

Towards Airtightness – The Contractor’s Role in Designing and Constructing the Air Barrier System

Michael P. Steffen¹

ABSTRACT

The design and construction of a continuous air barrier system at the building enclosure is fundamental to the creation of high performance buildings – buildings that are durable and energy efficient while providing a comfortable and healthy indoor environment for living and working. However, it is fair to say that implementing air barrier systems is “easier said than done.” Cost effectiveness, communication of design intent, constructability, coordination of trades, and material compatibility are just a few of the issues that come into play on projects that attempt to incorporate whole building air barrier systems.

This paper will discuss the contractor’s role in the commissioning process that is intended to deliver effective air barrier systems on large multi-unit residential buildings in the Pacific Northwest.² The paper will be presented from one general contractor’s perspective. Among the specific topics discussed are: 1) understanding the design of the air barrier from materials to assembly to system, 2) the importance – and challenges – of coordinating the design team and construction team efforts, 3) the need for clearly developed design detailing and specifications to document the air barrier requirements, and 4) the testing process – planning for it and knowing what to expect.

Case studies of commissioning process implementation on several large multi-unit residential projects will be used to illustrate the ideas and concepts discussed in the paper including a review of newly implemented code requirements for air barriers and testing performance.

¹ Michael P. Steffen, AIA, LEED AP, Vice President / General Manager, Walsh Construction Co., Portland, OR

² The term “Contractor” as used in this paper refers to the construction management or general contracting firm which contracts with an Owner for construction of a building.

Introduction

The design and construction of a continuous air barrier system at the building enclosure is fundamental to the creation of high performance buildings – buildings that are durable and energy efficient while providing a comfortable and healthy indoor environment for living and working. Numerous studies have demonstrated that infiltration – and exfiltration – related heat transfer through building enclosures accounts for 20% - 50% of the heating and cooling loads in buildings (Emmerich et al. 2005).³ However, it is fair to say that implementing air barrier systems is “easier said than done.” Cost effectiveness, communication of design intent, constructability, coordination of trades, and material compatibility are just a few of the issues that come into play on projects that attempt to incorporate whole building air barrier systems.

As a general contracting firm, Walsh Construction Co. (WCC) began in 1999 to implement a quality process initially intended to reduce the potential for water leakage problems at our projects. After a short time, it became clear to us that air leakage control had a direct relationship to water leakage control, given that air pressure differential is one of the key driving forces behind water infiltration. As we began to work together with design teams to develop various rainscreen systems for frame wall assemblies, we came to understand the importance of including a layer of airtightness in the wall assembly and found that, ideally, that layer was located at the outer face of the exterior sheathing (i.e. the inner boundary of the rainscreen drainage/ventilation cavity). Through field testing experiences, the importance of airtightness in reducing water leakage through and around glazing assemblies also became clear. We soon learned that connecting the layer of airtightness of the wall to the layer of airtightness at penetrating components such as windows, doors, and vents was also important. The primary intent of the measures was to reduce air leakage so that we could reduce the risks of water leakage.

As our quality process has developed over time, it has become clear that airtightness provides other benefits: eliminating drafts through the enclosure improves comfort for building occupants; controlling infiltration and exfiltration through insulated enclosure assemblies reduces the potential for condensation within the concealed areas of those assemblies. With the burgeoning interest in energy efficiency in recent years, airtightness is now clearly understood to reduce heat transfer through the enclosure. HVAC systems can be designed with more precision – and typically can be downsized – when a high degree of airtightness is provided. Actual energy use data recorded on several recent projects that incorporated air barrier systems has confirmed that the performance benefits of airtightness are achievable and significant.

Given the many benefits associated with airtightness, WCC has advocated for the inclusion of air barrier systems in the buildings with which we have been involved. At the same time, we – and our project partners – have struggled at times with the implementation of these systems in the design and construction of building enclosures. We have learned a few things along the way, particularly regarding the various players’ roles in the process. This paper will outline some of those lessons and provide a few illustrative examples of implementation of air barrier systems on large multi-unit residential and commercial buildings in the Pacific Northwest.

³ See also the Air Barrier Management Fact Sheet, published by the Northwest Energy Efficiency Council, July 2011.

The Contractor's Role in Design of the Air Barrier System

The contractor can play a productive role in the design process, providing cost and constructability input that may have an impact on assembly selection, material/product selection, detailing, etc. The contractor's knowledge of different air barrier approaches and how the various approaches are better suited to certain building types can be highly valuable as the design decision making is underway. The contractor's budget input early during the design phase can have significant influence on the approach that is chosen, as well as material/product selection. For this reason, it is important that the contractor's cost input is based on reliable information, ideally founded on previous experience with various approaches and materials.

To achieve a continuous and effective air barrier system, the design must be well-conceived and then fully and clearly documented. The design must provide for air barrier continuity not only in the field areas of the enclosure assemblies, but also at the interface conditions where walls and roofs intersect or where windows, doors or other items penetrate those assemblies. Many architectural firms are well served by including an enclosure consultant or commissioning agent on the design team to assist with the conceptualization and detailed design of the air barrier system. The enclosure drawings developed by the design team must clearly indicate the materials/products/components that are serving as the primary air barrier material at each enclosure assembly. Transition components, such as flashings or sealants, must be clearly indicated as well. Some design firms have begun to show these transitions on a separate drawing sheet that clearly indicates the requirements at the most typical enclosure details; this is an excellent method to foster clear, unambiguous communication with members of the construction team. However, there is a need to indicate requirements at the atypical detail conditions as well. These often are the details where it can be most difficult to provide for air barrier continuity.

The enclosure and air barrier system design process typically has a logical flow: 1) selection of enclosure assemblies, 2) selection of air barrier system approach, 3) selection of air barrier materials, and 4) detailing of the air barrier system. To begin, the design team will consider options and then select assembly designs for the exterior walls and roofs. Heat, air and moisture transfer mechanisms are all considered together when deciding upon the assembly designs that are likely to achieve the optimal balance of hygrothermal performance versus cost.

Selection of Air Barrier Approach

A wide variety of approaches can be utilized to create the air barrier system for a given building. The thermal barrier approach that is implicit to an enclosure assembly design will typically dictate what air barrier system approaches should then be considered. A concrete frame building with light gauge steel framed exterior walls, for example, will likely utilize an exterior continuous insulation approach for the thermal barrier. This approach makes a great deal of sense since it will substantially mitigate the thermal bridging effects that would otherwise occur if the exterior walls utilized a cavity insulation approach (e.g. insulation within the light gauge steel framing cavities). In the case of the assembly with exterior continuous insulation, an exterior sheathing membrane approach to the air barrier at the exterior wall assemblies is an excellent choice. The membrane can be applied over the exterior sheathing at the frame walls and over

the concrete slab edges that interrupt the frame wall expanses. If the membrane is waterproof, it will also serve as a highly effective water-resistive barrier. This approach to the air barrier is highly constructable and relatively cost-effective. An exterior sheathing approach could also be considered. In this case, the sheathing itself would serve as the primary air barrier material of the exterior wall assembly and all joints and fastener penetrations of the sheathing would be sealed. The sheathing would also serve as the primary water-resistive barrier material of the exterior wall assembly. This assembly with its respective air barrier and water-resistive barrier approaches may be well-suited to a building with low exposure to wind-driven rain but would not be a good choice for a building with moderate to high exposure to wind-driven rain.

Selection of Primary Air Barrier Material

Once the air barrier approach has been determined for the exterior wall assembly, the design team will need to select the primary air barrier material for that assembly. Material properties such as air permeance, vapor permeance, water resistance, tensile strength and puncture resistance may all need to be considered to determine the best material to utilize with the given air barrier approach. The team must determine if the air barrier material specification should be open or closed. The team will usually benefit from choosing a specific product and developing the design (both drawings and specifications) around that product. Within this process, manufacturers' technical representatives can often be relied on to provide detailed guidance on the project-specific use of their product. However, it may be unwise to specify only a single product as acceptable for the project, as this is likely to increase costs by limiting competition amongst potential suppliers and installers. A judicious middle ground is to specify a "basis of design" product on which the specification and detailing can be premised, and then to also specify a minimum of two other products/manufacturers that are highly similar in material properties and are acceptable for use with the given design. This approach will usually entice the helpful involvement of a manufacturer in the project-specific design process while still allowing for competitive procurement of the materials.

Similar considerations apply to the selection of air barrier approach and primary material selection at the roof assembly. In general, buildings with low slope roofing are well served by the roof membrane air barrier approach, utilizing the roof membrane itself as the primary air barrier material at the roof assembly. This assumes a conventional roof membrane assembly or protected roof membrane assembly, where the assembly is not vented to the exterior for moisture control purposes and the insulation is located above the structural roof deck. At buildings with steep slope roofing, a vented roof framing cavity – or vented attic – is typically required for moisture control purposes. At these roof assemblies, an airtight drywall approach is typically constructable and cost-effective. This approach utilizes the drywall applied to the interior side of the roof framing as the primary air barrier material.

By bringing ancillary issues into consideration, the contractor's viewpoint can be highly valuable during the material/product selection process. Is there a track record with this material/product? Are there approved applicators in the area where the building will be constructed? Is temporary protection of the enclosure necessary to allow the material/product to be installed properly? Can the material be applied to damp substrates? If a liquid-applied product is specified at the

exterior wall, how thickly must it be applied, and can that be achieved in one, two, or three passes over the wall? If a single-ply membrane product is specified at the roof, is a fully-adhered installation option provided? These are just a few examples of the multitude of questions that a contractor will bring to the table that can influence material/product selection.

Selection of Air Barrier Approach and Material – A Case Study

The variety of considerations that apply to the selection of approach and material is illustrated by the example of a large four-story wood frame multi-unit residential building situated on a highly exposed site in southwest Washington, directly facing the Pacific Ocean. The initial design for this project called for an exterior insulated exterior wall assembly, with an exterior sheathing membrane approach utilizing a vapor impermeable, waterproof, and airtight self-adhering rubberized asphalt membrane applied over the sheathing of the wood frame walls. The choice of an exterior insulation approach at the exterior wall assembly was not driven by thermal performance considerations, since the wood frame structure did not present major problems in terms of thermal conductivity; rather, the exterior insulation approach was chosen to allow the use of the self-adhering rubberized asphalt membrane material.

Although the air barrier approach and material proposed in this initial design were unquestionably appropriate to ensure a high degree of water penetration control and air leakage control on this highly exposed building, the contractor questioned whether the use of the impermeable self-adhering membrane material on a large wood frame building could cause problems with the building dryout process during construction, especially given that a significant portion of the framing was scheduled to occur during the 10 month wet season. Additionally, it was assumed that some degree of temporary protection would be required to provide a quality installation of the proposed air material over the exterior walls, given the extensive wet season at the building site. Once the schedule impacts of an extended and more complex dryout process were factored in, as well as the cost impacts of temporary protection measures, together with the higher cost associated with an exterior insulated wall assembly as compared to a wall with insulation within the wall framing cavities, it was determined by the team that the overall assembly design was of questionable cost-effectiveness.

The team then considered other assembly designs utilizing different air barrier approaches and materials. At this point in the design process it was agreed that the assembly design for the project would include fiberglass batt insulation installed within the wall framing cavities – with no exterior insulation – and that fiber-cement siding would serve as the cladding, installed as a rainscreen system over the exterior wall. The contractor questioned the design team if an exterior sheathing membrane air barrier approach utilizing a vapor permeable, water resistant (but not waterproof), and airtight, mechanically fastened spun-bonded polyolefin sheet membrane would be acceptable for the application. With a track record of successful performance on many large wood buildings throughout the Pacific Northwest, the contractor felt it prudent that this approach and material should be considered. From an installation standpoint, this air barrier material can be applied over the walls with relative ease and speed, and temporary protection is not required for proper installation. However, the design team determined this type of air barrier material would not likely provide adequate water resistance

given that it would be serving as the water resistive barrier at the wall as well. The design team considered the exposure of this oceanfront site too high to accept that approach.

The design team instead proposed an exterior sheathing membrane approach utilizing a vapor permeable and waterproof liquid-applied membrane as the primary air barrier material – a material relatively new to the construction market and with little track record of use and performance in the Pacific Northwest. A product was proposed for specification based on positive experiences some members of the design team had with the manufacturer. The contractor had no prior experience with a large-scale application of liquid-applied membrane material on exterior walls, so a degree of skepticism was voiced. The contractor was also concerned about the relative lack of track record with this material – and the specific product – and this concern was shared by the entire team.

To improve understanding of the membrane product, the contractor invited the manufacturer to its offices to perform an installation demonstration. A large exterior wall mockup was constructed, including a typical window opening and several other typical penetrations such as exhaust vents and steel support plates (i.e. knife plates). A typical through-wall flashing and floor line joint condition were included as well. In addition to the contractor's personnel, the demonstration was observed by members of the design team and others from the local design community with an interest in learning more about liquid-applied membranes recently introduced to the market. The manufacturer's personnel detailed the window openings, penetrations and corners of the mockup first and then proceeded to install the membrane system over the field areas of the wall mockup (Fig. 1). Several issues became apparent during and after the demonstration. The first issue that was clearly apparent was that the membrane would require more than one pass over the wall to achieve the required minimum thickness. It was clear that there could be a significant constructability issue with ensuring proper material thickness during the installation. The material was spray-applied to the mockup. Build-up and run-off of material, and protection of adjacent work from membrane overspray, were all clearly significant issues.

Ten days after the demonstration, design team members visited the mockup again to make observations and to conduct peel adhesion tests. The liquid-applied membrane did not adhere well to the self-adhering membrane that had been used to detail around the window opening and the penetrations (Fig. 2). Subsequent review of the manufacturer's product literature indicated that the demonstration installation was not in compliance with the manufacturer's own published guidelines. Polyethylene-faced self-adhering membrane had been used at the mockup, whereas the installation instructions stated that foil-faced self-adhering membrane should be used with this specific liquid-applied membrane. On one hand, this was a simple mix-up on the part of the manufacturer's personnel; on the other hand, it demonstrated the relative lack of established installation methodology and track record, and reinforced a shortfall of confidence with this new material/product. The contractor ultimately lacked confidence to move forward with this product on a project where risks of water penetration were high.

To move forward, the contractor worked with the design team to identify other products that might meet the performance requirements for the air barrier material. Two other products were identified and the manufacturers were invited to conduct their own product installation

demonstrations on additional mockups at the contractor's offices. One of the demonstrations created the same concerns raised by the first manufacturer/product. The demonstration by the third manufacturer was conducted in a highly professional manner and appeared to be executed with relative ease compared to the other manufacturers (Fig. 3). The outcome of this demonstration instilled a measure of confidence in both the design and construction team members.



Figure 1. Installation demonstration by basis of design liquid-applied membrane manufacturer.



Figure 2. View of mockup after adhesion testing conducted 10 days after demonstration.



Figure 3. Installation demonstration by alternate liquid-applied membrane manufacturer.

The product investigation process – facilitated by the contractor in this case – addressed several important issues. First, the project team obtained a better understanding of the liquid-applied materials that are relatively new to the construction market. Second, potential problems with the liquid-applied material installation were identified so they could be adequately considered in the development of schedule and pricing for the project-specific application. Third, product options were identified that increased confidence in the use of liquid-applied membrane materials while also maintaining price competitiveness to the procurement of the air barrier materials. The design team agreed to add the third manufacturer and their liquid-applied membrane product to the specification as an approved alternate. The product that was originally proposed remained as the basis of design product in the project specifications.

Constructability of the Air Barrier System

To achieve a high level of performance, constructability considerations should be emphasized as the design of the building – and the air barrier system – are developed. The form and massing of the building plays a major role in the relative constructability of the air barrier. A greater degree of articulation in the building form tends to make for more complicated air barrier systems, typically resulting in higher costs, as well as increased chances of failure in the design or construction of the system. An exterior wall enclosure that moves in and out a great deal in plan or in section is likely to be challenging to design successfully from an airtightness standpoint. This is not to say the challenge cannot be met, but the design and construction team resources required to meet the challenge will likely be greater. A more highly configured design is essentially more challenging. Challenge is sometimes a good thing, sometimes it is not. For projects with limited budgets, or for projects where design or construction team members are less skilled at air barrier design or construction, the challenges presented by a highly configured design may be difficult to overcome. A good rule of thumb is to “keep it simple” to the extent possible for any given design, and for the details associated with that design. Simplicity in detailing should be recognized for its elegance of thought, its economy, and the likelihood that performance will more readily be achieved with a simple detail rather than a complex one.

Personal experience in the industry suggests that it is nearly always possible to keep the detailing simple if a reasonable degree of discipline is exercised during the design process. One key consideration is the alignment of components at the plane of airtightness within the exterior wall assembly. Ideally, the materials and components that make up the air barrier assembly and system are aligned to simplify the planar configuration of the air barrier to the maximum extent possible. For example, the outer surface of frame wall assemblies, such as gypsum sheathing on light gauge steel framed infill walls, should align with the outside face of primary structural elements such as concrete slab edges at the building floor lines. The same logic would apply where the wall system intersects the foundation at the bottom of the building and where the wall intersects the roof at the top of the building.

The interface of glazing systems with exterior wall assemblies is another key consideration. Windows are often placed within the wall assembly in a location based only on architectural considerations such as the visual depth, or “reveal,” that is created between the glazing and the adjacent cladding. The placement of glazing systems relative to the adjacent wall system can

be designed in a manner that allows for simple and elegant detailing or conversely, the relationship between the glazing and wall can be designed such that complex – and costly – detailing is required to achieve air barrier continuity. With excessive complexity comes the risk of failure in the design of the details or in the execution of the details during the construction phase.

The roof-to-wall interface can be particularly difficult to design and construct for airtightness. The use of vented roof assemblies where the insulation is placed to the interior side of the structural roof deck inherently creates issues with continuity of the air barrier at the roof-to-wall interface conditions. Air barrier detailing at these conditions typically must transition the plane of airtightness from the exterior side of the structure at the wall to the interior side of the structure at the roof. The detailing required for this transition is typically complex and difficult to construct. It also is difficult to visually inspect for quality control.

The constructability of various air barrier approaches is impacted significantly by the placement of the air barrier within the enclosure assembly. Air barriers that are placed on the exterior side of the exterior wall structure, for example, tend to be much more constructable than barriers placed at the interior side of the structure. This is primarily due to the many transitions inherent to an interior side air barrier approach, especially when applied at buildings of light frame construction. The exterior wall is intersected in plan by interior walls and is intersected by floors in section. Each of these intersections causes discontinuities in the primary air barrier material. Transition detailing must be developed to provide for air barrier continuity. This detailing can become complex, often involving numerous materials and components such as sheet membranes, sealants and/or gaskets that must be installed by a number of different trades. The more detailing complexity required, the more materials required, the more trades required – all raise the possibility for missteps along the way during design or installation.

Placement of the air barrier to the exterior side of the structure eliminates many of the complexities encountered with the interior side air barrier (Fig. 4). At exterior walls, the primary air barrier material is typically applied over the face of the exterior sheathing at frame walls. In the case of mass walls with overcladding, the primary air barrier material is applied directly over cast-in-place concrete or CMU backup wall. In some cases, the concrete wall is designated to serve as the primary air barrier material as well, as might be the case when the concrete is exposed to the exterior and there is no overcladding. In all of these cases, the plane of airtightness is likely to be relatively straightforward, especially if a less geometrically complex enclosure has been designed into the project. Once again, the point can be made to keep things simple to the maximum extent possible in the design of the air barrier system. A greater degree of simplicity is facilitated by placing the air barrier to the exterior side of structure. Transition detailing is reduced, fewer materials are involved, and fewer trades. Often a single trade can install all the materials and detailing required with an exterior side air barrier approach. An additional advantage results from the relative ease with which the installation can be inspected for quality control purposes.

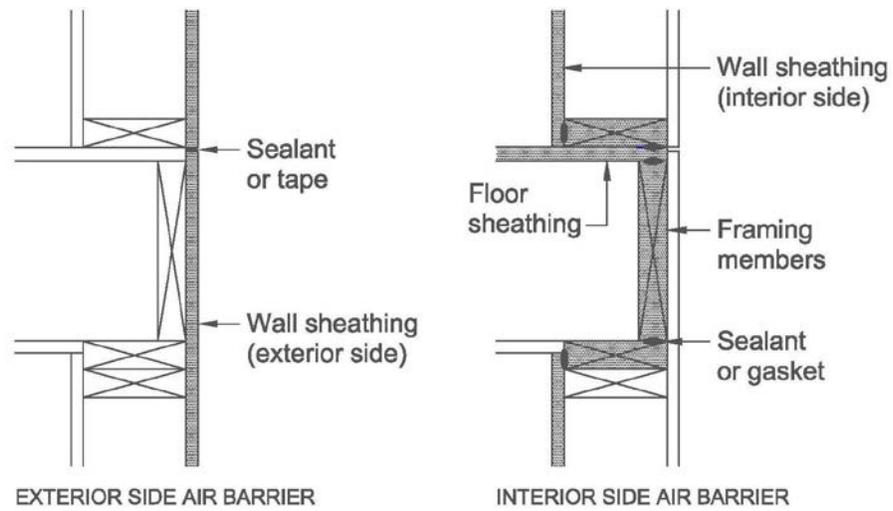


Figure 4. Air barrier complexity increases when an interior side air barrier approach is utilized at buildings of frame construction.



Figure 5. Exterior side air barrier during installation.

Additional constructability concerns come into play at the scale of the details. The contractor brings knowledge of the typical scoping and sequencing of trade work, which in turn affects how detailing is developed. For example, if a sheet metal flashing component is to be used at a window-to-wall interface – together with wet sealants – to provide air barrier continuity in addition to the role it will play in rainwater management, is it practical that the sheet metal installer be mobilized early during the enclosure construction to place that flashing within the overall assembly construction? Perhaps it would be better to use a self-adhering membrane flashing in the detail in lieu of the sheet metal flashing so that the wall membrane installer who is already on site can also install that transition component. If self-adhering membrane is suitable for the application, this change to the detail makes sense. If not appropriate, then the sheet metal flashing should remain in the detail, but now the contractor must be aware of this specific interface issue and must attend to it in the scoping of work for the different trades. Perhaps the wall membrane installer's scope should include the installation of that particular sheet metal component, whereas the sheet metal supplier will provide the material itself.

The contractor's knowledge of material compatibility issues – some of it acquired through experience on previous projects – can also be useful in the analysis of details. Wet-applied sealants are often utilized as air barrier components in transition detailing. These sealants tend to have highly varied adhesive and chemical compatibility with the multitude of other materials used in air barrier system detailing. It is important to investigate and verify the compatibility of these materials with one another. Design detailing may indicate dissimilar metals in contact with one another and compatibility here must also be verified. Since the specific detailing and material specifications vary from one project to the next, it is important to carry out this type of material compatibility investigation on every project. This typically must occur during the construction phase when each of the specific products have been finally determined; however, the knowledge from previous project experience can be used to inform detailing during the design process.

Design Impacts on the Successful Implementation of the Air Barrier System

To implement an effective air barrier system, the design must provide for system continuity. The drawings – and the enclosure details in particular – must be reviewed and analyzed to verify continuity has been provided. Although this “continuity exercise” is essentially a design team responsibility, the contractor can play an important advisory role during the analysis (Lawton 2010). Beginning with the enlarged wall sections and enlarged plan drawings, the reviewer will trace the continuity of each of the five critical barriers (water-shedding surface, water-resistive barrier, air barrier, thermal barrier and vapor barrier) through each of the drawings. It is particularly useful to analyze the continuity of the thermal barrier at this drawing scale, as the components that are functioning as thermal bridges are typically readily visible in the enlarged section and plan drawings. After reviewing these drawings, the exercise can then move to the enclosure details, where the continuity of the air barrier system can be fully established or any discontinuities can be identified. This is typically an iterative process that occurs in stages over the course of the design process. If diligence is applied to the review process by design and construction team members, many of the discontinuities can be identified and rectified in the detailing before the final drawings are issued for bidding and construction.

The Contractor's Role in Construction of the Air Barrier System

The general contractor plays a most pivotal role in the construction of the air barrier system, leading the overall construction effort in the field, providing coordination between the various trades involved in air barrier construction, and overseeing the construction team's quality control process. In addition to these core activities, the general contractor may recognize a need to educate and train field personnel regarding the purpose and design of the air barrier system on a given project. Interface conditions in particular may need to be explained and understood by multiple trades, including the general contractor's own forces.

Coordination of the work involved in the construction of the air barrier system should begin as early as possible during the construction phase. As a best practice, the general contractor will begin the coordination process by facilitating a building enclosure coordination meeting prior to commencing the project submittal process. This meeting is not to be confused with the pre-installation meetings which are typically held at the project site one to two weeks prior to the commencement of an individual trade's installation activities. The building enclosure coordination meeting includes all trades involved in the enclosure construction and is intended to provide an overview of the entire enclosure system design to the trade contractors and to give the general contractor an opportunity to highlight key scope or sequencing considerations. It also provides a forum for the individual trades to bring their questions or concerns to the table for review sooner rather than later in the construction process, as well as an opportunity to dialogue with the other trades whose work interacts most closely with their own scope of work.

This proactive stance towards coordination by the general contractor typically pays dividends by identifying potential scope gaps and sequencing problems between the construction team members. Issues relating to construction tolerances, material compatibility, access for installation, or requirements for temporary protection, can also be reviewed and discussed. Missing details or potentially problematic details that need additional review and consideration by the design team can also be identified through this process, as can any conflicts that are apparent between the drawings and specifications. A diligent quality assurance process during the design phase can be effective at reducing the number of potential issues within the design documents; however, it is not practical to eliminate all conflicts or other potential problems. By identifying potential issues early during the construction process, the issues can be addressed in a deliberate and reasonable manner, free of a crisis mentality that might otherwise prevail without a proactive stance. The discussions held at the coordination meeting, and the work products/documents that follow (e.g. meeting minutes, requests for information, architect's supplemental instructions), tend to substantially improve the quality of the submittal process by increasing the respective trades' understanding of the building enclosure design and its documentation, while providing the design team with a more direct understanding of the questions and concerns of the trades and the general contractor.

Depending on the relative complexity of the air barrier system design and the quality of design documentation that describes the requirements to implement a continuous system, it may be necessary for the contractor to work in a proactive manner to coordinate the work at the micro-scale of the details. It has been the experience of this construction professional that efforts to

clearly and comprehensively document the design intent of the air barrier system range from non-existent (typical of many projects) to somewhat successful. This observation applies even to the work product of design teams that are motivated to design and detail a highly functional, continuous air barrier system. Rarely has the design of the system been communicated in a comprehensive manner that is highly legible and clearly understandable to the construction team. It follows that some degree of responsibility can be placed with a committed construction team to make a dedicated effort to identify and fill in the gaps of the design documents regarding the provision of air barrier continuity. This is particularly the case when the contractor involved has substantial experience with air barrier design and construction and the construction contract has been procured in a context of negotiation. Placing this responsibility on a contractor that has procured the work through a hard bid process is likely to result in significant additional costs / change orders to the owner.

Coordination of the Work – A Case Study

The need for this type of coordination and documentation can be illustrated through review of the detailing of a brick veneer clad exterior wall assembly where it intersects a typical floor on a representative project. The owner's project program included a goal to provide a high level of airtightness at the building enclosure to achieve significant energy use reductions. The exterior wall design on this project included an exterior sheathing membrane air barrier approach utilizing a vapor permeable, water resistant, and airtight, mechanically fastened spun-bonded polyolefin sheet membrane. The detailing of the enclosure at this condition required that a number of components be utilized to provide air barrier continuity from the wall assembly below the floor line to the wall assembly above the floor line. The architect's detail included in the construction documents for the project (Fig. 6) clearly indicated each of the required air barrier materials and components necessary to provide continuity; however, the dimensional coordination of the detailing was left unspecified. Close review of the detail suggested that it would be necessary to provide a considerable degree of precision to the layout of these materials and components to one another, not only to ensure air barrier continuity but also to ensure the function of the water resistive barrier system at this detail condition. Many of the air barrier materials were also serving as water resistive barrier materials at this condition. To ensure precise execution of the work, the contractor developed a two-dimensional coordination drawing for this condition to clearly specify the dimensional layout of each of the interrelated materials (Fig. 7). Additionally, since multiple trades were to be involved in the installation of the various materials and components, it was deemed important to improve the understanding of each trade of the entire air barrier system installation and their respective scopes within that overall process. The contractor developed a series of three-dimensional coordination drawings to communicate the installation sequence (Figs. 8a-8h).

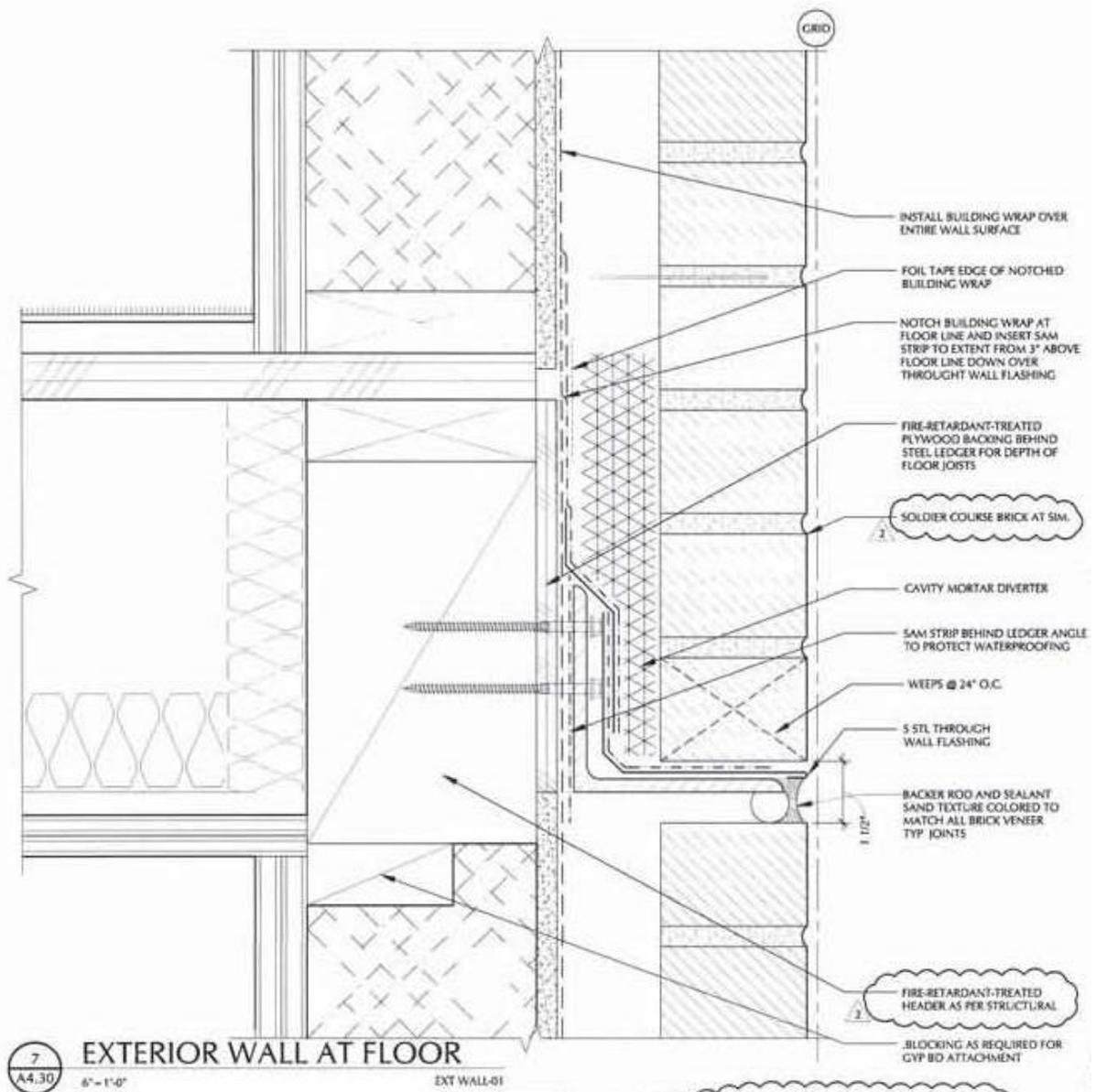


Figure 6. Architect's detail of brick veneer clad exterior wall assembly intersection with floor system (from "Construction Set" drawings, provided courtesy of Ankrom Moisan Associated Architects).

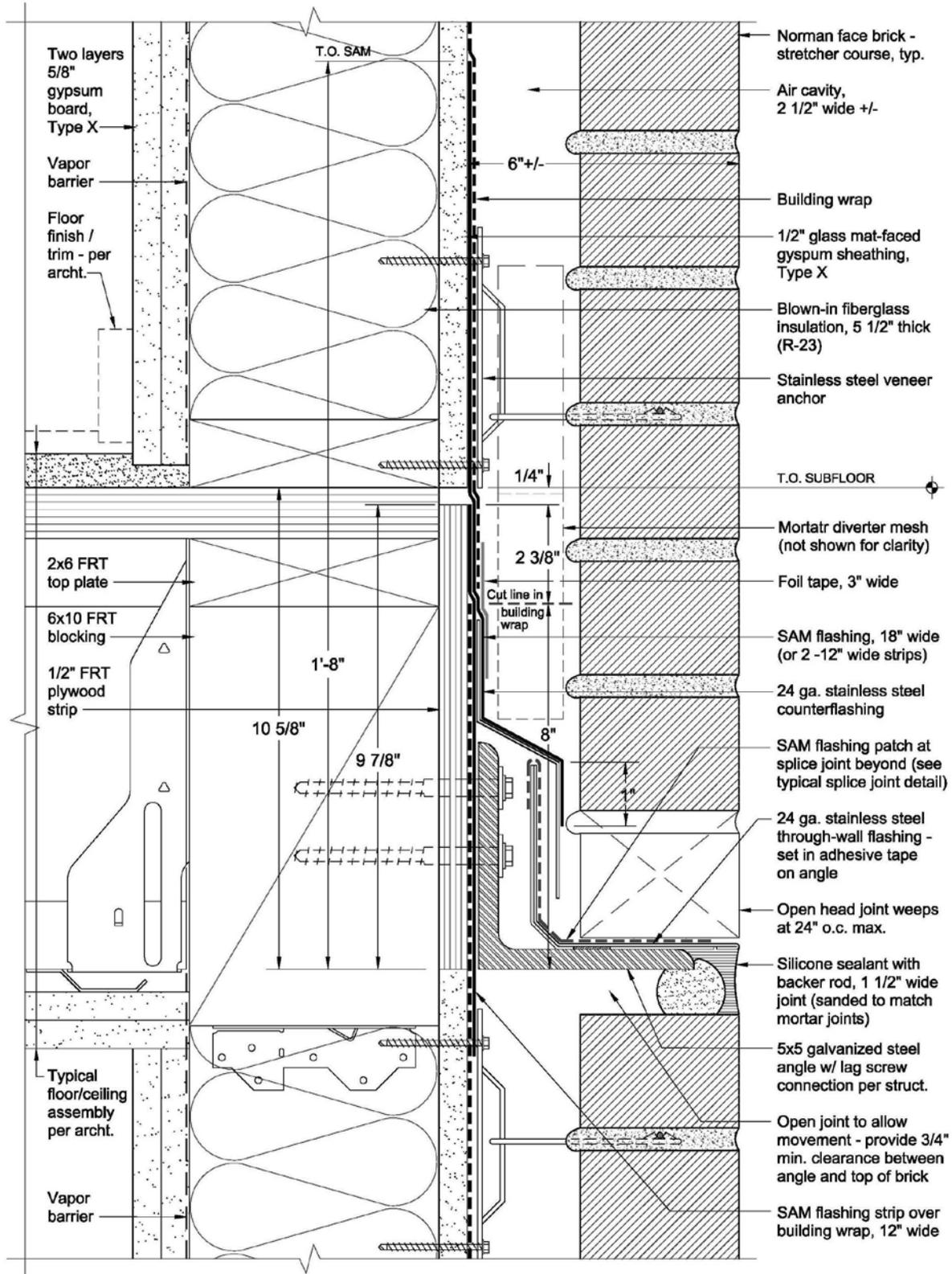


Figure 7. Contractor's 2D coordination drawing of brick veneer clad exterior wall assembly intersection with floor system (provided courtesy of Walsh Construction Co.).

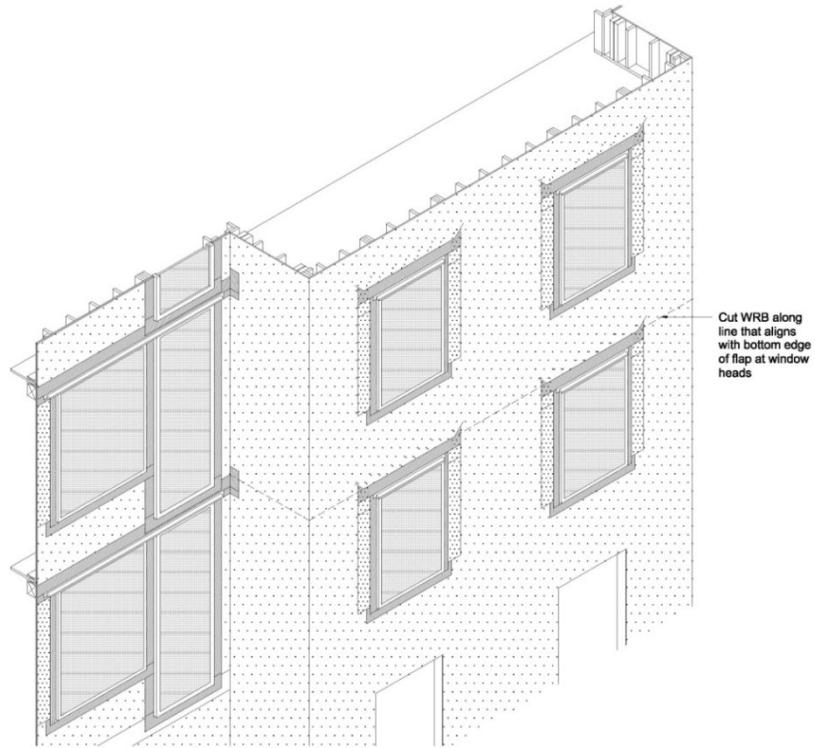


Figure 8a

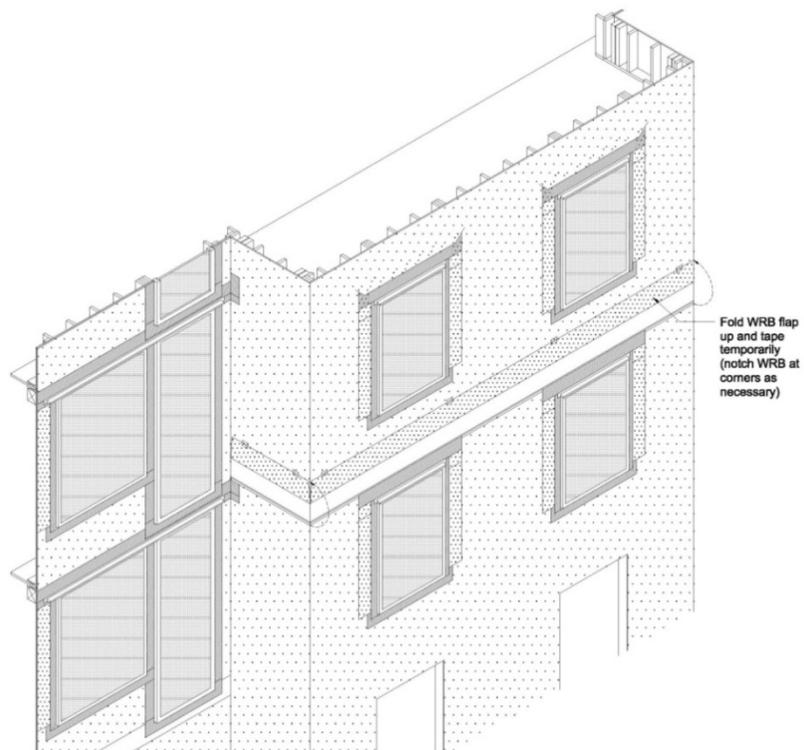


Figure 8b

Figures 8a-8h. Excerpts from contractor's 3D sequence coordination drawings of brick veneer clad exterior wall assembly intersection with floor system (provided courtesy of Walsh Construction Co.).

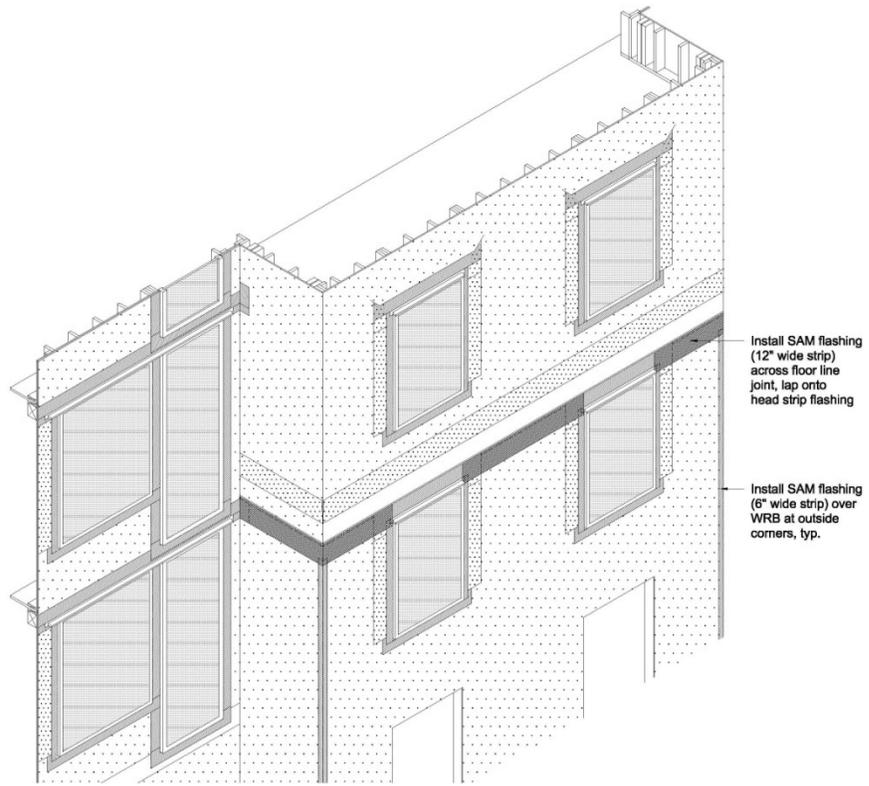


Figure 8c

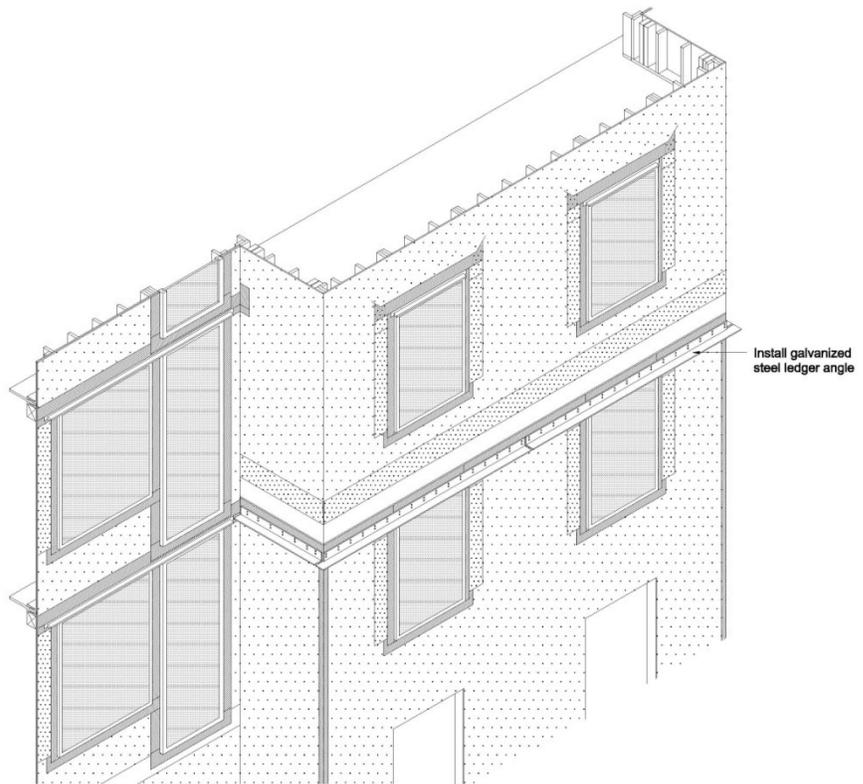


Figure 8d

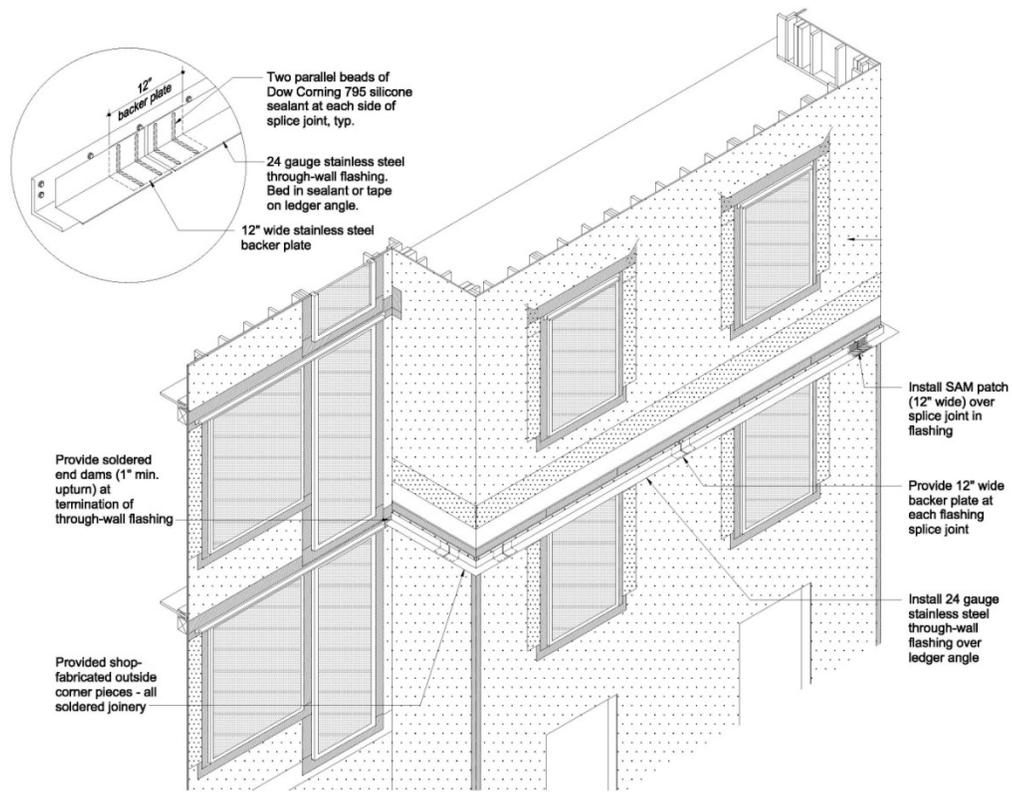


Figure 8e

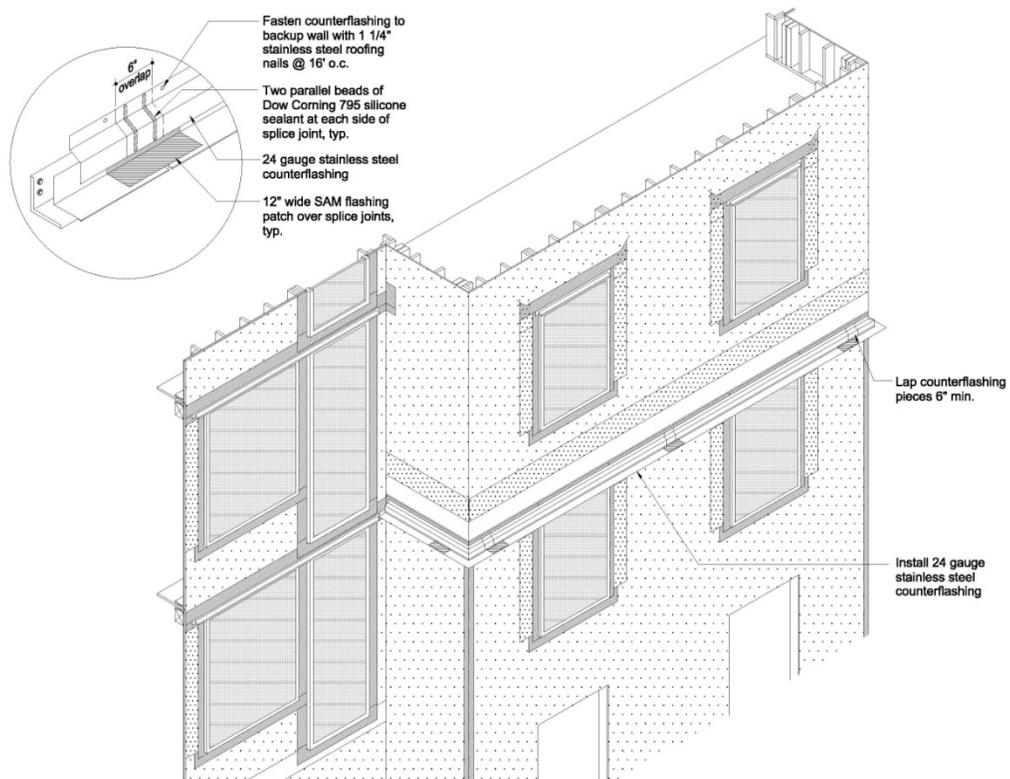


Figure 8f

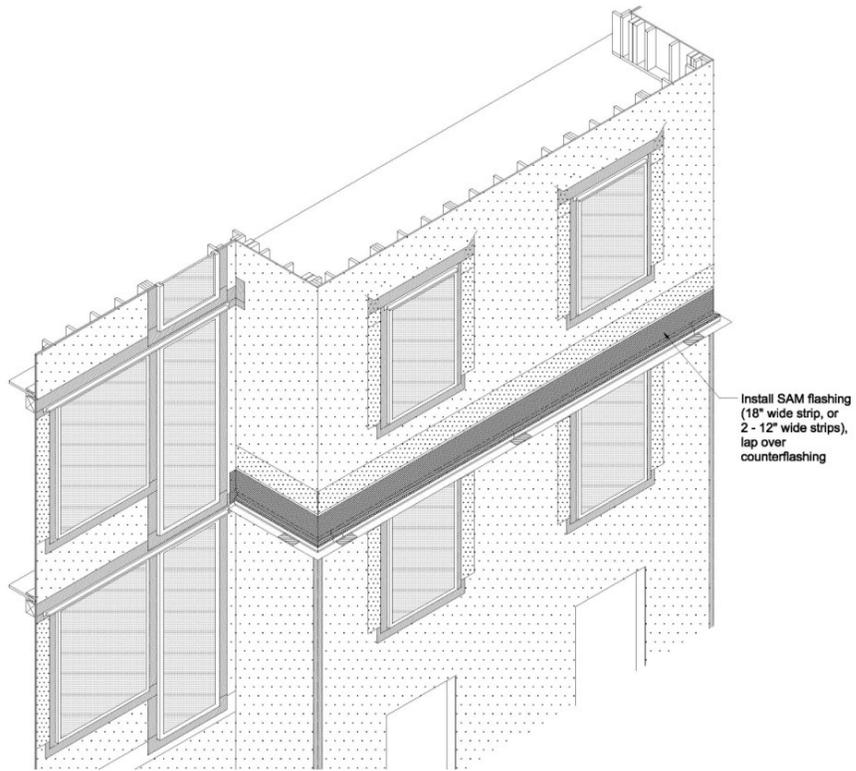


Figure 8g

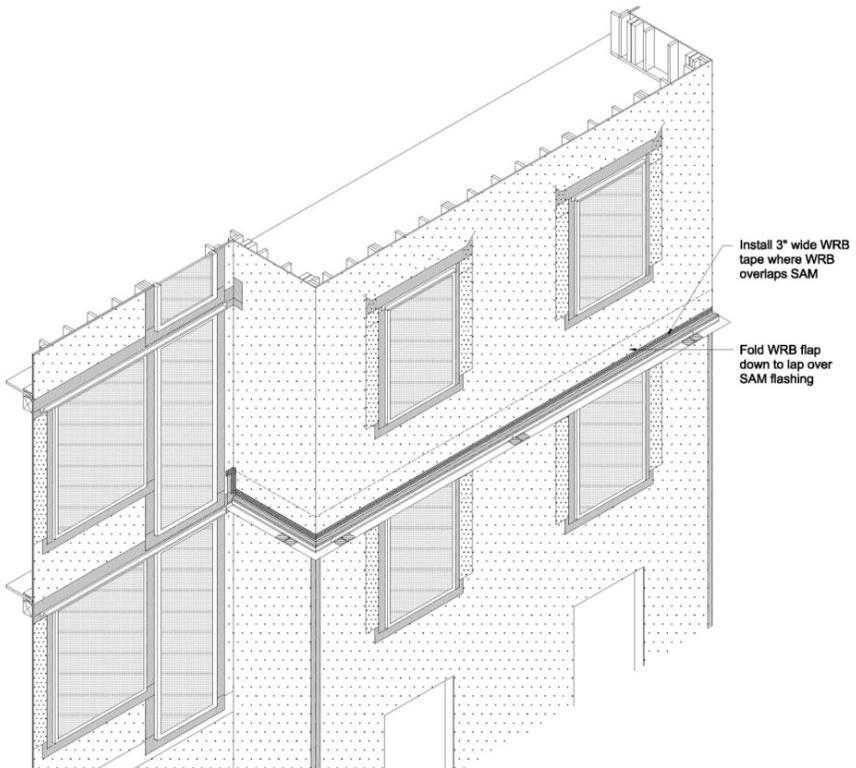


Figure 8h

Another essential component of the coordination process is the construction of a mockup of the exterior wall assembly (Fig. 9). The mockup represents the culmination of the contractor's coordination efforts and serves a number of purposes. It allows the construction team members to demonstrate to one another, and to the design team and owner, how they intend to construct the enclosure, using the specific materials and components selected and approved for the project. In a sense this is a "practice run" prior to the actual construction on the building and allows the team to identify any lingering questions or concerns that may remain with the design documents or the contractor's work plan, including sequencing considerations. The design drawings and specifications are referenced, as well as any shop drawings or coordination drawings developed by the construction team members. As discussed above, the sequencing and dimensional layout of the materials can be highly critical to establishing air barrier continuity, and the mockup provides an opportunity to look closely at the interrelationship between the various air barrier materials and components needed at each of the detail conditions included on the mockup. The contractor can ensure that the mockup is not a static artifact developed only to meet the requirements of the specifications, but rather that it is used as a dynamic learning tool by the entire team to increase understanding of the design and troubleshoot any potential problems that could occur during the construction process.

Once the air barrier system has been completed on the mockup, air leakage testing can be conducted to assess the airtightness of the assembly. Quantitative testing can be used to establish compliance with any specified project requirements. Qualitative testing can be used to identify leakage paths so that the team can assess how best to mitigate the leakage that is occurring at various detail conditions.



Figure 9. Exterior wall assembly mockup, including air barrier materials and components. Mockup shown under negative pressurization during quality assurance testing.

The practice run on the mockup may inform the project team about further adjustments that should be considered at specific details or specifications. For example, it may be determined that the lapping of wall membranes shown in a 2D detail drawing conflicts with information indicated in a 3D drawing sequence provided in the construction documents. In another instance, peel adhesion testing of sealants applied to self-adhering membrane flashing may indicate potential adhesive compatibility issues between these critical air barrier system components. As a result of issues identified through the process of constructing, reviewing, and testing the mockup, any necessary revisions can be implemented through the project documentation and change processes.

The Contractor's Role in Testing of the Air Barrier System

The commissioning process culminates in the air leakage testing program used to assess compliance of the air barrier with the established performance requirements. In some cases, these requirements are included in the project specifications. WCC is beginning to see a continuous air barrier requirement - and air leakage testing requirements - included in specifications for projects in the State of Oregon, although this is far from standard practice. The air leakage requirement is specified at the assembly level in some cases and at the whole building level in others.

In a number of jurisdictions across the United States, air barrier requirements are included in the prevailing building code. For projects in Washington, a continuous air barrier system is now required by the 2009 Washington State Energy Code (WSEC) and 2009 Seattle Energy Code (SEC). Air leakage testing is also required. The WSEC and SEC require that *"the building envelope be designed and constructed with a continuous air barrier to control air leakage into, or out of, the conditioned space."* Additionally, the codes require that *"all air barrier components of each assembly shall be clearly identified on construction documents and the joints, interconnections and penetrations of the air barrier components shall be detailed."* The WSEC requires whole building air leakage testing for buildings over five stories, where the SEC requires testing at all buildings governed by the SEC. The codes state that compliance with the continuous air barrier requirements shall be confirmed by testing the completed building and demonstrating that the air leakage rate of the building does not exceed 0.40 cfm/sf at an air pressure differential of 0.3 inch w.g. (1.57 psf; 75 Pa). However, strict compliance with the maximum leakage rate is not currently required. The current requirement is that buildings are tested and test results are reported prior to issuance of a certificate of occupancy. Whole building testing is to be conducted in accordance with ASTM E 779 or approved similar test. The air leakage rate is reported as a normalized value and reported in cfm/sf at 0.3 inch w.g. (1.57 psf; 75 Pa) over the total area of the building envelope air pressure boundary.

The design team is responsible for defining the bounds of the enclosure, calculating its surface area and providing this information in the building permit submittal documents. Surface area is important because air leakage rates are reported as a function of the surface area of the building enclosure.

These code requirements in the State of Washington have effectively imposed the testing component of the air barrier commissioning process on the construction industry. It will be

instructive to see how the code requirements are received in the industry and how the codification of these requirements will transform the design and construction of air barriers on buildings as we move into the future.

WCC has worked with owners, design teams and commissioning agents on several recent projects where assembly and whole building air leakage testing has been conducted. Assembly testing has been relatively straightforward. On several projects, the mockup has served as the test specimen for assembly testing. On one project, five 100-square-foot sections of the exterior wall assembly – randomly selected around the building – were tested for conformance to specified performance requirements. The wall assembly consisted of the opaque wall of wood framing, sheathing, and water-resistive barrier membrane, together with the glazing components – in this case, casement window units. ASTM E 783 was specified. This type of testing can be conducted with little impact on the construction team members and their typical sequence of work. Testing is performed from the building interior. A relatively minor degree of coordination is needed between the contractor and the commissioning agent to provide access to the testing areas.



Figure 10. Air barrier assembly testing in progress. (Photo courtesy of RDH Building Sciences)

Whole building air leakage testing can be a very different matter, as the amount of coordination required between the contractor and the commissioning agent can be extensive. Much is dependent on when the testing is conducted. Whole building testing can be conducted upon substantial completion of construction and this is the most typical approach. From a testing and construction coordination standpoint, this is the ideal time to test the building. All building

systems are complete and building users have not yet occupied the building. Coordination between the commissioning agent and contractor is typically minimal. The contractor may be asked to ensure that interior doors are kept open prior to and during the testing process, or may be asked to assist with access to mechanical system interfaces with the enclosure so that these openings can be temporarily modified for the test process (intentional openings in the enclosure, such as exhaust vents and air intakes, are typically sealed off in preparation for testing). There is an obvious problem with waiting until the building construction is completed to test for compliance, however. If the building's air leakage rate does not comply with requirements, then what is to be done? Remedial work will likely be required. How will this be accomplished? Who pays the cost of the remedial work? Is the leakage problem a design problem or a construction problem? If a construction problem, which trades are responsible? The potential for conflict and disputes is significant. With this "test at completion" approach, quality assurance and quality control measures have not been well-utilized in the commissioning process. Air barrier assembly testing during the course of construction can be useful; however, this type of testing does not incorporate some of the key conditions and interfaces that often lead to large amounts of air leakage in a building, such as where the exterior wall assembly intersects the interior floor assemblies, where the exterior wall intersects the roof, or where the roof assembly is penetrated by mechanical system components. A building that passes the assembly tests may still be found to exceed the maximum air leakage rate if leakage is occurring at the intersections of assemblies or at atypical penetrations in walls or roofs that are outside the scope of the assembly testing process.

To provide a greater degree of quality assurance and quality control of the air barrier system, whole building air leakage testing can be conducted during the course of construction. While the whole building air system is not yet complete, the air barrier system at smaller zones within the building may be complete or near completion (Finch et al. 2009). This type of testing, however, can be quite complex due to the highly variable nature of any building under construction. Systems are only partially complete and this creates many difficulties for testing. Substantial coordination between the commissioning agent and the contractor is necessary. Intentional and unintentional openings in the building enclosure, as well as the zone enclosure, must be identified and then assessed. The zone enclosure will likely include interior floors or walls that are not designed for airtightness but must be made airtight to allow for a test that has meaningful results to be conducted. Much depends on the type of construction. Buildings of light frame construction, with their hollow floor and wall assemblies, are inherently more difficult to isolate into smaller zones that can be tested. Buildings of heavy frame construction typically have solid floors and often have solid walls which can result in a much more straightforward testing process.

Discussion

As the construction industry moves towards the implementation of airtightness in buildings, there are a number of issues and questions that have come to light. Particularly as the pursuit of more airtight construction has moved from voluntary standards to mandatory codes, there are serious questions about what level of airtightness is achievable broadly across the industry.

Designers, builders and owners have all become concerned about how the bar has been raised in some jurisdictions by code requirements for airtightness.

Airtightness standards for single family residential buildings have been established based on a large amount of data developed over more than two decades (Sherman et al. 1998). Data regarding the airtightness of larger buildings (i.e. buildings exceeding 10,000 square feet in floor area) is not yet fully developed. The current standards for airtightness (e.g. ABAA, USACE) have been established based on previous research and practice involving a limited range of building types and limited number of buildings. Is 0.25 cfm/sf the right target? Is 0.40 cfm/sf the right target? There are so many variables that play into the potential that an individual building design can be made airtight, how should those variables factor into the airtightness requirements? Should different requirements be established for rehabilitation projects as compared to new construction? Clearly – on one hand – more data on what can be achieved with the airtightness of larger buildings is needed to develop and finalize the airtightness standards. Conversely, the standards can be established and the industry will then need to go through a learning curve – small or large – to determine how to meet those standards. As long as the standards are voluntary, this is a reasonable and viable approach.

Things get trickier when the codes begin to incorporate the standards. Taking a voluntary standard and making it a performance requirement on an individual project is a matter of choice for a project team. The design team can determine if it has the capacity to develop a design that meets an established performance requirement. The construction team (if involved during the preconstruction phase of the project) can determine the same. The owner can determine if it is willing to absorb the costs of the additional design and construction efforts that may be needed to provide compliance with an established performance requirement. All team members need to consider the implications of including a performance requirement in the specifications for an individual project and come to agreement regarding the costs and benefits of including such requirements. As airtightness standards are incorporated into the code, choice disappears. Owners and their design and construction team members must be prepared to meet the performance requirements established in the code regardless of their understanding of the implications of these requirements.

The approach taken by Washington State code officials – to require air leakage testing but not compliance – is a good middle ground. This approach will, over a number of years, provide what is currently missing: data on airtightness gathered from a wide range of building types and large number of buildings. This approach also allows the industry in Washington State time to evolve, to understand the implications of the performance requirements, and to determine what measures are required during design and construction to meet those requirements.

Should building codes include requirements for airtightness? This is a question that is now hotly debated in the industry, particularly in areas where code requirements have been set. It has been clearly demonstrated that airtightness provides numerous and significant performance benefits to building owners and occupants (e.g. reduced energy consumption, improved comfort, enhanced durability). On balance, the question is not whether airtightness should be mandated through codes but rather what requirements should be set. Qualitative requirements

(i.e. requirements that call for provision of a continuous air barrier system that is clearly indicated in drawings) are much more critical to achieving airtightness than quantitative requirements (i.e. air leakage testing). Quantitative requirements are worthless and potentially problematic if qualitative requirements are not also established. It is arguable that qualitative requirements – if embraced by design teams and enforced by building officials – can produce a high level of airtightness without imposing quantitative requirements. Testing is useful for diagnostic purposes and to verify compliance with performance requirements; however, whole building air leakage is costly for building owners and may not be necessary if the design team provides a continuous, clearly identified air barrier system design and the construction team diligently executes the work in accordance with that design.

Placing mandatory quantitative requirements for airtightness in the codes raises questions about which party will be held responsible in the event the building does not comply with the requirements. It is possible that a construction team could diligently execute the design of an air barrier system for a building and that building could fail to pass the whole building air leakage test. If the design of the system – as documented in the drawings and specifications – does not fully and clearly provide for continuity, which party will be deemed responsible for the failure? The costs associated with failure, the repairs necessitated to rectify the failure, and the cost of retesting to verify compliance, are likely to be very high in many cases. Will the building not receive a certificate of occupancy? Will it be necessary to remove the brick veneer cladding system so that repairs to the air barrier system design or construction can be implemented? Are design professionals and contractors ready to absorb these costs? Are owners ready to absorb the costs they may incur through higher fees requested by architects and contractors in an effort to manage – and price – their respective risks?

How do we know how any given building will “test?” Today, with any large building, the project team does not know with any degree of certainty how the building is going to test for airtightness, or if it will meet the specified performance requirements (or mandatory code requirements should they be in force in a given jurisdiction). This is unlike the concrete that will be included in the primary structure, which is required to meet a specified slump and compressive strength requirement. Members of the project team have a fair degree of certainty these requirements can be met because there is a track record of meeting those requirements on previous projects. With a quantitative requirement for airtightness at buildings, we have very little experience with performance results, therefore we cannot have certainty about achieving a specific level of airtightness until we have more experience with success and failure.

The position presented in this paper is that the contractor can play a major role in successful implementation of air barrier systems at buildings. The manner by which the owner decides to procure construction management and general contracting services on a project will have a major impact on the ability of the contractor to play a positive role in air barrier implementation. Owners that procure construction services through a negotiated contracting process are likely to obtain the best balance of performance and cost. A contractor who is at the table and engaged during the design process can provide vital constructability and cost input to the owner and design team. This input can help to guide the design towards cost-effective solutions to air barrier assemblies and details, ensure that the design is constructable, and ensure the design is

well-documented and provides clear, complete detailing and specifications of the air barrier system and its associated materials and components. Owners that procure their construction services through a competitive “hard bid” process are likely to obtain the lowest pricing at first; however, it is quite possible the price will rise over the course of the project. Particularly when it comes to air barrier systems, where it is difficult to design the system for full continuity and where it is even more difficult to document the system continuity fully in the design details and specifications, owners that procure through the hard bid process are likely to face significant cost impacts during the construction process as requirements for air barrier system continuity are refined and clarified. Change orders related to the air barrier system could be extensive on projects where the design is complex and system continuity has been poorly conceived. Where code requirements are in place, the certificate of occupancy could lie in the balance.

Regardless of how construction services are procured, the contractor’s role as central coordinator of the work and key agent in construction quality control does not change. Whether the contractor has been the successful low bidder on the work in a highly competitive “hard bid” environment or has been at the table all along the way as part of a negotiated process that is focused on providing “highest value,” the same proactive stance to coordination and quality control described above is necessary if the contractor is to be successful at delivering a building that meets the specified or code requirements for airtightness. Contractors that are not prepared to manage this aspect of the work in a proactive manner are likely to face significant challenges with meeting the established requirements and, in turn, could open themselves to substantial consequences due to non-compliance.

Conclusion

The contractor can play a major role in successful implementation of airtightness at buildings. Air barrier systems involve many materials and components and, typically, a number of different trades are involved in their installation. Proactive, diligent work by the contractor – in combination with a similar effort by the design team – is likely to result in the delivery of functional systems that add value to buildings by improving comfort, increasing durability, and reducing energy usage and costs.

Contractors working in a negotiated contract setting are likely to provide more proactive support for successful implementation. Conversely, projects that utilize hard bid procurement are more likely to suffer from inconsistent implementation, increased risk of substantial change orders, and potential conflict regarding which parties bear responsibility for failure to meet established performance requirements.

More data on the airtightness of buildings is needed to establish industry standards that can be reached consistently. It is not yet clear that the construction industry has the capability in the design or contracting sectors to consistently implement air barrier systems. Understanding of the nature of air leakage, how it impacts building performance, and of how air barrier systems should be designed and built is growing, but is still relatively limited when considered across the industry. The approach taken by the Washington State code officials is an example of how such data can be developed across a wide range of building types and project teams.

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