

Building Enclosure Commissioning Process

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ABSTRACT

The building enclosure is comprised of various sub-assemblies that, in combination, must achieve the proper balance in an interacting network of many building materials and components to properly control heat, air, and moisture. Without proper coordination and review during design, construction, and implementation of these systems, buildings have an increased risk of long-term problems including moisture and indoor air quality (IAQ) related issues. The interaction between the building enclosure and HVAC, lighting controls and other building systems is key to proper long term performance of the building and its systems. Without proper integration and interaction, occupant comfort and productivity can suffer.

Using examples from several projects, we will discuss the commissioning process for building enclosures from the design development phase through post-occupancy. We will discuss how this process provides a higher level of quality assurance for building owners and property managers, and helps minimize or eliminate long-term problems related to improper design and construction practices. We will use current ASHRAE and NIBS published guidelines as references.

INTRODUCTION

The commissioning of building systems is not a new concept. Although awareness of the process is now heightened through the efforts of the US Green Building Council (USGBC), the basic process has long been in place. Early commissioning programs for buildings date back to the Roman, Greek, Egyptian, and earlier eras as a “trial and error” approach. The architects and master builders introduced new design concepts, built them and then observed how they worked over time. If the builders found the features withstood the test of time, the features would be repeatedly implemented.

In the modern era, the term “commissioning” started in the Heating Ventilation and Air Conditioning (HVAC) industry as an extension of the basic verification and balancing of systems by an independent testing agency. The extended services tested the functionality of equipment controls, and ultimately included reviews of the HVAC design before construction. The current commissioning process is meant to verify that the design, construction and operation of any building system (whether lighting, HVAC or the building enclosure) meets the design intent, and to verify that the design intent is sound and reasonable. The review and testing is completed by an independent commissioning agent to provide an additional quality check to the process of design and construction.

In the building enclosure commissioning process, the enclosure design is checked against the design intent; a flawed design will result in a flawed enclosure without the appropriate checks and balances at the beginning of the commissioning process. As defined by the National Institute of Building Sciences (NIBS) *Guideline 3 – Exterior Enclosure Technical Requirements for the Commissioning Process* [1], the enclosure commissioning process needs to start at the basis of design. In general, a building enclosure commissioning process is comprised of the following elements:

- Initial meetings to discuss and refine the Owner’s Project Requirements (OPR) and the Basis of Design (BOD).
- Design review, typically at three stages: Schematic Design, Design Development and Construction Document Phases; the review is intended to ensure the OPR and BOD are being met. In addition, hygrothermal and thermal analysis where needed to validate the design against the OPR and BOD.
- Secondary review of submittals for any and all substitutions, shop drawing review and addendum drawing reviews, in addition to the Architect-of-Records review.
- Construction observation to verify the enclosure installation meets the OPR and BOD, particularly verification of water and air tightness, and thermal barrier continuity.
- Performance testing, such as thermography, water leakage testing and air tightness testing including laboratory and field testing of mock-up(s), and of the on-going construction.

- Review of closeout documents such as warranties, as-built drawings, and final submittals that will be included in the systems manual.
- Assistance in developing the building enclosure long-term maintenance plan that is to be included in the systems manual.
- Post-construction services, such as review of the building enclosure systems prior to warranty expiration.

We will use examples from projects we have worked on, some of which are LEED certified, to show how commissioning the building enclosure can be used effectively.

COMMISSIONING PROCESS

As described above, the process can be structured into about eight general steps. We will discuss each step in further detail below with examples from actual projects.

Initial Meetings – Owner’s Project Requirements and Basis-of-Design

A series of initial meetings between the owner, architect, the mechanical engineer, the mechanical commissioning agent, and the building enclosure commissioning agent are necessary to define the performance intent of the building enclosure, the Owner’s Project Requirements (OPR) in this regard, and the interaction of the building enclosure with the mechanical systems. At a minimum, discussion needs to include:

- the level of energy efficiency the Owner/design team will require, which is key to defining the thermal barrier requirements as well as the need for an air barrier system;
- structural systems under consideration, which is fundamental for integration and support of thermal, water and air barriers;
- the requirement for additional mechanical ventilation when implementing more air tight construction, as is experienced in a building with a properly designed and constructed air barrier system;
- the general roofing, wall, fenestration and below grade systems being considered for the design, general information on the site and water table heights, and what mechanical systems are being considered; these initial discussions will typically provide immediate refinement to the options and make the design review process more cost effective;
- identification of elements and penetrations that will breach the building enclosure and will require special effort to make water and air tight, and to prevent the creation of thermal bridges; initial strategies to deal with these conditions can be discussed at this stage or during the design review process.

These initial meetings streamline the process, reduce the expense of implementing changes to the commissioning program later in the project, and generally create a collaborative atmosphere and effective dialogue within the project team. In design-build projects, the contractor is encouraged to participate in these initial meetings.

Design Review

Review of the design documents should be completed at three stages: Schematic Design (verify concepts, provide initial guidance on options), Design Development (review initial details and concepts), and Construction Document phases. The reviewer should identify constructability, durability, and maintainability issues found in the drawings and specifications as well as missing information that needs to be provided for a building enclosure design that is complete and constructible. The reviewer needs to check, among other things, for thermal continuity, air tightness, and water tightness. The reviewer must be well-versed in the design and construction of air barrier systems, water management systems and thermal barrier systems, and should be able to identify and resolve thermal bridging issues. The commissioning agent will therefore require extensive knowledge in all aspects of building technology and building science related to heat, air and moisture. As such, a collection of individuals or a single firm with breadth of expertise is typically needed.

Conditions that will require special consideration and review include all interfaces between elements such as roof-to-wall, wall-to-wall when various wall types are used, and window-to-wall. Additional discussion on the interaction between the mechanical systems (interior temperature, pressure and RH that is being designed for, zones

and layout of the equipment to heat, cool and ventilate) and the building enclosure need to occur to ensure design intent is met and that condensation and poor air movement for ventilation does not occur. The commissioning agent should also identify what mock-ups are recommended, at a minimum, and assist the design team in selecting a program for the mock-ups and construction performance testing. Additional tasks for the commissioning agent may include life-cycle assessment of elements for the building enclosure and embodied energy calculations.

During review work, conceptual details are typically developed to identify key elements that are not clearly shown in the design set. Figure 1 shows a window-to-wall conceptual sketch used for a natatorium project; Figure 2 is for an interface between an exterior wall water management system elements and interior waterproofing.

In addition, the review of enclosure systems (i.e. roofing, waterproofing, air barriers, water resistive barriers (WRB) and flashings), should provide the architect, owner and others involved with building enclosure design guidance for comparing and selecting material alternatives. Below we present a typical comparison for three generic below-grade waterproofing systems, identifying market familiarity with respect to local waterproofing subcontractors, durability, ease of installation, and additional items that may be required for installation. These systems reviews also provide additional information to the design team on potential material compatibility issues that may require transition accessories.

Comparison of Three Waterproofing Systems Considered for Below-Grade Waterproofing

Step 1: State Project Parameters

The drawings and specifications for this Sample Project include, in part, the following information regarding the below-grade construction:

1. The building has cast-in-place concrete spread footings and a concrete slab-on-grade over a vapor retarder and free-draining gravel. The design does not include waterproofing membrane below the slab-on-grade.
2. The new addition will be above the water table; the drawings were reviewed with this understanding. Should the lowest floor slab be found to be below the water table, additional waterproofing provisions would be required, including continuous wall-to-slab waterproofing, and a sub-slab drainage system.
3. The building will have a number of elevators that will have an elevator pit requiring waterproofing (not given as part of this example for this paper).
4. The foundation walls will be cast-in-place concrete, and will be backfilled after installation of the waterproofing membrane.
5. The below-grade exterior wall waterproofing is intended to be a sheet applied waterproofing membrane, with limited use of bentonite clay waterproofing at locations where shored walls may need to be used.

Step 2: Provide General Guidance for Waterproofing Based on Design Review

The waterproofing system is to be covered by drainage protection board and routed to a perimeter drain located at the footing level; the perimeter drain is surrounded by gravel and filter fabric. Various manufacturers have an accessory available to tie the waterproofing drainage board directly into the perimeter drain.

According to the specifications, the waterproofing system is to be terminated at the top of the foundation wall in a reglet. The waterproofing should not terminate in a reglet; it should be carried up above the height that the return leg for the above-grade wall through-wall base flashings will sit and be terminated with a termination bar into the exterior sheathing prior to installing the wall flashings.

At doors and windows near grade, the waterproofing should be extended under the window or door pan flashing. Additional metal flashing may be required near grade to protect the below-grade waterproofing

membrane that extends above grade; the additional metal should be hooked into the flashing drip edge and can be used to hold the protection board/drainage layer in place during backfilling operations.

Step 3: Provide System Specific Guidance for Waterproofing System Options

A Self-Adhered Membrane Waterproofing

The waterproofing option specified for below grade walls is self-adhering waterproofing membrane. These membranes incorporate a flexible pre-formed waterproof membrane consisting of a cross-laminated reinforced polyethylene carrier film bonded to a self-adhering rubberized asphalt backing. The seams are lapped joints and interfaces can be sealed with mastic for enhanced durability. Damage to the membrane can be repaired relatively easily prior to back-filling. This system, if constructed properly, is a durable choice for a waterproofing membrane. However, the adhered seams used with these systems are vulnerable to deterioration under hydrostatic pressure. Proper installation of the joints, membrane terminations, and interfaces is critical to its long term performance. The hydrostatic pressure against the membrane can be reduced by the installation of an efficient drainage board and sub-surface drainage system.

At the base of the foundation wall, the self-adhered sheet can be susceptible to water migrating beneath its leading edge, causing the waterproofing to debond and eventually fail. At the lowest portion of the wall, a termination bar should be added to minimize the amount of membrane that may debond, and the edge of the membrane sealed.

The advantages of this system in this application are as follows:

- Reliable protection if properly detailed and installed. The membrane adhesion and waterproofing performance can be improved by using manufacturer's primer.
- Lower cost than heat-welded PVC.
- Readily available in this market. (Provide regional and location specific information on the availability of the product)
- Does not rely on confinement pressures (like bentonite).

Disadvantages for this application include the following:

- The membrane must be installed over fully cured concrete surfaces to prevent formation of blisters.
- The many seams leave the membrane vulnerable to leakage under hydrostatic conditions, e.g. when underdrain system fails and if water back flows to the lowest edge of the waterproofing or if the foundation drain system fails.
- Wrinkles due to manufacturing process in, or misapplication of, the membrane introduces the possibility of tunneling at seams, leading to localized failure of the seam

An alternative to the sheet-applied waterproofing is heat-welded PVC.

B Heat-welded PVC – Fiberglass Reinforced Thermoplastic (Polyvinyl Chloride PVC) Sheet Membrane

This system consists of PVC sheets with seams that are heat-welded in the field. The membrane is loose laid. This system's heat-welded seams make it less vulnerable to degradation and leakage under hydrostatic pressure.

Advantages include:

- Durable and relatively puncture resistant compared to HDPE (primarily due to sheet thickness)
- Integral fiberglass mat carrier sheet results in good dimensional stability, lower coefficient of thermal expansion and contraction.

- Hot-air welded seams result in continuous membrane and, if intact, are impervious to moisture infiltration. Similarly, heat-welded flashing details will not deteriorate under hydrostatic conditions.
- Membrane does not absorb water and is unaffected by ponding water
- Ability to design systems to accommodate over-excavated sites and system flexibility to waterproof areas where the two conditions merge.
- Many available accessories to waterproof penetrations.
- Does not rely on confinement (like bentonite).
- Can be installed over wet and irregular surfaces.

Disadvantages include:

- Highest installed cost of systems under consideration.
- Heat-welded seams require diligent workmanship.
- Membrane contains chlorine (some clients are concerned about long-term disposal issues with PVC).
- Multiple penetrations require detailed and costly hand-welding.
- The availability of this membrane may be limited in this market.

C Bentonite Sheet Waterproofing Membrane

Bentonite sheet waterproofing is intended for use at limited locations where shoring may be needed. It is desirable to have a bentonite system that is from the same manufacturer as the sheet applied waterproofing system to provide a single source for warranties and to avoid conflicting responsibility for the below-grade waterproofing. Consider other alternatives in areas where even small amounts of leakage are deemed unacceptable, such as below-grade finished spaces. We have the following general comments regarding bentonite waterproofing systems:

Advantages include:

- Somewhat reliable, but not perfect waterproofing protection for below-grade structures
- Bentonite clay requires confinement to function properly as waterproofing once it has been activated by water. Bentonite can perform reasonably well where it is well confined, such as between the lagging and concrete foundation wall in blind-side applications.

Disadvantages include:

- Will generally experience some leakage, often at shrinkage cracks in the foundation walls and in response to seasonal changes in the water table. The volume of chronic leaks can often be reduced by injecting cracks in the foundation walls with urethane grout. However, some leakage can still occur. As there will be finished space below grade on the Sample Project, and leakage is not desirable, we recommend limited use of bentonite.
- Back-filled open cut excavations may not provide sufficient confinement.

In addition, note the following:

- The specified product is one of the lower performance grades of bentonite waterproofing offered by this manufacturer. Higher performance grades offered include Option A (which includes a polyethylene liner), and Option B (which includes a polyethylene liner in addition to polymer-modified bentonite clay). If bentonite will be used, we recommend switching to one of these products to improve the reliability of the system.
- Some bentonite systems perform poorly if exposed to some groundwater contaminants and saltwater. If bentonite will be used on this project, a test with the locally available water and ground water it will come in contact with should be performed before the project is bid to avoid a material change order during construction.

By providing these system comparisons for a variety of elements on the project, the Owner, Architect and Contractor(s) can verify that they have picked the appropriate product for the use it is intended for, understanding risks versus cost.

Hygrothermal and Thermal Analysis

The use of hygrothermal and thermal analysis in reviewing the design of the walls, some below grade elements, the roof, and various interface conditions is necessary to determine risks for energy loss due to thermal bridging as well as condensation risk. The analysis can also be used to gauge the robustness of one system over another with respect to heat and moisture transfer. If the design team has already completed these tasks, the commissioning agent can review their work product. If not, and the OPR requires analysis for verification, then the commissioning agent is to complete these tasks. Figures 3 and 4 show a ceiling system for a low temperature/high humidity building that will be used for storage of collectibles. The analysis was, in this case, a critical component of the review process to help determine insulation strategies required to reduce condensation in the ceiling construction, and to reduce thermal bridging for the framing for the ceiling. The analysis and calculation helps the design team assess the extent to which their design will perform as intended, and how its performance may be optimized. The analysis also allows the design team to review various options and determine the relative cost-benefit for each option in finalizing the design.

Review of Submittals, Addendums and Shop Drawings

Submittal review, addendum review and shop drawing review are critical steps, sometimes missed in a project commissioning program. The design may have changed and improved overall due to the design review process. However, subsequent material substitutions and design alternations in the addenda, or shop drawings could easily override design key design and detailing decisions made during the design review process. These modifications made just prior to construction may compromise the initial design intent. The commissioning agent should be reviewing heat, air and moisture concerns, as well as durability, maintainability and constructability issues through the shop drawing phase. On substituted product submittals, the experience of the commissioning agent with the various product systems is important. The commissioning agent should review the submittals, etc. concurrently with the design team to avoid delays in the project schedule.

Construction Observation

Even the best building enclosure designs are not always implemented in the finished building without proper oversight during construction. Construction oversight by the commissioning agent provides an additional level of quality control over the typical QC/QA program completed by the general contractor by an independent agency, thereby reducing the likelihood of installation errors.

The process begins with a kick-off (pre-construction) meeting with all of the trades, and sometimes an additional kick-off meeting for trades involved with a specific assembly, for example, roof construction and all of the items to be placed on the roof. These meetings are useful in identifying scheduling, sequencing and staging issues that could impact the quality of the enclosure systems. The experience of the various contractors is also brought to the table in an open forum, improving communication within the project team and promoting collaboration in achieving the design intent. These meetings address key procedural issues that are not typically addressed in the design documents, and that can significantly impact the performance of the building enclosure. For example, coordination of electrical, plumbing or mechanical conduit penetrations through the enclosure will help ensure that they are properly sealed and detailed; uncoordinated installation of these can easily result in a compromise in the thermal, air and water barriers, if not all three. Discussion of these issues ahead of time will allow for a process to be put in place to identify how this possibly added or missed element is to be installed so as to not compromise the enclosure. The project manager, superintendants and foreman and lead trades person for each contractor affected should attend the meeting so that the knowledge is directly disseminated to the parties that will be in control of constructing the building enclosure.

In addition to these meetings, on-going construction observation is a key step that is sometimes omitted for cost savings, without recognizing the risk of incurring significantly higher costs to dismantle and repair problems caused by deficient installation.

The field review process is best executed with a hands-on, up-close approach; many enclosure deficiencies are not readily seen from a distance. Figures 5 and 6 show examples of construction deficiencies that were caught from up-close review. This review should not be completed from the ground level or lower roofs, or through the use of

binoculars. The review should be conducted from scaffolding, staging, or other means of access to ensure up-close review.

Performance Testing

Typically, two major elements are identified for performance testing: air leakage and water penetration resistance. Additionally, thermography can be used to verify performance of the thermal envelope. Figure 7 shows a blower door test in progress. Figure 8 is of a thermographic image of an element of the building enclosure with air leakage near the roof eaves. Each of these processes is an important step to verify system performance. In addition to scheduled water leakage testing, walking the project during actual rain events provides a cost-effective and more complete review of the building's water-tightness. Figure 9 shows an example of an enclosure that failed during water testing; this phenomenon on this particular project was due to a systemic problem that the contractor also noted during subsequent rain events. Comments from the design review regarding sill flashing installation were not implemented; the leakage could have been avoided with proper construction oversight.

Closeout and Follow-up Services

During closeout, a Systems Manual for the building enclosure needs to be completed. NIBS Guideline 3 provides additional detail to what is provided in this paper. The manual will need an index of all as-built products, their color, manufacture, supplier, and local technical representative, and the contractor who installed the product. This data is very useful not only for warranty purposes, but for maintenance should a material or system require repair. The Systems Manual should be catalogued by product, and if possible, major system (roof, fenestration, wall system). The manual needs to include the warranties, manufacturer technical manuals, manufacturer maintenance and care manuals, and installation instructions. Many of these are readily available through the technical representative or electronically on the manufacturer's web page. A periodic maintenance plan and system review schedule needs to be included. For example, information on cleaning the roofing membrane as well as how often it should be inspected (reviewed every two to three years, and 6 months prior and right at warranty expiration dates).

The Systems Manual can be submitted in electronic format; at least one hard copy should also be prepared for facilities staff at the building.

The commissioning agent can also provide any of the following follow-up services on an as-needed basis:

- warranty walk through
- periodic inspections
- post-construction instrumentation and evaluation of the building enclosure
- thermography

CONCLUSIONS

The use of a building enclosure commissioning program, in our experience, is a cost effective way to provide a higher level of quality assurance to any project. The number of issues typically addressed by an experienced commissioning agent may result in additional upfront costs; however, the long term benefits of better energy inefficiency, controlled water and/or air leakage, improved general enclosure performance, and reduced possibly of post-occupancy failures far outweigh the initial investment. It is a process from which every construction project can benefit.

REFERENCES

NIBS Guideline 3-2006 – Exterior Enclosure Technical Requirements for the Commissioning Process, National Institute of Building Sciences.

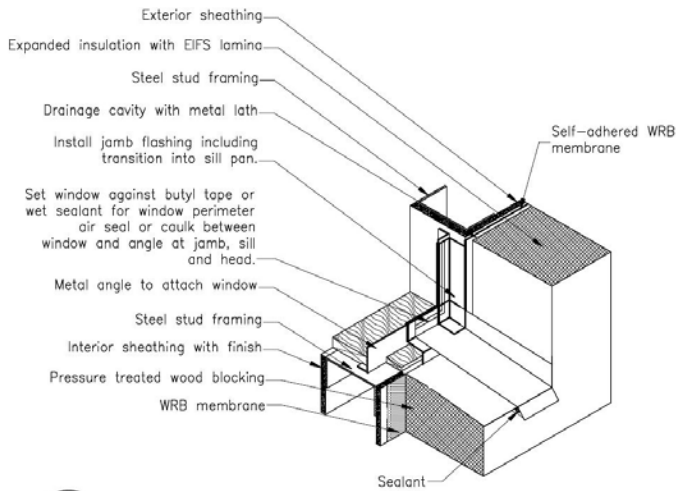


Figure 1

Conceptual sketch developed for a natatorium project for a window-to-wall interface; this is step 3 of 3 prior to setting the window.

2c Sill Pan Flashing N.T.S.

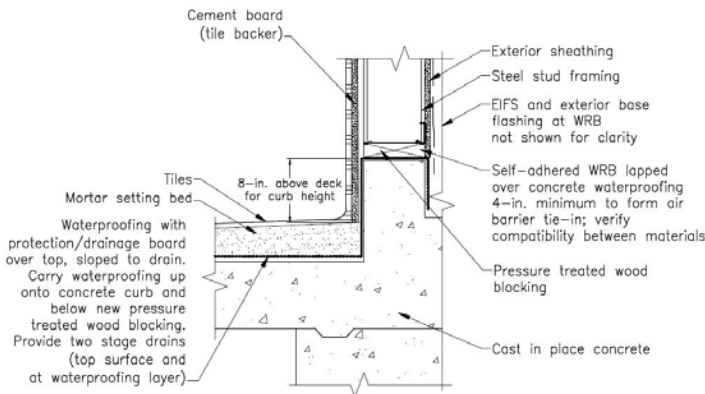


Figure 2

Conceptual sketch developed for a natatorium project for pool edge waterproofing to exterior wall water management system and air barrier tie-ins.

4 Wall to Slab Air Barrier Transition N.T.S.

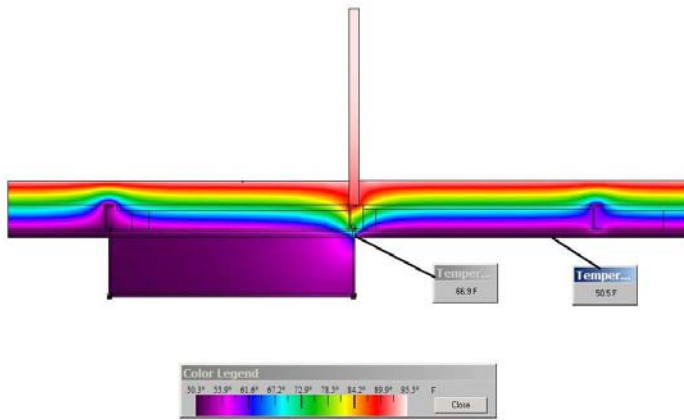


Figure 3

Summer ceiling thermal model to review thermal bridging and condensation risk for a specialty building (low temperature, high humidity)

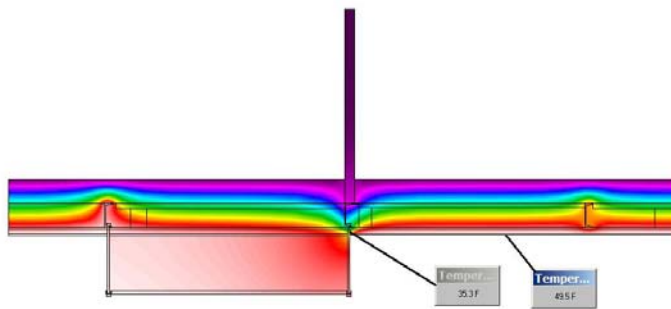


Figure 4

Winter ceiling thermal model to review thermal bridging and condensation risk for a specialty building (low temperature, high humidity)



Figure 5

Vertical mullion window joint on retrofit project sealed with preformed silicone tape. Without hands-on, up-close inspection, this section of debonded joint would not have likely been found until leakage occurred that resulted in visible interior damage.



Figure 6

Improperly installed sealant found during an investigation project; the remainder of the penetration was also not flashed properly.



Figure 7

Dual-fan blower door used to test whole-building air leakage rate.



Figure 8

Infrared (thermographic) scan of museum exterior. Lighter colors indicate higher temperatures at and below roof eaves.



Figure 9

Water leakage during spray rack testing; on this particular project, design review comments recommended installing sill pan flashing, but were not followed, ending up with a predictable result.