Where the Commissioning Rubber Meets the Road: Building Enclosure Performance Testing

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ABSTRACT

Building enclosure commissioning is a quality assurance process that focuses on verifying that building enclosures meet the owner's requirements for performance. Although the process requires the building enclosure commissioning agent be involved in the project during both design and construction for maximum effect, one of the most impactful roles of the building enclosure commissioning authority is overseeing the construction phase performance testing of the various components of the building enclosure. ASTM Standard E2813-12e1 – Standard Practice for Building Enclosure Commissioning – provides a broad list of mandatory and optional testing for the building enclosure commissioning process to cover multiple performance aspects of building enclosures. These tests need to be considered and defined during the design phase of the project so that they are most suitable for achieving the owner's goals, are tailored to the enclosure systems selected, and can be integrated in the construction process. Selecting the appropriate tests to perform, the test procedures, limitations of the tests, interpretation of results, and key times to perform the tests are critical to successfully implementing building enclosure commissioning. The paper provides a review of the most popular and effective performance tests and examples from building enclosure commissioning projects to show how selecting the appropriate testing regime can aid in building enclosure commissioning.

INTRODUCTION

Building enclosure commissioning (BECx) is a quality assurance process that focuses on verifying that building enclosures meet the owner's requirements for performance. BECx is an outgrowth of the success of building commissioning, specifically the mechanical systems, in the performance of buildings. Starting with the American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE)[1], moving to the National Institute for Building Sciences (NIBS)[2], and now continuing with ASTM International (ASTM)[3], the industry has defined and refined the goals and processes of BECx. The United States Green Building Council (USGBC) requires BECx to obtain a Leadership in Energy and Environmental Design (LEED)[4] rating. As a result, BECx is quickly becoming ubiquitous in the construction industry.

This paper will focus on the testing requirements for BECx, including selecting the appropriate tests, the procedures to follow, the limitations of the testing, interpreting the results, and when to perform the testing. Being the recognized industry standard, this paper will focus on the testing required and recommended in ASTM E2813. Many consider USGBC's LEED rating requirements the standard of BECx in the industry as they try to earn points in the LEED rating system. However, USGBC does not define the goals of BECx in general and provides limited clarity specifically regarding requirements needed for enclosure commissioning as part of their enhanced

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commissioning LEED points. While LEED may reference ASHRAE Guideline 0 and NIBS Guideline 3, the standard does not provide explicit information on what is required to earn the LEED points, which leads to owner and designer confusion and vastly different scopes of enclosure commissioning work applied to buildings. A requirement that has limited clarity and is dependent on interpretation of those performing the work cannot be considered an industry standard. However, one can use ASTM E2813, along with the companion ASTM E2947-16 Standard Guide to Building Enclosure Commissioning[5], to develop a testing program as part of the process of planning the enclosure commissioning process for LEED. This will be discussed further below.

ASTM E2813-12E1

ASTM standards are considered the industry standard for performing a particular function. ASTM E2813-12e1 – Standard Practice for Building Enclosure Commissioning – defines the industry standard for BECx. ASTM E2813 provides two levels of BECx – fundamental and enhanced – and defines the minimum services to meet each. Fundamental requirements provide a baseline for the minimum services performed to consider the building enclosure commissioned. Enhanced commissioning takes commissioning further through additional services designed to add value and make building enclosure commissioning more valuable.

Included with ASTM E2813 is Annex 2, which provides a list of mandatory BECx Performance Testing Requirements for both Fundamental and Enhanced BECx. Within Annex 2 is Table A2.1, which describes the following:

- Property the test is designed to evaluate.
- Industry testing standard and title that governs the testing. Annex 2 provides some leeway in Section A2.3 to the Architect of Record (AOR) and the BECxA to select a different test standard that achieves the same end result.
- Where the test is performed – laboratory or field.
- Whether the field test is a mockup or in situ test.
- Whether the test is mandatory or optional for fundamental or enhanced commissioning.
- The number of tests.

For instance, water testing is commonly performed on building fenestration. Per Table A2.1, static water penetration must be completed per ASTM 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. It is a field test (as described in its name). It must be performed once on a field mockup and once on in situ installations for fundamental commissioning. If enhanced commissioning is required, the testing must be performed once on a field mockup and twice on in situ installations. However, per Section A2.3, the AOR may specify AAMA 501.1[6] testing in lieu of ASTM E1105 testing, in consultation with the BECxA and acceptance by the owner. It is important to evaluate these substitutions carefully as the test procedures may result in substantially different outcomes. This will be revisited later in this paper.

The mandatory testing required in Table A2.1 is a minimum for fundamental and enhanced commissioning. Table A2.1 also includes a lot of optional tests that can be performed on building enclosure systems. The questions that a BECxA must consider and answer are as follows:

- What tests are required?
- What optional tests provide benefit to the project?
- How many of each test should be performed?
- Who should perform the testing?
- How should it be performed?

Of the questions above, the most critical is the last one, as how a test is performed can ultimately affect whether the system tested passes.

The remainder of this paper will discuss these questions and how best to answer them.

What Tests Are Required?

This is a fairly easy question to answer, as the table provides a list of mandatory testing needed for both fundamental and enhanced commissioning. The following table summarizes the testing required for fundamental and enhanced commissioning:

Table 1.

	Fundamental	Enhanced
Acoustic performance		ASTM E966 ASTM E1014 ASTM E1503
Air Testing		ASTM E779 ASTM E1827
	ASTM E283 ASTM E783 Opaque Walls ASTM E783 Windows ASTM E1186	ASTM E283 ASTM E783 Opaque Walls ASTM E783 Windows ASTM E1186
Insulation testing	ASTM C1153	ASTM C1153
Water penetration	ASTM E331 ASTM D5957 ASTM E1105 AAMA 501.2	ASTM E331 ASTM D5957 ASTM E1105 AAMA 501.1 AAMA 501.2
Adhesion and durability	ASTM D4541 ASTM E488 ASTM E2359 ASTM E488	ASTM D4541 ASTM E488 ASTM E2359 ASTM E488
Sealant durability	ASTM C794 ASTM C1193 Appendix X1 – Method A	ASTM C794 Appendix X1 – Method A

The main difference between fundamental commissioning and enhanced commissioning regarding testing is that enhanced requires acoustic performance testing, additional air testing, and additional water testing. Otherwise, the difference is limited to the types of testing (laboratory vs. field) or the number of tests. The required tests provide the knowledge needed to understand how the most critical aspects of most building enclosure systems will perform.

Both laboratory and field tests can provide significant information on the performance of the building enclosure systems. Laboratory testing can be performed in two manners. The first is product certification testing where a component, such as a window, is tested in a laboratory to confirm its performance and provide a rating (e.g., water penetration resistance). While this technically meets many of the required BECx laboratory test standards and is helpful in selecting products, it does not provide the necessary information on how the product will perform in a

project specific design, including flashing and interfacing systems. Completing a laboratory test on a mockup of the building enclosure system can provide this information. By completing mockup testing in the laboratory, the project team has the benefit of understanding the likely performance of the building enclosure system prior to manufacturing the components and installing them. Should a problem exist in the design, manufacturing, or installation, it can be discovered and remedied prior to construction. Laboratory testing can be very expensive and time consuming, so it is not appropriate for every project. It is most valuable on projects involving a unique system specifically designed for that building and where existing products are used in an unconventional manner.

Field tests also provide valuable information on the performance of the building enclosure system. In fact, the information can be more valuable than a laboratory mockup given that field testing involves testing actual products installed on the building enclosure of the actual building by the actual installers and includes the surrounding systems and details. However, field testing has the drawback of not being completed prior to construction, so if a failure is found, it needs to be diagnosed to understand whether it is an isolated or systemic problem. Finding a systemic failure during field testing can result in a significant cost and potential delay to the project given that repairs in the field may be considerably more difficult than if the issue had been discovered in a laboratory mockup test and fixed prior to construction.

What Optional Tests Provide Benefit to the Project?

This question is best answered on a project-by-project basis and is dependent on the needs and parameters to meet the owner's expectations. The following guidelines can assist with making decisions about the optional tests provided in Table A2.1 and how they can provide value to a project.

Starting with the Owner's Project Requirements, consider the goal of the building enclosure systems. Does the owner have expectations of the systems meeting the bare minimum requirements for performance, or is the owner looking to achieve enhanced performance from the building enclosure systems? For instance, one owner may only expect the curtain wall on a building to keep air and water out of the building while another owner may expect that same curtain wall to provide acoustical separation for a television studio. Dew point evaluation of insulated glazing units may not be important for typical installations; however, for a window located in a high-humidity environment (e.g., a museum or natatorium), it can be critical to test to verify that the designed fenestration will withstand the more-stringent performance expectations. The BECxA can help the owner understand these options and decide which tests will help most to meet their performance goals.

How Many of Each Test Should Be Performed?

Table A2.1 provides a minimum number of tests for required fundamental and enhanced commissioning tests. However, often the number of required tests is only one for a field mockup and one for in situ testing. While a single test on a field mockup may be appropriate given that it is only constructed once, one test on in situ installation that may be repeated tens or hundreds of times is typically not sufficient. While a statistical meaningful sample may be unrealistic for systems that are repeated significantly on buildings (e.g., punched window openings in a dormitory), performing more than one test on in situ installations verifies appropriate installation over time and by potentially different crews. Repeated in situ installations benefit from testing at the start of the installation and at two other milestones throughout the installation. In addition, to the number of tests, it is important to randomly select the specimens to be tested after installation. Otherwise, it is possible that crews are diligent and spend extra time on the installations they know will be tested and do not install similarly on those that will not be tested. Whenever possible, we recommend against selecting the specific test areas in advance to avoid inconsistent installation practices of the selected specimens by the installer.

In addition to the number of tests initially performed, it is prudent to require a number of additional tests to be performed should a test fail. The number should be substantial enough to determine whether the failure is a one-off or systemic.

It is important that the BECxA be aware of all testing conducted on the building enclosure. Contractors may pre-test the enclosure assemblies/components to verify the performance prior to official testing. Should they discover a failure, it allows them to make repairs prior to official testing, often without documenting the testing, failure, or repair. This can result in masking a potentially bigger issue with the design, product, or installation. The project documents, especially the building enclosure commissioning specification, should specifically prohibit any testing, including pre-testing, not witnessed by the BECxA. For example, if pre-testing is performed and a repair implemented, it may not be disclosed at the time of official testing witnessed by the BECxA and design team. The concern is that the issue may be systemic and not be fixed on futher installations, or the root cause may not have been repaired. It is important that all necessary parties be present for testing.

Who Performs the Testing?

This question seems straightforward, but it is not as nearly as it seems. The owner has three options available to them when considering this question. First, they can have the BECxA perform the testing. This is often preferred by the BECxA because it allows a level of control over the testing, including making necessary adjustments in the field to accommodate construction and performing diagnostic testing for failures. However, this may not be the most economical option for the owner as a BECxA may not be as cost effective as a testing agency that only performs testing as their service.

The second option an owner has is to directly engage a testing agency to perform the testing, overseen by the BECxA. This option allows the BECxA to retain control of the testing by directing the testing agency in the performance of the testing. However, this may also not be the best option for the owner as it introduces another firm working for the owner, puts coordination of testing on the owner and BECxA, and complicates the payment for retesting should a test result in a failure since the payment will need to be withheld from or backcharged to the contractor (this also occurs with the first option as well).

The third option is one that more owners select and that is to specify that the contractor must engage a third-party testing agency to perform the testing. It is in the owner's interest to have the BECxA review testing protocols in advance and witness the testing. It makes testing coordination easier, as the contractor is responsible for the project schedule and can more readily arrange for the testing. It also makes paying for failed testing easier, as the contractor owns all testing and pays the testing agency directly. The owner and BECxA loses some control over the testing given that the contractor engages and pays the testing agency. However, the BECxA, as well as the designers of record, are still involved in the evaluation, analysis, and repairs if a failure should occur, which provides the owner with several firms looking out for their interest.

How Should It Be Performed?

Testing performed on a project is best performed in accordance with recognized industry standards such as the ASTM test methods given in ASTM E2813 or as noted in ASTM E2813 Section A2.3. Often, it is possible to test assemblies to another standard that may incorporate the testing methodologies of the ASTM test but provide other restrictions elsewhere in the testing. One example of this type of discrepancy that can occur in a test is the difference between ASTM E1105[6] and AAMA 501.1[7]. ASTM E1105 is the recognized procedure for testing installed fenestration in a building and the referenced procedure in ASTM E2813. AAMA 501.1 is the field testing standard for products certified by AAMA member organizations. While AAMA 501.1 incorporates the testing procedures of ASTM E1105, it also provides several restrictions that do not actually help the owner or the BECxA understand the overall performance of the building enclosure; it is specifically designed to only provide the performance of the fenestration. For instance, AAMA allows a one-third reduction in test pressure to account for "damage" to the fenestration seals and other internal components that might affect performance during shipping and installation. Therefore, a fenestration rated for 12 psf at the laboratory is only tested to 8 psf in the field. Although it is not required to take the one-third reduction, the author has yet to observe a field window test performed by a

manufacturer to AAMA 501.1 where they proposed to test without the one-third reduction. In addition, AAMA 501.1 requires that the cladding be fully installed prior to testing, including all joint sealants. From a performance standpoint, the fenestration is part of the water barrier of the building and should be integrated with the water barrier appropriately. The building cladding is not part of the water barrier system if the building enclosure features a cavity wall system, as is common in the industry. Therefore, the BECxA may want to require testing once the water barrier and fenestration are installed, rather than waiting for the cladding to be installed. This evaluation needs to be performed on the other tests decided upon as part of the BECx process.

PREPARING A TESTING REGIME

Considering the information provided above, how can a BECxA develop a testing regime that helps and does not impede BECx? The following case studies illustrate how to best select a testing regime to get the most out of it and to avoid the pitfalls of specifying overtesting or tests that do not provide value regarding the results.

Case Study #1 Construction of a New Science and Engineering Research Building for a University

A university wanted to construct a new building that mixed research scientists with engineering faculty to help spark and generate interactions among the staff. Given the prominence of the building on campus, its high profile, its complicated geometric design, and the project team's goal of a LEED Gold rating, the university elected to include building enclosure commissioning.

The entire scope of building enclosure services performed on this building is beyond the scope of this paper. However, key to the testing scope eventually performed on the building was the development of the Owner's Project Requirements (OPR), the Enclosure Commissioning Specification, and the design reviews, especially the specifications for the enclosure components. We worked with the owner and project team, both the design and construction teams, to develop a testing plan for the building enclosure, with special attention paid to the complex curtain wall system.

Although the owner desired to commission the enclosure in accordance with ASTM E2813, ultimately the owner did not want to incur the costs of all of the testing required in the document. This is not uncommon, especially with the vague requirements in LEED for enclosure commissioning. As the BECxA, we worked with the owner to develop a testing plan that provided the owner with confidence that the key enclosure systems would be validated through testing. This provides a quandary for the BECxA. If all testing specified in ASTM E2813 is not performed, can the building enclosure be considered commissioned? The question has different answers in different contexts. In the context of LEED, the building enclosure was considered commissioned, as the testing completed was accepted (note that testing is only one portion of the LEED requirements for commissioning). In the context of ASTM E2813, the building enclosure would not be considered commissioned, as all mandatory testing was not performed. The owner considered the building enclosure commissioned as the testing focused on the key aspects of performance that concerned the owner as discussed in the OPR.

The testing protocol for the project involved the following:

Curtain Wall System. The curtain wall manufacturer completed a two-story mockup of the curtain wall in their fabrication plant for testing. As BECxA, we had representatives on site both for the fabrication and erection of the curtain wall mockup as well as returning to the fabrication plant for the testing with representatives from the entire project team. By visiting the fabrication plant during construction of the unitized curtain wall, we were able to evaluate the means and methods of the curtain wall fabricator, understand their quality control and quality assurance procedures, and look for potential weaknesses in the fabrication that could lead to performance issues in the field. While most of this work was observation only, we continually asked questions through the fabrication process both to fully understand the process and to challenge the manufacturer on processes that may result in potential issues during

testing. The attention to detail paid off with the mockup passing the tests on the first try. The mockup tests included ASTM E283 and E331.

In addition to the offsite mockup, we implemented an on-site testing protocol that evaluated performance of the curtain wall once erected on the building in accordance with ASTM E1105 and AAMA 501.2[8]. When testing found a water leakage path, we were quickly able to determine that it was an erection issue and not a fabrication issue, since we had participated in the fabrication mockup construction. Additional testing determined that water was trapped in the units while they were exposed onsite prior to installation, which led to better storage and handling by the contractor and field installation crew and an adjustment to the testing procedures to detect trapped water in advance.

Roofing and Waterproofing. We developed a testing protocol for the roofing and waterproofing systems as well, relying on ASTM E2813 to guide the selection of tests that would most benefit the project.

We performed ASTM C1153 – Standard Practice for Location of Wet Insulation in Roofing Systems Using Infrared Imaging[9] – testing coupled with roof cuts to determine whether thermal anomalies were areas of wet insulation. In addition, we required the roofing contractor to provide samples of the heat-welded seams produced by the automatic welder several times a day to confirm that the welds were sufficient.

In addition to the infrared testing, we also completed uplift testing on the roof in accordance with FM Global's Property Loss Prevention Data Sheet 1-52 (Field Verification of Roof Wind Uplift Resistance) utilizing the negative pressure test method. This is not a test listed in ASTM E2813, but it does provided additional verification that the roof will withstand the wind uplift loads on the roof. We worked with the owner to discuss the merits of this testing, along with FM Global, who insures the owner's buildings, to verify that the test was both reasonable and worthwhile.

Plaza waterproofing testing included both electric field vector mapping (EFVM) as well as ponded water tests to confirm that the plaza waterproofing membrane was not compromised.

We required joint sealant testing in accordance with ASTM C1521 – Standard Practice for Evaluating Adhesion of Installed Waterproofing Sealant Joints[10] – and performed periodic testing over the course of the project.

By considering what concerned the owner and the testing listed in ASTM E2813 for enclosure commissioning, the enclosure commissioning testing program provided value to the owner at a reasonable cost.

Case Study #2 Replacement of Roofs and Fenestrations at Existing K-12 Schools

A state agency responsible for upgrading roofs and fenestrations of existing K-12 schools has a requirement for BECx as part of the construction process. Over the course of eight years, the BECx process for this agency has changed to reflect lessons learned and to make the BECx work more efficient and effective.

During the initial start to BECx for this type of work, the state agency engaged the BECxA often close to, if not after, the completion of the 100% Construction Documents. This provided little opportunity to prepare a testing regime that would benefit the project, other than to specify the state mandated testing requirements (ASTM E1105 for fenestrations and ASTM E1521 for roofing). As the state started to engage the BECxA earlier in the process, it allowed for a more comprehensive testing regime, including testing that could be performed by the contractor at little to no cost or schedule impact to provide enhanced quality on the project. Instead of just doing infrared scans on completed roofs, additional testing requirements, such as flood testing drains and obtaining heat welded samples of the roofing membranes, are ways to verify continued quality without significant cost or test setups. The simplicity of these tests allowed them to be performed continuously, resulting in a continuous quality feedback loop rather than a point in time test. And since these tests were non-specialty tests, the contractor could perform them and provide documentation to the project team.

With the fenestration replacements, moving the project teams from AAMA 501.1 to ASTM E1105 was the first major impact of BECx. By doing so, the testing could take place earlier in the replacement process and could be performed by the BECxA as originally required by the owner. As failures occurred over multiple projects, the owner made a key change that allowed for a smoother testing process. Rather than having the BECxA perform testing, the owner specifically required the burden of testing be shifted to an outside testing agency engaged by the contractor

under the direction of the BECxA. This provided two benefits to the project. First, the BECxA controlled the testing process, and any further investigation needed to remediate a failure. Second, should a failure occur, the owner did not need to worry about withholding funds from the contractor to pay for the BECxA to perform additional testing; the contractor owned the cost of all testing and retesting. As part of the testing regime for the fenestrations, the BECxA required that three additional fenestrations be tested for every failed fenestration test. This requirement provides the opportunity to determinewhether a fenestration failure is a one-off issue or a systemic issue.

SUMMARY

Building enclosure commissioning (BECx) is a quality assurance process that focuses on verifying that building enclosures meet the owner's requirements for performance. By understanding the tests referenced in ASTM E2813 and any specific testing required per additional standards, the BECxA can prepare an appropriate testing regime that provides value to not just the building owner, but the entire project team throughout the project. The testing scope can be tailored by a knowledgeable and experienced BECxA to be impactful and and comprehensive while still being cost effective and efficient.

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