Building Enclosure Commissioning
A review of “commissioning under the influence”

Fiona Aldous
Senior Associate
Wiss, Janney, Elstner Associates, Inc.

Joseph J. Godfryt, AIA
Principal
Wiss, Janney, Elstner Associates, Inc.

Daniel J. Lemieux, AIA
Principal
Wiss, Janney, Elstner Associates, Inc.

Synopsis

This presentation will review the increasing role of building enclosure commissioning in the context of today’s design and construction environment related to performance-critical buildings. These buildings are identified by strictly controlled interior environments which are important for the building to function effectively and efficiently as a coordinated and integrated whole. For this reason, the building enclosure, the dividing element between the performance-critical interior and the uncontrolled exterior environment, must continuously operate in accordance with the specified requirements.

Beginning with the Request for Proposal (RFP) for Commissioning (Cx) of the Building Enclosure (BE), the paper examines the scope of the BECx plan. From design concept through substantial completion and post-occupancy evaluation, there are critical milestones that mark a comprehensive and successful commissioning process. For the Owner, perhaps the most critical step is the development of a carefully crafted and well-conceived RFP. If the RFP clearly defines the Owner’s Project Requirements (OPR) and performance objectives for the project, and outlines both the scope of work and baseline qualifications of the BE Cx Agent, it can be an essential tool to “jump start” the project in the right direction.

In summary, the presentation shall discuss how the individual performance requirements unique to each building subsequently can influence the building enclosure commissioning process, from RFP to validation of performance and post-occupancy. Attendees will gain an understanding as to what should be considered in the development of a concise RFP, and the building enclosure commissioning process that evolves. Case studies involving performance-critical buildings will be examined. The case studies shall include successful and unsuccessful designs, and building enclosure design and commissioning best practices.
About the Authors

Fiona Aldous is a Senior Associate in the Washington DC office of Wiss Janney Elstner, Inc (WJE). She has extensive experience in the peer review, construction observation and investigation of contemporary building enclosures. She is experienced in providing detailing assistance to architects and designing repairs for various building enclosures, including; rain-screen facades curtain wall, windows, roofing and waterproofing. She has lectured as an assistant professor at the School of Architecture at Ball State University in the area of design and construction, and worked as a field superintendent constructing new laboratories and pharmaceutical manufacturing facilities. She is co-chair of the local Building Enclosure Council, has recently been invited to be a member of the AIA National Building Commissioning Advisory Committee, and is a current committee member and co-author of NIBS Guideline 3: Exterior Enclosure Technical Requirements for the Commissioning Process.

Joseph J. Godfryt, AIA, is a Principal at the corporate offices of WJE in Northbrook, IL. He has maintained a professional focus on building enclosure forensics and rehabilitation over his thirty year career. He specializes in the correction of water entry problems, particularly that related to roofing and waterproofing system failures and has been involved with an extensive variety of roofing and waterproofing system issues on literally all types of buildings and materials. In addition to work throughout the United States he has successfully corrected building enclosure problems in Europe, Asia, South America, and Africa.

Daniel J. Lemieux, AIA, is Principal and Unit Manager for Wiss, Janney, Elstner Associates, Inc.’s (WJE) Washington, D.C. office. Since joining WJE in 1996, Mr. Lemieux has successfully completed over 300 projects in the area of building envelope failure investigation, repair design, and architectural rehabilitation, including projects that have been honored both locally and nationally for design and restoration excellence. Since 2004, he has written and published three peer-reviewed and widely recognized technical papers on the topic of building enclosure commissioning: Should Green Be Biodegradable?, Lemieux, D. J. and P.E. Totten, ICBEST 2004 Proceedings, Sydney Australia; The Importance of Building Envelope Commissioning for Sustainable Structures, Lemieux, D.J. and P.E. Totten, 2004 ASHRAE Buildings IX Conference, Clearwater, Florida, and; Commissioning Under the Influence: Redefining the Traditional Role of the Commissioning Agent in the Design and Construction of the Building Envelope, Lemieux, D.J. and F. Aldous, 2007 National Conference on Building Commissioning, Chicago, Illinois. In 2006 and 2007, Mr. Lemieux served as co-author and contributing editor for selected exterior wall chapters of the web-based Whole Building Design Guide sponsored by the National Institute of Building Sciences (NIBS), and is a member of the committee responsible for the development of NIBS Guideline 3: Exterior Enclosure Technical Requirements for the Commissioning Process.
Building Enclosure Commissioning

A review of “commissioning under the influence”

Why Commission a Building Enclosure?

Simply put: Uncontrolled rainwater penetration and moisture ingress are two of the most common threats to the structural integrity and performance of the building enclosure. Together, they represent up to 80% of all construction-related claims in the United States.\(^1\) Of these failures, there is a growing body of evidence that suggests that errors and omissions in the design and installation of the interfaces, rather than in the materials, components and systems themselves, are the primary (and most frequently overlooked) sources of uncontrolled rainwater penetration through the building envelope\(^2\).

These statistics, which have been widely cited and continue to have obvious implications for both the design and construction communities, take on added significance when one considers the factors beyond long-term durability and performance that now influence material selection, design in the context of the United States Green Building Council (USGBC) LEED rating system. Recent changes to AIA contract document language / public policy, and the International Building Code further reinforce this fact, and continue to remind us of the importance that society places on risk management as it relates to heat/air/moisture transfer through the building enclosure.

\textit{AIA Policy}

The increasing complexity of building enclosures for performance-critical buildings and sustainable design goals prevalent in current architectural practice has lead to an increase in responsibility (and liability) for the architect. This, in turn, has contributed to the challenges facing the design profession and further underscores the need for an independent, properly educated, experienced and trained design professional to augment the design and installation of the building enclosure. These issues combine to reinforce the argument for the building enclosure commissioning process.

AIA A101:

3.2.5.1 (Schematic Design): The Architect \textit{shall} consider environmentally responsible design alternatives such as material choices and building orientation, together with other considerations based on program and aesthetics, that is consistent with the Owner’s program, schedule, and budget for Cost of the Work.


\(^2\) Lemieux, D.J. and M.T. Driscoll (2004), “Breaking the Skin”, ICBEST, Sydney, Australia
AIA B214: LEED™ Certification Services:

2.4.1: The Architect shall prepare a LEED™ certification plan based on LEED™ certification points targeted;

2.5.1: The Architect shall organize and manage the LEED™ design documentation and certification process;

2.5.2: The Architect shall provide the services of LEED™ accredited professionals as necessary for certification;

2.5.4: The Architects shall register the project with the USGBC;

2.5.5: The Architect shall prepare submittals for credit rulings from the USGBC;

2.5.6: The Architect shall prepare and submit a LEED™ Certification Application for the Project to the USGBC including required calculation and documentation for each LEED™ credit claimed;

2.6: The Architect shall provide specifications that incorporate LEED™ requirements for inclusion in the contract documents.

Although noble in theory, each of these requirements arguably begins to establish a duty and standard of care for the design professional that, while perhaps consistent with the Owner’s expectations, may nonetheless be beyond the commonly held interpretation of that duty by architects more familiar with standard AIA contract document language. In the context of the design and performance of the building enclosure, the potential implication of these changes cannot be understated. As Mr. Frederick F. Butters, FAIA, Esq. predicts in a recent presentation on this topic:

“Architects are not typically certified in specialties; however, LEED™ Certification (as it is now defined under AIA B214) changes that general rule. The LEED™ certified Architect will, therefore, likely be held to a higher standard.”

The design and construction of the building enclosure and standard of care required of the architect to effectively manage that process for long term durability and performance (stewardship) will, by virtue of the statistics alone (recall that 80% of all construction claims arise from this area of practice), be significantly impacted by these changes. Although the courts have held that:

“…if an architect is licensed and registered, he has the capability of planning a building and supervising its construction in accordance with his plans…. if he [she] undertakes a project, he [she] alone will be held responsible therefor….”

Current Building Code Requirements

A further reflection of this trend can also be found in Section 106 of the International Building Code, 2000 wherein the construction documents require the following:

---

106.1.3: Exterior Wall Envelope: Construction Documents for all buildings shall describe the exterior wall envelope in sufficient detail to determine compliance with this code. The construction documents shall provide details of the exterior wall envelope as required, including flashing, intersections with dissimilar materials, corners, end details, control joints, intersections at roof, eaves, or parapets, means of drainage, water-resistive membrane, and details around openings.

The construction documents shall include manufacturer’s installation instructions that provide supporting documentation that the proposed penetration and opening details described in the construction documents maintain the weather resistance of the exterior wall envelope. The supporting documentation shall fully describe the exterior wall system which was tested, where applicable, as well as the test procedure used.

As alluded to previously, failure of the building enclosure can frequently be traced to errors and omissions in the design process that, in turn, leads to a shift in design responsibility “downstream” to the subcontractors and trades, ultimately leading to inadequate installation and performance in the field. This is particularly true at interface conditions in the building enclosure. In defense of their work in this regard, one architect offered the following testimony:

“It is not the standard of care to provide exhaustively detailed and annotated documents. If architects were expected to provide the level of detail, our fees would need to increase dramatically or we would be out of business quickly…”

Unfortunately, this is not an uncommon refrain. However, the language in the current building code appears to implicitly reject this logic and, in the second paragraph, further reflects what we know to be true: There is an increasing availability of two and three-dimensional interface detailing now available from the manufacturing community that, in addition to promoting proprietary products and systems, also provides the design professional with a useful tool that can further streamline and facilitate the building enclosure design and detailing process. This is particularly true with regard to effective detailing to ensure air and moisture barrier continuity at building enclosure interface conditions, and further underscores the advantages of a fully developed, comprehensive building enclosure commissioning process.

**Performance-Critical Buildings in the context of Sustainable Design**

Performance-critical buildings often require strictly controlled interior environments which rely upon a building enclosure which is installed, and continuously operates in accord with established criteria. They are typically associated with a high quality of materials and installation of systems, which is also particularly true in the context of sustainable design. In order to be rewarded for environmentally-conscious design and construction, the United States Green Building Council’s (USGBC) LEED™ rating system (USGBC, 2002) requires that all

---

4 State Board of Registration v. Rogers, 239 Miss. 35, 120 So. 2d 772, 775 (1960)
buildings and structures satisfy a required commissioning process that, in the words of the USGBC, is intended to “…verify and ensure that fundamental building elements and systems are designed, installed, and calibrated to operate as intended.” This concept, which arguably is nothing more than a broadly worded re-statement of what we already know to be good design and construction practice, has taken on added significance in the context of environmentally-conscious, or “sustainable” design. This is particularly true with regard to the effects of uncontrolled rainwater penetration and moisture ingress at the building envelope. Proper selection, use and integration of the materials, components and systems that comprise the building envelope are critical to the long-term durability and performance of any building or structure and, as such, should be fundamental to the mission of the USGBC, the commissioning process, and the steps necessary to achieve a LEED™ rating.”

The Building Enclosure Commissioning (BECx) Process

There is growing justification for commissioning of the building enclosure in the context of today’s design, construction and litigation environment. Unfortunately, an understanding of the process and its implications are yet to be fully comprehended by the industry as a whole. The Guideline 3-2006 Exterior Enclosure Technical Requirements for the Commissioning Process (available at: http://www.wbdg.org/ccb/browse_doc.php?d=7167), is the first comprehensive document to address building enclosure commissioning and provides the following definition:

“The Commissioning Process is a quality-oriented process for achieving, verifying, and documenting that the performance of facilities, systems, and assemblies meets defined objectives and criteria. The Commissioning Process assumes that owners, programmers, designers, contractors, and operations and maintenance entities are fully accountable for the quality of their work. The Commissioning Team uses methods and tools to verify that the project is achieving the Owner’s Project Requirements throughout the delivery of the project. The Commissioning Process begins at project inception (during the Pre-Design Phase) and continues for the life of the facility (through the Occupancy and Operations Phase). The Commissioning Process includes specific tasks to be conducted during each phase in order to verify that design, construction, and training meet the Owner’s Project Requirements.”

The Guideline describes the process of quality assurance and quality control throughout the project. From an Owner’s perspective, the Guideline is likely to be congruent with project objectives. However, what is the best approach and how does the rest of the project become impacted by the engagement of a Building Enclosure Commissioning Agent (BECxA)? The foundation for a successful BECx process can be established by the Owner’s request for proposal.

When to Start BECx?

The BECx plan is an on-going process that is best started at the early phases of design. At this stage, the project performance objectives can be outlined and a Cx plan tailored to suit the specific project. Although the building enclosure Cx process has been developed with new

construction projects in mind, the process itself can be adapted to an existing building performance analysis, or modernization project. The BECx process is also adaptable to any type of design and construction delivery method, in fact serving owners best in design-assist and design-build project delivery methods typical of specialized façade designs.

**The Owner Project Requirements**

The commissioning process begins with establishing the Cx team and the owner project requirements (OPR). The OPR is a critical document that must be comprehensively developed in accordance with the design goals and criteria for the interior conditions, including mechanical, electrical and plumbing (MEP), and all active or passive systems such as lighting and acoustics, and/or sustainable goals.

At the onset, the OPR can be quite varied: “Objectives can be as specific or as general as necessary. “Systems should have a return on investment of 30 percent,” or “systems should enhance the building’s and the organization’s image” are both examples of objectives, defined by Deringer.” As the project moves forward, the building enclosure performance criteria must be refined specific to the interior controlled environment and building enclosure means and methods to control heat, air and moisture established at the onset of the project. The basis of design (BOD or occasionally called the “Design Narrative”) document developed by the designers of the building should outline the materials and methodology for achieving the owner’s project requirements. The BOD is crafted following and in accordance with the OPR.

If the BECx Agent is brought on early enough in the process, traditionally serving as the owner’s guide, then the BECx Agent should have the opportunity to review these documents. Based upon their experience, the BECx Agent should verify the rationale for the goals, materials and methods, or provide recommendations for the refinement of these documents. The development of clear design and performance criteria is critical to a successful completion of the project, and the adherence to these two documents should form the foundation from which all BECx related decisions can be based.

“The pre and design development phase has the greatest possibilities for creating coordinated and detailed envelope assemblies to facilitate a quality installation. If left to the field installation phase, the building envelope commissioning process will serve only to document, rather than complement the overall design development and commissioning processes.”

---

6 M, Lobash, High-Performance Exteriors Offer Benefits in Energy Efficiency and Occupant Comfort; *Innovations in design and technology offer facility executives new opportunities to cut operating costs and to improve occupant comfort.* http://www.facilitiesnet.com/bom/article.asp?id=3089&keywords=exterior%20design,%20green%20building%20design,%20building%20environment

The Request for Proposal

The BECx process begins with the development of a well crafted Request For Proposal and a defined project procurement method. As the retention of a BECx A is relatively new, it appears that the most common means to obtain the BECx A or building enclosure specialist is through the MEP CxA. Through knowledge of the BECx practice it is anticipated that the BECx A shall be retained independent of the MEP CxA. Although it is somewhat logical for Owners to lump all aspects of Cx into a single known entity, the two Cx processes can differ vastly in scope, schedule and costs.

The type, performance requirements and materials of the building enclosure all can significantly impact the costs of the project. As such, even before the MEP Cx agent is brought onto the project, typically the role of the BECx A has begun. The prudent owner will begin the services of a BECx A independently and prior to that of a MEP CxA, yet should require that the two organizations work cohesively to achieve the OPR. This may be achieved as a two part engagement of design and construction phases, or a complete BECx process through occupation.

The iconic nature of architecture is typically defined by the building enclosure. As such, designs with greater complexity and uniqueness of form, usually require details that can often challenge traditional methods of construction. This suggests that the role of BECx A can move beyond the traditional role of a CxA typically associated with the MEP Cx process, and introduce to the BECx process a specialized service. The qualifications of the BECx A may therefore be defined as a firm experienced in the assemblies, systems, performance criteria and testing of the building enclosure. The extent of services expected of the BECx A must be clarified. Is the Owner expecting a commissioning process under the influence of a building enclosure consultant, or is the practice of BECx to be a role associated only with the implementation of checklists. The scope of commissioning services should be clearly outlined in the RFP and minimum qualifications provided based upon the extent of BECx services.

There is a wide field of personnel and organizations which may adopt work under the context of BECx. Possible candidates as outlined by the NIBS Guideline 3 include; the architect with sufficient distance from the design to be objective; the general contractor with expertise in the building enclosure; the MEP CxA with subcontracted BE expertise; and the building enclosure consultant, to name only a few. Regardless of the organization from which the BECx A is chosen, there remains one clear objective: the quality of the project. The quality of the details, specifications, and construction, including contractor means and methods must not waiver in their collective mission to achieve the owner project requirements. In essence, the BECx A must provide uncompromised, unbiased recommendations and raise all pertinent concerns to assure the owner’s expectations are understood and achieved.

The BECx A must provide sufficient expertise to complete the services, in addition to the sufficient manpower to staff all phases of the project. Although the BECx design phase is typically performed by professionals with specialized experience, the construction phase is of equal importance, and should be staffed appropriately and not abandoned only to the contractor’s quality control program. As such, an RFP may wish to require the submitting firm include the names and availability of key personnel for all phases of the project, in addition to their project
experience, professional affiliation and available references. It is highly recommended that references are followed up on as they provide unsolicited insight into the true functioning of a team or individual. It is suggested that individuals with no less than 7 to 10 years of experience in the specialized area of building enclosure design, design-assist and construction are retained for the design phase BECxA positions. The BECxA’s interface between the design and construction teams is critical to the project’s success and may include not one individual, but possibly a two person team to lead the design phase, as typically no one individual will possess all necessary skills to address all aspects of the building enclosure. It is also recommended that the BECxA submit as part of the RFP, the firm’s own quality assurance and control mission statement to provide the owner confidence that the firm unto itself is committed to providing a quality work product.

The design of the building, function and performance requirements influence the type of services to be provided by the BECx Agent. The RFP should reflect these various aspects of the project and also include the OPR and BOD. These documents can form the basis from which the BECxA can analyze and provide advice on the extent to which the building enclosure should be commissioned based upon their experience. It may be prudent for the Owner in the RFP to request input on the scope of Cx services in accordance with the OPR and BOD. Performance critical buildings are more likely to require a more demanding BECx plan in comparison to an office building or similar type of structure. Questions based upon the perception of the services being requested should be encouraged.

We recommend the RFP is divided into the phases of a project that follow the typical American Institute of Architects (AIA) standard procedures, commencing with the Design phase and including Schematic Design, Design Development and Construction Documents. The next phase is the Pre-Construction phase which includes the BECxA’s role in the bidding and negotiation, Value Engineering and award of contracts to the general contractor and subcontractors. This phase will possibly lead to a laboratory performance mock-up and the corresponding review of shop drawings and shop fabrication visits as necessary. Submittal reviews for field installation begins in this phase and overlaps into the following construction phase. The third phase will be comprised of the Construction activities and will typically include all field observations and testing. The extent of the testing program should be developed with the BECxA’s input to ensure that all aspects of the building enclosure are adequately tested in accordance with the appropriate industry standard tests, and clear pass/fail criteria established. The building enclosure maintenance and operations manual concludes the final phase of the BECx process and is defined by the occupation and operation of the building. The scope of services and work product should be clarified for each phase of the BECx plan, in addition to including meetings with all other parties to review the BECxA’s comments. It is critical that all other membranes of the design and construction team are aware of the intent to Cx the building enclosure so they may accommodate.

The RFP should outline the level of involvement of the BECxA at each of the design and construction phases, and possibly also request supplemental information from the BECxA. For example, during the design phase it should be clarified that the BECxA is to perform a technical review of the design drawings and specifications at various percent completion stages, i.e. 50%, 85% and 100%. The intent of the reviews should be clear. For example, the review(s) will
address conditions that might adversely affect the performance of the building enclosure related to the control of heat, air and moisture in the context of the OPR and BOD. The extent of review should also be clarified. Some suggest partial document reviews should be undertaken i.e. 20% or 30% of the documents as suggested by NIBS Guideline 3, 2006. The extent and type of review should be balanced with the risk management strategy of the project. The type of work product should be clarified by the RFP, including red-line mark ups on the design documents or written reports. Some reviews may wish the BECxA retain a log outlining concerns and issues. The log should reflect how all issues are resolved before proceeding to the next phase.

After reviewing the documents, the BECxA should be responsible for the development of the Building Enclosure Commissioning specification. Drafts of this document should be developed coinciding with the development of details and specifications. The BECx design phase should culminate in the development of the BECx specification. As the extent of the design details, materials and tests may not be known at the onset of retaining the BECxA, it is recommended that the testing coordination associated with the building enclosure is budgeted, however not included in the BECxA scope at the time of signing a contract. It is recommended the actual budget for field testing should be established by the Owner for management by the BECxA. The BECx specification should clarify the field testing and shall be included in the Project Manual, Section 1, in coordination with specifications addressing Contractor Quality Assurance and Control, Moisture Prevention Procedures during Construction, Building Enclosure Performance Requirements (inclusive of the Air Barrier), Testing and Inspection Services and a project specific Substitution Request Form for building enclosure components. It is recommended that a baseline fee allowance associated with the coordination and management of the field testing is established by the Owner and carried for all BECxA’s at the time of RFP. This can then be adjusted as further information and testing programs are determined.

The pre-construction phase requires slightly less involvement from the BECxA. During the contractor selection phase, the BECxA may be of assistance in determining the appropriateness of any substitutions or value engineering suggestions. It is highly recommended that the RFP address a limited involvement in this phase, until all the sub-contractors are signed and as required, preconstruction performance mock-ups are underway. Once the mock-up and/or submittal process is underway, the BECxA should be fully engaged as an integral component of the team and included in all pertinent communications, contractor and design initiatives, including the review of all pertinent submittals, Requests For Information (RFI), change orders and architect supplemental instructions (ASI).

The laboratory mock-up if included in the project will be the first opportunity for the actual performance of the building enclosure assemblies to be verified. The laboratory mock-up is an important tool in the design and construction process, and should be utilized on all projects where budgets allow, and especially on unique and performance critical building enclosures. The mock-up can provide information related to the structural, air, water and thermal performance aspects of the building components. This will likely be instrumental in assuring the materials, systems, and detailing can be constructed safely, repeatedly, and with the greatest degree of confidence, installed to meet the OPR. The RFP should include an active role by the BECxA during the mock-up, typically being in full time attendance during the construction and testing. The BECxA shall be experienced to address issues and offer solutions to the design and

construction team on the resolution of issues as they arise. For the RFP, it is typical to address this as an assignment of weeks to the process, inclusive of all time and expenses related to attending the laboratory mock-up facility, and a written report.

Following the performance mock-up, the BECxA role is to review the submittals and assure that the components that comprise the building enclosure are coordinated to achieve the designed air, moisture and thermal systems’ intentions. It is typically not known at the time of the RFP the extent of submittals, and as such we recommend a common allowance is provided and carried by all BECx firms in their responses. The allowance should be based upon the specific building enclosure design and will vary between buildings in accordance with size, complexity of systems and quality of submittals. The BECxA’s review of the submittals should be provided to the Architect-of-Record for their consideration in their response to each submittal. It is highly recommended that the Architect-of-Record respond to the BECxA’s recommendations to ensure that these have been duly considered, and the Owner given the opportunity to comment. If this type of interaction is included in the RFP, it is recommended also that the Architect-of-Record is compensated for the effort to address the BECxA’s review. However, it should be clear that all recommendations provided by the BECxA, if incorporated into the contract documents are done so with the full responsibility borne by the Architect-of-Record.

The concluding tasks of the preconstruction phase may include the visit to fabrication plants and facilities where components are assembled in-lieu of field assembly. This is typical of many glazed curtain wall assemblies, which use a unitized system to increase quality control as the units are assembled in a shop under a controlled environment versus the field, and can facilitate quicker installation schedules. If these types of façade assemblies are included in the design, it is prudent for the BECxA to visit the fabrication plants on more than one occasion to observe the prefabricated units in process and verify shop quality control measures. It is also recommended that the shop performs limited air and water testing on the individual units before shipping to validate performance. This process can be overseen by the BECxA, yet must also be included in the specification. It is recommended the RFP include an allowance per trip to visit the fabrication plant, at which point the Owner can determine the need for plant visits based upon initial reviews and performance at the mock-up. The work product should be clarified for this phase, in addition to meetings with all other parties to review the BECxA’s reports.

The construction phase of the building enclosure commissioning process endeavors to assure that the components installed meet the approved shop drawings and OPR. The field activities of the BECxA are largely centered around the observation and testing of the enclosure. Field observation of the installation of building enclosure components is typically undertaken at start-up, during complex installations and at milestone events. The timing for construction observation services will depend highly upon the type and complexity of the building enclosure. For example, some unitized curtain wall systems may require more preconstruction visits to the fabrication plant, whereas a field assembled curtain wall may require more time on site to observe the installation. The observations by the BECxA are performed to supplement, and not substitute for the contractor’s quality assurance and control program. The specification addressing the contractor QA/QC plan should be clear as to these expectations and coordinated with the efforts of the BECxA. The schedule is fundamental to include in the RFP to allow the BECxA to establish a period for construction related services. If no schedule is available, an
estimated period should be included. Adjustments should also be factored for lengthy project schedules for cost increases relative to inflation. A suggested commitment of time for construction observation is recommended to be provided to ensure an equal review between competing submittals from BECx Agents.

The field testing of the building enclosure is determined by the Building Enclosure Commissioning specification and should be coordinated and administered by the BECxA on behalf of the Owner. Many traditional specifications identify the contractor to perform these tests; however we recommend that the Owner retain the authority to test as required. The BECx specification should include that the contractor must allow for out of sequence work, access and coordinate with the testing agency and BECxA to facilitate the tests, yet is not responsible for the tests. Based upon the original RFP allowance, the costs and extent of field tests can now be refined to validate the performance in accordance with the overall risk management strategy. Although it is uncommon to perform testing on 100 percent of the building enclosure, it is not inconceivable that highly unique and performance-critical facilities would undertake this level of field testing.

The overall management of the BECx and documentation process should be requested by the RFP. The management and associated computer software may vary between BECx firms; however the protocols should be clear and evidence of a documented process of quality assurance demonstrated. On occasions, the software associated with the MEP Cx process may be utilized to also achieve the BECx process. However; the fundamental structure, process and Cx approach to the building enclosure and the MEP components, devices and systems, in our experience have not merged easily onto a single software platform.

If the Request For Proposal (or Request For Qualifications - RFQ) document addresses the owners project requirements, the specifics of the design, and clearly outlines the scope of work and the BECxA’s qualifications, it can be a tool to essentially “jump start” the project. As each project may have its own unique set of performance requirements, so should each BECx plan be tailored to suit the specific project requirements. It is the performance-critical building, with its unique or complex design, which can yield the greatest benefits from the commissioning process.

Performance-Critical Buildings

Although the trend towards commissioning of the building enclosure is primarily aimed at buildings requiring more specific performance attributes, the management of risk associated with all types of building designs often serves as ample justification for the building owner to seek a higher standard of quality associated with the BECx process. Sustainable design goals and unique, complex designs can increase the risk of failure. Condominium buildings, schools, hospitals, art museums, libraries, natatoriums, and specialized production, laboratory, and cold freezer storage facilities are all but a few building types that demonstrate the necessity of establishing and maintaining specific interior micro-climates, which depend upon a quality building enclosure.

The building enclosure is the physical element between the performance-critical interior and the uncontrolled exterior environment. Their interdependence mandates that the performance criteria
established for the exterior enclosure performs consistently, providing all interior spaces with stable HVAC operation for the entire service life of the facility.

What can go wrong with Performance Critical Buildings

The HVAC design for the performance-critical building may include specialized requirements for relative humidity, frequency of fresh air exchanges, positive or negative pressurized space, thermal consistency or similar. These strict requirements for the performance of the interior spaces can be influenced by the integrity of the exterior enclosure. It stands to reason, if the exterior enclosure is allowing air or moisture to pass uncontrolled through the materials, components, and systems of the building envelope, the ability to balance and maintain the air handling system as designed becomes increasingly difficult to control, often subject to operator adjustment outside of design specifications to achieve required interior air standards.

The mechanisms for failure of performance-critical building enclosure components are no different than the mode of typical building component failures. However due to the increased potential for conflict between the interior and exterior environments, there is a higher propensity for failure. Also, the type of failure may have greater impact than typical, given the nature of performance-critical building operations. Uncontrolled water infiltration or high humidity leading to the development of condensation can result in microbial contamination of building materials, and/or corrosion of metal studs, or anchors that attach the cladding to the exterior facade. Ultimately, structural failure is possible when corrosion of anchors or framing deteriorates the metal or causes failure of the cladding materials. Similarly, excessive air leakage, in the form of ex-filtration or infiltration can lead to condensation, mold, deterioration of materials subjected to excessive moisture and humidity, corrosion of metals and structural deterioration, and cladding attachment failure. In addition, air leakage can result in wasted energy due to the mechanical equipment operating inefficiently.

The performance-critical building operates most successfully as a coordinated and integrated whole. The commissioning of the building enclosure makes sense for quality and economics by assuring that the “whole” building performs in accordance with the design.

Criteria and Costs of Performance-Critical Buildings

The performance-critical building facades should achieve higher performance and should be subjected to stringent field testing programs. The water penetration tests are recommended to be conducted at full design pressure, and leakage defined as any water entering the interior of any building enclosure component. With respect to air infiltration, it is further recommended by the United States General Services Administration, that “the air leakage rate of opaque assemblies that comprise the air barrier system shall not exceed 0.04 cfm / ft² at 0.3 inches water gage (1.57psf) (0.2 L/s.m2 @ 75 Pa) when tested in accordance with ASTM E2357” and “the whole building shall not have an air leakage rate of more than 0.4 cfm/ ft² (2.0 L/s/m2) at a pressure differential of 0.3” w.g.(1.57psf) (75 Pa).” The facades of performance-critical buildings should strive to achieve greater efficiency than the average building, and yet ultimately must be designed for long term durability.
With respect to roofing and waterproofing system performance, the owner defined performance quality standard will inevitably focus on design parameters linked with providing superior wind uplift resistance, exceptional system durability, effective thermal performance, and increased system longevity. In that regard, high performance roof designs should not be developed to merely meet the general recommendations and standards prescribed in the industry. Rather, such industry guidelines presented to designers should be used as a springboard for refinement of the owner’s desired quality expectations. Once the desired performance goals are outlined, material selection becomes the focus of design and detailing attention. Clearly, anticipated system durability as well as desired roof service longevity is of equal importance with respect to achieving the desired performance of the roof installation. Creativity in the material selection process may be required to ensure that the desired performance is not ultimately constructed of roofing products intended for the “commodity” market.

The costs associated with the development of the design and the construction of a performance-critical building enclosure will often outweigh the costs of developing a conventional building. As such, the issues associated with long term service and maintenance of the building must also be factored into the building enclosure design. However, when the performance objectives are clearly established at the onset of the project, and a plan developed and implemented to achieve the objectives, the added costs associated with the BECx may not be as alarming as first thought. The value will be evident as upfront costs associated with a technically challenging building, are more than likely to dim compared with the quality of experience, comfort and long term service life of the building.

The BECx Process during the Design and Pre-Construction Phases

As discussed in a technical paper published by ASHRAE in the Proceedings for the Buildings IX International Conference in 2004, the design phase of the building enclosure commissioning process can be summarized as follows:

Schematic Design

“The architect of record, the mechanical engineer, the LEED™ consultant, and if appropriate, a separate building envelope consultant and the owner and owner representatives should meet to discuss the design intent, and complete design charrettes to determine potential design options and building enclosure systems for the design, the owner’s requirements, and develop an initial LEED™ scorecard. As part of this process, the design team should identify and review the overall design intent of the building envelope systems. (Barrier versus rain screen versus cavity wall), material selection choices, interface complexities, budget restraints, and specific site specific climate concerns that the envelope design will need to address. The design team should consider whole building integration and the interaction of the building enclosure with the mechanical systems. This set of charrettes may be done separately from initial charrettes with the LEED™ consultant to aid the team in determining initial project decisions and direction. The

---

architect will then need to prepare initial schematic designs and 3-D models of the intended structure and site-specific building orientation.”

**Design Development and Outline Specifications**

“The architect of record and other members of the design team with the building envelope consultant should review and research materials for the various systems and assemblies now identified as potential systems that will satisfy the owner requirements. In developing the design, computer modeling for a variety of different attributes and elements that will affect the system should be completed. Various system and sections should be evaluated and compared. The design team should model sections and different combinations of materials and assemblies for vapor drive, moisture storage capacity, environmental impact, geographic implications, siting, exposure, microclimate/macroclimate, solar/shading, thermal efficiency and rainwater resistance, especially wind driven rain. Energy modeling and moisture analysis modeling should both be completed. Computer modeling for heat and moisture transfer should be completed on wall, roof, window and similar building envelope components and assemblies. Moisture transfer modeling will aid the designer in determining if the envelope they have picked may experience long term or short-term moisture problems. Various programs are available to complete the moisture-modeling task, with the better programs being based on long-term historical climate data and region specific wind driven rain data. Energy modeling is useful in refining the thermal design characteristics that can in turn be used to optimize the mechanical system design. From this, a refined set of design documents should be developed, including initial material specifications.”

**Preliminary Construction Documents**

“Depending on the project stage for the design team, the commissioning agent will review one 50 percent to 95 percent set of the architectural drawings and applicable specification sections for the building envelope that has enough defined information on the envelope for this review, and provide comments on the set. The commissioning agent will perform an initial value engineering review, if applicable and indicate areas where cost tradeoffs can be used to enhance the building envelope systems (the systems intended for heat, air, and moisture control for the enclosure). During this portion of the commissioning process, the design team may need assistance in developing conceptual details and may require additional information for the building envelope systems. The commissioning agent will also provide comments as they pertain to LEED™ on the elements of the building envelope.

One or more meetings will need to be completed with the design team, the owner and owner’s representatives, the commissioning agent, and the LEED™ consultant to discuss design options and costs, systems and elements that should not be eliminated, and the inherent risk in doing so. “Value Engineering” decisions will be critical during these meetings. Interface conditions will need to be discussed. The following items should not be removed from the project as a means to save up front dollars. These include interface flashings, preconstruction mock-ups, and any and

---

9 Ibid
10 Ibid
all areas of envelope redundancy that are critical to the durability of the structure. It has been our experience that with many of the up-front dollars saved by say, eliminating flashings, the dollars for repair are much more than twice the cost.”

**Final Construction Documents**

“The architect of record and other members of the design team will now proceed with finishing the construction documents, including all drawings and technical specifications. The final assemblies and systems identified will have to again be checked to ensure that they will satisfy the owner requirements. Additional computer modeling including energy modeling and moisture analysis modeling will likely need to completed, depending on changes being made to the documents based on the initial review comments by the commissioning agent. The modeling should be useful in refining the decisions made during the design development phase. The impact of preliminary cost estimates may lead the team to look at a variety of alternatives. The design team will need to explore different and timely/more cost-effective means to achieve the same end, but without sacrificing core objectives of the commissioning process. The design team should emphasize long-term durability and performance of materials; components and systems that comprise the building envelope and consider the impact of each design decisions on the “whole building design”. Mechanical systems should be concurrently examined with the building envelope decisions.

If the process is managed properly by the architect, this step should be relatively easy in that proper materials are already in the budget for the project and adequate detailing is the only remaining hurdle. The commissioning process will help to ensure a more complete set of CDs as the design team will likely be more thorough in selecting materials not only as a renewable resource, but for long-term durability and performance. The interfaces and detailing completed should be at a much higher level than noncommissioned projects, partly based on the initial commissioning review.”

**Final Peer Review Prior to Bidding**

“The commissioning agent will review one set of the architectural drawings and applicable specification sections for the building enclosure and provide comments and concerns on the envelope design, as they relate to heat, air, and moisture transfer. The commissioning agent will also provide comments as they pertain to LEED™ on the elements of the building envelope. The commissioning agent will also review and comment on all components of the building envelope systems, paying particular attention to the requirements in the specifications for samples, technical data, mock-ups, performance testing, and the details and interfaces as shown on the drawings. The objective of this review is to identify details, requirements or methods which may compromise the water tight integrity and thermal performance of the building in order to call these identified items to the attention of the architect of record and the owner for their action. Issues such as constructability and material compatibility need to be examined by the commissioning agent and specific guidance should be supplied via written documentation to

---

11 Ibid
12 Ibid
the owner and the architect of record at each phase of review. Materials that appear to be poor choices based on durability and a potential for rapid replacement need to be identified, especially on sustainable projects, where product replacement requiring new resources in a short time frame should be examined versus the use of a more durable product that may not be as environmentally appropriate on first selection.

If any details, plans, or specifications are modified by the architect of record, the commissioning agent will need to review these prior to issuance of the design documents. If elements recommended for change have not been completed, the commissioning agent should provide written documentation to the owner, indicating what risks may be associated with not implementing these items.

The peer review process is an important step in assisting the architect of record in making good decisions on the selection of materials, and method of integrating those materials into a durable building envelope.”13

**Bid Review**

“The commissioning agent should be available to provide assistance to the owner and the architect of record in reviewing submittals, if included with the bid, for any proposed product substitutions for building envelope elements, to determine the risk or equivalence of the proposed substitution.” 14

**Submittal Review**

“Concurrent with the architect of record and engineer of record review of shop drawings, the commissioning agent will need to review shop drawings prior to release and fabrication for building envelope requirements and provide written comments to the owner and Architect of Record. Where appropriate, they should provide comments on LEED™ credits as they pertain to the envelope.”15

**Building Envelope Pre-Construction Coordination Meeting**

“The commissioning agent will need to participate in one kick-off meeting prior to beginning construction with the various members of the design and construction teams, including, but not limited to, the owner, owner’s representatives, architect of record, mechanical engineer, LEED™ consultant, general contractor, and all subcontractors that will be involved in the construction of the building envelope, including, but not limited to, the roofing, wall system, flashing, sealant, fenestration, concrete, steel, HVAC, electrical, interior framing and drywall contractors and the mechanical commissioning authority and other applicable members of the design and construction team. This meeting will be to discuss construction sequencing and the coordination of trades and the reporting that will be completed during construction of the building envelope

---

13 I bid
14 I bid
15 I bid
and related other elements. This meeting may also be in conjunction with project and LEED™ kick-off meeting to discuss the LEED™ submittal process and responsibilities of the different parties.”  

Building Envelope Pre-Installation Meetings with Individual Trades

“The commissioning agent will participate in each of the Pre-Installation Meetings to review and discuss critical aspects of the construction, as well as to re-emphasize the importance of coordination among the trades to ensure the successful integration and weather-tight installation of the various materials, components and systems that comprise the building envelope.”

Field-Constructed Mock-Ups and Performance Testing

“Field-constructed mock-ups need to be included in the contract documents to verify the constructability, integration and performance of the materials, components and systems that comprise the building envelope.

The commissioning agent should review mock-up construction of each element and interface determined in the specifications to be included in mock-ups. The commissioning agent will have to be present during performance testing to provide observations in written format to the owner, architect of record, and general contractor for resolution of concerns observed during this performance testing. This includes field air and water penetration testing of representative areas of the building envelope as specified by the architect of record, and/or as recommended by the commissioning agent and accepted by the owner, the architect of record and the general contractor.”

The BECx Process during the Construction Phase

Ideally, if all other phases of the commissioning plan have been executed successfully, the construction phase should serve to validate the performance of the installed components. But, the construction phase is fraught with issues often derived from the human practice of building itself. Too often installation is compromised by poor communication, improper sequencing, incomplete purchasing of the scope of work, lack of skilled labor and understanding of the design intent, lack of oversight, scheduling pressure and value engineering. Throughout the construction phase, the primary objective of the commissioning plan should be to maintain quality control.

The BECx construction phase is founded on a collaborative effort in which the contractor, design team and commissioning agent are motivated by the owner’s best interests and subsequently, achieve the established Owner Project Requirements (OPR). The construction environment must focus on the project and maintain an open forum for communication. Daily challenges to quality will arise which can be overcome through established procedures. The BECx plan establishes

---

16 I bid
17 I bid
18 I bid
these procedures and can guide the process to resolution through knowledgeable field observers, the use of check lists, field reports and the maintenance of an action item log to track issues.

Observation of the site work by the BECxA is not required to be full-time, but best coordinated with specific areas of complexity, new trades and predetermined milestones. Attention to resolution of issues is paramount to quality, as too frequently construction personnel will interrupt operations for only a short period of time. If answers to issues are not provided in a timely manner, it is likely the resolution may not achieve the performance intent. As such, BECx field personnel associated with the construction related activities must be fluent in the building enclosure systems and performance criteria, and prepared to offer solutions for consideration by the Architect-of-Record. When field conditions require a modified detail, best practice suggests field testing of the installation to assure it meets the design intent. This type of field testing is typically undertaken on a case by case basis and is outside of the standard predetermined field testing.

**Field Testing**

Typically, a suitable field testing program provides a sound platform for evaluation, assessment, problem identification, and correction of any flaws in the installed building enclosure. The goal is to assure that air leakage allowances, thermal continuity and water penetration resistance are in accordance with the OPR. Building enclosure water penetration and air infiltration tests are conducted in accordance with established standards. Several of frequently used test procedures and their primary role in the evaluation of constructed “quality” are discussed below.

ASTM E-783: Field Measurement of Air Leakage through Installed Exterior Windows and Doors:

This test method, which is included by reference under AAMA 502-02 (Voluntary Specification for Field Testing of Windows and Sliding Glass Doors) and AAMA 503-03 (Voluntary Specification for Field Testing of Storefronts, Curtain Walls and Sloped Glazing Systems - applicable to this project), is intended to measure the rate of air infiltration through an installed glazing product or assembly for compliance with the contract documents. It is typically performed as the first step in a two step field testing process that includes field testing for water penetration resistance when subjected to a simulated, wind-driven rain event.


These test methods are intended to determine the air leakage of an installed air barrier assembly under static air differential. The air barrier and associated performance requirements should be outlined in the separate sections and the Building Enclosure Performance Requirements section.
ASTM E-1105: Standard Test Method for Field Determination of Water Penetration of Installed Exterior Windows, Curtain Walls, and Doors by Uniform or Cyclic Static Air Pressure Differential:

This test method, which is included by reference under AAMA 502-02 (Voluntary Specification for Field Testing of Windows and Sliding Glass Doors) and AAMA 503-03 (Voluntary Specification for Field Testing of Storefronts, Curtain Walls and Sloped Glazing Systems) is intended to evaluate the water-tight integrity of the installed glazing system when subjected to a simulated, wind-driven rain event.

AAMA 501.2-03: Quality Assurance and Diagnostic Water Leakage Field Check of Installed Storefronts, Curtain Walls, and Sloped Glazing Systems:

This test method (commonly referred to as calibrated “nozzle” testing) is relatively easy to implement and is useful in determining the water-tight integrity of static (fixed/non-moving) and dynamic (movement) construction joints, external glazing gaskets and seals, and similar assemblies. (Note: This test is not intended for operable window or door sash perimeters, a common misapplication of this test standard.)

ASTM D-3617: Standard Practice for Sampling and Analysis of Built-up Roofing During Application:

This test procedure was specifically developed to assess the quality of field constructed multi-ply bituminous roofing membranes. It is destructive in nature, as it mandates randomly selected specimens of completed work to be sampled as work progresses. Evaluation of selected specimens shortly after installation requires experienced field personnel as well as follow-up laboratory analysis of completed work.


Field testing utilizing this procedure continues to gain popularity among designers, particularly in light of a heightened awareness of potential roof system failure due to “blow-off” during high wind incidents. The procedure was developed to provide a non-destructive means of confirming in-situ uplift resistance performance of roofing assemblies. A field constructed chamber is used to subject a portion of the completed roof assembly to negative pressure simulating wind effects across the roof surface. As a field evaluation procedure, such testing can be quite effective in confirming acceptable performance based upon the OPR.

ASTM D-5957: Standard Guide for Flood Testing Horizontal Waterproofing Installations:

Although this method is quite rudimentary, it can be effective in locating actual water entry paths in newly constructed, horizontal deck waterproofing installations. Testing requires general flooding of the waterproofing membrane surface at a pre-established water depth to subject the system to free water prior to proceeding with installation of
over-burden materials such as landscaping, deck surfacing, etc. When used in the BECx specification it must be understood that test referencing alone is **not** sufficient in water testing vertical surfaces, including often complex flashing provisions. Amplification of the specified test procedures is necessary in order to test all aspects of completed waterproofing system.

Electronic Leak Detection (ELD) and Electric Field Vector Mapping (EFVM):

ELD and EFVM testing procedures arguably can provide a far more specific procedure to approach field quality control on deck waterproofing installations. Both require specialized equipment and highly trained field personnel. ELD introduces an electric current over the membrane which can identify pathways where the current flows to ground, therefore pinpointing the leak or leaks. The EFVM procedure uses electric field and conductivity to detect defects. Electrical wiring “leads” can be left in place for use in long-term monitoring of system integrity.

In the event that water testing or more destructive testing is considered unfeasible, a thorough visual inspection plan should be implemented. While this is clearly the most common method of field quality assurance used in “conventional roofing” (insulation under membrane) one cannot underestimate the value of a detailed visual evaluation of completed work by fully trained personnel. Such inspections can, and should be supplemented with the use of infra-red imaging cameras and hand-held moisture detection devices as originally developed for use in the re-roofing industry. For recently completed conventional roofing systems, thermal imaging can readily detect “gaps” in the thermal insulation blanket that would otherwise be undetectable to the naked eye. For many single-ply roofing assemblies, non-destructive devices can often be effective in locating exposed membrane seam defects that are difficult to locate using visual inspection procedures alone.

**Documentation of Building Enclosure Performance**

Upon final review of the validation and commissioning efforts, the documented performance of the building enclosure is compiled. The building enclosure may be segmented into the various commissioned systems, or components, dependent upon the BECx plan. The final documentation will provide information regarding the commissioned building enclosure assemblies and provide the base for training, operations and maintenance of the building. The assemblies should be maintained in accordance with the system requirements and the manuals should indicate these requirements, such as inspections, cleaning and routine maintenance. The manual shall also provide information regarding contact information for suppliers and methods to effect field repairs as required, such as re-glazing of windows systems.

**Conclusion**

The early phases of any project have the potential to yield the greatest influence over the future development, and the building enclosure commissioning process is not different. The BECx process strives to define appropriate criteria for the performance-critical building enclosure. Through the evolution of the design, enhanced with technical competence, a well constructed,
validated and documented building enclosure should provide long term, reliable performance for the building owner and occupants. The building enclosure, when aligned and tested to meet the owner’s project requirements concludes a successful building enclosure commissioning process.

Case Study: A Need for Commissioning (Natatorium)

When the building enclosure and interior environment are not coordinated to perform as an integrated whole, there is serious risk of failure. This oversight in the process was recently uncovered in a natatorium building that was less than one year old. Combine an inappropriate HVAC system, with a weak building enclosure design, and failure of the building enclosure occurred rapidly. Continuous adjustments to the HVAC controls, loss of efficiency, wasted energy and intermittent loss of use of the facility, all proved to be of disappointment and expense to the owner.

The building was designed as a natatorium with the interior design temperature of 78 degrees and 60 percent relative humidity. The roof components included a faux-slate tile roof, roof self adhering underlayment, oriented strand board (OSB) sheathing, a 1 inch air vent spacer, 4.5 inches of polyisocyanurate insulation board and a self-stick modified bituminous vapor retarder adhered to the metal decking. The structural deck was 3 inch deep galvanized metal. A low-profile, continuous ridge vent was provided along with soffit vent provisions at the eaves.

The HVAC design for a natatorium is typically characterized by a slight negative pressurization. The HVAC design had been modified by the operators of the building to a slight positive pressurization of the building. The inappropriately operated interior mechanical environment had disastrous effects on the durability of the exterior enclosure.

Figure 1: Detail issued for construction, IR survey and “blower door” test
The design documents neglected to provide information regarding the continuity of the air barrier, closure of the metal pan flutes in the deck, thermal continuity or roof ventilation. Design drawings were not actually built, however failure of the system would also most likely have occurred had the details been constructed.

Non-destructive investigation of the building enclosure used an infrared camera to visually identify the air leakage paths in the air barrier. The greater the temperature difference between the areas under review, the more specifically the infrared camera depicted the relative amount of air exfiltration occurring under HVAC operation. The warm and humid air introduced into the building enclosure led to condensation and the extremely premature failure of the building wall to roof interface components and the roofing system. The moisture / condensation resulted from the lack of air and vapor barrier continuity, lack of thermal continuity, thermal bridging effects of the steel roof trusses and modification to the HVAC design, which “value engineered out” the upper most plenums at the roof gables resulted in interruptions to the operation of the facility and widespread discontent.

Field inspections, including an infrared camera survey along with selected destructive openings were necessary in order to confirm the following additional deficiencies:

- Roof ventilation directly beneath the faux-slate tiles was inhibited by the installation of the framing and fascia trim at the eave and the rake.
- The soffit was subjected to unobstructed moisture-laden air flow from the partially sealed open metal deck flutes along the rake of the roof. At the eave, the soffit was subjected to moisture-laden air flow from the voids in both the wall and truss interfaces.
- Moisture-laden, warm air from the interior space of the natatorium could readily migrate via the metal deck flutes and perimeter walls and into the enclosed soffits at the roof edges.
- The air barrier suffered from discontinuity along the perimeter walls and wall-to-roof interfaces. Discontinuities included defects in both the thermal barrier as well as the vapor retarder.
- The vapor barrier was discontinuous along the roof peak (ridge vent locations) allowing moisture-laden air to migrate from the interior space to the vented portion of the roof assembly.
• The dormer roof assembly was constructed in a similar manner, however venting of the dormer roofs was discontinuous and no ridge vents were provided. In addition, the open ends of the metal deck allowed moisture-laden air to migrate uncontrolled into the roof assembly.

Upon contact with cooler air, the interior moisture-laden air immediately condensed on surfaces exposed within the soffits, typically metal decking, wood framing and fascia trim. Condensation resulted in rapid degradation of exterior cladding and finishes. Roof deterioration had commenced as venting was obstructed and moisture-laden air from the pool’s interior space entered the roof assembly through voids in the vapor barrier and condensed. Large gaps between insulation were also observed during remediation which likely exacerbated the build-up of moisture in the roof. Fasteners were beginning to corrode from water due to condensation, which also in combination with adhesives used in the OSB, dripped into the interior and stained the ceiling.

The repairs required a reinstatement of the air and vapor barriers, thermal continuity and removal and replacement of some roofing insulation due to deterioration and loss of thermal efficiency due to moisture absorption. Repairs were undertaken utilizing spray polyurethane foam insulation, and a strict quality control program of observation and testing implemented throughout the repairs. A smoke pencil was utilized at the locations where spray polyurethane foam insulation was installed to identify any air leak paths, and corrections were made to deficiencies in the air barrier. The use of infrared camera and “blower door” testing in accordance with ASTM E779 Standard Test Method for Determining Air Leakage Rate by Fan Pressurization to re-commission the HVAC is anticipated.

Figure 3: Repairs to install an air, vapor and thermal barrier to the enclosure

Following the repairs to the air barrier, the air tightness of the building enclosure was substantially increased. This allowed for the HVAC system to be returned to the recommended pressure without compromising the interior conditions, exterior enclosure and with a substantial savings in energy use.

Fundamental design and construction errors may have been averted had a building enclosure commissioning plan been instituted on this facility.
Case Study: Commissioning in Action (Office Building)

During the design process, a unique building façade system with high standards of performance was required for the efficiency of the new chilled beam water system and radiant heat systems. The interior HVAC design inspired the development of building envelope commissioning program, due to the extent of the façade glazing system and complexity of building envelope interface conditions, excessive thermal loads, and moisture-laden airflow.

Due to the unique chilled beam design, assurance that the exterior enclosure performed in accordance with the design criteria was specified. The mock-up specimen was constructed and tested prior to commencing full scale fabrication of the exterior curtain wall components. The laboratory mock-up was performed to simulate conditions to which the building may be exposed. The testing procedures were completed in accordance with ASTM E 2099-00 (2007) Standard Practice for the Specification and Evaluation of Pre-Construction Laboratory Mockups of Exterior Wall Systems. It was performed at an independent qualified test lab following a predetermined test sequence and pressures:

- Structural Pre-Load Test (ASTM E330)
- Static Air Infiltration Test (ASTM E283)
- Static Water Penetration Resistance Test (ASTM E331)
- Dynamic Water Penetration Resistance Test (AAMA 501.1-83)
- Uniform Structural Load Test (ASTM E330)
- Static Water Test (ASTM E331)
- Interstory Drift / Lateral and Vertical Movement (AAMA 501.4-200)
- Static Water Test (ASTM E331)
- Thermal Cycle (AAMA 501.5. or AAMA 1503, Modified)
- Dynamic Water Test (AAMA 501.1-83)
- Structural Overload Test
During the construction of the laboratory mock-up and formulation of the mock-up test sequence itself, considerable attention was given to thermal performance and the potential for condensation to occur on interior curtain wall frame and wall assemblies. This was of particular concern at the 9th floor exterior wall transition ("light shelf") detail, where air barrier continuity and the risk for thermal "bridging" to occur at the metal panel and anchor assemblies was considered a significant risk on the project (see Figure 5). Testing in accordance with AAMA 501.5 and/or AAMA 1503 to assess the potential impact of thermal cycling and condensation potential on this condition, as well as the overall performance of the curtain wall, was the source of some controversy during this process. Important issues to consider when evaluating these tests include the following:

**Thermal Cycling (AAMA 501.5) vs. Condensation Resistance Testing (AAMA 1503)**

A brief history: AAMA 1503 was originally developed in 1972 in direct response to two influences: 1) the increased use of extruded aluminum (a highly conductive material relative to wood and vinyl) in the fabrication of residential window and door products, and; 2) the energy crisis at that time. It was intended simply as a means for consumers to comparatively evaluate the condensation potential of residential window and door products. In 1988, AAMA expanded 1503 to include thermal transmittance (U-value) and, in its current form, has been tailored to mirror NFRC 100, Procedure for Determining Fenestration Product U-Factors. In contrast, AAMA 501.5 was first published in 1998, and is intended only to allow for the evaluation of thermally-induced movement in large window and curtain wall assemblies on frame joinery, anchors, and similar, and the impact of same on air/water infiltration resistance.

AAMA 1503 is typically performed after the mock-up test sequence is complete, for two reasons: 1) it typically requires removal of the fenestration product, or portion thereof, from the
composite mock-up test chamber and reinstallation into a specially equipped AAMA 1503 test chamber that is designed specifically to control interior/exterior ambient air temperatures and relative humidity, and; 2) it requires several days to complete and, therefore, is impractical to include as part of the overall mock-up test sequence outlined in ASTM E2099. Although AAMA 1503 can be run using the composite mock-up test chamber, our experience with this approach suggests that it is often difficult to control interior ambient air temperatures and relative humidity due to defects that are generally more prevalent in the test chambers used for air/water/structural testing in accordance with ASTM E2099 than in chambers designed specifically for testing in accordance with AAMA 1503. To fully and effectively evaluate the potential impact of both thermal cycling and condensation potential on a given glazing system or assembly, we recommend the following:

- Include AAMA 501.5 as part of the ASTM E2099 test sequence, followed by air and water infiltration resistance testing in accordance with ASTM E283 (optional) and E331 (at a minimum) respectively. However, as noted previously, the use of thermocouples as part of this test in the absence of AAMA 1503 testing to determine condensation potential is not recommended due to the inability to adequately control interior ambient air temperatures and relative humidity.

- Prior to beginning the AAMA 1503 test, consider the execution of a computer simulation (using Therm 5.2 or similarly recognized software program) using the project-specific specification requirements for indoor/outdoor ambient air temperature and relative humidity requirements to evaluate condensation potential on interior frame and glass surfaces at building enclosure interface conditions (For example: In areas where a thermally-broken or otherwise thermally improved frame extrusion is centered over an unconditioned masonry wall cavity - a common design error and source of condensation on interior window and/or curtain wall frame surfaces).

- Complete laboratory testing in accordance with AAMA 1503 per: a) the test standard itself, for comparative purposes to other systems, as well as to determine the influence of the architect’s use/configuration of the system on the CRF published by the manufacturer (i.e. changes in glass-to-metal ratios, excluding externally-applied aluminum architectural “fins”, sunshades, and similar project-specific features), and; b) the project-specific ambient air temperatures and interior relative humidity specified by the Architect-of-Record for the project (including architectural “fins”, sunshades, and related features as part of the test specimen to fully evaluate the impact of those elements on the as-built thermal performance of the system).

- In order to identify particular areas of condensation risk or “cold spots” in the assembly, consider decreasing the exterior ambient air temperature to a reasonable minimum based on available data published by ASHRAE for a given geographical location in which the project will be built in order to force condensation to occur on the frame, thus establishing a failure threshold for condensation based on actual recorded (or otherwise specified) environmental conditions.
Note: It may also be useful to establish a worst case humidity level for use in establishing interior ambient air temperatures for rooms within the building that will be designated for “special use” (i.e. archival storage rooms, which often require an interior RH of 50% for proper preservation of artwork and paper; natatoriums; kitchen areas, and similar spaces with high interior moisture loads) and utilize this RH when establishing the threshold values for those locations.

The contractor, in this instance, elected to forego testing in accordance with AAMA 1503 as originally specified, instead choosing to rely upon published CRF data for the curtain wall system submitted and approved by the Architect-of-Record. The potential impact of this decision, which was undertaken without further input from the BECxA, remains to be seen.

**Return-Air Overhead and Underfloor Plenum Spaces**

Condensation potential in these spaces and the critical need for air barrier continuity where these plenum spaces meet the exterior wall line is a common concern among designers and building owners/end-users. In the mixed-humid climate that will surround this project, we will be relying upon air barrier/air seal continuity at the exterior wall and interfaces to prevent warm, moist air from entering the overhead plenum space, where it could then condense on the cooled surfaces of the passive chilled-beam condenser units. On-site construction observation and quality assurance measures undertaken as part of the BECx process on this project should serve to mitigate this risk.

**Spray-Applied Polyurethane Foam**

Changes in the application of the spray-applied polyurethane foam (SPF) and use of mineral-wool fiber insulation were adapted at perimeter column conditions to facilitate installation on behalf of the contractor, and a SPF alternative accepted by the architect to further enhance the sustainable design goals of the project.
The testing proved beneficial in identifying issues to be corrected, to assure constructability and resolve some previously unresolved design details. Following the testing at the laboratory lessons learned were incorporated into the project shop drawings for inclusion in the project.

Today, the project is currently under construction. The ongoing role of the BECxA has been substantiated; initially through the involvement with the mock-up and the diagnosis and repair of issues during testing, and currently on site. To reach this stage of construction, the BECxA was also fully engaged in the submittal reviews, preconstruction meetings, and value engineering decisions. The familiarity with the systems has facilitated the development of project specific exterior enclosure check lists, which are the framework for a collaborative contractor, subcontractor and BECxA quality oriented review of work installed. Periodic construction observation, reporting, and field testing will be an ongoing component of the field commissioning work.
References


M, Lobash, High-Performance Exteriors Offer Benefits in Energy Efficiency and Occupant Comfort; *Innovations in design and technology offer facility executives new opportunities to cut operating costs and to improve occupant comfort.*
http://www.facilitiesnet.com/bom/article.asp?id=3089&keywords=exterior%20design,%20green%20building%20design,%20building%20envelope


Lemieux, D.J. and M.T. Driscoll, *Breaking the Skin*, ICBEST 2004, Sydney, Australia


*State Board of Registration v. Rogers*, 239 Miss. 35, 120 So. 2d 772, 775 (1960).