Session 2.6 – Quality Management

Quality Management in the Design and Construction of Enclosure Systems

Michael P. Steffen[1], Martin J. Houston[2]

ABSTRACT

In recent years, building scientists and technically-grounded design professionals have established that durable, high performance building enclosures must incorporate the following five control layers: a water-shedding surface, a water-resistive barrier, a thermal barrier, an air barrier and a vapor barrier. These control layers have been characterized as the five "critical barriers" of the building enclosure. Not only is it important that these five barriers – and their continuity – are provided for in the design of the enclosure, but the continuity of those barriers must be provided for with the implementation of the design during the construction phase of the project. A lack of critical barrier continuity can lead to durability problems with rot or corrosion resulting from water leakage or interstitial condensation, and/or energy performance (or comfort) problems resulting from air leakage or thermal bridging.

This paper will discuss aspects of the quality management approach utilized by one construction firm working in the Pacific Northwest to provide cost-effective, high quality, durable enclosures for high performance buildings. It will trace the process by which continuity is established during the design phase and how that continuity is achieved during the construction phase. A key point of discussion is that a vital quality approach is not based primarily on the use of outside "third party" specialist consultants or by rote use of generalized quality checklists, but on the active, collaborative engagement of knowledgeable, diligent professionals, at all points along the project process, on all sides of the table, working to get the job done – one project at a time. Other key points include: 1) the purpose of quality management is to bring order to the chaos inherent in the modern day construction delivery system, 2) nearly all buildings are prototypes and this has an impact on how much standardization is possible in the development of quality processes, 3) the quality of detailing provided by the design team is of critical importance to a successful construction process, and 4) the general contractor fundamentally "owns" the coordination process and must have organizational capability to understand building science and direct the construction of building enclosures utilizing that understanding.

Case studies of the quality management process from several projects will be used to illustrate the ideas and concepts discussed in the paper.

[1] Michael P. Steffen, AIA, LEED AP, Vice President / General Manager, Walsh Construction Co., Portland, OR
[2] Martin J. Houston, AIA, LEED AP, Quality Director, Walsh Construction Co., Portland, OR

Introduction

In recent years, building scientists and technically-grounded design professionals have established that durable, high performance building enclosures must incorporate the following five control layers: a water-shedding surface, a water-resistive barrier, a thermal barrier, an air barrier and a vapor barrier (Lawton 2010). These control layers have been characterized as the five “critical barriers” of the building enclosure (RDH Building Engineering 2011). Not only is it important that these five barriers – and their continuity – are provided for in the design of the enclosure, but the continuity of those barriers must be provided for with the implementation of the design during the construction phase of the project. A lack of critical barrier continuity can lead to durability problems with rot or corrosion resulting from water leakage or interstitial condensation, and/or energy performance (or comfort) problems resulting from air leakage or thermal bridging.

Despite the efforts of many firms within the construction industry, durability and energy performance problems remain widespread in recently constructed buildings. Additionally, there are many older buildings that are suffering durability and other performance problems, and are in need of rehabilitation. How does a construction firm position its business model to address the realities of the current production environment and work with project partners to produce buildings with enclosures that are fundamentally sound and functional, avoiding the aforementioned problems? This paper will discuss the quality management approach utilized by one construction firm working in the Pacific Northwest to provide cost-effective, high quality, durable enclosures for high performance buildings. It will trace the process by which continuity is established during the design phase and how that continuity is achieved during the construction phase.

A Quality Management Process within the Construction Industry

Walsh Construction Co. (WCC) is a mid-size general contracting and construction management firm with offices in Portland, Oregon and Seattle, Washington. The firm employs approximately 350 people, with annual billings in the range of $200-$300 million, working primarily in the multi-family residential, educational and commercial building market sectors. The core client base for WCC includes non-profit community development organizations, public housing agencies, and public and private educational institutions. Upwards of 80 percent of the firm’s work is contracted at a negotiated price (rather than procured in a “hard bid” environment) and WCC is typically at the table with the owner and design team from the early stages of the design phase onward.

By the late 1990s, WCC had experienced water intrusion leading to durability problems on several buildings it had constructed during the preceding decade. This experience was not unlike that of many other construction firms in the Pacific Northwest. From Vancouver, British Columbia to Portland, Oregon, water intrusion problems were clearly prevalent in the building stock that was constructed during the 1980s and 1990s (Desjarlais et al. 2001; Lawton 1999; Morrison Hershfield 1996). Construction of very large wood frame buildings has become commonplace across the region, especially for multi-unit residential buildings, and it was at this construction and building type where problems appeared to be most widespread.[3]

In 1999, WCC initiated the development of a quality management process. This process was initially intended to reduce the potential for water intrusion problems on the buildings WCC was delivering to clients; however, the process has additionally served as an important tool in the delivery of high performance buildings – a touchstone for many of our clients in the Pacific Northwest. During the inception stage of this quality initiative, it was not clear where to look for direction to improve the quality of design or construction. Many buildings during this time period had been designed without adequate redundancy in terms of moisture management. Assembly designs and materials were often marginally appropriate relative to application or exposure, and design documentation was not well-developed on most projects, particularly with respect to the detailing of the building enclosure. For example, rainscreen cladding assemblies had not yet come into use in the Pacific Northwest. Window-to-wall interface detailing was still quite rudimentary. Construction means and methods were clearly at fault as well; however, there was a strong indication that design issues were central to the lack of performance on many buildings and some basic design premises needed attention. This was a matter of "putting the horse before the cart." The designs of assemblies and details needed to be improved first, and then, in turn, the construction process by which those improved designs would be executed needed to see improvement as well. To move forward with this initiative, WCC recruited an architect to join its staff as Quality Manager, to formulate a detailed quality process, and to serve as a key liaison to design teams during the design phases of projects. This paper will describe how this process has developed over the past decade as it may serve as a useful model for other construction firms working within certain industry sectors.

The construction industry presents unique challenges for the implementation of quality management. With very few exceptions, nearly every building is a prototype with a unique site, a unique program, and a need to be responsive to the particular climate found in different regions. A wide variety of structural, enclosure, and mechanical systems are used in modern day buildings. The project teams assembled to design and construct buildings vary significantly from project to project. Even when the same architectural firm and construction firm are utilized to lead the process, the broader design and construction team involving subcontractors, suppliers and design sub-consultants will likely be composed of disparate firms. The price-competitive procurement of goods and services that is the norm within the construction industry inevitably leads to this variation. This "norm" eliminates one of the key tools that could be used to improve quality: *consistency of the vendor and supply chains for both design and construction*. The resulting production environment has been characterized as fundamentally "chaotic" (Bertelsen 2003).

How does one provide order to the chaos? That, in essence, is what the quality management process is about in the construction industry: providing a semblance of order amidst what would otherwise be chaos. It's important to note that complete order is not really possible. There are too many moving pieces and parts. The goal should be to provide an adequate level of order to

---

[3] Five story wood frame buildings have been allowed in Seattle and Portland since the late 1990s. Six story wood frame buildings are now allowed in British Columbia.

the chaos in order to deliver an end product to the customer that meets their specified requirements for quality. This has been the focus in the development of the quality management process at WCC.

Quality Process during the Design Phase

As owners have pushed more and more for high performance buildings, it has become clear that an integrated design approach is essential to successful project delivery. To achieve high levels of building performance, all key design team members must be present at project inception to incorporate their respective ideas and analysis into the project's formative conversations, so that synergistic directions can be identified and then further developed. This requires that all team members are present, but also that they work in a highly collaborative manner to produce effective design solutions. This same synergy that is so useful to establishing a path to high performance is also what will most effectively yield a high quality building. There is no simple formula. There is no single path. It can be difficult work, but all parties are rewarded when highly synergistic solutions are found. Project success ultimately depends on the active, collaborative engagement of knowledgeable, diligent professionals, at all points along the project process, on all sides of the table, working to get the job done – one project at a time.

The design team takes the lead on the project quality process during the design phase. Overall design responsibility, including the quality of the design, lies with the architect. But where does the general contractor come in? The contractor can play a vitally important role, providing real-time feedback to the owner and design team about costs and constructability issues, as well as potential quality concerns, as the design is developed. Construction firms often have a long-term relationship with the owner, and over time a perspective regarding what works well and what doesn't on certain building types has been developed within that relationship. This perspective and knowledge can be brought to the table and integrated into the programming and design process from the beginning.

One of the key activities of the construction firm during the design phase is to provide cost estimating services. It is important that quality reviews – by both the design and construction teams – are conducted concurrently with the cost estimating exercises so that the technical and process issues associated with costing are exposed and discussed early on. As part of this process, it is critically important to budget adequately for quality. Early during the design phase on most projects, many variables are at play and program definition and material/product specifications are typically quite loose. There can be a tendency for construction team members to assume the "lower" quality standard or material during the estimating process. This allows the estimates for various scopes of work, and ultimately the cost of the entire project, to appear to be lower than if a higher quality standard were assumed. Taking on these assumptions allows the construction team to present a veneer of competitive, aggressive pricing – something that all contractors would like to present to their customers. This is all well and good during the early conceptual pricing rounds of the design phase; the problem results when the project budget is established in accordance with these early assumptions and these assumptions are then found to be inadequate from a quality level standpoint. A rebalancing of the assumptions must then take place later during the design phase or, worse, the poor assumptions may take hold and become incorporated into the design due to budget pressures. To avoid these problems, early budgeting should be based on assumptions regarding the level of quality that is commensurate with the owner's expectations.

An example is an exterior cladding system to be applied over a light gauge steel frame wall on a commercial building. The owner has clearly stated expectations for a durable, low-maintenance exterior and has set goals for a very high level of energy performance. The architect has issued an outline specification that calls for profiled sheet metal cladding with a specific type, thickness and finish. Does the contractor's first estimate for the exterior wall system include a cladding system that incorporates an exterior insulation approach? If so, what type of insulation, and how much? Does the estimate include a thermally isolated sub-framing system to support the cladding while minimizing thermal bridging effects through the exterior insulation layers? What is the nature of that framing system? These few items alone could swing the unit cost of the exterior wall assembly significantly and thereby impact how the budget and quality level is established for the project early during the design. This in turn will impact the options that can be considered and choices that can be made later.

The construction team has the potential to add significant value to the design process by conducting diligent and informed constructability reviews. These reviews bring a field perspective to the review of the design. A capable contractor is informed by years of experience with different materials, means and methods of construction. Experience with success – and with failure – fundamentally informs the contractor's thinking. Constructability reviews should occur early on at the larger scale with the plans, sections, and elevation drawings and then later during the design phase at a smaller scale with the building details. Open communication and collaborative questioning between the design team and construction team members will help to move the design forward and leverage a better set of construction documents for the bidding and construction phases of the project. How will the construction work be sequenced in the most logical manner? Is that consistent with the configuration of components? Where is the insulation occurring at the intersection of this floor with the exterior wall? Should this fully exposed door be covered with a protective overhang of some sort? How can the cladding system be built cost-effectively when the lipped brick detailing indicated at the floor line ledger angle appears to eliminate any tolerance between the cladding and building structure? How will this trim piece be fastened? Is there backing in the wall at that location to fasten into? Is there a way to access this sealant joint for initial installation of the sealant? For maintenance of the sealant five years down the road? These are just a few of the hundreds of questions that might be asked on even a moderately sized building.

With respect to the building enclosure, these constructability reviews are a fundamental aspect of quality management. It is vitally important during the design process to establish continuity of the five critical barriers and then to clearly indicate that continuity in the design drawings. Members of both the design and construction teams can utilize a review exercise where they trace the barriers through the drawings of the building enclosure (Lawton 2010). The essential function of this exercise is to identify any discontinuities that may occur in the barriers. This can be done at the larger scale with the wall sections and enlarged plan drawings, and then again at the smaller scale with the section and plan details. As discontinuities are identified they can be addressed by the design team in the next iteration of the drawings. Thermal barrier continuity is best traced and analyzed at the level of the wall section and enlarged plan, whereas each of the other barriers is best traced and analyzed at the detail level.

It is important to consider the scale of building enclosure details to allow for effective communication of the quality requirements. Ideally, the building enclosure details will be drawn at half scale (6' = 1'-0") to adequately communicate the requirements for critical barrier continuity. Quarter scale details (3" = 1'-0") can be used as well; however, it is often challenging to clearly indicate requirements at this scale, especially with respect to the materials and components required for air barrier continuity and water-resistive barrier continuity. The following details clearly show the distinction between detailing that effectively communicate the requirements for critical barrier continuity and that which does not (see Fig. 1 and Fig. 2).

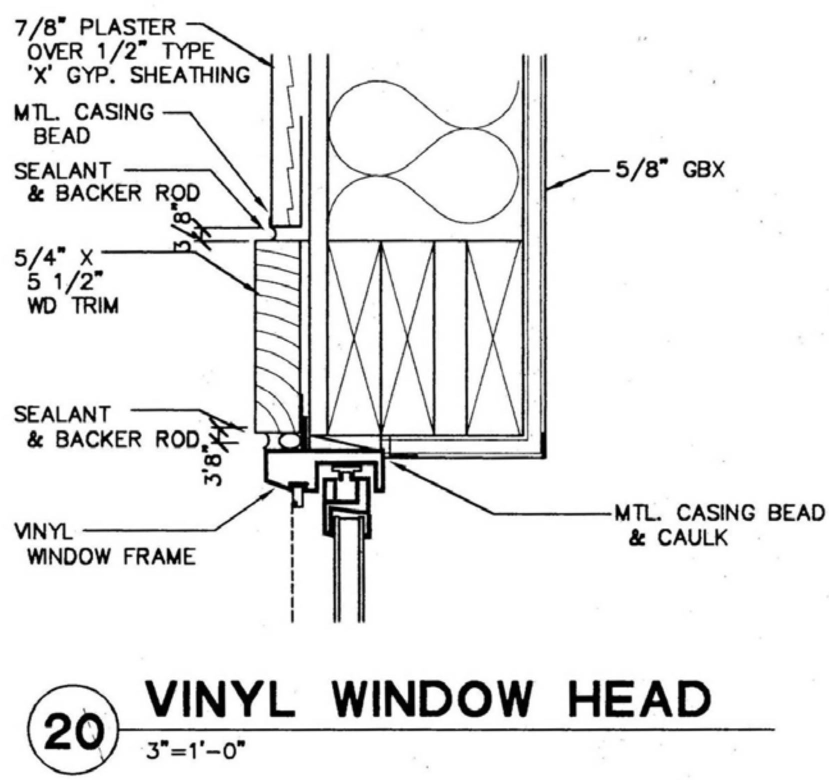
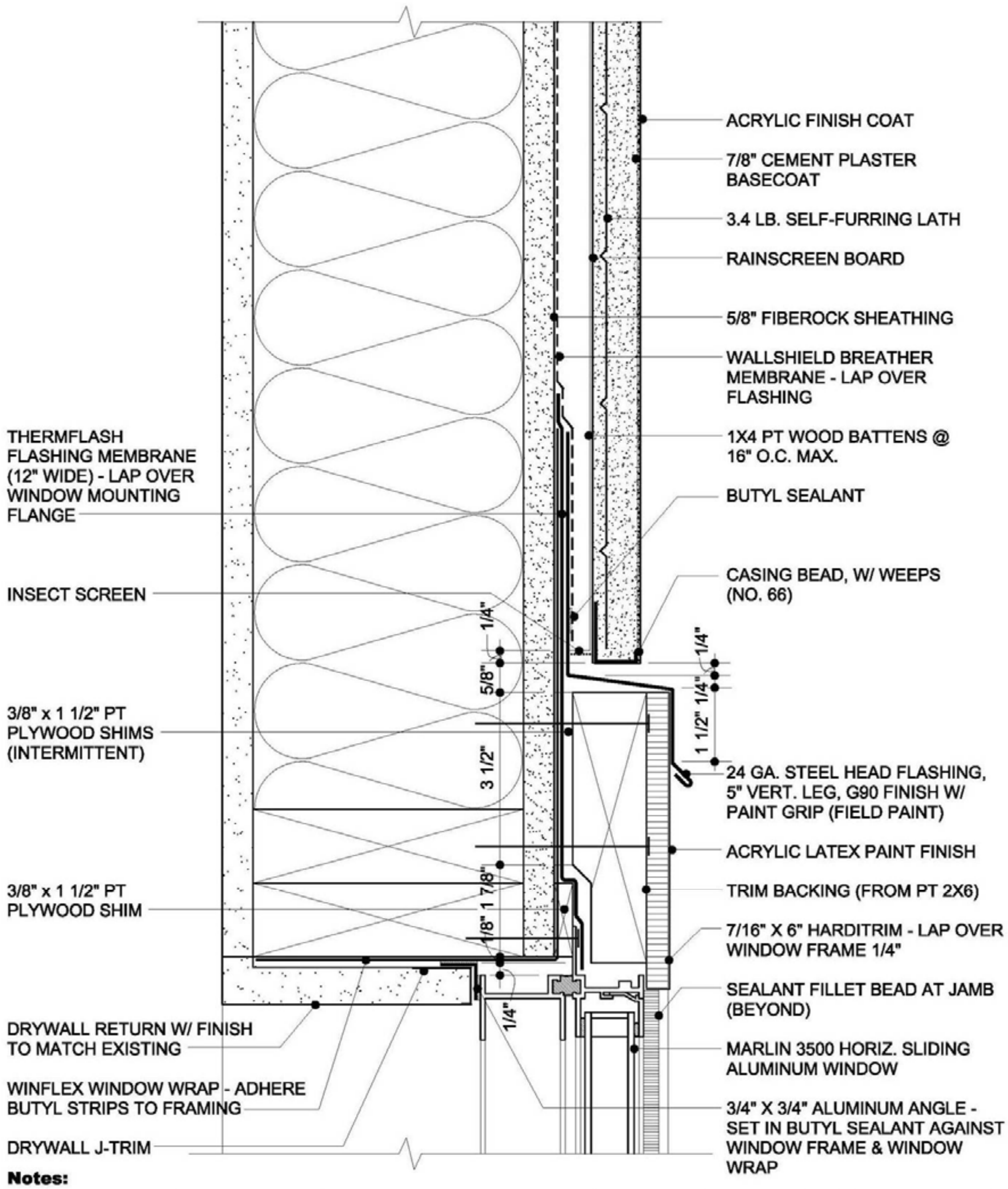


Figure 1. Example of an enclosure detail developed at quarter scale. The reader should attempt to trace continuity of the five critical barriers through this detail. It will be noted that quarter scale detailing typically does not allow the design professional to fully and clearly indicate requirements for critical barrier continuity. In the case of this detail, many critical barrier components are not indicated at all.



Notes:

1. SEE ERD DWG. 12/A-108 FOR ADDITIONAL INFORMATION. THIS COORDINATION DRAWING DOES NOT SUPERSEDE THE DESIGN DRAWINGS AND SPECIFICATIONS BUT IS INTENDED TO COORDINATE THE WORK IN ACCORDANCE WITH THE DESIGN DRAWINGS AND SPECIFICATIONS.
2. FASTEN WINDOW FLANGE TO WALL FRAMING WITH #8 x 1 1/2" STAINLESS STEEL PAN HEAD SCREWS @ 12" O.C.
3. WCC SUPT. TO VERIFY ACCEPTANCE OF WINDOW INSTALLATION DETAILS BY WINDOW MANUFACTURER PRIOR TO INSTALLATION
4. FASTEN HARDITRIM TO BACKING WITH 1 1/4" STAINLESS STEEL CASING NAILS @ 8" O.C., STAGGERED PATTERN

Figure 2. Example of an enclosure detail developed at half scale. The materials and components that constitute the critical barriers (i.e. water-resistive barrier, air barrier, etc.) – and their respective continuity – can be clearly indicated in detailing provided at this scale. This is a detail of the same condition (on the same building) that is indicated in Fig. 1. The detail in Fig. 1 contributed to a widespread enclosure failure. The detail above was utilized during the successful rehabilitation of the building's enclosure.

It is important to note that continuity cannot be effectively provided in the design by use of broad or vaguely worded performance specifications. For example, phrases such as “seal all openings and penetrations to make building airtight” or “provide flashings at joints as needed to achieve watertightness” do not adequately communicate the requirements for quality. These requirements must be clearly indicated in the drawings, particularly at the details. That is not to say there isn’t a role for the specifications in ensuring continuity of the critical barriers: clearly worded specifications that are well coordinated with the drawings can reinforce the requirements for quality as far as the building enclosure design is concerned.

To be an effective participant during the design phase, the contractor should proactively and knowledgably review the drawings and specifications developed by the design team and advise the team on the communicative effectiveness of those documents. Without clear communication of the requirements for quality (including continuity of the five critical barriers), the contractor – as well as the subcontractors involved in the building enclosure construction – will likely miss key necessary materials and components, or sequencing requirements, needed to achieve the continuity of those barriers.

Value engineering exercises are commonly utilized during the design phase to evaluate the project design and discern whether cost reductions can be achieved without lowering the quality of the end product or, alternatively, if significant increases in quality can be achieved for little or no increase in cost. On some projects, value engineering is required regardless of whether the project is tracking on its established budget or not. As all practitioners who have experience with the design process understand, these exercises often devolve into cost-cutting exercises that in fact reduce the quality of the end product. All parties involved in the design process - including both the contractor, who is typically eager to please with proposed cost reductions, and the owner, who is typically happy to receive the news of such reductions – need to reflect on the fundamental purpose of value engineering and to remain firmly committed to this purpose as well as to the project goals. Short-sighted decision-making during value engineering exercises can fundamentally alter the quality of the end product – in many cases to the detriment of overall quality. Again, open communication and collaborative questioning of design assumptions is needed in this process, but the consequences of changes in specifications and detailing to reduce cost should be fully understood by all parties. Caution is warranted, and a rush to accept the proposals should be avoided so that design team members, including sub-consultants with particular expertise related to the areas under consideration, can be enlisted to help with analysis of the value engineering proposals. In particular, the owner should clearly understand the pros and cons involved with accepting proposed cost-reduction measures. At the same time, it is important that design team members avoid holding firmly to recommending that only the best or highest quality systems or products be utilized. This can be effective in terms of risk management for design professionals, but service and value are ultimately provided by design professionals when they inform their clients (typically the owner) of the respective pros and cons of the design options and alternatives proposed during value engineering. All projects have budget limitations, and system and material selection often revolves largely around the process of making decisions to achieve the best balance of quality and cost with the many different systems and materials needed to create a building. Something has to give, and typically it is best if everything gives a little in the pursuit of that balance. Having the contractor involved in the design provides a useful tension, but it is critically important that the contractor remain committed to the project goals, especially when a value engineering process is used. The best results are achieved when value engineering is integrated into the process during the entire design phase, from beginning to end.

Throughout the design phase it is useful for the contractor to bring key subcontractors or suppliers into the process. These potential construction team members can significantly leverage the quality process further by providing insight and detailed input on issues related to their specific areas of expertise. Though they are aware that subcontractor and supplier selection on a given project will be based on competitive bidding, many firms are willing to share their expertise and perspective with the understanding that such involvement may provide them a competitive advantage at bid time. With certain large or complex scopes of work, the project team may decide that the highest quality end product would result from early selection of subcontractors or suppliers in order to obtain their early and in-depth involvement in the development of design. One example where this would likely be appropriate on a project utilizing a custom unitized curtain wall design, especially in an area where there might be only one or two prospective contractor/vendors. Another example would be a project where the design envisions the use of an innovative but complex cladding system that has been newly marketed in the project area.

The final area of preconstruction where the contractor can have a major influence on quality outcomes is the bidding process. By breaking down the work into individual bid packages and providing clearly defined scopes of work within those packages, the contractor can help ensure thorough scope coverage by each of the individual trades when bids are received. This scope definition can help immensely with analysis of the bids to ensure “apples to apples” proposals are received. This proactive position tends to have major benefits during construction by reducing the potential for holes in the scopes of one trade or the other, or uncovering misinterpretations of the design drawings or specifications that would cause difficulties for any of the parties involved in the project, including members of both the design team and the construction team.

Durability – A Fundamental Premise for High Performance, Sustainable Buildings

Over the past decade, design and construction professionals have been challenged to deliver high performance buildings to owners that are intent on improving the environmental and economic sustainability of their organizations. A fundamental premise in the creation of a high performance, sustainable building is the inclusion of a high performance building enclosure, one that is durable and provides for a high level of energy efficiency. Durability must be given primacy as a concern since it is clear that an enclosure that lacks durability will cause other performance problems. A lack of durability can be understood to be fundamentally unsustainable. However, some rating systems developed to assess the “greenness” or sustainability of new construction and rehabilitation projects – such as the LEED rating system – have notably lacked any criteria to address the relative durability of a given building design, its components, or its construction. Numerous buildings that have received high levels of LEED certification *have in fact suffered enclosure durability problems within the first decade of the building's service life (Lemieux et al. 2004). It is clearly important that durability must be emphasized in the performance criteria for high performance buildings in addition to other elements such as energy efficiency and indoor environmental quality.*

Design elements that enhance durability should be incorporated into the design based on building's regional climatic conditions and site-specific exposure. For example, wide overhangs should be considered in areas of significant exposure to wetting, along with protective flashings that include pronounced drips to positively shed water from the outer surface of the enclosure.

The materials and components that are proposed for use in the building enclosure must be suitable for their intended application. For example, embedded metal components specified for use within a brick veneer cladding system must have the requisite durability for the application (i.e. 100 year service life). Wood components designed to support apartment balconies must be specified to be fabricated from material that is suitable for the frequently wet conditions that will be encountered in that application, as must all of the metal components used in the balcony structural connections.

The use of new materials or technologies that are untested is questionable from a durability perspective. This is not to say that new materials and technologies should not be used but rather that the vetting process should be rigorous. Will the materials perform in the intended exposure? An example of poor choice would be specifying the use of manufactured wood components at exterior framing conditions that are exposed to frequent wetting and UV radiation. Until a track record of durable performance under these exposures is established, the use of manufacturer wood components in this application should be questioned. Alternately, it may be possible to responsibly use new materials if their exposure in service can be sufficiently mitigated by design or detailing of associated materials and components.

Designs should account for the differential durability of the various materials and components utilized in the building enclosure. Depending on the design approach taken, the overall durability of an enclosure assembly may be limited by the durability of the shortest service life components within the assembly. To go back to the brick veneer example, if the prefinished galvanized steel flashings proposed for use within the veneer system have a expected service life of 20 years, that does not align well with the 100 year service life expectation of the brick itself. The detailing approach provided at many interface conditions will impact the serviceability of the enclosure. For example, where a balcony assembly meets an exterior wall assembly, accommodation must be made in the detailing for the repair or replacement of the balcony waterproofing membrane such that the building owner does not have to undertake a complete removal of the cladding system in that area to access the membrane. The cladding may have a service life of 50 years, whereas the membrane may have a service life of 10-20 years. Appropriate detailing at this condition will allow for the servicing of the membrane as necessary during the building's service life.

With the expanding outlook regarding the sustainability of our buildings, embodied energy has become an important consideration in material selection. Materials with low embodied energy are considered to be more aligned with a sustainable approach, however a low embodied energy material used in an inappropriate manner in a building enclosure design may lead to premature failure of the enclosure. Again, it is important to overlay a rigorous analysis during the material selection process to ensure that materials and components specified for the enclosure are appropriate for the application and exposure.

More broadly considered, embodied energy is utilized superbly through the reuse of existing buildings. Existing buildings with "good bones" that have stood the test of time are the very embodiment of a durable approach to the design and construction of buildings. But as existing buildings are rehabilitated for future use, owners and their design and construction teams must be careful that the methods and materials used to improve energy efficiency and indoor environmental quality do not create unintended durability problems with the buildings. Adding insulation, mitigating thermal bridges or increasing a building's airtightness inevitably creates major changes in the heat, air and moisture flows through the building's enclosure assemblies. Airtightening is also likely to have a significant impact on indoor air quality. It is critically important that the modifications implemented during the rehabilitation process must be assessed in detail with respect to hygrothermal performance so that the building does not suffer unintended consequences as a result of those modifications.

Quality Process during the Construction Phase

Moving from the design phase into actual construction of the project, how does the contractor approach quality management to achieve an effective implementation of the design? Assuming the project quality process has successfully produced a design that is technically sound and has been well documented in drawings and specifications, how does the contractor now build it right? At the most fundamental level, the effort to achieve quality in construction revolves around proactive planning, effective communication, and diligent execution.

Good planning is the foundation of all successful construction efforts. Proactive, effective planning not only produces optimal results with respect to quality, it is also the key to developing and maintaining the safest possible work environment on the construction site. The construction phase schedule is the key tool the contractor uses to plan and manage the work. Regarding the construction of the building enclosure, the proper sequencing of the work of individual trades must be considered in detail and then appropriately incorporated into the schedule. The importance of the schedule cannot be underestimated. The four "legs" of the stool that lead to project success are safety, quality, schedule and budget, but it is the schedule "leg" that essentially integrates the efforts – and plans – to achieve the other three.

Often, planning for construction can be analogous to planning for war. The best plans can be laid but due to the chaotic nature of the overall production system, problems are likely to occur along the way. Contingency plans must be utilized or, in some cases, completely new plans must be developed. How does one plan for a flood that shuts down the factory that produces the aluminum framing components of the project's glazing systems? How does one plan for material failure of a membrane product that has been used successfully on many previous projects? The contractor does not carry a contingency in the estimate for "material failure." There is no line item in the schedule for delayed material delivery. How does the contractor respond to these problems? Proverbially known as "getting blind-sided," it is critically important to recognize that problems will occur during construction and the contractor must be able to effectively manage such occurrences. Level heads and a commitment to working together with other team members to get the project back on track is important to identifying solutions to the problem at hand while maintaining an effective quality process during the later stages of the construction phase.

Planning and coordination of the work go hand in hand. The quality-oriented contractor understands that a significant degree of coordination must occur between the individual trades. The general contractor is fundamentally responsible for the coordination between all the trades associated with construction of the building enclosure. For example, the dimensional coordination of a modular brick veneer cladding must be tightly coordinated with the layout of window openings in the wall framing system, and both the cladding and the window dimensions must be coordinated with the configurations and dimensions of sheet metal trim elements that have been designed to transition between the cladding and the windows. Slab edges at a concrete frame building must be tightly coordinated with the cladding system support elements such as the steel ledger angles that are utilized at brick veneer, and with fenestration system components that bypass the slab edge. A lack of adequate layout and control at structural/framing systems can cause serious problems with enclosure system components that are installed later during the construction sequence, leading to substantial (and costly) rework and potentially compromised installations. A proactive approach to dimensional coordination by the general contractor typically pays off in reduced rework and enhanced quality during the enclosure system installation.

Another important aspect of coordination is verification of compatibility between materials proposed for use by the different trades. For example, the compatibility of sealants proposed by the sealant subcontractor must be verified with respect to the wall membrane product (and accessories) proposed by the water-resistive barrier/air barrier contractor and the balcony waterproofing membrane product (and accessories) proposed by the waterproofing subcontractor. Because there are a large number of materials that interface with one another on any given project, the verification process can be a significant effort – contacting manufacturers to verify compatibility, requesting documentation of such compatibility, and pre-construction testing of both adhesive and chemical compatibility between materials all must be conducted. Because chemical reactions between differing materials may take time to surface, this process must be initiated well in advance of when the materials are to be installed so that compatibility can be confirmed or other materials investigated if the testing process reveals compatibility problems.

The submittal process should be used to verify compliance with project specifications which are themselves the result of a collaborative preconstruction effort and represent, in part, the project quality goals. Materials and systems selected to provide the level of quality and durability desired cannot be substituted by alternative products. Substitutions, often proposed due to subcontractor familiarity with certain products, or to reduce project costs, may have unforeseen results, as the overall quality of the project may be reduced by substituting an inferior product which is a critical component of the building envelope (windows, roofing, sealants, WRB for example). Furthermore, design risk and liability may be transferred to the subcontractor and to the general contractor by substituting different products. The general contractor and subcontractor then essentially own the liability for that product by submitting the new product as equal to the quality requirements described by the specification.

The submittal process (inclusive of shop drawings) is the primary vehicle for carrying out the many levels of coordination needed during the construction phase. Submittal requirements contained in the specification describe more than just the products to be used: they identify warranty, installation and quality control requirements. The submittal review process should be used to verify that the subcontractor understands and has acknowledged responsibility for meeting all of these requirements. Shop drawing review must similarly be used to verify that the contractor understands the specific conditions and details for the project at hand. It is not uncommon for subcontractors to submit “typical” details – or details that describe common construction practices; however, these are not the project-specific details that may be required to develop a fully understanding and coordination of the work for the project at hand. The shop drawing review process is instrumental in verifying compliance with job-specific enclosure detailing requirements and manufacturer’s installation requirements.

While a thorough and collaborative preconstruction effort will result in a higher quality of both the systems selected and the enclosure detailing provided, there is always additional coordination that is needed, and typically there are lingering design issues that must be resolved. Very early during the construction phase, WCC organizes a Building Enclosure Coordination (BEC) meeting to review, coordinate and verify issues related to the building enclosure. This meeting also serves as a forum for expediting the resolution of unresolved design issues, related to both the details and specifications. The BEC meeting is a vital tool for improving the submittal process and for elevating the attention to building enclosure quality amongst all members of the construction team.

Attendance by construction team key personnel at the BEC meeting is critical to its success. As the meeting is focused around planning, coordination, and communication, absence of key members can lead to mis-communication about detail coordination, scope interface between different subcontractors, and the project-specific quality goals. Furthermore, documentation of items resolved during the meeting or still requiring resolution must be broadly communicated to ensure that scope changes, interface between trades, quality requirements and detail revisions are understood by all trades involved in the enclosure construction. Design issues requiring confirmation or additional follow-up by the design team are clearly identified and a plan and schedule is established for their resolution.

Upon resolution of major design and detailing issues, and as closely following the BEC meeting as possible, a building enclosure mockup should be constructed to demonstrate typical construction methodology, to serve as a tool to verify the acceptance of the enclosure design and to serve as the quality standard for the project. While mockups constructed on the actual building frame can serve this purpose, this approach can lead to the discovery of key tolerance and detailing issues too far down the road. It is preferable to construct a free-standing mockup composed of as many typical details as possible, including representative fenestration products and their interface with adjacent cladding components, WRB, air barrier, flashings and sealants. Much like the BEC meeting, involvement of key individuals is essential. The installing foreman for each enclosure trade ideally is assigned to work on the mockup and thus can carry to the project what was learned in terms of sequence between trades, product installation requirements, adherence to project-specific detailing and specific quality issues associated with individual products and overall assemblies.

Because the mockup is intended to represent the actual project, the materials specified and approved for use on the project must be used. An assumption is often made that since this is not the final construction, some liberty can be taken with the materials used on the mockup. This could not be further from the truth. Installation instructions for specific products will influence detail sequencing and substitution of different components at the mockup will result in modified details. Materials that are different from the specified/approved products may also have different performance characteristics and may result in unforeseen interface between adjacent products (see discussion on chemical and adhesive compatibility).

The mockup must be constructed well in advance of enclosure construction to allow proper sequencing and review of constituent components by the contractor, architect, owner and envelope consultant. This also allows enough time to address compatibility, adhesion or sequencing issues that may arise while constructing the mockup. It further allows for testing of assemblies for airtightness, testing of fenestration product interface with adjacent assemblies for airtightness and watertightness, and testing for adhesion of sealants to adjacent substrates. Changes to the design as a result of the mockup process need to be communicated clearly to the project team and subcontractors, and the design documents modified to address those revisions.

Although for many projects testing of enclosure components on the mockup will suffice, many projects are of sufficient size that additional testing is required. For instance, a project with over 1,800 windows is not well-served by a single test on a mockup for water and air infiltration. The project benefits greatly from testing of a representative sample of installed product. Ongoing testing verifies the quality of the product being received from the manufacturer as well as the quality of the installation on site and integration with adjacent components. If subcontractors know that additional random testing will be required, greater attention to detail and to the quality of the installation will result. The same is true for sealants and other enclosure components. The mockup serves to illustrate how the installation should look, to confirm adhesive and chemical compatibility, but with miles of sealant to be installed, verification of the installation with project requirements and manufacturer's installation requirements necessitates additional testing – and to keep installers focused on quality. Communicating the testing regimen on the project to subcontractors informs them that, at any time, any installation will be tested for conformance. In essence, the subcontractor is informed that they are charged with delivering quality, and that there exists a trust that they will perform according to project requirements, but that quality will be verified through testing. This helps to ensure that subcontractors bring their best to the table.

Even with diligent preconstruction constructability reviews, excellent communication about and discussion of detail, materials and quality requirements, and a well-coordinated mockup process, actual execution of the work presents many opportunities for the project quality to be diminished. Continuous verification that the design is being executed according to the project documents and manufacturer's requirements is essential, as subcontractor crews can change during the course of construction, key personnel may not be available and material quality issues can arise. In addition, weather can affect installation quality and the installer's focus can vary greatly during the course of a project (e.g. 2pm on a Friday occurs once a week). The consistent supervision of enclosure construction by qualified personnel intimately familiar with the project documents, goals and strategic decisions cannot be overlooked.

Because the construction of the enclosure occurs for some duration and because neither the architect, envelope consultant, nor the superintendent can focus their attention on the enclosure construction full-time, additional trained resources are needed. The general contractor should assign specific personnel to the task of quality control review of the work executed by the various trades involved in the enclosure construction. These personnel should be trained in building enclosure design and construction principles. They essentially serve as the eyes and ears of the project superintendent, with a specific focus on enclosure quality control. These personnel need to be familiar with the project through review of the plans, specifications, submittals and RFIs as well as participation in the BEC meeting and mockup processes. Their primary focus on site is to review and observe the construction of the enclosure, document via photographs and supporting notes the quality of the installation, and assist in the removal and re-installation of sub-par quality work in concert with the project superintendent and subcontractor's foreman.

It is often said (and was stated earlier in the paper) that successful project execution relies on four legs of a stool: safety, quality, schedule and budget. The use of the general contractor's own crews to execute specific scopes of building enclosure work can put the contractor in the position to use all four legs to fullest advantage to deliver a successful project. Safe work habits are essential. They create a safe work environment for all members of the construction team, an attitude about safety throughout the job site, and the ability to focus on executing the project design precisely because safety is assured. The loss of well-trained crews due to unsafe practices and the accidents that result may put a less-qualified crew in place to execute the work. Quality can be closely controlled by proper selection of both foremen and crew members, by training for quality, by achieving buy-in that quality is of utmost importance throughout the company, and by rewarding excellent performance. Schedule can be controlled and managed by having greater control over available qualified crew members and by continual review of project milestones within the crew and with the project superintendent. The budget can be managed similarly, and because a self-performed trade group can share the details of their costs, the team can work collaboratively to manage deviations from planned budgets. Additionally, self-performed work should be chosen based on the risk inherent in specific scopes of work. If there are available subcontractors who can execute safely, according to budget and schedule at a high level of quality, it would be imprudent to assemble a self-performed team to perform this work. The general contractor's own crews should be assembled to construct components of the enclosure (or the entire enclosure) when no other subcontractor can execute compliantly with the project's budget, schedule and quality requirements, and the safety and quality requirements of the general contractor.

Turning the building over to the owner is typically associated with delivering keys, providing instructions on mechanical, electrical and plumbing systems operation, and supplying the owner with operations and maintenance manuals. But one cannot make assumptions that an owner (or their tenants) understands fully how the enclosure works – something as simple as the operation of a window can influence the energy performance and durability of the building enclosure. Failure to operate the locking mechanism correctly on a window can result in long-term damage to the window's ability to resist water and air infiltration. Therefore, additional training on operable enclosure components is necessary to ensure that the high performance enclosure continues to operate according to the project goals.

Developing Quality Management Knowledge During the Post-Construction Period

The process of continual improvement is an essential characteristic of a well-designed quality program. Immediately following construction, there is great value in gleaning from the project team input and feedback on the constructability of enclosure components. Materials and systems which suggest fitness and promise during the design stage should be reviewed and may need to be re-considered based on feedback regarding the sequencing, workability and functionality of those components. Similarly, subcontractors should be evaluated for how well they deliver on the four legs of the stool of success: safety, schedule, quality and budget. The subcontractor that can provide a balanced package of these criteria is a subcontractor that the general contractor will want to develop and maintain good relations with. The subcontractor who performs poorly must be evaluated for their fitness to contribute on future projects.

After the building has been turned over to the owner, there is a wealth of information to be learned that informs the quality management team and can contribute significantly to future constructability reviews and the success of future projects. One year warranty reviews are typically conducted to address issues with building performance discovered during the first year of its use. The information gleaned from the building managers and occupants about basic building functioning, comfort and operability of systems is an invaluable component of the feedback loop that can positively influence system and enclosure design on future projects.

However, information and analysis gathered but not shared is a value only to the select few to whom the feedback has been delivered. For that reason, sharing the lessons learned regarding materials, systems, details and subcontractors with the entire ranks of the construction firm allows the whole organization to improve as a result of the lessons learned on individual projects.

The warranty phase is an important aspect of project delivery and evaluation. It is in this phase that the owner evaluates the results of his or her prior decisions as well as evaluating the quality of the contractor's execution. A positive project experience, including a positive warranty experience, creates loyal clients – repeat clients who advocate for the contractor who excels in all phases of project delivery. For the contractor, the warranty phase provides an opportunity to manage risks, to evaluate the performance of the project design and construction in order improve their understanding of how to avoid warranty calls on future projects. The performance feedback becomes part of the knowledge base that informs constructability reviews on subsequent projects, helping to ensure that problems are not repeated.

It is essential that the owner have a primary point of contact should warranty issues arise. This gives the owner some comfort in knowing that they have a dedicated resource who will respond to warranty issues in a timely manner. At WCC, the project manager is assigned responsibility for the project from inception through the life of the project (including post-occupancy), serving as the client's first point of contact to assist in assessing and managing warranty issues. This ensures that client concerns are addressed immediately and that the project manager has the opportunity to evaluate the risks inherent in warranty claims. Beyond the one year warranty, the project manager can determine whether there is greater value in addressing the issue and assuming the costs for repair versus engaging subcontractors and/or product manufacturers in the evaluation and repair of warranty issues. It is often less expensive and less time-consuming to address the issue immediately without assigning responsibility and cost for the problem to others; and one cannot dismiss the value in solving problems for a client, even if they are not of the contractor's making.

Managing the warranty process is not a passive activity. Rather, it involves proactive evaluation of the project quality one year after turning over the building to the owner as well as providing regular reminders to the owner about maintenance of building components to ensure durability. One year after construction, the building must be evaluated to determine the condition of materials and components both interior and exterior, including sealants, traffic coatings, roofing materials, gypsum wallboard and other finishes. It is quite common that wood framed buildings exhibit a considerable number of drywall cracks and nail pops due to frame shrinkage. The issues that arise during the one year warranty inspection must be evaluated and then addressed to the satisfaction of the owner. As a helpful service, the contractor can provide annual or seasonal maintenance reminders to the owner, identifying typical and specific maintenance requirements at the building. These reminders should include clearing of gutters, downspouts and roof drains, inspection of sealants, paints, coatings and other enclosure components of a limited life span to determine their condition and to determine replacement schedules. Helpful reminders such as this are an important step in proactively evaluating enclosure components to avoid major damage due to lack of maintenance.

Failure – A Tool for Learning

Over the course of a building's construction phase – and certainly during a building's service life – failures are likely to be encountered. Failure is an excellent teacher. In developing the battery, Thomas Edison went through thousands of trials to get it right. Noted Edison: "I haven't failed. I've found 10,000 ways that won't work." Failure can only be avoided by not trying, and not trying in the construction industry is not an option. In the climate where the development of high performance enclosures is an industry wide *goal, failure is inevitable. Each building is a prototype, a collection of details and interfaces that may never have been tested before. So it is no surprise that failure occurs with some regularity. Determining the failure mechanism can often be an exasperating search for answers, but for simplicity's sake can be attributed to one of three sources: material/product failure, design failure, or execution failure. What ultimately matters is how we learn from failures.*

Material (or product) failures are to a large extent beyond the general contractor's control. While it is infrequent, the risk of material failure can be further minimized by choosing products with a demonstrated service history. But in pursuing the goal of a high performance enclosure, new products or systems may need to be considered. Proper risk management would suggest that products from a well-established company with a good history of product performance is a better risk than a new product from a start-up company. However, failure of established products from reputable companies will and do occur. The value in failure is in how it changes what we do. If a product fails due to improper handling of the product, procedures for handling that type of material should become standard practice for the contractor. If improper inspection of delivered product results in failure, procedures for inspecting the quality of delivered product should become standard practice for the contractor. If the product does not provide the service life promised by the manufacturer, the contractor has an obligation to inform the owners and design teams with whom they partner of the risks associated with that product. This feedback loop is especially important as material/product failures are often dealt with by the contractor without design team input after occupancy of the building. It is important that the lessons of material failure are learned by all parties.

Design failures occur at the material, assembly and detail level. A material improperly chosen to perform a function for which it is not designed may result in failure. It is incumbent on both the design team and the construction team to evaluate product selection based on the material's fitness for use. Assemblies can produce failure in their inability to provide for the five critical barriers – or by a failure to provide adequate redundancy in the design of the critical barriers. An example is a wood framed assembly that includes Class I vapor barriers on both the interior and exterior sides of the assembly. This can lead to moisture entrapment between two layers of vapor impermeable material, resulting in damage to moisture intolerant materials located within the assembly. One only need see the result of this failure once to learn the lesson. It is incumbent on the design team and construction team to evaluate the basic enclosure assemblies of the building to verify that they adhere to fundamentals of basic building science. Detail can produce failure if materials within the detail are used incorrectly, if compatibility issues between materials occur or if materials are sequenced poorly (e.g. a design that results in reverse laps of the materials/components that constitute the water-resistive barrier). It is incumbent on the design and construction teams to verify that materials are compatible with one another and are being used correctly – according to the manufacturer's published instructions and for the use for which they are intended.

The opportunities for execution failures are many. Although a detail may only be drawn once, it may be executed dozens of times on a project. Each execution is an opportunity for success or failure. As mentioned earlier, the composition of installation crews can change over the course of a project, meaning that proper installation sequence and requirements may be lost with such changes. Some subcontractors are simply better suited to execute the work and the competitive bid process means that the best contractor may not get the job. And 2pm on Friday happens every week. It is incumbent on the general contractor to choose wisely the subcontractors that will execute the work, weighing the risk of a low bid by an unknown subcontractor against a higher bid from a contractor of known quality. It is important for the general contractor to clearly communicate the project quality goals, to coordinate the installation of materials, and to provide sufficient quality control to verify the installation of details in accordance with the project documents, applicable industry standards and manufacturer's installation instructions. Finally, it is paramount that the general contractor enforce quality standards by rejecting work that does not meet the requirements of either the project or the manufacturer.

Failure will happen, no matter how diligent the contractor is in controlling quality. The most important thing to do with failure is to learn from it. Failure must be studied to determine the cause. The cause must be understood to refrain from repeating it, and the lesson learned from failure must be widely communicated to the design and construction teams to ensure that all understand the failure mode and the opportunity to improve the next time around.

Conclusion - The Value Proposition of Quality

The implementation of quality management by construction firms presents a compelling value proposition. Certainly there are costs associated with providing an increased level of focus on quality process during the design and construction phases, and then on into the post-construction/warranty phase of projects. It is likely necessary to create specialty positions within the firm to manage quality to an elevated degree. It is possible that people already on staff can be assigned to these positions, or it may be necessary to acquire the resources from outside the firm. Additionally – for contractors – there are risks associated with taking a proactive position regarding design issues and concerns during the design phase. That said, it is highly likely that the benefits of a proactive approach to quality management will include a reduced risk of failure of systems, components, and materials, and accordingly a reduction in warranty costs. There is a possibility that insurance costs can be reduced as well, especially over a period of time when the benefits of reduced call-backs, warranty issues and insurance claims can be documented. As the discipline and planning that go into producing a quality end product are very much connected to the efforts that go into providing a safe work environment and managing the work diligently in accordance with a set budget, the time and money spent on planning well and then executing the work according to that plan, are well spent.

The reputation for producing quality, durable work is a hallmark of many construction firms. The investment in quality management to produce those results provides substantive payback in terms of maintaining or even enhancing the contractor's reputation over time. A reputation for delivering quality buildings on a consistent basis can be greatly beneficial to obtaining future work in a highly competitive construction marketplace.

References

Bertelsen, S. 2003. Complexity – Construction in a new perspective. Proceedings of the 11th International Conference on Lean Construction. IGLC.

Desjarlais, A.O., A. Karagiozis, M. Aoki-Kramer. 2001. Wall moisture problems in Seattle. Proceedings of the Buildings VIII Conference. ASHRAE.

Lawton, M. 1999. Vancouver's rotting condominium problem – How did we get into this mess? Journal of Thermal Envelope and Building Science, Vol. 22.

Lawton, M. 2010. Troubleshooting in design of construction details, walls. Proceedings of the Building Envelope Science and Technology (BEST2) Conference.

Lemieux, D., P. Totten. 2004. The importance of building envelope commissioning for sustainable structures. Proceedings of the Buildings IX Conference. ASHRAE.

Morrison Hershfield Limited. 1996. Survey of building envelope failures in the coastal climate of British Columbia. Report commissioned by Canadian Mortgage and Housing Corporation (CMHC).

RDH Building Engineering Limited. 2011. Building enclosure design guide – Wood-frame multi-unit residential buildings. Guide commissioned by British Columbia Homeowner Protection Office (HPO).