be adjusted to scratch the painted plate as the joint is subjected to movement.

X1.9 Evaluation

X1.9.1 In addition to the general protocol described in the body of this guide, the following warrant particular attention in the evaluation of exterior sealants:

X1.9.2 Review construction documents, including architectural, erection, and shop drawings.

X1.9.3 Review reports of complaints, including leakage.

X1.9.4 Review sealant specifications. The specifications may require the use of several types of sealant. Describe where each type is to be used.

X1.9.5 Survey interior and exterior wall conditions.

X1.9.6 Test specific wall components including joints where individual units abut and where dissimilar materials adjoin.

X1.9.7 Consider that many wall assemblies are altered using remedial sealants incorrectly. Common misapplication of sealants includes the sealing of weep tubes, flashings, and open masonry head joints, all of which are intended to be left open to dissipate water from within a cavity wall system.

X1.10 Sources of Additional Information

X1.10.1 *ASTM Standards*:²

C717 Terminology of Building Seals and Sealants

C920 Specification for Elastomeric Joint Sealants

C1193 Guide for Use of Joint Sealants

X1.10.2 *ASTM Special Technical Publications*—A series of symposia sponsored by ASTM have addressed construction sealants. The proceedings from these symposia are published by ASTM as “Special Technical Publications.” Those dealing with sealants are STP606, STP1054, STP1069, STP1168, STP1200, and STP1334.

X1.10.3 *American Concrete Institute*:⁶

504R Guide to Sealing Joints in Concrete Structures

X1.10.4 *Textbooks*:

Klosowki, J. M., *Sealants in Construction*, Marcel Dekker, Inc., New York, 1989.

Panek, Julian R., and Cook, John Philip, *Construction Sealants and Adhesives*, John Wiley & Sons, New York.

⁶ Available from American Concrete Institute (ACI), P.O. Box 9094, Farmington Hills, MI 48333-9094, <http://www.concrete.org>.

X2. MASONRY

X2.1 Scope

X2.1.1 **Appendix X2** provides specific investigation and evaluation practices for water leakage of masonry walls. Critical issues and details for water penetration resistance of masonry walls are defined. Methods of inspection and evaluation of water penetration through masonry wall assemblies are addressed. Masonry unit materials within the scope of **Appendix X2** are clay, concrete, terra cotta, glass block, and stone.

X2.1.2 Surface-applied coatings or sealers may also be used to create a barrier wall. The performance of a coated masonry wall depends on the properties of the coating as well as the

masonry. Coated masonry walls are not included in the scope of **Appendix X2**. Drainage walls and barrier walls with concealed barrier layers are included. Barrier walls created by an applied coating on the exterior masonry wythe are not included.

X2.2 Referenced Documents

X2.2.1 *ASTM Standards*:²

E514 Test Method for Water Penetration and Leakage Through Masonry

X2.3 Method of Water Penetration Resistance

X2.3.1 There are basically two different masonry wall systems used to resist water penetration: the drainage wall and the barrier wall.

X2.3.2 *Drainage Walls*—Drainage walls include cavity walls and anchored veneer walls. Water penetration resistance of drainage walls is achieved by collecting, controlling and draining water that penetrates the exterior wythe of masonry. Water that penetrates the exterior wythe is intended to flow down the back face of the exterior wythe, collect on the flashing, flow laterally, and exit the wall system through weeps to the exterior.

X2.3.2.1 Drainage walls may also contain vents in the exterior wythe, an air barrier at the interior wythe or backup, and compartmentalization of the wall cavity to provide a pressure equalized rain screen.

X2.3.3 *Barrier Walls*—Barrier walls include single or multi-wythe walls and adhered veneer walls. Water penetration resistance of barrier walls is provided by a water resistant layer in the wall assembly that blocks the movement of water to the interior. The barrier layer may be a masonry wythe or multiple wythes, a continuous grouted or mortar filled collar joint between wythes, grout fill within masonry units, or a concealed coating or membrane.

X2.3.4 *System Resistance*—The resistance of a masonry wall results from the combined resistance of the masonry units, the mortar, the interface between the units and the mortar and either the drainage cavity or the water resistant barrier layer. Leakage occurs when one or more of the component resistances is inadequate relative to the others. For example, a customary drainage system might not be effective if the exterior wythe permits more water to penetrate than can be controlled and discharged. Similarly, leakage could occur in a wall with an exterior wythe that permits a customary volume of water to penetrate, but which has a defective drainage system or a deficient barrier. The ability of a masonry wall to resist water leakage depends on the interaction and balance between the component resistances.

X2.4 Critical Material Properties

X2.4.1 *Absorption and Water Penetration*—With the exception of glass block, masonry materials and mortar absorb water. A distinction must be made between normal water absorption and water penetration of a wall system. A drainage cavity or a water resistant barrier is intended to interrupt the movement of water through a wall caused by either absorption or penetration.

X2.4.2 *Exterior Wythe of Masonry*—The exposed exterior wythe of masonry provides the first layer of water resistance for the wall system. The masonry units and mortar may permit water movement by diffusion, but leakage due to this property alone is unlikely. Water is more likely to penetrate at the interface between the units and the mortar and physical deficiencies such as cracks or open joints.

X2.4.3 *Masonry Units*—The strength properties of the masonry units are usually more critical to the structural capacity and durability of a wall than to the leakage resistance of a wall. The units should comply with applicable guidelines for the

environmental exposure of the wall. Several physical properties of the units can have an effect on the water resistance of a wall including:

X2.4.3.1 Compatibility of the unit's absorption characteristics and the properties of the mortar.

X2.4.3.2 Bonding surface conditions, such as surface roughness and irregularities that might interfere with proper mortar bond, or the presence of contaminants and residues from the manufacturing process, handling, and storing procedures.

X2.4.3.3 Fissures or voids that extend through the body or face shell of a unit.

X2.4.4 *Mortar*—The properties of mortar that relate to workability and durability can affect the leakage resistance of a wall. Mortar that has good workability allows masons to achieve optimal performance. Poor workability properties of mortar can result in poor bond, voids within the mortar, ineffective tooling, and premature deterioration. Mortar properties that should be considered in assessing bond and leakage resistance include:

X2.4.4.1 Absorption and water penetration resistance of the mortar and the mortar-unit interface.

X2.4.4.2 Compatibility with the masonry unit suction properties.

X2.4.4.3 Proper cold weather or hot weather procedures.

X2.4.4.4 Appropriate air entrainment for the exposure conditions.

X2.4.4.5 Appropriate retempering of the mortar for consistent workability.

X2.4.4.6 Proper mix proportions.

X2.4.4.7 Carbonation along the unit/mortar interface.

X2.4.4.8 Proportions and type of colorants and additives.

X2.4.5 *Barrier Layer*—The water resistance of barrier layer must be sufficient to interrupt the movement of water through a wall. The required resistance will depend on the absorption and penetration properties of the wall assembly and on the cumulative water resistance of all of the layers.

X2.5 Critical Details

X2.5.1 *Cavity Drainage System*—A cavity drainage system is an open vertical space through which water that penetrates the exterior wythe can flow to embedded flashing, where the water is controlled, collected, and discharged through weeps.

X2.5.1.1 *Flashing*—Embedded flashing is customarily located at: wall base, window heads and sills, lintels and shelf angles, arches, projections, recesses and caps, and coping or other interruptions of the cavity. Exposed flashing is customarily integrated with other building waterproofing systems, such as roofs, terraces, and balconies.

X2.5.1.2 *Weeps*—Weeps provide the discharge route for draining the flashings. Weeps include rope wicks, open head joints, plastic tubes, and louvered or honeycombed vents. Large weeps, such as open head joints, may function in combination with vents in a pressure equalized rain screen wall.

X2.5.1.3 Water can reliably drain only through a clean unobstructed cavity. A mason using ordinary technique may not be able to keep a cavity clean if it is less than 2 in. wide.

X2.5.2 Barrier Layer—The barrier layer should be continuous. Voids in the barrier layer can result in localized water penetration of the wall.

X2.5.3 Joints—Joints accommodate volume changes and differential movements and are necessary to control cracking. There are several types of joints used in masonry construction. Movement joints accommodate lateral drift and vertical deflections of a structural frame; they are intended to prevent movements from inducing inappropriate loads in the masonry. Expansion joints accommodate volume increases due to thermal or moisture expansion. Control joints accommodate volume reductions due to shrinkage or thermal contraction.

X2.5.3.1 The spacing, size, and details for joints must comply with appropriate guidelines. The anticipated movement requirement for the joint, as well as an assessment of construction tolerances, are considered in establishing the joint size.

X2.5.3.2 The joints themselves should resist water penetration, consistent with the adjacent masonry. This is usually achieved using an elastomeric sealant and backer rod. Joints may also contain a water stop such as a compressed pad or a pre-formed molding. A compressible joint filler can also help keep joints free of mortar.

X2.6 Workmanship

X2.6.1 The successful installation of masonry is a craft as well as a technology, dependent on the skill and experience of the individual mason. The subjective aspects of the mason's skill are demonstrated by the appearance and water penetration resistance of the finished masonry. There are also objective aspects of a mason's skill that can be assessed in a systematic way, including:

X2.6.1.1 Using proper techniques appropriate to the materials involved.

X2.6.1.2 Adequately filling mortar joints, which are less likely to permit water penetration than partially filled or furrowed joints.

X2.6.1.3 Using good joint tooling technique, executed at the appropriate mortar hardness.

X2.6.1.4 Achieving optimal bond and water penetration resistance for the materials involved.

X2.6.1.5 Providing a clean cavity without mortar bridging and with minimal mortar droppings.

X2.6.1.6 Providing parge coats and grouted or mortared barrier layers that are free of voids.

X2.6.1.7 Providing clean and open movement and expansion joints where required by the project documents.

X2.7 Inspection

X2.7.1 Many causes of leakage can be identified by visual inspection. Both the exterior and interior wall faces should be inspected to the extent possible. Making openings from the exterior or through the backup from the interior to expose the internal construction of a wall, or making observations with a fiber-optic borescope, can permit visual inspection of concealed conditions.

X2.7.2 Indicators of Possible Water Penetration—There are several symptoms of water penetration that are worth noting during a visual inspection. Observation of these symptoms can also serve as a rational basis for further investigative activity.

X2.7.2.1 The presence of efflorescence indicates water exiting the masonry. Areas of heavy efflorescence can provide valuable information about the source of penetration. Persistent efflorescence due to water penetration must be distinguished from a one-time overall appearance of efflorescence soon after construction.

X2.7.2.2 Corrosion of embedded metals such as joint reinforcement and ties may indicate water penetration. Stresses from the accumulation of corrosion byproducts may cause cracks that permit water penetration.

X2.7.2.3 Biological growth such as moss or fungi on masonry may indicate prolonged dampness. Exposure of the masonry surface to the sun should also be considered since biological growth is more likely on north elevations and on surfaces shaded from direct sun exposure.

X2.7.2.4 Spalled units may indicate prolonged saturation or inadequate drainage in geographic areas subjected to freeze/thaw cycles. Spalling of glazed masonry might also indicate inadequate venting.

X2.7.3 Possible Leakage Sources—The following possible sources of leakage should be considered during an inspection:

X2.7.3.1 Flashing must collect and control water that penetrates the masonry. Considerations in assessing the flashing include:

(1) Dimensional and chemical stability of the flashing material and compatibility between the flashing material and the adjacent materials that it contacts.

(2) Adequate height of the upturned back edge and end dams.

(3) Proper overlap and seal of joints.

(4) Properly installed end dams.

(5) Proper installation at atypical locations, at interruptions and at corners.

(6) Proper closure of the top edge, such as embedment into or a seal to the backup.

(7) Open edge to the exterior that is free to drain, and which is not blocked by adjacent construction. Alternatively, if the flashing is intended to drain only at the weepholes, then water retained on the flashing until it reaches a weep must be prevented from bypassing the front edge of the flashing and flowing into the construction below either by flowing vertically through the cores holes in masonry or flowing around the toe of concealed shelf angles or lintels.

(8) A seal along the bottom that would prevent infiltration under the flashing.

X2.7.3.2 Weepholes provide a drainage path for water collected by flashing. Considerations in assessing the weepholes include:

(1) Adequate size and spacing.

(2) Location of the weepholes in relation to the location of the flashing.

(3) Blockage from the exterior, by insects or by sealant.

(4) Blockage from the interior by excessive mortar droppings.

(5) Cracks greater than 0.1 mm that are functioning as unintended weeps.

X2.7.3.3 Loose or dislodged units.

X2.7.3.4 Mortar bridging that permits water which penetrates the exterior wythe to cross to the interior side of a cavity.

X2.7.3.5 Improper tooling of mortar joints or mortar joints that were chemically burned during cleaning.

X2.8 Testing

X2.8.1 Testing may be needed to supplement visual inspection and to determine or verify water entry locations and water paths.

X2.8.2 *Water Spray Testing*—Water penetration locations and water paths can be assessed by water spray test. This test can be simply a wall hose test or a more controlled and reproducible test, such as a modified Test Method E514 laboratory test for field applications.

X2.8.3 *Moisture Meters*—Moisture meters are useful for comparing different areas of masonry to establish a relative moisture content. The cause of relatively high moisture meter readings should be determined by additional investigation using other techniques.

X2.8.4 *Sonic Pulse Testing*—Sonic pulse testing can be used to find void areas in grouted collar joints or hollow unit, grouted masonry in barrier walls.

X2.8.5 *Thermography*—Infrared thermography can be used to find void areas in grouted collar joints or hollow unit, grouted masonry in barrier walls. It can also be used to identify areas of saturated masonry. Thermography techniques require careful interpretation by a skilled and experienced operator.

X2.9 Evaluation

X2.9.1 It is essential to keep in mind when evaluating the data and information gathered during the inspection and testing activities that some water penetration of the exterior face of the masonry is anticipated and normal. A systematic evaluation of leakage of masonry walls consistent with the general protocol in the body of this guide would include consideration of the following items:

X2.9.2 The water path or paths causing the leakage problem. This will include an assessment of the exterior wythe of masonry and either the drainage system or the barrier layer.

X2.9.3 Identification of the component(s) with water resistance performance that is deficient relative to the other components of the wall system.

X2.9.4 The contribution of each deficient component to the leakage problem. Failure or deficient performance of certain components of a wall system may not be as critical as other

components. For example, the exterior wythe of masonry may permit more than the customary amount of water penetration to occur, but the wall may not exhibit leakage problems if the drainage system or barrier layer function properly. However, a wall with a deficient drainage system or barrier layer is likely to exhibit leakage problems even with a properly functioning exterior wythe.

X2.9.5 An assessment of repair options. The difficulty and cost of repairing the failed component can be compared to enhancing the performance of some other component. For example, achieving acceptable performance by enhancing the water penetration resistance of the exterior wythe may be more expedient and economical than reconstructing the drainage system or barrier layer. The longevity, durability, and maintenance requirements for alternate repair approaches should also be evaluated.

X2.10 Sources of Additional Information

X2.10.1 *Conference and Symposia Proceedings:*

ASTM Special Technical Publications (STP778, STP874, STP992, STP1063, and STP1248), American Society for Testing and Materials, West Conshohocken, PA.

North American Masonry Conference Proceedings, 1 through current, The Masonry Society, Boulder, CO.

X2.10.2 *Industry Publications and Magazines:*

Brick Industry Association, *Technical Notes on Brick Construction*, Reston, VA (also available on CD-ROM).

National Concrete Masonry Association, *TEK Manual for Concrete Masonry Design and Construction*, Herndon, VA.

The Aberdeen Group, *The Magazine of Masonry Construction*, 426 S. Waukegan Street, Addison, IL.

X2.10.3 *Research Reports:*

Grimm, Clayford T., *The Hidden Flashing Fiasco, Construction Research Center*, University of Texas at Arlington, Arlington, TX, 1992.

X2.10.4 *Bibliography:*

Grimm, Clayford T., “Water Permeance of Masonry: A Review of the Literature,” ASTM STP 778, American Society for Testing and Materials, West Conshohocken, PA, 1982, pp. 178–199.

X2.10.5 *Books:*

Beall, Christine, *Masonry Design and Detailing*, McGraw-Hill, NY, 1993.

Plummer, Harry C., *Brick and Tile Engineering*, Brick Institute of America, McLean, VA, 1962.

X3. WINDOWS AND GLASS/METAL CURTAIN WALLS

X3.1 Scope

X3.1.1 **Appendix X3** provides specific investigation and evaluation practices for water leakage through windows and curtain walls. Critical issues and details for water penetration resistance, and methods of inspection and evaluation of water penetration through window and curtain wall assemblies, are addressed.

X3.1.2 There are two basic types of glass/metal curtain walls: stick walls assembled and glazed on site, and unit walls of prefabricated assemblies erected on site. Each type has characteristic water resistance details and components. The discussion in **Appendix X3** applies to both types.

X3.2 Referenced Documents

X3.2.1 *ASTM Standards*:²

E1105 Test Method for Field Determination of Water Penetration of Installed Exterior Windows, Skylights, Doors, and Curtain Walls, by Uniform or Cyclic Static Air Pressure Difference

X3.2.2 *AAMA Standards*:³

AAMA 501 Methods of Test for Metal Curtain Walls

AAMA 501.2 Field Check of Metal Storefronts, Curtain Walls, and Sloped Glazing Systems for Water Leakage

AAMA 502 Voluntary Specifications for Field Testing of Windows and Sliding Glass Doors, Optional Sill Dam Test

AAMA 503 Specification for Field Testing of Metal Storefronts, Curtain Walls, and Sloped Glazing Systems

X3.3 Method of Water Penetration Resistance

X3.3.1 There are basically two different methods used in window and curtain wall systems to resist water penetration:

X3.3.2 *Draining Systems*—The basic concept behind the draining system is that some amount of water will penetrate the exterior weather seals of the window or curtain wall. When it does, this moisture will flow down to the glazing pocket sill or onto the flashing and exit the wall system through weep-holes.

X3.3.2.1 Pressure equalized systems incorporate the principles of rainscreen design. Venting of an internal chamber to the exterior is intended to reduce the differential pressure across the exterior seals during wind-driven rain. Proper determination of vent size and location, an air seal between the vented chamber and the interior, and an effective drainage system are essential for a functional pressure equalized system.

X3.3.3 *Barrier Systems*—The basic concept behind the barrier system is that an impervious layer, usually sealant, is placed at or near the face of the wall assembly to prevent water from entering the system.

X3.3.4 *Mixed Systems*—The method of water penetration resistance can vary from location to location, and from subsystem to subsystem in a curtain wall. This often is the design scheme when other materials in addition to glass, such as panels, masonry, stone, or precast concrete, are incorporated into the curtain wall.

X3.4 Critical Details

X3.4.1 Curtain wall and window detailing features that are useful to consider in a leakage evaluation include the following:

X3.4.2 *Flashing*—In general, flashings are installed at the perimeter of the curtain wall or window. Sill flashings are most critical because they customarily provide secondary back-up for intended drainage paths or are part of the primary drainage system. Alternatives to jamb and head perimeter flashings, such as double sealant joints with a drainage cavity between them, can be effective at directing infiltrated water to the sill flashing if the inner seal can be inspected and maintained for long-term performance. Considerations in assessing the effectiveness and durability of flashing include:

X3.4.2.1 Dimensional and chemical stability of the materials used and compatibility with adjacent materials that the flashing contacts.

X3.4.2.2 Adequate height of upturned back edges and end dams.

X3.4.2.3 Lap joint seals.

X3.4.2.4 Properly installed end dams.

X3.4.2.5 Open edge to the exterior that is free to drain, and which is not embedded into or sealed to the adjoining construction in a manner which prevents drainage.

X3.4.2.6 Adequate projection from the wall, with a drip edge.

X3.4.2.7 A seal along bottom front edge to prevent rain from blowing in underneath the flashing.

X3.4.3 *Weepholes*—Weepholes are provided at the sill of glazing pockets and at flashings. Weepholes in glazing pockets may include drilled holes, slots, or notches. Weepholes at flashing locations may include rope wicks, gaps in perimeter sealants, plastic tubes, and louvered or honeycombed vents. Considerations in assessing the effectiveness of weepholes include:

X3.4.3.1 Proper height, position, and slope.

X3.4.3.2 Blockage by insect nests, dirt, and debris.

X3.4.3.3 A shape and size that will not be blocked by surface tension. Experience has shown that round holes less than ¼-in. in diameter and slots less than ⅛-in. high can support a significant head of water before they will drain.

X3.4.3.4 Cover or fillers intended to control internal air velocities, which may become jammed or blocked, or are too dense to permit prompt drainage.

X3.4.3.5 Blockage by original or remedial sealants.

X3.4.4 *Expansion Joints*—Expansion joints are necessary to accommodate volume changes in response to temperature and moisture changes, to accommodate differential structural movements, and to account for construction tolerances. Considerations in assessing expansion joints include:

X3.4.4.1 Spacing, size, and details tailored to the movement requirements and construction tolerances for the project.

X3.4.4.2 Movements within the range and strength of the sealants used.

X3.4.4.3 Opening movements within the range of gasket precompression to avoid loss of seal and closing movements within the compression capacity of gaskets to avoid crushing and extrusion of the gasket.

X3.4.4.4 Maintenance of a viable backup seal in the event of primary joint failure.

X3.4.5 *End Dam Blocks*—In stick wall systems, end dam blocks are often part of the seal between horizontal and vertical glazing pockets. Dam blocks are generally preformed rubber inserts that are compression fit between the vertical and horizontal framing members. Sealants are typically used at the interfaces between the end dams and the glazing pocket members to prevent water that enters the glazing pocket from bypassing the end dams. Considerations in assessing end dam blocks include:

X3.4.5.1 Seal of gasket and screw splines that extend past end dam block. If gasket grooves are not terminated and sealed, water can follow them, bypass end dam block, and drain to the head of the glass below or enter the building.

X3.4.5.2 Proper size, seating, and compression.

X3.4.5.3 Proper sealant application at the interface of the end dam block.

X3.4.5.4 Adequate weeping of glazing pocket.

X3.4.6 *Thermal Breaks*—Aluminum extrusions may have integrated plastic sections that are intended to reduce the thermal conductivity of the extrusion and enhance its condensation resistance. Plastic is used for these “thermal breaks” because it is a poor thermal conductor compared to aluminum. The thermal breaks are typically either poured-and-debrided or crimped into place.

X3.4.6.1 Some formulation of plastic used for thermal breaks have exhibited axial shrinkage sufficiently large to cause a failure of the seal at window frame corners. This can open gaps at corner joints in sill and head sections that were intended to hold and drain water, causing leakage beyond the window perimeter.

X3.4.6.2 Deformations of the thermal break can cause rotation of one part of an extrusion relative to other parts. The rotation can reduce the compression on glazing gaskets and increase the likelihood of water penetration around the perimeter of the glass lite.

X3.4.6.3 Some thermal break plastic formulations resist the adhesion of sealants. Sealants used to seal the internal corners of aluminum frames may adhere properly to the aluminum surfaces but not to the thermal break surface. When evaluating internal corner sealants, distinguish between adhesion to the aluminum and adhesion to the thermal break plastic.

X3.4.7 *Sealants*—Sealants are used at expansion joints, control joints, frame corners, and at interfaces between glazing elements and other wall components. Sealant materials must provide adequate elasticity, strength, and adhesion to accommodate joint movements. They must also be resistant to weathering and deterioration from ultraviolet light, ozone, and pollutants. Refer to [Appendix X1](#) on Sealants for additional information.

X3.5 Workmanship

X3.5.1 Many of the components and the application of sealants that are critical to the water resistance performance of windows and glass/metal curtain walls are concealed in the completed installation. They cannot be readily inspected and are difficult to access for inspection and maintenance. It is therefore essential that the installation be performed by skilled and informed mechanics.

X3.5.2 Mechanics should adhere to the manufacturer’s installation manual for the basic system and to the shop drawings for interfacing the system with adjacent construction and the structural frame.

X3.5.3 For windows and unit wall components, factory installed seals can be damaged by careless transportation, handling, and storage.

X3.5.4 Careless handling of metal components can cause dents and bends that prevent the proper mating of parts. Poorly mated parts are potential leakage paths.

X3.6 Inspection

X3.6.1 *Visual Inspection*—Visual inspection is a critical first step to the investigation of leakage. Many causes of water penetration can be identified by visual inspection, though

subsequent testing is almost always required to confirm what may be apparent from visual inspection alone. Both the exterior and interior surfaces should be inspected. Observations of the type listed below are useful:

X3.6.2 *Interior Observations*

X3.6.2.1 *Water Damage*—Consequences of water infiltration include water stains on interior mullions or finishes, or both; paint blistering; damp interior wall face; and mildew.

X3.6.2.2 *Weather Seals of Operable Sash*—Water may penetrate around weather seals at operable sashes and enter to the interior at metal-to-metal joints in the frame construction or protruding hardware elements such as hinge mounts, operator arms or fasteners for stops.

X3.6.3 *Exterior and Internal Observations:*

X3.6.3.1 *Frame Construction*—Water may penetrate metal-to-metal butt joints that are unsealed or that have failed seals.

X3.6.3.2 *Missing/Clogged Weepholes*—Ineffective weepholes hinder the speed of water removal from the system. Review the condition and placement of setting blocks and foam baffle strips, if applicable. Setting blocks placed over weep holes will prevent water removal from the system if they do not have integrated drainage grooves. Foam baffle strips can collect dust, dirt, and debris that may enter the glazing pocket and may eventually clog. Weepholes may also be obstructed by the improper or over-enthusiastic application of sealant on the exterior perimeter of the unit. This problem is most common when the weepholes are on the underside of a sill component rather than the exposed vertical face.

X3.6.3.3 *Deteriorated/Failed Sealants*—Dysfunctional sealants that may permit water infiltration at the joint.

X3.6.3.4 *Shrinkage of Thermal Breaks*—Gaps that exceed the capacity of sealants or gaskets can open up in frame corners due to shrinkage of the plastic used for thermal breaks.

X3.6.3.5 *Flashing/Counterflashing Details*—Problem areas for flashing/counterflashing include missing end dams, missing flashing, open lap joints, inadequate integration to adjoining construction, and installation that permits bypassing the flashing.

X3.6.3.6 Performance critical features and seals are often concealed. Inspecting their installation, and assessing their condition and functionality, may require exposing them by partial disassembly or observing them using a fiber-optic borescope.

X3.7 Testing

X3.7.1 *Water Spray Testing*—Water penetration resistance and locations of trouble spots can be assessed by subjecting the window or curtain wall to a water spray test. This test can be simply a wall hose test or a more elaborate test, such as Test Method [E1105](#), [AAMA 502](#), or [AAMA 503](#).

X3.7.2 *Hose Spray Tests*—Simple hose spray tests are conducted without a pressure chamber. For the test to be controlled and reproducible, it should be conducted with a calibrated nozzle described in [AAMA 501.2](#), operated at the prescribed pressure, distance, and sweep rate. Calibrated nozzle tests rely on the kinetic energy of the spray to simulate the effect of wind-driven rain and the accumulation of water on surface to simulate run-down. Tests of this type can produce

useful information if the leakage mechanism controlling performance does not depend on the effects of differential pressure or concealed features. Hose tests can also deliver a concentrated or localized spray to help isolate a leakage path or water entry path.

X3.7.2.1 Hose spray tests should be conducted in a systematic fashion starting from the lowest point for evaluation on the wall and working up to the highest point for evaluation.

X3.7.2.2 Masking off portions or segments of the window/curtain wall, or adjoining wall construction, using polyethylene film and duct tape can be used to isolate particular areas for evaluation.

X3.7.3 *Differential Pressure Chamber Tests*—Water spray-tests can be performed in conjunction with differential pressure application with the use of a chamber on the inside or outside of the area of interest. These tests model the physics of wall behavior and the effects of wind-driven rain more completely and more accurately than isolated hose spray tests.

X3.7.3.1 When these tests are used, it is crucial to use realistic pressures for evaluation, based on actual weather conditions and wind pressures for a particular site. In lieu of actual on-site weather records, use weather records from the nearest airport or National Oceanic and Atmospheric Administration (NOAA) station and accepted wind engineering guidelines that account for terrain and building geometry.

X3.7.3.2 Masking off portions or segments of the window/curtain wall, or adjoining wall construction, using polyethylene film and duct tape can be used to isolate particular areas for evaluation.

X3.7.3.3 Water spray using a multi-nozzle spray racks to deliver a controlled and calibrated volume of water uniformly dispersed over larger areas.

X3.7.4 *Flood Testing*—Enclosed or discrete chambers within the system, such as sill sections, panning, and rails can be tested by filling with water as described in AAMA 502. If the chamber is weeped, the weeps can be taped closed or blocked temporarily. The head of water in the chamber should be controlled and consistent with the intended test pressure.

X3.7.5 *Component Disassembly*—Partial disassembly of window or curtain wall components permits a review of the wall construction and leakage paths after water testing. Also, the as-built construction of adjoining walls can be evaluated for

their relative contribution to leakage. Disassembly may also facilitate flood testing of isolated components such as sill extrusions, glazing pockets, and joints. Items for consideration during flood testing include clogged weepholes, position of setting blocks, and condition of frame seals and flashing.

X3.8 Evaluation

X3.8.1 A systematic evaluation of leakage of windows and glass/metal curtain walls consistent with the general protocol in the body of this guide would include consideration of the following items:

X3.8.2 Review documents of the existing construction, including architectural, erection, and shop drawings.

X3.8.3 Review reports of complaints, including leakage and condensation.

X3.8.4 Review specifications and manufacturer’s literature.

X3.8.5 Survey interior and exterior wall conditions.

X3.8.6 Probe internal wall conditions by selective disassembly of wall and window components.

X3.8.7 Test the existing window/curtain wall system, including perimeter joints and adjoining wall and roof surfaces.

X3.8.8 Make a careful distinction between leaks caused by the windows or glass/metal curtain wall system and leaks originating in other wall components that appear to be window or curtain wall leaks on the interior. Windows are often wrongfully blamed for leaks because the interior symptom of the leak appears at a window, even though the cause is elsewhere.

X3.9 Sources of Additional Information

X3.9.1 *Conference and Symposia Proceedings*:

ASTM Special Technical Publications (STP606, STP1034, STP1168, and STP1200), American Society for Testing and Materials, West Conshohocken, PA.

X3.9.2 *Industry Publications*:

AAMA manuals and technical publications, particularly the multi-volume Curtain Wall Manual series, American Architectural Manufacturers Association, Schaumburg, IL.

X3.9.3 *Books*:

Bateman, Robert, *Nail-On Windows: Installation & Flashing Procedures for Windows and Sliding Glass Doors*, DTA Inc., Mill Valley, CA, 1995.

X4. EXTERIOR INSULATION AND FINISH SYSTEMS (EIFS)

X4.1 Scope

X4.1.1 **Appendix X4** provides specific investigation and evaluation practices for water damage to and leakage of exterior insulation and finish systems (EIFS). Critical issues and details for the water resistance of EIFS are discussed. Methods of inspection and evaluation of EIFS are reviewed. Materials within the scope of **Appendix X4** are Class PB and Class PM EIFS.

X4.1.2 Direct-applied coating systems that do not use insulation and one-coat stucco systems are not classified as EIFS and are outside of the scope of **Appendix X4**.

X4.1.3 The term “lamina” as used in **Appendix X4** is defined as the overlay portion of the EIFS consisting of a base coat, reinforcing mesh and finish coat.

X4.2 Referenced Documents

X4.2.1 *ASTM Standards*:²

C79 Specification for Treated Core and Nontreated Core Gypsum Sheathing Board

C578 Specification for Rigid, Cellular Polystyrene Thermal Insulation

C1177 Specification for Glass Mat Gypsum Substrate for Use as Sheathing

C1186 Specification for Flat Fiber-Cement Sheets

C1289 Specification for Faced Rigid Cellular Polyisocyanurate Thermal Insulation Board

E331 Test Method for Water Penetration of Exterior Windows, Skylights, Doors, and Curtain Walls by Uniform Static Air Pressure Difference

E514 Test Method for Water Penetration and Leakage Through Masonry

E1105 Test Method for Field Determination of Water Penetration of Installed Exterior Windows, Skylights, Doors, and Curtain Walls, by Uniform or Cyclic Static Air Pressure Difference

X4.2.2 Other Standards:

U.S. Voluntary Product Standard for Construction and Industrial Plywood, PS1-95, U. S. Department of Commerce⁷

U.S. Voluntary Product Standard for Wood-Based Structural Use Panels PS2-92, U. S. Department of Commerce⁷

Performance Standards and Policies for Structural-Use Panels APA PRP-108, Manufacturing and Performance Standards for APA Rated Sidings, 1986⁸

X4.3 EIFS Types

X4.3.1 There are two types of EIFS, Class PB and Class PM. The systems are distinguished by their thickness and typical details.

X4.3.1.1 PB systems are characterized by attachment of rigid insulation board such as Specification C578 Type I expanded polystyrene insulation to a structural substrate using mechanical fasteners, a notched-trowel or ribbon-and-dab application of adhesive, or polyisocyanurate insulation such as Specification C1289 Type II using mechanical fasteners, a reinforced base coat approximately 2 mm ($\frac{1}{16}$ -in.) thick, and an architectural finish coat. PB systems are quite flexible and require fewer control joints than conventional cement/lime stucco.

X4.3.1.2 PM systems are characterized by mechanical attachment of reinforcing mesh and rigid insulation board such as Specification C578 Type IV or denser extruded polystyrene insulation or polyisocyanurate insulation such as Specification C1289 Type II to a structural substrate, a base coat approximately 6 mm ($\frac{1}{4}$ -in.) thick base, and an architectural finish coat. PM systems are more rigid than PB systems and have detailing requirements that are similar to conventional cement plaster (stucco), such as frequent control joints and edge beads.

X4.4 Methods of Water Penetration Resistance

X4.4.1 There are two basic ways to configure EIFS to resist water penetration: surface sealed barrier wall and water managed wall. These designations apply to the EIFS itself and not necessarily to other components of the wall and other surfaces that intersect the EIFS.

X4.4.2 Surface sealed barrier applications of EIFS rely on the exposed exterior face of the cladding to resist water penetration.

X4.4.2.1 When installed on a substrate that is not water resistant such as gypsum sheathing and the sheathing is not protected by a water-resistant barrier, such as building paper, building felt, or housewrap, the EIFS must function as a surface sealed barrier wall. Substrate surfaces of this type are vulnerable to damage, deterioration, and biological growth if subjected to more than incidental water.

X4.4.2.2 In a surface sealed barrier application, the EIFS surface, sealant joints, interfaced components such as windows, and the intersection with other surfaces such as roofs and chimneys must be installed in watertight manner and maintained for the life of the system. If an interfaced component or a surface intersection does not also perform as a surface-sealed barrier, flashing must be installed to prevent the intrusion of water through these other components and surfaces from getting behind the EIFS.

X4.4.3 Water managed EIFS walls rely on the water penetration resistance of both the exterior surface of the wall and a concealed water resistant barrier within the wall.

X4.4.3.1 The concealed water resistant barrier system, it is assumed that water will reach the concealed barrier. Therefore, the concealed barrier must be drained to the exterior at the bottom of the wall area and other appropriate locations. The barrier must also be sealed or flashed, or both, at the perimeter of all penetrations in the EIFS.

X4.4.3.2 Water resistant barriers using sheet materials such as No. 15 building paper are usually not suitable for adhesive application of EIFS and require the use of mechanical fasteners for the EIFS. Proprietary liquid applied or trowel applied water resistant barriers may be suitable for the adhesive application of EIFS.

X4.4.3.3 Drainage of the concealed water resistant barrier can be achieved by using a variety of methods, including grooves in the back of the insulation board, inclusion of a layer of material capable of draining such as lath, textured, or grooved barrier sheets, or the application of large vertically-oriented adhesive beads with a notched trowel. Other methods for draining the concealed weather resistant barrier currently being considered by the task group include textured, or grooved barrier sheet materials.

X4.4.4 Insulation board is not considered a water barrier.

X4.4.5 Detailing features such as a concealed water resistant membrane, double seals, and sloped horizontal joints can contribute to the water penetration resistance of an EIFS wall.

X4.5 Critical Material Properties

X4.5.1 EIFS are proprietary systems. All component materials should be obtained from a single manufacturer or from suppliers specifically approved by the manufacturer. Generic guide specifications are available from EIMA.

X4.5.2 The water resistance of the EIFS lamina is achieved primarily by the thickness, density, and composition of the reinforced base coat.

X4.5.3 A coarse-textured finish coat provides relatively little water resistance. The texture is achieved by dragging the

⁷ Available from National Institute of Standards and Technology (NIST), 100 Bureau Dr., Stop 1070, Gaithersburg, MD 20899-1070, <http://www.nist.gov>.

⁸ Available from APA – The Engineered Wood Association, 7011 S. 19th Street, Tacoma, WA 98466-5333, <http://www.apawood.org>.

aggregate through the finish, creating furrows virtually the full depth of the finish coat.

X4.5.4 Substrates—EIFS can be applied to a variety of structural substrates. The substrate may consist of masonry, concrete, or a board material spanning between wood or metal studs.

X4.5.4.1 Exterior gypsum sheathing with paper facing complying with Specification C79 or with glass mat facing complying with Specification C1177 have been common substrates for adhered PB systems. The sheathing can be damaged by prolonged wetting from any leakage source such as lamina failure, sealant failures, or leakage from windows, roofs, or coping. The most common failure mechanism for gypsum sheathing is delamination of the facing paper to which the EIFS is adhered and softening of the gypsum core around screw heads securing the sheathing to studs. Adhesive applied by the notched trowel method can localize damage of this type. Adhesive applied by the ribbon-and-dab method permits migration of water between the sheathing and the back of the insulation board, with the possibility of large areas of damage resulting from a small localized water entry point.

X4.5.4.2 Fiber-cement board complying with Specification C1186 and some cementitious backer units are also used as substrates for EIFS. These materials generally have significantly better resistance to water damage than gypsum sheathing.

X4.5.4.3 Plywood conforming to PS-1 Exterior or Exposure 1 or to PS-2, or oriented strand board (OSB) conforming to PRP-108 or PS-2 are also used as a substrate. Exposure to wetting where the moisture content of the panel exceeds 20 % for prolonged periods of time can result in wood decay.

X4.5.5 Class PB EIFS walls at high traffic areas are often provided with high impact mesh to increase impact resistance. Impact damage, which can be extensive at high traffic areas, can be a source of water penetration.

X4.5.6 If glass mat faced gypsum sheathing is used as a substrate for adhered PB systems, the facing may be in contact with adhesives containing cement. The facing must be adequately protected or resistant to alkalinity.

X4.6 Critical Details

X4.6.1 EIFS are proprietary systems and the manufacturer's specific recommended guide details should be followed. Guide details cannot cover all possible circumstances, but can serve as the basis for adaptation for special situations. Manufacturer's technical representatives can be requested to review details for a specific project. Generic details are available from EIMA.

X4.6.2 Cracking of the lamina is a serious problem because it can allow water penetration. The following practices have been shown to increase the likelihood of lamina cracking and should be avoided.

X4.6.2.1 Insulation board joints that align with the edges of wall openings.

X4.6.2.2 V grooves that fall over EPS board joints, that are aligned with wall openings, or which result in inadequate EPS thickness at the root of the groove.

X4.6.2.3 Corners of openings not reinforced with both diagonal mesh on the surface and mesh on the opening returns connecting vertical and horizontal return surfaces.

X4.6.2.4 Gaps between insulation boards left unfilled or filled with base coat material rather than slivers of insulation board.

X4.6.2.5 Adjacent EPS board surfaces that are not rasped flush and thus cause large differences in base coat thickness.

X4.6.2.6 Major changes in geometry such as re-entrant corners.

X4.6.3 Sealant joints are critical to the performance of EIFS; sealant failures can cause extensive system failures. A properly applied base coat is essential for good sealant joint performance.

X4.6.3.1 There must be adequate base coat thickness to fully embed the mesh without exposed mesh or mesh pattern at the edges or at surfaces to receive sealant.

X4.6.3.2 Joints must be wide enough to assure that the movement is well within the sealant's movement capability.

X4.6.3.3 Low modulus sealants should be used because they place less stress on the bond line.

X4.6.3.4 Sealant should generally be applied to the base coat, not the finish. Time must be allowed for the base coat to achieve adequate strength before sealant is applied. The EIFS manufacturer and the sealant manufacturer should be consulted regarding sealant type and placement.

X4.6.4 Horizontal surfaces hold moisture that in turn deteriorates the lamina. EIFS surfaces should have adequate slope to release snow and shed rain and are not intended for use on horizontal or near-horizontal weather exposed surfaces.

X4.6.4.1 Metal flashing should be used to protect window sills, projecting belt courses, and similar surfaces unless the surface has a pronounced slope for rapid drainage.

X4.6.4.2 Parapets should be protected by metal coping.

X4.6.5 The termination and interface of EIFS areas with other materials such as low roofs, balconies, porches, or masonry and the closure around penetrations such as windows and louvers are also critical to overall EIFS performance.

X4.6.6 Where metal is used to protect the top edge of EIFS, such as coping on a parapet or panning at a window sill, the lap of the metal over the EIFS must be sufficient to prevent wind-driven rain from blowing up under the metal. Alternatively, the interface between the metal edge and the EIFS can be sealed.

X4.7 Inspection

X4.7.1 Visual inspection is the most common means of EIFS wall evaluation.

X4.7.2 Quality workmanship is critical to the performance and durability of EIFS. The inspection program should have sufficient scope and extent to determine compliance with installation requirements.

X4.7.3 Promotional literature and design guidelines may not contain sufficient information for a complete understanding of system installation requirements. The manufacturer's technical bulletins, design manual, and installation manual should be consulted for a more complete understanding of application recommendations.

X4.7.4 The thickness of the base coat and the location of the mesh within the base coat are critically important. Most manufacturers' systems have a minimum base coat dry thickness of 1.6 mm. It is difficult to control the thickness of field

trowel-applied materials to exact tolerances, possibly resulting in areas significantly thinner than 1.6 mm ($\frac{1}{16}$ -in.) if proper application techniques are not utilized. Thin spots have been shown to allow water penetration through the lamina, which affects EIFS durability and sealant adhesion.

X4.7.5 All EIFS surfaces and sealant joints should be reviewed for cracking, sealant failure, efflorescence, mildew and algae growth, debonding, erosion of the finish, visible reinforcing mesh and mesh pattern, and visible board pattern.

X4.7.6 Conditions at wall penetrations and at abutting materials should be inspected. Sealant failures, flashing deficiencies, and unsealed penetrations are common sources of water entry. Locations that typically should be inspected include:

- X4.7.6.1 Windows, doors, and louvers.
- X4.7.6.2 Intersection of roofs and walls.
- X4.7.6.3 Balconies and porches.
- X4.7.6.4 Coping, gutters, and downspouts.
- X4.7.6.5 Chimney enclosures.
- X4.7.6.6 Handrail connections.
- X4.7.6.7 Utility penetrations such as water pipes, air conditioner lines, telephone lines, and electrical lines.

X4.8 Testing

X4.8.1 Moisture meter readings are useful to survey large areas and can indicate moisture in the sheathing. They give reliable relative moisture readings and can give reliable absolute moisture content readings if properly calibrated for the sheathing material.

X4.8.1.1 Resistance meters are more accurate than capacitance meters but require puncturing the lamina. Resistance meters are often used to verify capacitance readings.

X4.8.1.2 Resistance meters have insulated prongs that are intended to make electrical contact only at the tip. Electrical contact anywhere on the prong except at the tip may cause incorrect readings. The prongs should be replaced when their insulation becomes scratched or worn from use.

X4.8.1.3 The moisture content of the gypsum sheathing is a key indicator of the condition of the EIFS. Prolonged and significant leakage resulting in sheathing with a moisture contents above approximately 20 % will cause the paper facing to delaminate from the core of gypsum sheathing or the degradation and decay of plywood or OSB sheathing.

X4.8.2 Water testing to determine infiltration entry points and internal water paths is a useful diagnostic tool. An exterior pressurized chamber such as described in Test Methods **E331** or **E1105** can be used. The apparatus described in Test Method E514 can also be adapted for use with EIFS. Flood testing using temporary wax or tape troughs, or temporary dams, with a controlled water depth have also been successfully used for water testing. In assessing behavior during controlled water testing, the following should be considered:

X4.8.2.1 The insulation board is not a water barrier. Water that reaches the insulation board indicates a lamina failure even if there is no damage to the interior directly attributed to the entry path. It is necessary to make an inspection cut in the test area to determine if the insulation board got wet.

X4.8.2.2 Since EIFS is a multi-layer assembly, water may move between layers before it is observed on the interior. It is

advisable to disassemble a small portion of the test area from the interior so that water movement between layers can be observed. This is particularly important for an installation with a “ribbon-and-dab” adhesive pattern.

X4.8.3 A light mist spray with a simple hose spray can be effective in locating and accentuating hairline cracking.

X4.8.4 Test cuts are used to visually inspect the details of the application and the sheathing and to verify moisture meter readings. Details such as base coat thickness, mesh location, insulation board attachment, insulation board gaps, and edge back wrapping can be determined. Test cuts taken from the field can be tested for water permeability.

X4.8.4.1 Impact testing of the lamina can be performed in the field and indicates reinforcing mesh tensile strength.

X4.8.5 RILEM tubes can sometimes be used to determine if a hairline crack is allowing water penetration.

X4.8.6 Infrared thermography has been used to locate wet insulation and gaps between insulation boards but is often unsuccessful in locating moisture in the sheathing.

X4.9 Evaluation

X4.9.1 A systematic evaluation of leakage EIFS walls consistent with the general protocol in the body of this guide would include consideration of the following items:

- X4.9.2 Extent, severity, and location of cracking.
- X4.9.3 Debonding of the system from the substrate.
- X4.9.4 Debonding of the lamina from the insulation board.
- X4.9.5 Deterioration of the lamina, primarily at sloped surfaces and horizontal edges.
- X4.9.6 Severity and location of moisture.
- X4.9.7 Condition of sealant joints.
- X4.9.8 Condition of seals at penetrations.
- X4.9.9 Impact damage.
- X4.9.10 Condition of the sheathing, including moisture content, delamination, decay, and loss of structural integrity.
- X4.9.11 Condition of abutting materials and seals.
- X4.9.12 Condition of the finish, including fading, chalking, and erosion.
- X4.9.13 Mildew and algae growth.

X4.10 Sources of Additional Information

X4.10.1 *Conference and Symposia Proceedings:*
ASTM Special Technical Publications (STP1187 and STP1269), American Society for Testing and Materials, West Conshohocken, PA.

X4.10.2 *Books:*
Thomas, Robert G., *Exterior Insulation and Finish System Design Handbook* Exterior Insulation and Finish System Design Handbook, CMD Associates Inc., Seattle, WA, 1992.

Thomas, Robert G., *Exterior Insulation and Finish System Inspection Program Reference Manual* Exterior Insulation and Finish System Inspection Program Reference Manual, CMD Associates, Seattle, WA.

Williams, Mark F., Williams, Barbara Lamp, *Exterior Insulation and Finish Systems—Current Practice and Future Considerations*, American Society for Testing and Materials, ASTM Manual Series MNL 16, West Conshohocken, PA, 1994.
EIFS Restoration Guide, Dow Corning.

X4.10.3 *Industry Publications:*
EIMA Information Handbook, EIFS Industry Members Association, Morrow, GA.

X5. CEMENT STUCCO AND TILE SYSTEMS

X5.1 Scope

X5.1.1 **Appendix X5** provides investigation and evaluation practices for water leakage through cement stucco and tile veneered systems. The tile may be set using the thin-set or thick-set methods in a cement mortar, latex-modified mortar, or epoxy bonding mortar setting bed. The spaces between the tiles are grouted.

X5.1.2 *Definitions:*

X5.1.2.1 The term “stucco” is used to mean cement plaster for coating exterior surfaces. It is a mixture of Portland cement or other cementitious materials, sand, water, admixtures including pigments, and may contain lime. The term is not restricted to a factory-prepared finish coat mixture.

X5.1.2.2 The term “tile” is used to mean a fired clay manufactured product or natural stone up to 1-in. thick. It may be glazed or unglazed and have dimensions up to 24-in. It is intended for use in a bed of mortar to adhere it to a structural substrate.

X5.1.2.3 The term “base” is used to mean the surface or component to which the stucco or tile setting bed are applied. It may be concrete, stable masonry, metal lath on sheathing, metal lath on studs, or furring.

X5.1.2.4 In multilayer applications, the first coat is called the “scratch coat,” and the second is called the “brown coat.” These terms are based on traditional plastering terminology. A “finish coat” or tile is then applied as the weathering surface.

X5.2 Referenced Documents

X5.2.1 *ASTM Standards:*²

C1088 Specification for Thin Veneer Brick Made from Clay or Shale

E514 Test Method for Water Penetration and Leakage Through Masonry

E1105 Test Method for Field Determination of Water Penetration of Installed Exterior Windows, Skylights, Doors, and Curtain Walls by Uniform or Cyclic Static Air Pressure Difference

X5.2.2 *ACI Standard:*⁶

524R Guide to Portland Cement Plastering

X5.3 Method of Water Penetration Resistance

X5.3.1 Cement stucco systems generally resist water penetration by functioning as a barrier. The barrier is provided by a water resistant membrane applied between the base and the structural substrate or by the structural substrate itself. Stucco alone should not be considered a permanent barrier to water penetration.

X5.3.2 Tile systems generally resist water penetration by functioning as a barrier. The barrier is provided by the structural substrate or by a water resistant membrane applied between the base and sheathing or other structural substrate.

X5.4 Critical Material Properties

X5.4.1 Cement stucco and tile systems are built up in layers that must bond together. Reducing the interlayer bonding will diminish both the structural capacity and water penetration resistance of the system.

X5.4.1.1 Plasticizing admixtures may inhibit the interlayer bond.

X5.4.1.2 Excessive vitrification that limits the ability of mortar to bond to tiles may cause debonding and entrapment of water behind the tile. The requirements of Specification C1088 are intended to prevent this potential problem.

X5.4.2 Cementitious materials shrink as they cure. Excessive shrinkage can cause cracking in stucco and in mortar setting beds that will permit water penetration.

X5.4.2.1 Shrinkage cracking is affected by both material properties such as the water/cement ratio and additives and by the placement and functioning of joints.

X5.4.3 The material properties of the structural substrate are also critical to the water penetration resistance of the stucco or tile system. If the structural substrate is masonry or concrete, it must be dimensionally stable to avoid telegraphing cracks through the system. If the structural substrate is wood studs, they must be dry and stable at the time of stucco installation to avoid cracks due to twisting and warping.

X5.4.4 The freeze/thaw resistance of the stucco is important in cold climates. Freezing may cause cracks that permit water infiltration. Air-entraining is often used in cement stucco systems to help control freeze/thaw cracking.

X5.4.5 The material selected for the water resistant membrane must provide adequate protection for the structural substrate. If a sheathing material such as plywood or oriented strand board is used, a membrane material capable of providing protection for at least one hour is recommended in ACI 524.

X5.4.6 The material selected for use in stucco lathing accessories, such as expansion and control joints, corners, screeds, etc., must be corrosion resistant and stable under ultraviolet exposure. Deterioration of accessories can cause gaps and cracks in the surface that permit water penetration.

X5.4.7 The layers of a stucco or tile system must bond to each other and to the base. If surface absorption or material properties inhibit the required bond, surface-applied bonding agents are used. They would be used on smooth or very dense substrates or substrates with friable surfaces. Bonding agents can also be integrated in the mix. They are usually water-based acrylic or latex formulations that are added to the stucco or mortar during the mixing operation.

X5.5 Critical Details

X5.5.1 The water resistant membrane applied as part of a stucco or tile system must be drained to the exterior. At a penetration, this requires the use of flashing or integrating the

membrane with some other feature such as a nailing flange, water resistant trim or a weep screed.

X5.5.2 The structural substrate must be stiff enough to avoid cracking of the stucco or tile system from excessive bending.

X5.5.3 Sections of metal lath used in the base must be lapped to provide a continuous base for stucco and tile systems. Insufficient laps or butted lath does not provide continuity and can lead to a crack along the lap line. Excessive laps can also cause cracks. It is critical that industry standards based on the type of lath and the structural substrate be adhered to. The water resistant membrane must not interrupt or interfere with the lap region of the metal lath.

X5.5.4 Control joints are required to relieve stresses and control cracking in stucco and tile systems. Control joints can be created in stucco by scoring or cutting, grooving by using a temporary ground, or by installing manufactured control/expansion joint. The weather resistant membrane barrier should continue unbroken behind the control joint. Joints and intersections in manufactured control joint sections should be sealed. Sealant should be installed in grooves and scores used as control joints.

X5.5.5 There is no definitive requirement for the spacing of control joints. Recommendations range from 10-ft. to 18-ft., or spaced so that the panel size is between 100 and 144 square ft. and as close to square as possible. Other locations where joints are needed to relieve stresses are: corners of windows and other penetrations of the stucco, floor lines, changes in structural substrate, over construction joints, expansion joints, control joints in the structural substrate, and at junctures of dissimilar bases.

X5.5.6 Other accessories used in stucco systems are: corner reinforcement to protect stucco from damage at corners, weep screeds used at grade to permit drainage of water trapped behind the stucco, and casing beads to permit isolation of stucco areas from adjacent dissimilar construction.

X5.5.7 For systems in which the structural substrate is also the base, such as stucco applied directly to concrete or masonry, the base should be clean and free of voids, surface defects, and offsets so that the scratch coat of stucco has a uniform thickness. The absorption of the base should be as uniform as possible to avoid differential shrinkage of the stucco. It may be necessary to moisten highly absorptive surfaces prior to the application of the scratch coat.

X5.6 Workmanship

X5.6.1 The water penetration resistance of stucco and tile systems depends on both the proper installation of accessories and peripheral items such as the water resistant membrane, control joints, casing beads, etc., and the proper application of the stucco and tile.

X5.6.2 The layers of a stucco or tile system must be applied to the required thickness and be free of voids, entrapped air, and contaminants. The layers should have uniform thickness and be mixed and placed so that the drying characteristics are as uniform as possible.

X5.6.3 The scratch coat is usually scored horizontally to enhance the bond of the brown coat. Scores are approximately 1/8-in. deep. Deep scoring may cause voids during the application of the brown coat.

X5.6.4 Excessive troweling should be avoided because it can weaken the interface between layers.

X5.6.5 To achieve bond between the scratch and brown coats, the scratch coat is traditionally allowed to cure independently. Another accepted method is the "double back" application, with little or no delay between coats. In a double back application, the brown coat should not be applied until the scratch coat is rigid enough to resist cracking and should only be used over a solid base or on lath applied over sheathing.

X5.7 Inspection

X5.7.1 Many causes of leakage can be identified by visual inspection. Both the exterior and interior wall faces should be inspected to the extent possible. Cutting sections from the stucco, or making observations with a fiber-optic borescope, can permit visual inspection of concealed conditions.

X5.7.2 *Indicators of Possible Water Penetration*—There are several symptoms of water penetration that are worth noting during a visual inspection. Observation of these symptoms can also serve as a rational basis for further investigative activity.

X5.7.2.1 The presence of efflorescence indicates water exiting the stucco or tile system. Areas of heavy efflorescence can provide valuable information about the source of penetration.

X5.7.2.2 Corrosion of embedded metals such as lath, fasteners, and wire lacing may indicate water penetration.

X5.7.2.3 Biological growth such as moss or fungi on stucco or on tile grout many indicate prolonged dampness. Exposure of the stucco or tile surface to the sun should also be considered since biological growth is more likely on north elevations and on surfaces shaded from direct sun exposure.

X5.7.3 Visual inspection of the water resistant membrane, including laps and closure at penetrations, is usually the most important first step in evaluating water leakage problems in a stucco or tile wall system. Destructive openings are usually needed to expose the membrane for inspection.

X5.7.4 The proper thickness of coats, both individually and combined, the proper bond between the base and successive coats, the proper bonding and grouting of tiles if used, and the proper curing of the various layers, should all be considered since they can affect water penetration resistance of the system.

X5.7.5 The locations, installation details, and current condition of control joints and casing beads should be determined as part of the inspection.

X5.7.6 The condition and adhesion of sealants, particularly at the perimeter of penetrations and at the transition to other wall construction should be determined as part of the inspection.

X5.8 Testing

X5.8.1 Testing may be needed to supplement visual inspection to determine or verify water entry locations and water paths.

X5.8.2 *Water Spray Testing*—Water penetration locations and water paths can be assessed by a water spray test. This test can be hose test or a more controlled and reproducible test, such as a modified Test Method E514 laboratory test for field applications or a Test Method E1105 chamber test.

X5.8.3 *Moisture Meters*—Moisture meters are useful for comparing different areas of masonry to establish a relative moisture content.

X5.9 Evaluation

X5.9.1 A systematic evaluation of leakage of cement stucco and tile system walls consistent with the general protocol in the body of this guide would include consideration of the following:

X5.9.2 Some water penetration of the exterior face of stucco is anticipated and normal.

X5.9.3 Even minor water penetration of tile systems subjected to freeze/thaw climates may cause damage.

X5.9.4 Assessment of the exterior surface and the barrier layer.

X5.10 Sources of Additional Information

X5.10.1 Sources:

Bucholtz, John J., *Water Leaks and Water Traps in Stucco Buildings - How to Prevent Them*, Construction Quality Engineers, San Jose, CA, no date

Handbook of Ceramic Tile Installation, Tile Council of America, Princeton, NJ (updated periodically)

Gorman, J.R., Jaffe, Sam, Pruter, Walter F., and Rose, James J., *Plaster and Drywall Systems Manual*, BNI Books Division of Building News, Inc., Los Angeles, CA, dist McGraw-Hill, NY, 1988

Lavenburg, George N., and Jaffe, Sam, ed., *Ceramic Tile Manual*, Building News Inc., Los Angeles, CA, published for the Ceramic Tile Institute, 1979

Melander, John M., Isberner, Albert W., *Portland Cement Plaster (Stucco) Manual*, Portland Cement Association, Skokie, IL, 1996

X6. WOOD AND MANUFACTURED WOOD-BASED SIDING SYSTEMS

X6.1 Scope

X6.1.1 **Appendix X6** provides investigation and evaluation practices for water leakage through wood and wood-based siding. Siding systems included within the scope are: lumber siding, wood shingles, wood shakes, plywood, and wood composition sidings such as hardboard, oriented strand board, and waferboard, referred to collectively as wood-based siding.

X6.1.2 Comments concerning wood decay refer to degradation by loss of weight and strength due to air-borne and water-borne fungi. Problems associated with termites and other wood-consuming insects are not included in the scope.

X6.2 Referenced Documents

X6.2.1 *ASTM Standards*:²

D779 Test Method for Water Resistance of Paper, Paperboard, and Other Sheet Materials by the Dry Indicator Method

D4444 Test Method for Laboratory Standardization and Calibration of Hand-Held Moisture Meters

X6.2.2 *Other Standards*:

American National Standard for Hardboard Siding, ANSI/AHA A135.6-1990, American National Standards Institute⁹

Performance Standards and Policies for Structural-Use Panels APA PRP-108, Manufacturing and Performance Standards for APA Rated Sidings, 1994⁸

U.S. Product Standard for Construction and Industrial Plywood, PS1-83, U. S. Department of Agriculture⁷

X6.2.3 *Other Publications*:

AATCC-127 “Water Resistance: Hydrostatic Pressure Tests,” American Association of Textile Chemists and Colorists

General Technical Report FPL-GTR-69, “Exterior Wood in the South: Selection, Application, and Finishes,” U. S. Department of Agriculture, Forest Products Laboratory

X6.3 Methods of Water Penetration Resistance

X6.3.1 Individual units of wood-based siding in good condition are normally resistant to water penetration. However, the cladding system has several potential water entry paths such as: (1) through deteriorated or damaged units, (2) at interfaces between units, (3) at the interface with trim and casing, (4) at penetrations such as vent hoods, electrical fixtures, spigots, etc., (5) at the intersection of walls with roofs, and (6) at the intersection of walls with patios, decks, and grade.

X6.3.2 Wood or wood-based siding is expected to resist water penetration, but usually is not expected to act as a perfect barrier. Water that is absorbed into or penetrates the exterior cladding material is intended to be evaporated directly to the atmosphere or to be temporarily retained by the siding system and subsequently evaporated. A continuous water resistant barrier such as a building felt or synthetic fiber membrane is often necessary as a secondary barrier to retain water within the siding system and to prevent infiltration to the frame and interior. However, large panel wood-based siding can be effective without secondary barriers if special precautions are taken at edges and butt joints.

X6.3.3 Wood-based siding materials can be used in drainage and rain screen wall systems if a complete water and air infiltration resistant barrier is used behind the siding.

X6.4 Critical Material Properties

X6.4.1 Wood-based siding materials are expected to provide effective resistance to water penetration and maintain the integrity of the barrier for years of exposure.

X6.4.2 *Defects and Voids*—Siding that is free of defects and voids that create openings through the material can function as a barrier. Defects such as loose knots may develop into voids upon weather exposure.

X6.4.3 *Dimensional Stability*—Wood swells when it absorbs water and shrinks when it dries. Wood-based sidings are anisotropic and their moisture-induced dimensional changes

⁹ Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, <http://www.ansi.org>.

usually differ in the length, width, and thickness directions. Accepted installation practices account for anticipated dimensional changes.

X6.4.3.1 Problems associated with excessive dimensional changes that cannot be accommodated by standard installation practices include warping, buckling, and splitting, which can result in water penetration past the siding and possible environmental degradation of the secondary water resistant barrier. Warp includes cup, twist, and crook. It can result from grain deviations, juvenile wood, and moisture gradients. Buckling results from restrained increases in the length or width of siding material. Shrinkage of framing headers and band joists can cause buckling of siding. Splitting results from restrained shrinkage or crook that exceeds wood strength.

X6.4.4 Durability—Durable wood-based sidings retain their structural and water resistance integrity.

X6.4.4.1 Decay Resistance—Decay resistance can be achieved by using naturally durable wood species, or by treating with a toxic preservative. Decay resistance can be enhanced by treatment of concealed edges and backs with a water repellent. Selection of a vapor permeable finish can also enhance decay resistance by allowing rapid drying.

X6.4.4.2 Delamination Resistance—Plywood and wood composite sidings can maintain their integrity if adequately bonded. Inadequate bonding of wood composite sidings usually results in delamination and excessive and irreversible edge swelling and can lead to joint and finish failures and the onset of decay and leakage.

X6.4.5 Material Selection—Wood and wood-based products should be certified as suitable for use as a siding material under industry-recognized rules.

X6.4.5.1 Lumber Siding—Grading rules and the certifying agency for siding applications vary with the source and species used. Narrower width vertical-grain siding is generally preferred because of its ability to accommodate moisture-induced volume changes. Vertical-grain, rough or saw-textured surfaces also retain finishes better than flat-grain smooth-surface siding.

X6.4.5.2 Shingles and Shakes—Clear shingles and shakes will serve the purpose of a barrier better than those that include defects. Vertical grain shingles and shakes will be more dimensionally stable across their width and will retain finish better than those of mixed or flat grain. Heartwood generally has better decay resistance than sapwood. Industry grading rules take defects, face grain, and heart-wood/sapwood into account. Shingles and shakes of lower grade can be used effectively if used as undercoursing or at lower exposures.

X6.4.5.3 Plywood—The interply adhesives used must be classified for exterior exposure, have adequate resistance to delamination, and meet the requirements in U.S. Department of Commerce Standard PS-1 for Exterior Exposure or APA PRP-108 for Exterior Siding. In addition, the plywood should be certified as a siding material conforming to accepted industry standards that vary with the source and species used.

X6.4.5.4 Wood Composition Siding (Waferboard, Oriented Strand Board and Hardboard)—These products may be certified as conforming to an industry standard for wood-based siding, such as APA. Hardboard siding is usually certified as

conforming to ANSI/AHA A135.6-American National Standard for Hardboard Siding.

X6.4.6 Finishes—Finishes are expected to protect the wood siding from the degrading influences of light and moisture. The ability of a finish to limit water absorption results in reduced time and spatial variation in moisture content and in reduced cyclic shrinkage and swelling stresses in the siding and at the wood/finish interface. The finish must also be vapor permeable to allow drying and to minimize peeling and blistering of the finish.

X6.4.7 Water Resistant Membrane—A water resistant membrane is used under siding to protect the framing and interior from water that does penetrate the exterior siding. Traditionally, No. 15 asphalt-saturated felt or an equivalent synthetic sheet material has been used for this purpose. The required water penetration resistance as measured by Test Method D779 or AATCC-127 depends on the environmental exposure. Some alternative systems rely on a water resistant surface of the sheathing to serve as a membrane, but the sheathing joints may be water leakage paths.

X6.4.7.1 Air Movement Resistance—The membrane also resists the exchange of air between the interior and the exterior. In addition to improving the overall thermal performance of the wall, controlling air movements will influence the moisture conditions within the siding materials.

X6.4.7.2 Water Vapor Transmission—The membrane will have some resistance to water vapor transmission. The acceptable rate of water vapor transmission is a design decision to limit potentially damaging condensation problems.

X6.4.8 Fasteners—In addition to their structural function, fasteners are important to resist distortion of wood siding and trim that could contribute to water penetration. Corrosion of fasteners can effect holding power and contribute to finish failure. Only non-corrosive fastener materials, such as stainless steel, aluminum, or zinc-coated steel, should be used for siding installation.

X6.4.9 Sealants—Wood is not an ideal substrate for active sealant joints. Sealants should be used in wood siding systems as gap and crack fillers rather than engineered dynamic joint systems. Modern polyurethane and silicone sealants have the necessary flexibility, resistance to weathering and UV degradation, and adequate bond and are, in some cases, paintable.

X6.5 Critical Details

X6.5.1 Separation from Grade—Wood-based siding must be isolated from wood-degrading organisms and moisture at grade. The minimum recommended separation varies with climatic conditions. The customary minimum separation is 15 cm (6 in.). In the warmest and wettest areas, 30 cm (12 in.) to 46 cm (18 in.) may be recommended. Separation from grade also limits splash-wetting and allows clearer inspection for termite tunnels. As a further means of isolation from soil moisture and rising dampness in foundation walls, a capillary break between the siding and foundation is often recommended.

X6.5.2 Orientation of Installation—Siding materials can be installed horizontally or vertically, depending on the geometry of the pieces and the system design. Manufacturer's or trade

association guidelines should be followed. Diagonal installation can channel water into window and door casings and other joinery details. If diagonal installation is used, the wall must be designed to accommodate the direction of runoff.

X6.5.3 Joints, Transitions and Laps—Sealants are generally not relied upon as the sole barrier to water penetration in wood siding joints. Overlapping siding materials in a “shingle” fashion is a traditional and effective method of controlling water penetration for lumber, shingle, and shake systems. The greater the overlap, the greater the differential pressure the siding system can accommodate during wind-driven rain. Typical overlaps vary from 25 mm (1 in.) for plywood to 40 mm (1.5 in.) for lumber siding. Lap type trim designs have also proven effective, and if properly designed and installed, can accommodate moisture-induced dimensional changes. Backpriming with water repellents is usually recommended to control water penetration by capillary action. Alternatives to overlapping have additional special requirements:

X6.5.3.1 Machined Edges—Shiplap and tongue-and-groove edges can be effective means of controlling leakage. Joints should be sized to accommodate the expected differential pressure during wind-driven rain. Treatment of machined edges with a water repellent is usually recommended to limit water penetration by capillary action.

X6.5.3.2 Batten Strips—Vertical batten strips can be effective and are in essence a form of lap joint. In contrast, horizontal batten strips can trap water, which promotes leakage and decay.

X6.5.3.3 In the absence of an overlap in horizontal joints, flashings are essentially the only reliable means to prevent water penetration. “Z” shaped metal strips with a drip edge are commonly used for this purpose in panel systems.

X6.5.3.4 Prefabricated butt caps are often used at outside corners in horizontally installed lap siding systems. These are generally more reliable and durable than sealant joints at outside corners.

X6.5.3.5 Panel Vertical Joints—Vertical butt joints in square-edged panels are not water resistant and should be covered with battens and installed over a secondary water resistant membrane. Shiplap vertical edge joints can be used in panel installations. The effectiveness of this system without a secondary water resistant membrane depends on the environmental exposure of the wall.

X6.5.4 Roof Edges—The traditional method of achieving water resistant performance at the top of a wall is to provide an adequate roof overhang and to include a fascia, soffit with a continuous drip, and gutters. In the absence of an adequate overhang, the roofing membrane and the coping should lap the top of the wall. The height of the lap must be sufficient to resist upward vertical movement of wind-driven rain at the roof edge. If sufficient lap height is not practical, then the roofing membrane should be lapped and fully adhered to the vertical face of the siding to preclude wind-driven rain from reaching the top of the wall.

X6.5.5 Window and Door Openings—Traditional door and window installations include casing trim that laps the siding. The head and sill should slope downward to the exterior, extend beyond the siding and the window, and have a drip

edge. Many contemporary products incorporate flanges that are nailed over the water resistant membrane; their performance can be enhanced by adding another layer of membrane to the perimeter. Nailing flanges are usually the best method for installing flush or untrimmed windows and doors. Exposed door sills present special problems; they are subjected to both wear and wetting. Water leakage under the door sill and water flowing from an adjacent deck or step are common problems.

X6.5.6 Penetrations—Sealants are generally relied upon to prevent water infiltration around small penetrations such as spigots and outlets. Judicious use of the water resistant membrane and flashings are required for larger penetrations. Framing members that penetrate the wall, such as cantilevered balcony framing, are especially troublesome. The use of ledgers and posts is generally preferable to framing that penetrates the wall.

X6.5.7 Finishes, Including Backpriming—Finishes on the exposed and concealed faces and edges of wood-based siding enhance the dimensional stability of the installed products. Finishes reduce the fluctuations in moisture content and reduce the moisture gradient within the pieces. Finishes on plywood siding are needed to prevent delamination of the veneers.

X6.6 Workmanship

X6.6.1 Moisture Content at Installation—To avoid excessive shrinkage or swelling, siding should be installed at a moisture content close to its equilibrium moisture content in service. Moisture content can be easily determined during installation, but it is nearly impossible to precisely determine retroactively. Performance characteristics such as buckling or bowing probably indicate incorrect moisture content at installation, possibly combined with other installation problems.

X6.6.2 Fasteners—Problems with siding fasteners include over driving by pneumatic nailers, inadequate length, incorrect and nonuniform nailing patterns, missing the required substrate, corrosion, and inadequate edge distances. Excessive spacing can cause buckling and distortions of the siding. With lumber siding, the fastener pattern must accommodate cross-grain dimensional changes in order to prevent splitting.

X6.6.2.1 Under conditions of substantial thermal or moisture cycling, ring-shank or spiral-shank nails, or screws, provide superior resistance to thermal withdrawal.

X6.6.3 Membrane—The membranes should be sealed or flashed at large penetrations. It should be installed in shingle fashion with a minimum horizontal lap of 5 cm (2 in.) and a minimum vertical lap of 15 cm (6 in.). At locations where the membrane may be subjected to severe wind pressures and at penetrations and openings, the lap should be increased. An additional split sheet of half-width felt is often applied at corners because these areas are subject to greater physical abuse during construction.

X6.6.4 Finishes—Finishes should be applied promptly after siding installation. Even short delays can reduce final adherence. Surface preparation and ambient conditions must comply with the finish manufacturer’s recommendations. Brush applications generally provide the best finish adherence; roller, spray, or pad methods can speed depositing the finish on the siding, but superior adhesion is obtained if they are followed by brushing.

X6.6.5 Maintenance—Exposure to excessive roof runoff will eventually cause siding facades to leak. Gutters and downspouts must be maintained to flow freely and be kept clear of leaves and other debris. If blockage by ice buildup occurs, heat trace wires can be used to keep the gutters and downspouts flowing in cold weather. Wetting of the base of the wall should be anticipated unless the down-spout discharge is unobstructed and directed away from the wall. The finish that protects the wood siding must also be maintained in good condition and periodic reapplication should be anticipated. Where sealants are used as part of the exterior, periodic inspection, and prompt repair is prudent.

X6.7 Inspection

X6.7.1 Exterior Inspection—Exterior inspection can often identify if joint, trim, flashing, and fastening details are proper. Symptoms that may indicate water leakage can be categorized as: siding mechanical failures; finish failures; and staining.

X6.7.1.1 USDA. Report GTR 69 provides guidance on interpreting finish failures and staining, many incidences of which relate to water penetration.

X6.7.1.2 Since maintenance is critical to the performance of wood siding systems, a thorough inspection will include maintenance items such as gutters, downspouts, and sealants.

X6.7.2 Interior Inspection—Deterioration of interior finishes, particularly paint on interior trim around wall openings, should be noted. The locations of stains and mildew, and the presence of a musty odor, also can provide information about wall leaks.

X6.7.3 Concealed Conditions—Wood siding systems on wood framed structures have a large absorption and retention capacity that may cause concealed damage. It is important to include observations of the mud sill, top and bottom plates, sheathing, insulation, headers at openings, framing below openings, membrane condition and installation, flashing terminations, and soffit framing in the scope of the inspection. Use of a fiber-optic borescope will minimize damage during inspections for concealed conditions.

X6.8 Testing

X6.8.1 In addition to spray testing and system disassembly described in the guide, the following test methods have also been found useful for wood-based siding systems:

X6.8.2 Moisture Meter Measurements—Moisture meter measurements can be used to determine the moisture content of wood siding and framing components in accord with Test Method D4444. Species and temperature corrections, or corrections for integral adhesives, may be necessary if an accurate absolute measurement is required, but uncorrected relative measurements can also provide useful information. Plotting variations in meter readings with location helpful in locating the source of a leak.

X6.8.3 Relative Humidity Measurements—Wand style electronic relative humidity meters can be used by inserting through small diameter holes drilled through the interior or exterior surface of the wall. In-wall relative humidity data can help determine if condensation is a contributor to water damage problems and help identify areas where water is accumulating in the wall.

X6.8.4 Water Path Tracing—Water that enters the wall may be retained or migrate along concealed paths and not be readily observable. Two methods of tracing concealed water paths have been used successfully with wood siding systems: monitoring of variations in an induced alternating current electromagnetic field; and the addition of alcohol to water used for spray testing and subsequent tracing using an organic vapor detector. Alcohol is combustible and must be used with caution.

X6.9 Evaluation

X6.9.1 A leakage evaluation of wood siding systems should include consideration of the following:

X6.9.2 Windows, doors, and other manufactured products in wall penetrations should be potential entry paths. A distinction should be made between water infiltration through the basic wall system and infiltration through other components in the wall that may appear to be wall leaks.

X6.9.3 Proper orientation and lapping of flashing and the water resistant membrane in a shingle fashion or proper sealing of these components to flashing flanges of doors and windows, and around other large wall penetrations, should be verified.

X6.9.4 Installation details and the interface between door sills and jambs, should be examined. Door sills, particularly at decks and balconies, are a common source of water infiltration if not properly flashed and raised above the adjacent surfaces.

X6.9.5 Copings, roof edge treatments, gutters, and downspouts must prevent excessive roof runoff from washing down over the wall. Coping must sufficiently lap the top of the wall so that wind-driven rain cannot be blown into the top of the wall.

X6.9.6 Distressed siding, with symptoms such as warping, cupping, splits and checks, or wood decay should be studied. Also, adequate accommodation of moisture induced distortions and dimensional changes must be accommodated by the installation.

X6.9.7 Maintenance items such as clean gutters and downspouts, functional sealants, and viable finishes should be verified. Finish failures such as blistering or peeling may be a sign of leakage or of excessive water absorption by the siding or a failure of the wall system to adequately drain and dry.

X6.10 Sources of Additional Information

X6.10.1 Sources:

Bateman, R., “Nail-on Windows: Installation & Flashing Procedures for Windows and Sliding Glass Doors,” DTA Inc., Mill Valley, CA, 1995.

Cassens, D., and Feist, W., “Finishing Wood Exteriors: Selection, Application and Maintenance,” Agriculture Handbook #647, U. S. Department of Agriculture Forest Service, 1986.

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X7. FIBER-CEMENT AND CEMENT-BONDED PARTICLE BOARD SIDING SYSTEMS

X7.1 Scope

X7.1.1 **Appendix X7** provides investigation and evaluation practices for water leakage through fiber-cement and cement-bonded particle board siding. Siding systems included within the scope are lap siding, shingles, shakes and slates, and flat sheets and panels.

X7.1.2 Comments concerning wood fiber decay address only air-borne and water-borne fungi.

X7.2 Referenced Documents

X7.2.1 *ASTM Standards*:²

D779 Test Method for Water Resistance of Paper, Paperboard, and Other Sheet Materials by the Dry Indicator Method

X7.2.2 *Other Standards*:

AATCC-127 “Water Resistance: Hydrostatic Pressure Tests,” American Association of Textile Chemists and Colorists

X7.3 Methods of Water Penetration

X7.3.1 Individual units of fiber-cement and cement-bonded particle board siding in good condition are normally resistant to water penetration. However, the cladding system has several potential water entry paths such as: (1) through deteriorated or damaged units; (2) at butt and lap joints between units; (3) at the interface with trim and casing; (4) at penetrations such as lighting fixtures, vent hoods, outlets, spigots, etc.; (5) at the intersection of walls with roofs; and (6) at the intersection of walls with patios, decks, and grade.

X7.3.2 Most fiber-cement and cement-bonded particle board siding systems are intended to be barrier walls. Water that may penetrate the exterior cladding material is intended to be evaporated directly to the atmosphere or to be temporarily retained by the siding system and subsequently evaporated. A continuous weather-resistive barrier such as building felt or proprietary sheet membranes are often necessary as a secondary barrier to retain water within the siding system and to prevent infiltration to the framing and into the interior. Fiber-cement panel siding can be an effective weather-resistive barrier without secondary barrier if special precautions are taken at edges and joints.

X7.3.3 Fiber-cement and cement-bonded particle board products may be used in drainage and rain screen wall systems if a complete primary weather-resistive barrier is used behind the siding.

X7.4 Critical Material Properties

X7.4.1 Fiber-cement and cement-bonded particle board siding materials used in a barrier wall systems should provide effective resistance to water penetration and maintain the integrity of the barrier for years of exposure.

X7.4.2 *Decay Resistance*—Fiber-cement is inherently decay-resistant due to its constituent components and its manufacturing processes. Cement-bonded particle board exposed to similar corrosive environments may result in some surface deterioration. The resulting moisture in the cement-bonded particle board elevates the equilibrium moisture content of the product that may lead to fungal attack of the wood fiber matrix.

X7.4.3 *Dimensional Stability*—Long-term exposure of unsealed or unpainted cement-bonded particle board may demonstrate some swelling as it absorbs moisture and may shrink as it dries. These changes in dimension result from different rates of drying shrinkage in different directions within the sheet; the edges, especially cut edges, may be more susceptible to dimensional change than the body of the boards because of the openings between the fibers and the exposed cement matrix. Such dimensional changes may expose the secondary weather resistive membrane to environmental deterioration.

X7.4.4 *Matrix Integrity*—Fiber-cement and cement-bonded particle board siding materials should be free of defects and voids that could result in leakage and free of defects that could develop into voids, such as broken corners. Cyclic exposure to temperature and moisture changes may cause changes in the volume of these siding products. Volume changes cause stress in restrained pieces used in siding systems. Cracks around fasteners may develop when volume changes are large and the resulting stresses exceed the strength of the siding products, thereby opening paths for water penetration.

X7.4.5 *Material Selection*—Fiber-cement and cement-bonded particle board products should be certified as suitable for use as a siding material under international, national or industry-recognized grading rules. These standards may also specify dimensional tolerances, dimensional stability, and other physical or mechanical product characteristics.

X7.4.5.1 *Fiber-Cement Siding*—National standards currently exist to uniformly describe the grades and types of these building products. The products should be certified as suitable for use as exterior siding materials in applicable building code compliance reports.

X7.4.5.2 *Fiber-Cement Shingles, Shakes, and Slates*—National standards currently exist to uniformly describe these types of building products. The products should be certified as suitable for use as exterior siding materials in applicable building code compliance reports.

X7.4.5.3 *Cement-Bonded Particle Board Siding*—Industry-recognized guidelines currently exist to uniformly describe these types building products. The products should be certified as suitable for use as siding materials in applicable building code compliance reports.

X7.4.6 Finishes—Finishes should enhance the weather-resistiveness of fiber-cement sidings and protect cement-bonded particle board siding from the potential degrading influences of light and moisture. Maximum protection is provided by the high-solids content of opaque finishes. Semi-transparent and transparent finishes generally provide less protection than good-quality exterior paint and opaque stains. The ability of a finish to limit moisture absorption results in reduced cyclic shrinkage and swelling stresses in the siding and at the product interface. The finish must also transmit moisture to allow drying and to minimize the potential for peeling and blistering of the finish.

X7.4.7 Weather Resistive Membrane—A weather-resistive membrane used under siding is intended to protect the framing and interior from water that may penetrate the exterior siding. Traditionally, a No. 15 asphalt-saturated Kraft paper has been used for this purpose. Other proprietary sheet products may also be acceptable as membranes and should have at least the same water penetration resistance as the No. 15 asphalt-saturated paper as measured by Test Method D779 or ASTCC 127. Some alternative systems rely on the water resistant surface of the sheathing to serve as a membrane, but the sheathing joints may be water leakage paths.

X7.4.8 Air Movement Resistance—The membrane also resists the exchange of air between the interior and the exterior. In addition to improving the overall thermal performance of the wall, controlling air movements will also influence the moisture conditions within the siding materials.

X7.4.9 Water Vapor Transmission—The membrane will have some resistance to water vapor transmission. The acceptable rate of water vapor transmission is a design decision. In cold climates, the rate of water vapor transmission should be a least equivalent to the No. 15 asphalt-saturated paper to limit potentially damaging condensation problems.

X7.4.10 Fasteners—In addition to their structural function, fasteners are important to resist distortion of fiber-cement and cement-bonded particle board siding and trim that could contribute to water penetration. Corrosion of fasteners can effect holding power and contribute to finish failure. Only non-corrosive fastener materials such as stainless steel, zinc-coated steel, or other corrosion-resistant coated steel should be used.

X7.4.11 Sealants—Fiber-cement provides an adequate substrate for active sealant joints. Cement-bonded particle board is not an ideal substrate for active sealant joints. Therefore, sealants should be used in cement-bonded particle board siding systems as gap and crock fillers rather than engineered dynamic joint systems. Modern polyurethane and silicone sealants have the necessary flexibility, resistance to weathering and UV degradation, and adequate bond and are, in some cases, paintable.

X7.5 Critical Details

X7.5.1 Separation from Grade—Cement-bonded particle board should be isolated from wood-degrading organisms and moisture at grade. The minimum recommended separation varies with climatic conditions; in the warmest and wettest areas of the United States, 15 cm (6 in.) is usually recommended. Separation from grade also limits splash-wetting and

allows clearer inspection for termite tunnels. As a further means of isolation from soil moisture and rising dampness in foundation walls, a capillary break between the siding and foundation is often recommended.

X7.5.2 Orientation of Installation—Fiber-cement and cement-bonded particle board products can be installed horizontally or vertically, depending on the geometry of the pieces and the system design. Manufacturer's or trade association guidelines must be followed. Diagonal installation can channel water into window and door casings and other joinery details. If diagonal installation is used, the project must be designed to accommodate the direction of runoff.

X7.5.3 Joints, Transitions, and Laps—Some fiber-cement panel and cement-bonded particle board systems rely upon sealants as the sole barrier to water penetration. Overlapping siding materials in a "shingle" fashion are also a traditional and effective method of controlling water penetration for lap sidings and shingle and shake systems. The greater the overlap, the greater the differential pressure the siding system can accommodate during wind-driven rain. An overlap of 3 cm (1¼ in.) is usually the minimum overlap for horizontally installed fiber-cement lap siding and 4 cm (1½ in.) for cement-bonded particle board lap siding. Lap type trim designs have also proven effective and, if properly designed and installed, can accommodate moisture-induced dimensional changes. Backpriming of cement-bonded particle board siding with water repellents may be recommended to control water penetration by capillary action. Alternatives to overlapping have additional special requirements.

X7.5.3.1 Machined Edges—Shiplap and tongue and groove edges can be effective means of controlling leakage. Joints should be sized to accommodate the expected differential pressure during wind-driven rain. Treatment of machined edges of cement-bonded particle board with water repellent may be recommended to control water migration by capillary action.

X7.5.3.2 Batten Strips—Vertical batten strips can be effective and are in essence a form of lap joint. In contrast, horizontal batten strips can trap water thereby increasing the potential for leakage.

X7.5.3.3 Panel Vertical Joints—Vertical butt joints in square-edged panels are not weather-resistant and should either be covered by battens, caulking, or sealants or installed over secondary weather-resistive membranes. Shiplap vertical edge joints can be used in panel installation and are often installed without a secondary weather-resistive membrane. The effectiveness of the system depends on the environmental exposure on the wall.

X7.5.3.4 Internal and External Corner Trim—Prefabricated butt caps or lap type trim applications are often used at outside corners in horizontally installed lap siding systems. These are generally more reliable and durable than sealants joints at outside comers.

X7.5.3.5 In the absence of an overlap in horizontal joints or use of elastomeric joint sealants, flashings are essential. "Z" shaped metal strips with a drip edge are commonly used for this purpose in panel systems and direct-applied exterior finish systems.

X7.5.4 Roof Edges—The traditional method of providing water resistant performance at the top of a wall is to provide an adequate roof overhang and to include a fascia, soffit with a continuous drip, and gutters. In the absence of an adequate overhang, the roofing membrane and the coping should lap the type of the wall. The height of the lap must be sufficient to resist upward vertical movement of wind-driven rain at the roof edge. If sufficient lap height is not practical, then the roofing membrane should be lapped and fully adhered to the vertical face of the siding to preclude wind driven rain from reaching the top of the wall.

X7.5.5 Window and Door Openings—Traditional door and window installations include casing trim that laps the siding. The head and sill should slope downward to the exterior, extend beyond the siding and the window, and have a drip edge. Contemporary products can incorporate flanges that are nailed over the weather-resistive membrane; their performance can be enhanced by adding another layer of membrane to the perimeter. Nailing flanges are the best method for installing flush or untrimmed windows and doors. Exposed door sills present special problems; they are subjected to both wear and wetting. Water leakage under the door sill and water flowing from an adjacent deck or step are common problems.

X7.5.6 Penetrations—Sealants are generally relied upon to prevent water infiltration around small penetrations such as spigots and outlets. Judicious use of the weather-resistive membrane and flashings are required for larger penetrations. Framing members that penetrate the wall, such as cantilevered balcony framing, are especially troublesome. The use of ledgers and posts may be preferable to framing that penetrates walls.

X7.5.7 Finishes, including Backpriming—Finishes on the exposed edges of cement-bonded particle board may be necessary to enhance the dimensional stability of the installed products. Finishes reduce the fluctuations in moisture content and reduce the moisture gradient within the pieces. Finishes on fiber-cement siding may be needed to enhance their weather-resistive properties.

X7.6 Workmanship

X7.6.1 Moisture Content at Installation—To avoid potential shrinkage, fiber-cement and cement-bonded particle board should be installed at a moisture content close to their equilibrium moisture content in service. The products should be kept covered and dry prior to installation. Performance characteristics such as buckling, bowing, or warping problems may indicate incorrect moisture content at installation, other installation problems, or excessive panel volume change properties related to moisture content.

X7.6.2 Fasteners—Problems with siding fasteners include under driving or over driving by pneumatic nailers, inadequate length, incorrect and nonuniform nailing patterns, corrosion, and inadequate edge distance. Excessive spacing can cause buckling and distortions of the siding.

X7.6.2.1 Staples should not be used to fasten fiber-cement or cement-bonded particle board sidings as the crushing of the matrix may result in the holding power in the products being inadequate for the design loads.

X7.6.2.2 Thermal changes in the fastener material, and cyclic swelling of the surrounding cement-bonded particle board, can cause fastener “withdrawal.” For this reason, ring-shank or spiral-shank fasteners should be used.

X7.6.3 Membrane—The membranes should be sealed or flashed at large penetrations. They should be installed in shingle fashion with a minimum horizontal lap (headlap) of 5 cm (2 in.) and a minimum vertical lap (sidelap) of 15 cm (6 in.). At locations where the membrane may be subjected to severe wind pressures, and at penetrations and openings, the laps should be increased. An additional split sheet of half-width felt is often applied at corners because these areas are subject to greater physical abuse during construction.

X7.6.4 Finishes—Finishes should be applied promptly after siding installations. Surface preparation and ambient conditions must comply with the finish manufacturer’s written recommendations. Brush applications generally provide the best finish adherence; roller, spray, or pad methods can speed the process of depositing the finish on the siding, but superior results are obtained if they are followed by brushing.

X7.6.5 Maintenance—Exposure to excessive roof runoff may eventually cause siding facades to leak. Roof valleys, gutters, and downspouts must be maintained to flow freely and be kept clear of leaves and other debris. If blockage by ice buildup occurs, heat trace wires can be used to keep the gutters and downspouts flowing in cold weather. The downspout discharge must be unobstructed and directed away from the wall, and the splash must not continually wet the base of the wall. The finish, which protects the fiber-cement or the cement-bonded particle board siding, including any sealants, must also be maintained in good condition, and periodic re-application should be anticipated.

X7.7 Inspection

X7.7.1 Exterior Inspection—Exterior inspections can often determine if joint, trim, flashing, and fastening details are proper. Symptoms that may indicate water leakage can be categorized as: siding mechanical failures; finish failures; and staining.

X7.7.1.1 Since maintenance is critical to the performance of cement-bonded particle board siding systems, maintenance items such as gutters, downspouts, and sealants must be included in the inspection.

X7.7.2 Interior Inspection—Deterioration of interior finishes, particularly paint on interior trim around wall openings, should be noted. The locations of stains and mildew, and the presence of a musty odor, also can provide information about wall leaks.

X7.7.3 Concealed Conditions—Cement-bonded particle board systems on wood framed structures have a large absorption and retention capacity that may cause concealed damage. It is important to include observations of the mud sill, top and bottom plates, sheathing, insulation, headers at openings, framing below openings, membrane condition and installation, flashing terminations, and soffit framing in the scope of the inspection. Use of fiber-optic borescope will minimize damage during inspections for concealed conditions.

X7.8 Testing

X7.8.1 In addition to spray testing and system disassembly described in the guide, the following has been found to be useful for testing fiber cement and cement-bonded particle board systems:

X7.8.2 *Relative Humidity Measurements*—Wand style relative humidity meters can be used by inserting through small diameter holes drilled through the interior or exterior surface of the wall or soffit. Since the hole is small, the readings are taken immediately, the effect of the hole itself should be insignificant. In-wall relative humidity data can help determine if condensation is a contributor to water damage problems and help identify areas where water is accumulating in the wall.

X7.9 Evaluation

X7.9.1 A leak evaluation of fiber-cement or cement-bonded particle board siding systems should include consideration of the following:

X7.9.2 Windows, doors, and other manufactured products in wall penetrations should be potential entry paths. A distinction should be made between water infiltration through the basic wall system and infiltration through other components in the wall that may appear to be wall leaks.

X7.9.3 Proper orientation and lapping of flashing and the weather-resistive membrane in shingle fashion or proper sealing of these components to flashing flanges or doors and windows and around other large wall penetrations.

X7.9.4 Installation details of the interface between door sills and jambs should be examined. Door sills, particularly at decks and balconies, are a common source of water infiltration if not properly flashed and raised above the adjacent surfaces.

X7.9.5 Copings, roof edge treatments, gutters, and downspouts must prevent excessive roof runoff from washing down over the wall. Coping must sufficiently lap the top of the wall so that wind-driven rain cannot be blown into the top of the wall.

X7.9.6 Distressed siding, with symptoms such as warping, cupping, splits and checks, or framing decay, should be studied. Also, adequate accommodation of moisture induced distortions and dimensional changes must be accommodated by the installations.

X7.9.7 Maintenance items such as clean gutters and downspouts, functional sealants, and viable finishes, should be verified. Finish failures such as blistering or peeling may be a sign of leakage or of excessive water absorption by the siding or a failure of the wall system to adequately drain and dry.

X7.10 Sources of Additional Information

X7.10.1 *ASTM Standards*:²

C1186 Specification for Flat Fiber-Cement Sheets

X7.10.2 *ISO Standards*:

ISO 8335 Cement-bonded particle-boards of Portland or equivalent cement reinforcement with fibrous wood particles

X8. PRECAST CONCRETE PANELS

X8.1 Scope

X8.1.1 **Appendix X8** provides investigation and evaluation practices for water leakage through precast concrete panels. Concrete panels with integrally attached facings such as tile and thin stone are included in this section. Thin precast panel systems such as GFRC are not included in **Appendix X8**.

X8.2 Referenced Documents

X8.2.1 *ASTM Standards*:²

E1105 Test Method for Field Determination of Water Penetration of Installed Exterior Windows, Skylights, Doors, and Curtain Walls by Uniform or Cyclic Static Air Pressure Difference

X8.2.2 *AAMA Standards*:³

AAMA 501.2 Field Check of Metal Storefronts, Curtain Walls, and Sloped Glazing Systems for Water Leakage

X8.3 Method of Water Penetration—Resistance

X8.3.1 Precast concrete panel systems generally resist water as barriers. They consist of a barrier element (panel) and a perimeter joint usually sealed with an elastomeric sealant or gaskets. The panel may contain windows or other penetrations.

X8.3.2 The joint system can be a single line or multiple lines that could configure a pressure equalization chamber. For multistage sealant applications, the seal exposed to the weather may contain openings such as weeps.

X8.3.3 Flashing is usually not a part of a barrier system. Flashing can be incorporated at the windows and other openings of precast panels and would normally be subject to the water resistive requirements applied to windows.

X8.3.4 Secondary water drainage systems can be incorporated by means of cavities and drains inside the building or on the backside of panels.

X8.4 Critical Material Properties

X8.4.1 The water resistance of the precast concrete panel itself relies upon the quality of the concrete mix, methods of forming, placing, reinforcing, curing of the panels, handling, and final finishing.

X8.4.2 Cracking of panels from handling in their early cure can lead to leakage problems. Knowledge of the methods of curing and handling is critical to the investigation of leakage.

X8.4.3 Final finishing by sand or water blasting and the installation of coatings can have an effect upon surfaces to receive sealant. Sealant surfaces should not be contaminated by coatings. Exposed aggregate surfaces should be prepared to receive sealant by grinding or filling.

X8.4.4 A gap-graded face mix, which omits intermediate sizes of aggregate, is intended to provide a concentration of coarse aggregate on the surface. This may also result in reduced bond of the cement paste at the surface, which may reduce the adhesion strength of sealant.

X8.4.5 Mechanical tooling such as bushhammering is done to surfaces to achieve texture. Fractures on mechanically tooled surfaces may propagate to other surfaces intended for sealant application.

X8.5 Critical Details

X8.5.1 Joints between panels, or between panels and other materials, are the normal source of water entry problem.

X8.5.1.1 The typical conditions dictated by proper sealant design apply to joints between precast.

X8.5.1.2 Improper substrate preparation and condition can result in sealant application that does not adhere to the concrete.

X8.5.1.3 Joints are often large ($\frac{3}{4}$ in. or greater) and require effective tooling to assure adhesion to porous concrete. Backer rod placement must be proper to achieve a well-configured sealant joint.

X8.5.2 Panel facing materials may be absorptive. Applied veneers may mask panel cracks that cause leakage.

X8.5.3 Panel anchorage points may be locations of cracks.

X8.5.3.1 Restrained connections of panel to structure can result in panel cracks due to stresses from panel volume changes or bending.

X8.5.4 Vapor condensation problems are often mistaken for panel leakage. Uninsulated panels in cold climates can produce substantial quantities of water during certain weather conditions. Vapor retarders, air barriers, and troughs to capture condensate are useful in these climates.

X8.6 Inspection

X8.6.1 Close-up visual inspection of exterior and interior is the best method to determine leakage paths.

X8.6.2 Removal of interior finishes is usually necessary, to observe the back side of the panel. This also provides access to view the completeness of the vapor retarder seal.

X8.6.2.1 Smoke testing the interior finishes can reveal air paths and direction to determine the influence of air leakage and potential condensation on the apparent leakage.

X8.7 Testing

X8.7.1 Water testing panel joints is a useful method to determine water entry paths.

X8.7.2 Strategic masking during the water test can help isolate the leaks as they are tested.

X8.7.3 **AAMA 501.2** is particularly useful to test sealant joints and other linear arrangements. Chamber tests require seals around the entire chamber perimeter. Chamber tests are used for windows and can be adapted to include perimeter precast panel/window interfaces as described in Test Method **E1105**.

X8.7.4 RILEM tubes and hand held spray testing can be used to test suspected cracks.

X8.7.5 Laboratory testing of sealant surfaces may be necessary to determine the makeup of bond surfaces. Chemical coatings or concrete admixtures could inhibit adhesion.

X8.8 Evaluation

X8.8.1 The following items should be included in the evaluation:

X8.8.2 Review of the construction documents and shop drawings to determine panel anchorage and panel construction.

X8.8.3 Survey of interior and exterior to observe signs of leakage and conditions of the panels and joints.

X8.8.4 Review of report of leakage.

X8.8.5 Water test of exterior panel conditions, including windows, and observe water entry from the interior.

X8.8.6 Test of interior air paths through finish surfaces to determine the contribution of air leakage and condensation to the leakage problem.

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