ACHIEVING TIGHT BUILDINGS THROUGH BUILDING ENVELOPE COMMISSIONING

Bryan J. Boyle, B.Comm (Hons)*[1], John Runkle, P.E.[2], and Richard Ziegler[3]

1 Architectural Testing Canada, Inc.
356 Saulteaux Crescent
Winnipeg, Manitoba, Canada
**bboyle@archtest.com*

2 Architectural Testing, Inc.
130 Derry Court
York, Pennsylvania, USA

3 Architectural Testing, Inc.
2825 E. Cottonwood Parkway, Suite 540
Salt Lake City, Utah, USA

ABSTRACT

In an effort to improve building energy efficiency, functional performance, and life cycle durability, a noticeable trend in building codes, standards, and individual project specifications has been towards the 'tightening' of buildings; that is, greater control of air movement across the building envelope. Standards across the world vary with respect to airtightness requirements; in the United States, it is not uncommon to see specified performance requirements as tight as 0.10 cfm/ft^2. It is expected that these mandated improvements in air leakage resistance be achieved despite a declining pool of skilled trade labor asked to construct increasingly complex designs and details under stringent budgetary and time constraints. Notwithstanding these concerns, these stricter airtightness performance requirements are being realized, and recent data has shown Building Envelope Commissioning (BECx) to be an effective means of quality assurance that aids in the achievement of these more rigorous performance requirements.

This paper will discuss the Building Envelope Commissioning process, identifying the critical procedures of which it is comprised. Examples will be cited that demonstrate how, through the BECx plan, proactive steps are taken prior to and during the construction process to improve the completed building's air leakage performance through design concept consultation, peer review of construction documents, mock-up review and testing, and on-site inspections. Special consideration will be given to functional performance testing, and the more commonly used airtightness testing standards and procedures. Of particular interest are whole building airtightness tests and other 'end' tests that, while effective in measuring or verifying a building's air leakage rate, are often insufficient as the sole means of quality assurance in which they are often specified.

KEYWORDS

Commissioning, Building Envelope, Airtightness, Air Barrier, Testing, High-Performance

1. INTRODUCTION

The control of air movement across the building envelope is critical for three primary reasons (*Straube, 2007*): (a) The control of water vapor which, if permitted to infiltrate or exfiltrate through the building envelope and condense within the wall system, can lead to extensive damage to building components (*CMHC, 2001*); (b) Air quality and comfort, which includes reduction in air quality resulting from molds and mildews, the transmission of sound and odor from the exterior environment to the interior, and infiltration of cold air to the interior, and; (c) Energy savings, which simulation studies have shown can increase between 5% and 45% as building air leakage decreases, depending upon climate zone (*Zhivov et al., 2009*).

Energy efficiency in particular, through LEED enhanced commissioning, has been a driving force in the noticeable trend in building codes, standards, and individual project specifications towards the 'tightening' of buildings. While a whole-building air leakage characteristic of 0.40 cfm/ft^2 was once - and to some degree still is - considered 'tight', it is now common to see specified whole-building air leakage rates as low as 0.10 cfm/ft^2 under the same pressure parameters. The question becomes how these air leakage rates are achieved given a declining pool of skilled trade labor working under stringent project budgetary and time constraints with increasingly complex designs and details.

2. BUILDING ENVELOPE COMMISSIONING

Building Envelope Commissioning (BECx) is a systematic process to help ensure that the building envelope, as designed and installed, performs interactively according to the Basis-of-Design (BOD) and Owner's Project Requirements (OPR) through verification of the system's performance (*Knight et al., 2008*). ASTM E 2813 Standard Practice for Enclosure Commissioning which also references ASHRAE Guideline 0 and NIBS Guideline 3, identifies the tasks that should comprise a BECx program. While the precise tasks and frequency of those tasks may differ between individual projects, basic practice usually follows a defined series of steps that are categorized into five phases with the following goals (*de Sola et al., 2011*):

- Pre-Design Phase: Defining the OPR and developing a design concept which will satisfy the OPR given the expected external factors - including geography, climatic conditions, complexity of design, occupant usage, etc. – that may affect long-term durability and functionality of the building envelope.

- Design Phase: Reviewing design/contract documents for conformance with the OPR and BOD, and drafting the BECx specification, Functional Performance Testing (FPT) specification, and preliminary BECx Plan - including quantifiable performance metrics and quality assurance procedures – so that when the building is constructed compliant to said documents, the building envelope will function in a manner to satisfy the OPR.

- Pre-Construction Phase: Reviewing shop drawings and submittals pertinent to the building envelope, including scheduling and sequencing, material selection, quality control procedures, and assembly functionality verification. Construction of a performance mock-up will be reviewed and the mock-up tested to verify functionality of the assemblies. A Pre-Construction/Pre-Commissioning Meeting(s) will be conducted with all building envelope trades prior to the onset of construction to discuss project details, scheduling and sequencing, performance requirements, quality control and quality assurance protocols and materials compatibility.

- Construction Phase: Observing and documenting that the building is constructed in keeping with Codes, manufacturer's recommendations, construction documents, shop drawings, and good industry practice, with verification through functional performance testing.

- Operations and Maintenance Phase: Finalizing the BECx record, and compiling warranty and training documents with the intent that the building envelope remains functional over its expected life cycle.

While is it beyond the scope of this paper to discuss all of the individual tasks that comprise each phase of the BECx process, some of the tasks identified below provide results, analysis, or feedback which, when addressed, can significantly improve the air leakage characteristic of the completed building.

2.1. Design Review

During the Design Phase, project plans and specifications are reviewed by the Building Envelope Commissioning Agent (BECA) to assist in developing a fully functional building envelope. Individual details are reviewed to ensure compatibility within the confines of the system; this includes assessing the continuity of the functional layers of the building envelope through the wall plane and at all junctions between adjoining components or assemblies (including penetrations, fenestration integration, wall-to-grade beam, roof-to-wall junction, etc.), highlighting problematic details and design considerations with respect to constructability, and assessing the performance of the envelope in terms of water penetration resistance, air movement, vapor protection, thermal protection and drainage. Additionally, the overall building is evaluated to help ensure all critical or atypical conditions are details. Project specifications are reviewed to ensure the same, and that appropriate performance requirements, quality control, and quality assurance measures are in place.

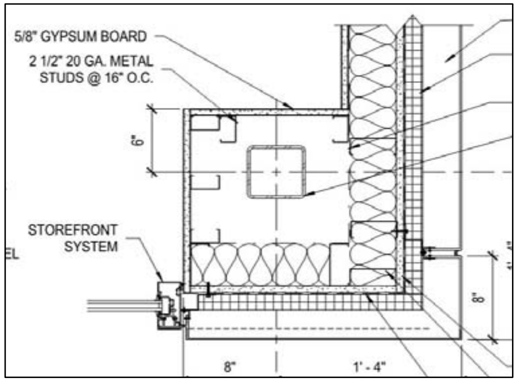

Figure 1: Wall-to-storefront system detail,
depicting a misalignment between the fenestration and opaque wall.

As they pertain specifically to airtightness, most commonly found issues relate either to discontinuity in the plane of airtightness at junctions between adjoining assemblies, non-constructability of details or unrepaired damage to the air barrier due to the sequencing of component installation, and misplacement of the air barrier relative to the other functional planes. The detail in Figure 1 depicts the junction of a wall-to-storefront. The primary sealant at the fenestration perimeter needs to be in place at the laboratory tested, warrantable location; typically, the exterior of the frame for storefront systems. Fenestrations are often misaligned with the opaque wall such that they are extended to the exterior, resulting in a disconnection between the fenestration and the opaque wall and creating a discontinuity in the air barrier.

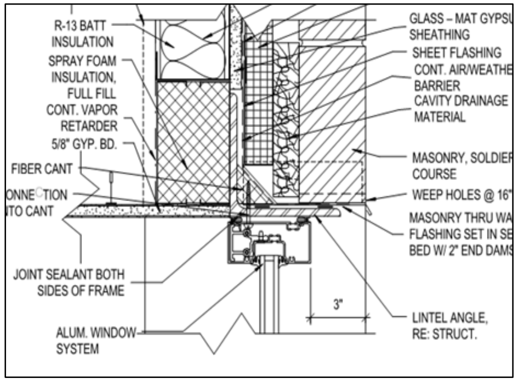

Figure 2: Sequence of work will lead
to blind penetrations being made through the air barrier membrane.

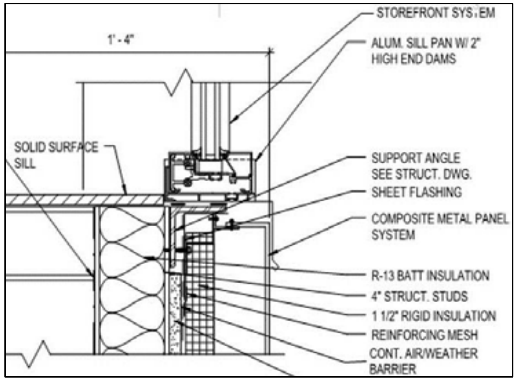

Figure 3: Flashing interrupts the air barrier.

In Figure 2, the sequence of work is such that blind penetrations through the air barrier are made, which often go unsealed. In Figure 3, the flashing interrupts the air barrier instead of the air barrier being installed continuously and flashing subsequently stripped in. If each of these details is typical on a given project, the consequence of leakage at any one of the details is amplified due to the frequency of occurrence. In some cases, only one poor detail can be enough to prevent a successful whole building airtightness test result even if the remainder of the facility is designed and built effectively airtight.

2.2. Mock-ups

Knight, Runkle and Boyle (*Knight et al., 2009*) provide a treatise on how to best utilize mock-ups within the BECx process. Mock-ups built using the exact construction techniques, materials, and technicians that will be used on a project provide the project team an opportunity to identify and resolve potential areas of conflict prior to the commencement of construction and to verify, through inspection and performance testing, that design details of assemblies/systems will function per the design intent given the skill level of the installers.

Requirements for the construction and testing of mock-ups are usually defined in Division 1 of the Project Specifications in both the BECx specification and FPT specification. The BECA typically assists the designer in developing a mock-up construction and testing protocol, identifying the specific components to be included, the number of mock-ups, performance requirements, configurations, test parameters, and inspection/documentation requirements. Other requirements peculiar to a particular component or assembly are included in the corresponding sections of the specifications.

While mock-ups can be specified for any building envelope component or assembly, functional performance testing of building envelope mock-ups primarily refers to the testing of window/curtain wall assemblies (and other fenestrations), the opaque wall system or roofing to assess or measure air leakage, water penetration resistance, vapor diffusion, and thermal performance. Common on-site test methods for airtightness testing are described below.

2.3 Visual Verification

Throughout the construction process, the BECA should perform visual examinations of the air barrier system to identify deficiencies in the installation that may affect the airtightness (or other properties) of the system. While emphasis should be on the initial stages of installation, reviews should continue throughout to ensure that the quality standard remains consistent. This includes not only the air barrier and all components that comprise the air barrier system but also, where applicable, ensuring that the substrates onto which they will be installed are acceptable (i.e. dry, clean, properly primed). Identifying deficiencies through visual examination helps prevent overusing the testing budget on samples that are obviously non-compliant. While minor discrepancies in installation can often be easily addressed if detected early, major or repeat deficiencies may be an indication that the workforce does not possess the requisite skill level or experience to install the products.

Types of ‘gaps’ in the system that the inspector should be aware include (Knight et al, 2004):

- ‘Flutes’ (long, narrow passageways that run from open membrane seams through to midfield areas of the membrane).
- Unsealed, non-airtight penetrations through the membrane. Sometimes, leaky penetrations may be obvious to the eye, but on most occasions, some form of airtightness testing will have to be conducted in order to determine whether or not the penetration has been sealed adequately.
- Unrepaired damage to the air barrier from other trades.
- De-bonded areas of membrane, especially around penetrations, window frames and other intricate or difficult to construct details.
- Discontinuities in the plane of airtightness with adjacent systems.

2.4 Airtightness Testing

Most associate building envelope airtightness testing as testing of the air barrier membrane. But many other components are installed continuous to the air barrier membrane which function as a part of the plane of airtightness. Several test methods are commonly used during the BECx process to evaluate or measure the airtightness of components, assemblies, and systems. Some of these test methods are more complex and best suited for testing mock-ups and on a limited basis during work-in-progress construction. Others are simple tests that can be performed quickly and without major disruption to the construction schedule and therefore practical for use throughout construction. Yet others are end tests that are conducted upon building completion.

The airtightness of fenestrations and/or opaque wall systems can be quantifiably measured in-situ in general accordance with ASTM E 783. To conduct this test, a test chamber – usually rigid but sometimes polyethylene sheeting – is constructed around the test sample and is pressurized and/or depressurized in order to measure the rate of air flow through the test area. Often, the test specimen consists of multiple assemblies, for example, window unit and adjacent surrounding opaque wall, where the allowable air leakage rates of the two assemblies are different. Here, a rigid chamber is often most effective, as it can be more successful in dealing with extraneous air leakage and other inherent characteristics of the polyethylene which may influence test results. This, in turn, results in a higher confidence in the numerical data obtained during the test (*Knight et al., 2011*).

ASTM test method E1186 contains numerous qualitative test procedures that can be performed relatively quickly and with minimal disruption to the construction process. Method 4.2.7 can be used to evaluate the airtightness of air barrier membrane seams, overlaps and T-joints, and penetrations through the membrane (i.e. masonry ties, through-wall piping, and fastener penetrations) through pressurization of a test chamber in conjunction with leak detection solution. Methods 4.2.2 and 4.2.6 involve the pressurization/depressurization of a zone (i.e. the room in which the test sample is housed) or a test chamber installed around the test sample in conjunction with smoke generators to provide a visual depiction of the air leakage through the test area. These ‘smoke’ tests are effective in pinpointing the precise location of air infiltration or exfiltration, and are often used in combination with quantitative tests methods to provide a more complete diagnosis of component or assembly airtightness.

3. WHOLE BUILDING QUANTITATIVE AIRTIGHTNESS TESTING

As its name implies, whole building airtightness testing is used to assess the air leakage characteristic of a completed building. The most common methods, ASTM E 779 and ASTM

E 1827, rely on quantitative measurement techniques utilizing fan pressurization or an orifice blower door in conjunction with computer software. As it relates to testing of new or retrofit projects for compliance to specification, typically, the pressure boundary area of the building – including the total surface area of the "six-sided" box which is the roof/ceiling, walls and ground floor – must have a total air leakage rate not to exceed a prescribed amount. For example, a single-story building with a flat roof measuring 200 feet long by 100 feet deep by 22 feet high, with an airtightness performance requirement of 0.25 cfm/ft^2 at 0.3 in. H_20, is allowed no greater than 13,300 cfm of air leakage (*Brandt, 2012*).

The benefits of whole building airtightness testing are numerous: for compliance, it provides a means of determining whether a building's air leakage characteristic meets prevailing codes and standards; as a quality tool, it assesses the effectiveness of the air barrier system; as an analysis tool, comparisons of airtightness measurements pre- and post-retrofit can be drawn; as a maintenance tool, results at different points in time post-construction can be compared to detect changes in the effectiveness of its air barrier system over time.

3.1. Quantitative Airtightness Testing is Not Commissioning

Whole building airtightness testing is not commissioning, nor should it be used as the sole means of quality assurance on a given project. While it can be an effective end test to verify the quality of the building as designed and constructed - and therefore an effective tool *as a part of the commissioning process* - it does not provide a means of quality assurance to help ensure that specified performance requirements are achieved in and of itself; that is, there is not a 'preventative' component to the test. Any deficiencies or malfunctions resulting in an air leakage characteristic greater than the allowable are only detected upon completion of the entire system. This poses several problems: (a) extensive remedial work which may be both costly and time-consuming may be required and may have been preventable had the deficiencies been discovered earlier; (b) the air barrier may be 'non-maintainable'; in other words, the air barrier may not be exposed and accessing that air barrier for the purposes of remediation may not be practical; (c) the test result provides a quantified measurement of the building's air leakage characteristic, but it does not identify where or what the breaches in the air barrier system are that are causing the elevated air leakage rates, and; (d) the measured air leakage rate for the entire building may be below the allowable, but individual components or assemblies comprising the air barrier system may have air leakage rates greater than the allowable for that given component or assembly.

Whole building airtightness testing is therefore best utilized in conjunction with other, qualitative methods when used as a tool to evaluate a building's air leakage characteristic. The other factor to consider is that airtightness testing is just that – it tests for air leakage. It does not consider other factors that may affect the performance, functionality, and durability of the building envelope system, including water penetration resistance, drainage, vapour protection, thermal performance, and acoustics.

4. CASE STUDIES

4.1 Dixie State College

The Holland Centennial Commons building at Dixie State College was a new five-story building to include a library, classrooms, office space and a data center, and requiring a low tolerance for air infiltration. A BECx protocol was established in order to help attain a whole building air leakage rate no greater than 0.15 cfm/ft^2. Several challenges were discovered and addressed during the BECx process that, left undiscovered, may have compromised the functionality of the air barrier system:

- Portions of the opaque wall consisted of masonry and metal panel cladding over insulation, air barrier, and exterior sheathing, with adjacent opaque wall sections consisting of GFRC cladding with an insulated metal back pan. Transitioning between these opaque wall assemblies and incorporating the numerous curtain wall and storefront fenestration openings presented a significant challenge for the design and construction teams. For instance, the interfaces at the GFRC panels (which were intended to work as a unitized panel with a metal back pan that functioned as the primary air, water and vapor barrier) were originally designed with a silicone sheet set in sealant at the metal back pan. Due to "true" geometry of the metal back pans, it was anticipated that achieving a continuous and robust detail using the silicone sheet would be difficult. Instead, the project team decided to use sprayed-in-place polyurethane foam (SPF) at transitions and panel-to-panel joints to ease the installation of this seal.

- Many of the subcontractors had challenges coordinating with the other trades, especially trying to show a continuous air barrier on their shop drawings. To address these concerns, weekly coordination meetings with trades and manufacturers were conducted, and air barrier coordination drawings were developed which were believed to be critical in achieving sufficient system airtightness. Building Information Modelling (BIM) was also used extensively to identify key transitions and details for air barrier continuity.

- Testing of a stand-alone mock-up of the wall assembly prior to the onset of construction identified numerous breaches that were contributing to an excessive rate of air infiltration – critical points that would require greater diligence during installation and subsequent field inspection and testing. The contractor's proactive response to these items, and other field inspection punch list items such as discontinuities in the air barrier, sealants or SPF, led to the continual improvement in airtightness as verified through functional performance testing throughout the remainder of the construction process.

Upon completion of the project, the building air leakage rate was measured at 0.07 cfm/ft^2.

4.2 Weber State University, Residential Life Phase II – Building 2

Weber State University Residential Life Phase II – Building 2 was an 81,000 square foot new construction project with a specified whole building air leakage rate of 0.10 cfm/ft^2. Several issues were identified during the design review process: (1) The storefront windows were not interfaced with the air barrier; (2) The roof vapor barrier and roof membrane were not interfaced with the air barrier at the exterior wall, and; (3) The air barrier was not continuous at soffit locations.

A stand-alone mock-up of the air barrier system was constructed, an enclosure consisting of a four-sided 'box' with roofing and five punched openings each representing a type to be installed on the building. The mock-up achieved an air leakage rate of 0.02 cfm/ft^2, well below specification, which verified that the building, all things being equal, should be able to achieve the specified airtightness characteristic. Additionally, the mock-up set the benchmark for future installations on the project; as an example, all air barrier membrane overlaps on the mock-up were sealed. On-site reviews of the work-in-progress revealed that the vapor permeable air barrier was not adhering sufficiently at overlaps due to a low amount of adhesive, and were peeling back. To keep consistent with the mock-up, all membrane overlaps throughout the building were sealed.

Upon completion of the project, the building air leakage rate was measured at 0.099 cfm/ft^2.

5. CONCLUSIONS

Energy and environmental codes continue to evolve, the prevalence of "green" building continues to intensify, and building performance requirements are becoming increasingly stringent, especially as they pertain to building airtightness. Given the resources that can be saved by achieving a functional building envelope and a reduction in energy consumption, effective quality assurance mechanisms must be in place during new and retrofit building construction projects to help minimize uncontrolled air leakage through the building envelope, a critical factor that also affects not only energy consumption, but also building durability and occupant comfort.

Building envelope commissioning has proven to be an effective process in reducing building envelope leakage and achieving a high-performance building envelope. The progressively stringent specified airtightness requirements, which are verified via whole-building airtightness testing, are often significantly exceeded by well-commissioned building. Through involvement during all phases of the project, building envelope commissioning can detect or identify design errors, material incompatibilities, and installation deficiencies sufficiently early so to prevent costly remediations and delays to project completion. And while the BECx program can be tailored to suit the parameters of any particular project, and it may tempting to limit the program to isolated activities, it is imperative to include all key tasks in the process to best reap the quality assurance benefits that it provides.

6. REFERENCES

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