
Developing an Exterior Enclosure Commissioning Plan

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ABSTRACT

Every building is unique; however, performance testing identified in typical project specifications usually approaches the building enclosure in the same manner. Similarly, a predefined commissioning plan will not likely be appropriate for every project. Commissioning, similar to the design and construction of a building enclosure, is a dynamic and complex process; responsive to the Owner's Project Requirements (OPR), the design, the function, and the occupant needs. The process must be tailored to suit and adaptable.

The building enclosure commissioning process is defined by the design and the construction phases. The construction phase validates the design phase. A commissioning plan's construction phase must respond to the unique attributes of each design detail by establishing a comprehensive schedule of tests and reviews. The objective is to ensure the building enclosure performs in accordance with the OPR and functions as both a coordinated whole and separate components.

This paper briefly outlines the building commissioning plan from project inception through occupancy. Various approaches to the design phase of the commissioning plan are examined. Through the use of case studies, the construction phase of a building enclosure commissioning plan is reviewed. The case studies focus on the parameters for defining the testing type, extent, and methodologies utilized to conduct the schedule of tests in addition to lessons learned from the commissioning of these case study buildings.

INTRODUCTION

For years, conscientious project teams composed of owners, architects, contractors, and specialized consultants have strived to achieve quality buildings that meet all the owner's requirements. Now more than ever, contemporary designs for the exterior enclosures of buildings comprise a sophisticated assemblage of systems, components, and unique design details. Add to this situation design and construction delivery methods that challenge the traditional development of design, construction schedule, and budget, and too often quality is sacrificed. As architectural design pushes the envelope, combined with sustainable, energy-efficient, durable owner initiatives, it is not surprising that occasionally the actual performance of these buildings fails to achieve these objectives.

The practice of exterior enclosure commissioning begins to address these issues through a comprehensive exterior enclosure commissioning process. The plan must be developed specific to each project owner, architect, contractor, and building, and it addresses fundamental issues to verify and validate the performance objectives.

THE COMMISSIONING CONCEPT

The commissioning process as outlined by the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (ASHRAE) in *ASHRAE Guideline 0, The Commissioning Process* (ASHRAE 2005), is defined as "A quality-focused process for enhancing the delivery of a project. The process focuses upon verifying and documenting that the facility and all its systems and assemblies are planned,

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designed, installed, tested, operated, and maintained to meet the Owner's Project Requirements" (p. 2). Further, a guide to the commissioning of an exterior enclosure is provided by the National Institute of Building Sciences (NIBS) in *NIBS Guideline 3, Exterior Enclosure Technical Requirements For the Commissioning Process* (NIBS 2006). The content of NIBS Guideline 3 is specific to the exterior enclosure; this guideline is a supplementary technical guideline to ASHRAE Guideline 0 and is in the NIBS total building commissioning guideline series currently under development. A consistent commissioning process is encouraged through coordination of the content and phases that follow a typical project delivery schedule. The phases are generally defined as

1. predesign,
2. design,
3. construction, and
4. occupancy and operations.

Although four general phases form the delivery process, each project's predesign and occupancy phases are influenced by the intermediate design and construction phases. The Owner's Project Requirements are realized at these intermediate phases, as the design intent verification/quality assurance process transforms into a construction validation/quality control process.

THE EXTERIOR ENCLOSURE

NIBS Guideline 3 defines the exterior enclosure as "all systems separating the interior environment from the exterior, including exterior walls, fenestration, and roofing and roof openings, below-grade perimeter walls and slab-on-grade or crawlspace" (NIBS 2006, p. 6).

Arguably, architecture is defined by the external form or shape of a building. Although architectural design of the exterior enclosure is subject to opinion, and may be categorized as too simple or unduly complex, it is only through the development of a technical detail and material applied in a workmanlike manner that either is achievable. Regardless of the form, "the over-all function of an exterior wall, in conjunction with floors and roofs, is to provide a barrier between indoor and outdoor environments, so that the indoor environment can be adjusted and maintained within acceptable limits" (Hutcheon 1963).

Design of the Exterior Enclosure

The early phase of design provides the architect the opportunity to explore the form of a building. This is often a collaboration of the owner's vision for the building and the architect's inspiration. From these early beginnings, an owner can provide the foundation for his or her vision of the building in a document known in the commissioning process as the *Owner's Project Requirements* (OPR). An OPR outlines the owner's requirements; for example the function, durability,

aesthetics, and sustainability goals. More specific to the exterior enclosure, an OPR may address owner needs for daylighting, thermal comfort, indoor air quality, and materials or quality attributes of the exterior enclosure components. The OPR also outlines broad objectives from which the architect can develop both the appearance and functioning performance criteria of the building's program as the Basis of Design (BOD). The difference between the two documents is defined by the *Whole Buildings Design Guide* thus: "The Basis of Design (BOD) is a narrative and analytical documentation prepared by the design A-E along with design submissions to explain how the Owner's Project Requirements (OPR) are met by the proposed design... An OPR is developed for an owner/user audience while the BOD is typically developed in more technical terms" (NIBS 2010).

As a rule, each owner and each architect engage in a marriage of sorts and combine to develop a unique exterior enclosure design for each building project. A building's function, design, and location make every building a unique example of an interior (typically conditioned) space defined by an assemblage of components forming an enclosure. As such, each review of building construction documents should be approached with an awareness of the risks and issues that could result in premature failure.

Location and characteristics of weather and geography can both inspire and define the parameters of the exterior enclosure design. An attractive view can inform the initial design toward expansive areas of glazing. Yet weather patterns and projectiles may require additional performance measures to ensure the view remains pleasurable. Enjoyment of the view can be decreased by compromises in the performance due to excessive thermal drafts and discomfort, increased energy costs due to glass's insulating limitations, noise, water leakage, or structural failure. Typically, a balance in design and accommodation of the building's external environment is required to achieve the owner's requirements.

The function or use of a building can be a source of design innovation and influence the architectural form of the exterior enclosure. Buildings created to house art, museums, and similar distinct, unusual, or complex architectural forms created by iconic architects challenge both the normal public perception of a building and the performance of the exterior enclosure. These sophisticated buildings typically require finely balanced interior conditioned spaces to protect the unique artifacts or operations housed within. If the exterior enclosure fails to perform due to excessive air infiltration/exfiltration and compromises the heating, ventilating, and air-conditioning (HVAC) system balance or develops condensation or water leakage, the overall operation and contents of these buildings are at risk. Typically, attention to the exterior enclosure's materiality and details to manage risk and prevent design- or construction-related failures are required to achieve the owner's requirements.

According to ASCE 7 (ASCE 2006), “essential” buildings intended to remain operational even in cases of extreme weather events, such as a hospitals, emergency shelters, or similar structures, can require special design criteria for the exterior enclosure to ensure the operations of the building are not compromised. Although not addressed by code definitions, many buildings that house scientific research or critical communications, among others, can also be categorized as “essential” to the ongoing objectives and operations of these owners. Failure in the exterior enclosure during occupancy resulting in water leakage, air or surface contamination, or changes in the quality of indoor air can all negatively impact the operations of these facilities.

Buildings with unique interior functions, such as natatoriums, library archives, ice-skating rinks, and cold storage facilities, mandate that the exterior enclosure performs appropriately to protect the interior use. Typically, these buildings appear simple in contrast to complex forms associated with iconic architecture, yet these buildings can sometimes offer greater challenges. The demands of the interior conditioned spaces often result in dynamic and complex air, vapor, and moisture transfer through the exterior enclosure. Failures can result from condensation, microbial contamination, and material/structural deterioration. The extreme indoor environments of these building types require that the building enclosure be carefully designed and constructed to successfully achieve the owner’s requirements.

Design associated with the preservation, revitalization, rehabilitation, retrofit, re clad, or reuse of a building can often create a complex interaction between the new and the existing. Infinite combinations of existing exterior enclosure building component interactions with new building components can exist. As such, numerous opportunities exist for immediate or long-term problems. Situations requiring a project-specific response may include a new window placed within a masonry veneer wall in which the window perimeter seal may not protect from air or water leakage from the cavity; sheet metal blast protection placed to the interior of a mass masonry wall, altering the traditional drying characteristics of the wall assembly; or an overclad of the existing exterior wall creating a double vapor barrier or dual façade, resulting in the development of visual or concealed condensation. Each separate component of an exterior enclosure must result in a properly functioning whole assembly, including consideration of the interior HVAC conditions, to achieve the owner’s requirements.

The exterior enclosure must consider not only the aesthetic design and functional attributes of the building but also how each component of the enclosure relates as a whole to provide protection from the external environment. The enclosure assembly must control the path of water or vapor, air, heat flow, light, and noise and be durable and structurally sound. The enclosure assembly must consider the building’s structure, applied loads, resistance to fire and pests, and security and be constructible and economical.

The exterior enclosure includes the areas of the building that extend below grade, the façades, the roof, and all appendages to the building, including items such as canopies and penthouses. Each of these areas is typically composed of sophisticated individual systems, with each system having various separate components collectively forming a whole. The systems can interface in various planes, elevations, or angles. Coordination of these interfaces must consider the unique performance attributes of each system, for example a rain screen or barrier design approach, and be successfully integrated to achieve an exterior enclosure that meets the owner’s requirements. The exterior enclosure is, without a doubt, a complex assembly and requires a commissioning plan and tasks that respond to the unique attributes of each project.

THE EXTERIOR ENCLOSURE COMMISSIONING PLAN

Commissioning is outlined by a plan in which the process for commissioning is defined. Total building commissioning requires that each system to be commissioned develop a plan that is unique to that system. An exterior enclosure commissioning plan follows the established phases of a construction project; however, each plan’s tasks and objectives may vary depending upon the owner’s requirements and the exterior enclosure design. Each plan requires comprehensive documentation throughout each phase of the process.

Employing a standardized exterior enclosure commissioning (EECx) approach to building projects could lead to the perception that all exterior enclosures function in the same way, even if they look different or are used in various ways. Prescribing a standard of performance and an associated risk management strategy to a building typology would require an evaluation of each design element, detail, and/or unique function of a building. To ensure a standardized commissioning process is repeatable, measurable, and comprehensive, each design, performance criterion, environment, function or use, operation, and owner requirement would need to be assessed to ascertain a building’s required level of commissioning. Thankfully the built environment lacks standardization, and in response, EECx is a dynamic and adaptable program to achieve, verify, and validate based solely upon the individual merits and challenges of each unique exterior enclosure.

The development of an exterior enclosure commissioning plan is a task to be undertaken by professionals with tenured experience in the design and construction attributes of the exterior enclosure. A team of individuals is typically most appropriate, as rarely does one individual possess all the qualifications (and time) to proficiently encompass all the exterior enclosure design- and construction-related tasks of a commissioning plan. As the commissioning process is one initiated by the owner, it is desirable the Commissioning Authority be directly retained by the owner to objectively advise the owner and facilitate achieving the Owner’s Project Requirements.

Exterior Enclosure Commissioning Phases

A summary of the EECx tasks is broken down into the design and construction phases as follows:

Pre-design Phase

- OPR document/EECx plan

Design Phase

- Document reviews and report
- Project team meetings following each review
- EECx Specification

Preconstruction Phase

- Observation of laboratory mock-up and performance testing
- Shop drawing and submittal review
- EECx meeting and trade preconstruction meetings
- On-site quality awareness seminar

Construction Phase

- Construction milestone site visits
- Functional performance testing
- EECx meetings
- EECx report

Occupancy and Operation Phase

- Exterior enclosure occupancy training
- Exterior enclosure warranty review
- Whole-building test
- Ongoing commissioning

Pre-design Phase. The pre-design phase of EECx includes the development of a plan that reflects the project phases, process, resources, and documentation requirements. The plan must be project specific, considering the unique design and, most importantly, a well-conceived OPR report. The pre-design phase is defined by the following:

1. OPR report
2. draft of the EECx plan

The OPR report, and hence the unique qualities of each project, is the primary ingredient in the development of a commissioning plan and the ensuing process. The OPR is also used as the foundation in coordination with the architect's BOD for the subsequent design process and construction initiatives, such as value engineering and substitution requests. Once the OPR report has been established, a suitable risk management strategy should be determined in association with the design team. This strategy is to be embraced in the development of the design details and specifications.

Design Phase. In developing a project-specific commissioning plan, the exterior enclosure design influences the extent of each task in the plan. The design phase of the plan is defined by the following:

1. OPR report
2. Construction documents review and report
3. Refinement of the EECx plan
4. Project team meetings
5. EECx specification

Various quality assurance approaches to the design phase commissioning tasks may be undertaken. A priority regardless of function or form of the building is to achieve a durable, sustainable, and maintainable watertight and airtight building with a continuous plane of thermal insulation and due consideration given to the control of vapor to reduce the risk of condensation. The control of vapor requires an understanding of the heating/cooling source(s) and interior conditions in combination with the external summer and winter design conditions, the thermal insulation properties, and the overall permeability of the exterior enclosure components.

Through a series of construction document reviews, the design phase verifies the design addresses the project requirements. Overall risk management objectives are considered, and design parameters to meet the owner's requirements, such as a redundant design approach, should be verified. If the building includes three- and four-component interface details, the design details and commissioning review tasks should focus on these aspects to achieve the required performance. Review methods that trace the designs' control of water or vapor in a system, verifying continuous moisture-resistant materials and flashings to direct water to the exterior, should be established. Review methods that trace the designs' control of air leakage, requiring a continuous, durable, or maintainable flexible air barrier system, should be confirmed. Review methods that trace the designs' continuous plane of thermal insulation and thermal breaks should be implemented. A hygrothermal evaluation may be necessary to verify the exterior enclosure does not develop condensation. The design details and peer review focus on critical performance attributes.

The peer review and report document efforts to achieve performance intent in addition to recommendations to enhance or resolve issues that may impact the long-term service of the exterior enclosure. Each review is discussed with the project team to ensure issues are understood and addressed as deemed necessary by the architect-of-record (A-o-R). The construction document review conducted by the exterior enclosure commissioning agent (EECxA) does not supersede or replace the responsibilities of the architect but provides the owner an impartial opinion of the work, while maintaining and enhancing quality. Throughout the review process, the EECxA refines the commissioning plan and develops a project-specific exterior enclosure specification to be included in the project manual.

The exterior enclosure specification outlines the roles and responsibilities of the project team, in addition to providing a project-specific schedule of tests to evaluate the installed performance of the exterior enclosure. The extent and types of tests are derived from industry standards yet may require modification or invention to ensure the specific design attributes are tested to validate their performance.

The design phase of the commissioning process is fundamentally the most important phase of the project. All ensuing phases of construction rely upon the construction documents developed during this phase to be complete, accurate, and

constructible and to comply with all codes. Incomplete communication of the design intent or performance criteria can result in severe impacts on the quality, schedule, and budget, negatively affecting the entire construction phase of a project. Following the traditional project delivery method, the construction phase of a commissioning plan can only attempt to validate the design phase.

Preconstruction and Construction Phases. The design phase, which strives to verify the design meets the OPR, is followed by the pre-construction and construction phases, which include quality control and validation methods to achieve the OPR. In coordination with the contractor's quality control program, the tasks during this phase engage the EECxA in the project-specific materials and details. This is an effort to verify that the design details and specifications are being comprehensively addressed by the contracting team and that all the owner's requirements are being met. This phase often utilizes a comprehensive and project-specific schedule of submittal reviews, milestone field observations, and tests to validate the as-built performance of the exterior enclosure assemblies. The construction phase of the commissioning plan may include the following:

1. Preconstruction mock-up submittal review assistance (as applicable)
2. Observation of preconstruction mock-up construction (as applicable)
3. Preconstruction mock-up performance testing (as applicable)
4. Shop drawing and submittal review assistance
5. Preconstruction on-site quality control seminar
6. Preconstruction EECx meeting
7. Exterior enclosure trade coordination/preconstruction meetings
8. Periodic on-site "construction milestone" observations
9. Functional performance testing
10. EECx construction meetings
11. EECx report

During the transition between the design phase and the construction phase, the intent and importance of the enclosure's performance is communicated to the construction team. In preparation for construction, tasks such as preconstruction mock-ups, meetings, and submittals all include efforts to verify materials and details and communicate expectations, sequencing, coordination, and quality control. The construction team should comprehend the extent of tests and performance criteria that are outlined by the exterior enclosure specification and other enclosure-related sections of the project manual. Upon installation of the work, tests are conducted early and systematically throughout the process. It is critical that the schedule of tests is understood and accounted for by the construction schedule.

Finally, an EECx report and maintenance manual is provided to the owner. This report documents the entire exterior enclosure commissioning process. Specifically, docu-

mentation is to be provided for all issues, tests, and construction phase activities. A schedule of maintenance and inspections will assist the new building engineering staff in maintaining the building.

Occupancy Phase. The final phase of the commissioning process centers on the functioning building. This phase assists in the process subsequent to occupation. The EECxA visually reviews the exterior enclosure to confirm its performance is in accordance with the OPR and BOD and provides education to the maintenance staff on the operation and function of the exterior enclosure. The occupancy phase of the commissioning plan may include the following:

1. Building enclosure owner occupancy training
2. Warranty review and report
3. Whole-building testing
4. Ongoing commissioning

CASE STUDY

Case studies are used to review the construction phase of a building enclosure commissioning plan. These case studies focus on the parameters for defining the testing type, extent, and methodologies utilized to conduct the schedule of tests. In addition, lessons learned from the commissioning of these case study buildings are discussed.

Specifically, the case study discussed in this paper is the Wisconsin Institutes for Discovery—Morgridge Institute for Research (WID-MIR) in Madison, Wisconsin (see Figures 1 and 2). According to the University of Wisconsin WID Web site, "The Wisconsin Institutes for Discovery is a one-of-a-kind structure under construction in the heart of the University of Wisconsin-Madison campus. Opening in December 2010, the building is designed for scientists to work side-by-side in two interdisciplinary research institutes under one roof, the private Morgridge Institute for Research and public Wisconsin Institute for Discovery. On the main floor, a Town Center will welcome all with food, interactive displays and activities, inviting the public to explore, engage and discover" (UW 2010).

The WID-MIR is a 300,000 ft² four-story building located in climate zone 6, described by the *International Energy Conservation Code* (ICC 2006). The architects, Ballinger/Uihlein and Wilson, designed a high-performance exterior enclosure to be durable and sustainable and to optimize thermal performance. The building is designed for a life cycle of 100 years and to reduce energy consumption and green house gas emissions. These program objectives were derived from discussions with the owners, a public and private partnership comprising the State of Wisconsin, the Wisconsin Alumni Research Foundation, and The Morgridge Institute for Research. The building is being delivered via an integrated designer, builder, and owner team. The building is currently under construction by a joint venture between construction companies J.H. Findorff & Son Inc. and Mortenson Construction.



Drawing courtesy of Ballinger Architects, 2007

Figure 1 Conceptual design elevation drawing, south elevation.



Figure 2 WID-MIR under construction, south elevation, January 2010.

The architects pursued the following concepts to achieve the OPR:

- Minimized air infiltration
- Solar control (sunshades and automated roller shade system)
- Thermal mass
- Motorized windows for night cooling
- Atria daylighting and thermal nesting
- Cool roof
- Control-flow roof drains to reduce the rate of storm water runoff

The design team established the following design criteria:

Roof assembly: R-value = R-35 average

Wall assembly: R-value = R-23 total

Double-glazed curtain wall system:

U-factor = 0.36 (or R-2.8)

Triple-glazed curtain wall system:

U-factor = 0.30 (or R-3.3)

Design pressure: 30 psf

The exterior enclosure is comprised of below-grade waterproofing and an underslab vapor barrier. The façades (Figures 3a and 3b) are composed of various materials, including a sheet applied air/vapor barrier over concrete masonry unit or light gage framing with sheathing backup walls. Mineral wool fiber insulation is installed outboard of the air/vapor barrier utilizing a clip attachment to the cladding's frame to eliminate penetrations in the air/vapor barrier and reduce thermal bridging while keeping the insulation in contact with the air/vapor barrier. The cladding comprises a terra-cotta rain screen panel and stone rain screen design. The fenestration comprises fixed and operable units in a curtain wall and punch windows, including double- and triple-insulated glass units. An extruded silicone sheet seals the transition between the air/vapor barrier and the fenestration. Large skylights introduce daylight into the atria below. The roof is a polyvinyl chloride single-ply fully adhered roof membrane over tapered polyisocyanurate insulation. The single-ply roof membrane is fully integrated with the façade air/vapor barrier, curtain wall, and skylight flashing systems. Every effort was made to eliminate exposed sealant weather seals from the building.

The EECxA developed a plan to commission the exterior enclosure that was specific to the project. A EECx plan was developed during the design phase. The final EECx plan outlined below was followed for the construction phase of the project.

Project Information

The Wisconsin Institutes for Discovery—Morgridge Institute for Research, Madison, Wisconsin (WID-MIR). The WID-MIR is a 300,000 ft² four-story building located in climate zone 6 per the 2006 IECC. The building shall facilitate scientific research and education. The exterior enclosure comprises a terra-cotta rain screen and stone cladding over insulation and an air barrier. Fenestration includes curtain wall, punch

WID-MIR: Terra Cotta Rainscreen Wall Details

Thermal Resistance

- Terra Cotta Tiles (no R-value - open joints)
- 2" Air Space (no R-value - open joints)
- Air Film Resistance (R-value=0.17)
- 3 1/2" Mineral Fiber Insulation (R-value=14.7)
- Membrane Air & Vapor Barrier (no R-value)
- 8" Concrete Block, Grout Filled (R-value=1.0)
- 2 1/2" Steel Stud Furring (no R-value)
- 2 1/2" Mineral Fiber Insulation (R-value=6.0) due to Thermal Bridging of Steel Studs
- 5/8" Drywall (R-value=0.56)
- Inside Air Film (R-value=.68)

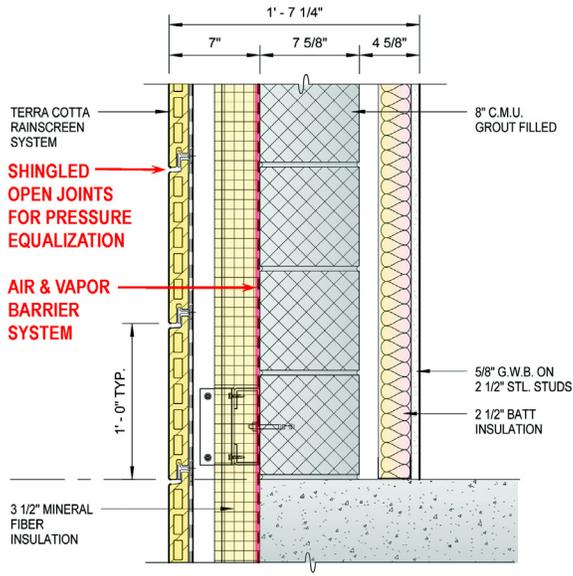
Total Assembly R-value = 23.11

Airtightness

- Tremco ExoAir 110 - Air & Vapor Barrier
- Air Permeance < 0.04 cfm/ft² at 1.57 lb/ft²
- Vapor Permeance < 0.05 perms

Performance Mockup Testing

Air Permeance = 0.03 cfm/ft² at 1.57 lb/ft²

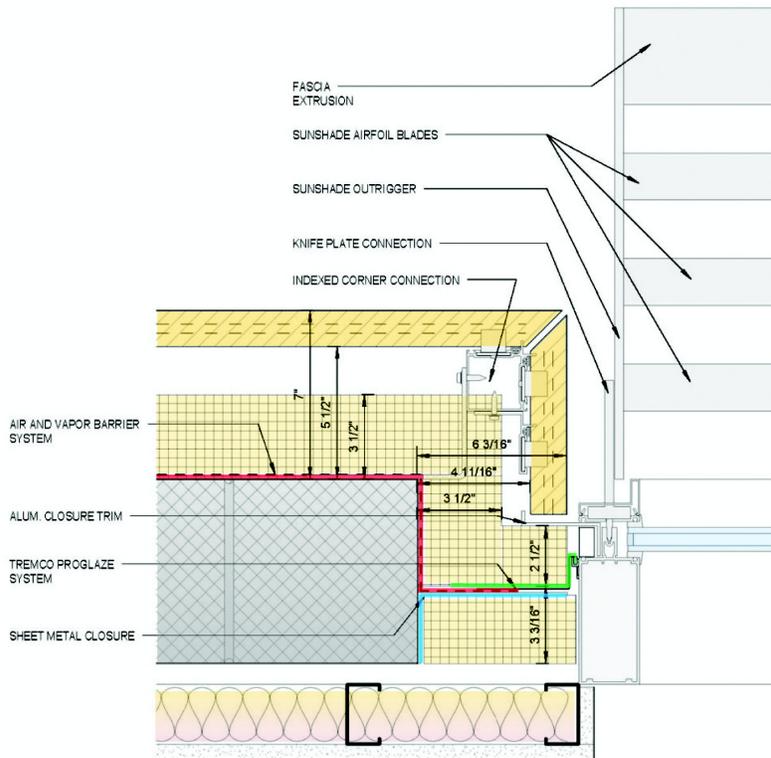


Typical Wall Section Detail

(a)

Ballinger

WID-MIR: Terra Cotta Rainscreen Wall Details

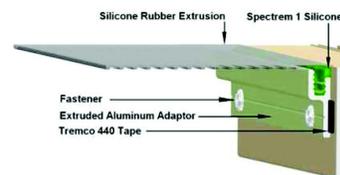


Typical Jamb Detail at Office Windows

(b)



- Aluminum Closure Plate
- Tremco Proglaze ETA



Tremco Proglaze ETA Flashing

Ballinger

Drawings courtesy of Ballinger Architects

Figure 3 (a) Typical wall section detail and (b) typical jamb detail at office window.

windows, and skylights. A single-ply PVC roof membrane is installed at the main roof, penthouse roofs, and the terrace. Below-grade HDPE composite sheet waterproofing membrane is installed at below-grade areas of the building. The estimated cost of the facility is \$160 million USD.

Overview and Scope of the Project Commissioning

Exterior Enclosure Commissioning (EECx) is a quality-focused process of enhancing the delivery of a project to verify and document that all exterior enclosure components are installed and perform collectively, according to the Exterior Enclosure Design Intent, and that the installation is adequately tested to the specified performance. It serves as a tool to identify deficiencies in the exterior enclosure during the preconstruction and construction phases in an effort to advance the exterior enclosure components from mock-up installations, through installation of the separate components on the structure, to a fully integrated, airtight and weather-tight assembly prior to occupancy, thereby reducing impact on the building end user.

The EECx plan follows the tasks outlined below:

Pre-design Phase

- Owner's Project Requirements (OPR) Document/
EECx Plan

Design Phase

- Document Reviews and Report
- Exterior Enclosure Commissioning Specification

Preconstruction Phase

- Observation of Warehouse Mock-up and Performance Testing
- Shop Drawing and Submittal Review
- EECx Meeting and Trade Preconstruction Meetings
- On-Site Quality Awareness Seminar

Construction Phase

- Construction Milestone Site Visits
- Functional Performance Testing
- EECx Meetings
- EECx Report

Occupancy and Operation Phase

- Exterior Enclosure Occupancy Training
- Exterior Enclosure Warranty Review
- Whole Building Test
- Ongoing Commissioning of Whole Building

Commissioning Protocols and Communications

Refer to Section 01 91 13 – Exterior Enclosure Commissioning. Part 1.8.

Commissioning Process, including Team Responsibilities

Refer to Section 01 91 13 – Exterior Enclosure Commissioning. Part 1.9, 1.10, and 1.11.

Commissioning Schedule

The EECx schedule shall be coordinated with the established design and construction schedule for the project. Following award of contract, the Contractor shall review the Exterior Enclosure technical specifications, identify required EECx items (including field and laboratory test requirements, specified test standards, mock-ups, product submissions, milestone installations, and similar), and provide a schedule to the EECxA with anticipated dates for each. It is the responsibility of the Contractor to provide adequate time from submission of each EECx requirement to response from the EECx and resolution of any identified deficiencies without unnecessary deleterious impact on the project schedule.

Functional performance testing and retesting (as needed) shall be coordinated with the overall construction schedule so as not to delay work.

Commissioning Documentation

Refer to Section 01 91 13 – Exterior Enclosure Commissioning. Part 1.7.

Appendices (not attached)

- Testing and Inspection Plans
- Prefunctional and Functional Test Procedures
- Construction Checklists
- Issues Logs

To validate the performance of the exterior enclosure, a comprehensive schedule, listed by system, was presented in the EECx specification. The schedule outlined the performance criteria and type of testing to be performed. The locations for tests were determined in the field and coordinated with the contractor's schedule and sequencing of work. An excerpt of the schedule is included below:

Air leakage:

- Fixed window area, allowable air leakage
0.06 cfm/ft² at 6.24 psf.

- Air barrier assembly, allowable air leakage
0.04 cfm/ft² at 0.3 in. wg (1.57 psf).

Water leakage:

- Fixed window area, static pressure water penetration testing (ASTM E 331) at 8 psf. No water leakage.

- Fixed window area, dynamic pressure water penetration testing (AAMA 501.1) at 8 psf. No water leakage.

- Below-grade waterproofing, flood tests (ASTM D5957). No water leakage.

Thermal resistance:

- Condensation resistance (AAMA 1503-985) at winter design conditions: 0°F exterior and 15 mph wind velocity, 68°F interior temperature

and 30% relative humidity. No condensation or surface temperatures below the dew point.

Adhesion of air barrier seals:

The nondestructive procedure (ASTM C1521) places strain on the sealant and a stress on the adhesive bond. No adhesive or cohesive failure.

Test Parameters

The specific physical properties of each component and interface condition were assessed to determine the extent, location, and type of testing to be performed at each specimen. Beyond industry standard system tests, such as those typically conducted on a curtain wall assembly, the characteristics of each design detail and interface were reviewed to determine risk as well as the propensity for success or failure. Many parameters contribute to the overall performance of a design detail. Some of the most significant detail parameters to consider for testing are the following.

- Details that comprise more than one system, such as the interface between the curtain wall frame and the air barrier assembly. At these locations, more than one subcontractor is responsible for creating a watertight and airtight connection.
- Details that comprise more than one material, such as the interface between the curtain wall and the roof. At these locations, more than one material is required to be installed so as to create a watertight and airtight seal, in addition to ensuring material adhesion and compatibility.
- Details that require a change in plane or direction. At these locations, materials may resort to their original form and can be problematic to install. Materials that return to the underside of an adjacent surface are subject to increased risk of failure due to gravity and strain on the adhesion.
- Details that are scheduled to be installed in extreme weather, where surface preparation and installation techniques may be compromised.
- Details that include terminations and transitions that are subjected to excessive water due to exposure to rain, snow, or wind.
- Details that must accommodate for movement, such as horizontal and vertical expansion joints in the primary air and moisture barrier, or involve movement joint transitions between systems.
- Details that result in anchor penetrations through the primary air and moisture barrier, including attachments to curtain wall assemblies that breach the primary air and water seals of the system.
- Details that potentially facilitate thermal bridging, thereby increasing the risk of condensation on these surfaces.
- Details that are exposed to ultraviolet rays or construction traffic for long periods following the initial installation of the system.

- Details that include new materials, unfamiliar installation practices, and systems without proven long-term performance records.

The aforementioned parameters were only some of the issues considered in the choice of test specimens. At most locations, tests were conducted in a field mock-up before construction began and were followed by systematic tests at 10%, 50%, and 90% completion. At isolated locations, testing identified problems in the workmanship or design of a detail. Diagnostic tests were undertaken at these locations to determine the causes of the failures and necessary repairs. Additional quality control practices by the contractor were implemented to overcome the failures. In the event of failures, test specimens were added to the original schedule to validate the installation of those components identified as problematic.

Tests

Functional performance testing of the exterior enclosure needed to overcome many site- and system-related conditions to enable accurate measurement and understanding of performance and diagnostic efforts. As outlined below, testing of the exterior enclosure was performed, and accommodations to ensure testing could be properly completed were installed or are now lessons learned.

Air Leakage Tests. Testing fenestration for air leakage in accordance with *ASTM E783, Standard Test Method for Field Measurement of Air Leakage Through Installed Exterior Windows and Doors* (ASTM 2002), may not yield accurate results unless all sources of extraneous air can be eliminated from the chamber. A complete understanding of the components to be tested is required. Air seals may need to be incorporated during the construction in some curtain wall assemblies to facilitate tests (Figures 4a and 4b).

Testing air barriers for air leakage in accordance with *ASTM E1186, Standard Practices for Air Leakage Site Detection in Building Envelopes and Air Barrier Systems* (ASTM 2009a), is a qualitative test and is not intended to quantify air leakage (Figures 5a and 5b). The test is intended to identify the location of an air leak. Various methods can be used to detect air leakage under the aforementioned standard. The methods employed in the case study were chamber pressurization or depressurization in conjunction with smoke tracers as well as chamber depressurization in conjunction with leak detection liquid. Both methods employ visual leak detection methods. Smoke is visible on the interior side of the specimen with an externally mounted chamber, or leak detection liquid is applied to the surface and a bubble forms at an air leak location. Ensure sufficient leak detection liquid is placed at the areas to be tested and the liquid is not beyond the useful life identified by the manufacturer.

Water Leakage Tests. Testing for water infiltration in accordance with *ASTM E-1105, Standard Test Method for Field Determination of Water Penetration of Installed Exterior Windows, Curtain Walls, and Doors by Uniform or Cyclic*



(a)



(b)

Figure 4 (a) Overall view of curtain wall framing with air seals installed into the mullion tube and (b) close-range view of spray polyurethane foam air seal inside of the mullion to limit air drawn from areas of the curtain wall outside of the test specimen.



(a)



(b)

Figure 5 (a) Leak detection using smoke and chamber pressurization and (b) leak detection using leak detection liquid at cladding anchor penetration.

Static Air Pressure Differential (ASTM 2008), during weather that may result in freezing of water within the system can alter the performance or drainage aspects of the fenestration system. Testing below freezing should be avoided.

Testing for water leakage using dynamic testing equipment (Figures 6a and 6b) can be an effective means to evaluate numerous areas simulating a wind driven rain without the need to construct a test chamber. The field version of *AAMA 501.1-05, Standard Test Method for Exterior Windows, Curtain*

Walls, and Doors for Water Penetration Using Dynamic Pressure (AAMA 2005), is not an industry field-test standard. However, testing in the field using dynamic pressure is a valuable tool to determine the field performance of façade assemblies and can be used efficiently to test numerous areas in less time when compared to ASTM E-1105 methodology.

Determination of appropriate pass/fail criteria is important when testing for water leakage of new fenestration systems. The definition of water leakage, per the American



(a)



(b)

Figure 6 (a) Interior view of dynamic water test and visual leak observation and (b) exterior view of dynamic water test at punch window opening.



(a)



(b)

Figure 7 (a) Interior view of static water test and visual leak observation and (b) identification of water leakage using water indicating paper.

Architectural Manufacturers Association (AAMA) and ASTM E1105, allows water leakage that enters the interior but does not penetrate beyond the innermost plane of the framing to be considered a “pass.” *AAMA 502, Voluntary Specification for Field Testing of Newly Installed Fenestration Products* (AAMA 2008a), parallels ASTM E1105’s definition of water leakage. *AAMA 503, Voluntary Specification for Field Testing of Newly Installed Storefronts, Curtain Walls and Sloped Glazing Systems* (AAMA 2008b), allows for up to 1/2 oz of water that collects on top of an interior frame surface and does

not spill over to be considered a “pass.” Without a project-specific definition and strategy to manage risk, an industry-defined leak could occur in a building that cannot tolerate this type of uncontrolled water infiltration to the interior (Figures 7a and 7b).

Testing for water leakage by flood testing waterproofing in accordance with *ASTM D-5957, Standard Guide for Flood Testing Horizontal Waterproofing Installations* (ASTM 2005) (Figure 8), may not yield a comprehensive result. Testing at the interface between curbs and the waterproofing and at pene-

trations may be needed to evaluate the performance beyond the areas submerged by 2 in. of water. All flood tests must consider the capacity of the structure to accommodate the load of the water test.

Thermal Resistance Tests. Field testing for thermal resistance and condensation, performed under a modified AAMA 1503 (AAMA 2009) approach, may assist in evaluating the risk of condensation by monitoring the surface temperature (Figures 9a and 9b). Determining the temperature of the interior surface and simulating an exterior winter design temperature can determine the dew point. However, the accuracy of this test may be questioned unless all interior compo-

nents, including insulation and window attachment clips, as well as a humidified conditioned interior air environment can be simulated. Careful placement of the monitoring gauges is also necessary.

Unfortunately, at this time in the project, if the condensation resistance factor has not been appropriately specified, the likelihood of wide-scale window replacement on the building is minimal, and alternative design details to minimize this risk may need to be developed.

Adhesion Tests. Testing for adhesion of sealants in accordance with *ASTM C1521-09e1, Standard Practice for Evaluating Adhesion of Installed Weatherproofing Sealant Joints* (ASTM 2009b), requires that sufficient time has elapsed before performing the tests (Figure 10). In the case of some sealants, adhesion properties develop over time. A number of test beads may be required to verify the adhesion if time or weather conditions do not allow for a full schedule of cure before determining field adhesion characteristics. Surface preparation can significantly impact the ability of the sealant to achieve adhesion; this should be monitored in accordance with input from the manufacturer.

Testing Summary

An experienced, safe, and innovative testing agency is an essential component of the EECx team. Functional performance tests of the exterior enclosure differ from the most common type of commissioning of the mechanical system. Testing must be done early and, unlike equipment validation, does not involve a simple adjustment of a dial. As needed, testing may require work to be performed out of sequence to validate the initial work before proceeding with building-wide



Figure 8 *Water test at horizontal below-grade waterproofing.*



(a)



(b)

Figure 9 *(a) Thermocouple locations installed before insulation to measure risk of concealed condensation at wall with exterior insulation and (b) insulation installed over the top of the thermocouples.*

installation. Weather and site access limitations may severely impact the ability to test. In the event that failures of the exterior enclosure are identified through performance tests, a diagnostic and repair approach may be required. A collaborative effort to determine the source of the failure and determine a sustainable repair often takes patience, technical knowledge, and a willing attitude. Documentation of the tests is critical and must be maintained throughout the commissioning process (Figures 11a and 11b).

CONCLUSION

Commissioning the exterior enclosure requires knowledge, experience, and dedication beyond a generic plan. The EECx process institutes a plan with project-specific tasks that transition from the role of verification to validation. The

process requires a team of dedicated professionals from the project’s design and construction teams working in a collaborative environment to achieve the Owner’s Project Requirements.

ACKNOWLEDGMENTS

I sincerely thank my colleagues from WJE, especially Ms. Elizabeth Ordner, for the assistance at the WID-MIR project, in addition to the support provided by Architectural Testing Inc. The successful exterior enclosure commissioning plan would not have been possible without the dedicated efforts and professionalism of the team from Ballinger, Uihlein-Wilson, Findorff-Mortenson, Wisconsin Alumni Research Foundation, and Mr. Bob Coleman of Huffman Facility Development.

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Figure 10 Sealant adhesion failure.



(a)

ASTM E1105 (Static Water Tests)- 3 locations at 10% completion				
Test No.	Location	Test Parameters	Results	Failure Mechanism
1	7	North, Room 4160 No water at 10 psf for 15 minutes	Fail- H2O entering through glazing, corresponding to knife plates	knife plates
			Fail- H2O entering at splice in closure plate, poor adhesion	sealant adhesion
			Pass	NA
2	9	South, Room 2310 No water at 10 psf for 15 minutes	Fail- H2O between metal back pan and c.w. framing	SSG
			Fail- H2O between metal back pan and c.w. framing, incomplete structural seals	SSG
			Pass	NA
3	11	South, Room 2200L No water at 10 psf for 15 minutes	Pass	NA
4	12	South, Room 3324A No water at 10 psf for 15 minutes	Pass	NA

(b)

Figure 11 Extract from documentation records of façade testing. Façade testing (identified in a log by number) is shown on a façade elevation with identification of the test type and the result included in the final EECx report.

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