Session 2.2 – Next Generation of Integrated Building Enclosures

Five Not So Easy Pieces - Designing and Building the Passive House Enclosure

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ABSTRACT

This paper describes the development and execution of the enclosure system design on a multi-unit residential building designed to meet Passive House standards: The Orchards at Orenco in Hillsboro, Oregon. A highly integrated process involving heightened collaboration between the design and construction teams has resulted in an enclosure design that is constructable and cost effective, yet is expected to deliver the high level of energy performance required to meet the Passive House standard. The primary building enclosure assemblies are described and five important interface details are examined in terms of their design as well as their implementation during the construction phase of the project.

The design of the building enclosure assemblies - and the detailing - have been developed to manage moisture effectively, as this is fundamental to ensuring long-term durability and certainly becomes a more critical concern as airtightness of the enclosure is increased and heat flow is reduced. Central to the design process is *critical barrier analysis*: each of the five barriers critical to enclosure performance has been analyzed to ensure continuity through each detail condition.

It is important that the project team maintain a relentless focus on keeping things as simple as possible in the detailing of the enclosure. A disciplined approach is needed to ensure that an inordinate amount of complexity is not forced on the construction trades. Unnecessary complexity inevitably drives up costs and increases the chances for non-compliant construction and lower performance.

Successful implementation of the design requires proactive coordination by the construction team. This process is led by the general contractor and involves all subcontractors and suppliers associated with the enclosure construction. No design is ever perfect: a proactive, diligent construction team will help to finalize the details for execution, involving the architect and other design team members in that process. Critical barrier analysis can be employed by the construction team also, to ensure continuity is maintained, particularly when detail adjustments are made during the coordination process. Coordination meetings, submittals, and mockup construction are all important steps in the coordination process.

An effective quality control and commissioning process is also essential to successful implementation. Many of the activities associated with this process are well-defined and may even be standardized; however, some activities or methods may be developed by the team for project-specific application depending on the unique needs of the project.

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Introduction

The Passive House certified building stock in the United States is no longer limited to single family housing. With a drive to provide housing that is affordable in the deepest sense of the word, non-profit housing developers have recently begun to pursue the benefits of ultra low energy building strategies in multi-unit residential buildings. REACH Community Development, based in Portland, Oregon, is among a network of non-profit developers dedicated to lowering overall living costs for the residents in their housing. In REACH's view, delivering truly affordable housing means delivering housing with low monthly rents, but it also means the housing should place a minimal burden on the finances of low income families by keeping utility costs as low as possible. Additionally, housing should ideally be located in close proximity to regional transit lines to provide residents with accessible, low cost travel options. This combination of increased mobility, low rents, and minimal utility costs has the potential to provide low income families with more practical access to school and work opportunities while helping to keep monthly expenses manageable.

In 2010, REACH began an update of the 5 Year Strategic Plan that guides their organization's work. When finalized, the plan included a goal to achieve Passive House certification on a new development by 2015. The first phase of The Orchards at Orenco ("Orchards") - comprising 57 units of workforce housing - was selected to target Passive House certification through Passive House Institute US ("PHIUS"). The fully realized Orchards development - situated adjacent to a Portland-area light rail system station - is envisioned to provide 150 units of workforce and family housing, built over three phases. REACH committed to pursue Passive House certification on the first phase of Orchards in order to fully explore the benefits and challenges of applying this rigorous standard to affordable housing development. When construction is complete and the building is operational, it will provide a living example of the benefits of utility cost

Fig. 1 - Street view of the building from Northwest corner of the site. Image courtesy of William Wilson Architects

reduction while also shedding light on the qualitative improvements to comfort and indoor air quality that are integral to the Passive House concept.

Building Design Overview

The Phase I building is laid out in an L-shaped form, with two wings of residential units and a “knuckle” of common spaces at the corner (Fig. 2). Although in terms of energy efficient design the building form is not optimal from an orientation or massing standpoint, the “L” shape - and the considerable amount of articulation of the building - were required to meet design guidelines established for the Orenco Station district of Hillsboro.

Fig. 2 - Aerial view of the site and building. Note the three penthouses at the roof which house the mechanical equipment and are included within the Passive House enclosure. Image courtesy of Ankrom Moisan Architects

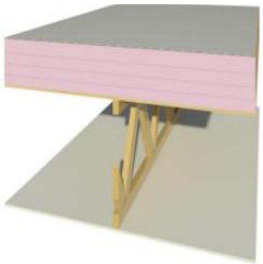
During schematic design, the project team chose to remove the trash room, elevator, laundry rooms, and fitness room from the conditioned Passive House envelope and treat them as “tempered areas” (Fig. 3). These spaces require high ventilation rates, which would have resulted in large volumes of conditioned air being exhausted from the building had they been within the Passive House zone (i.e. “treated floor area”). There were also concerns about the degree of airtightness that could be achieved at these spaces given the number and size of vents that would be required at the laundry rooms and elevator shaft. This early decision has had significant ramifications on later design decisions and is currently being studied for revision as construction is progressing.

The building structure consists of three-story wood-framed construction on top of a concrete slab-on-grade foundation. Typical enclosure walls have 2x10 framing with blown-in fiberglass cavity insulation in the stud cavities and 1-1/2” of rigid mineral wool exterior insulation (Fig. 4). Mineral wool was chosen specifically due to its permeability and capacity to facilitate drying to the exterior as environmental conditions allow.

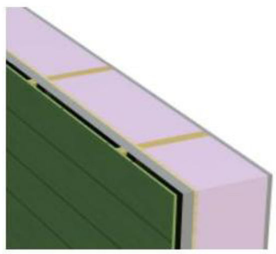
Fig. 3 - First Floor Plan Image courtesy of Ankrom Moisan Architects

Plywood exterior sheathing (with taped seams) serves as the primary air barrier at the enclosure walls. A mechanically-attached spun-bonded polyolefin sheet membrane, installed over the plywood sheathing, serves as the water-resistive barrier. The vapor barrier is located on the interior face of the wall framing. This is a polyamide membrane with variable perm rating to facilitate wall drying to the interior.

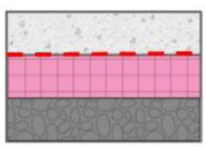
The ground floor slab sits atop a 4” layer of EPS insulation, which also wraps around and under the perimeter and interior footings. Type II EPS is used under the slab and at the sides of the footings; however, Type IX EPS is used under the footings for its higher bearing capacity. Capping off the building structure is a prefabricated wood truss roof with 12” of polyisocyanurate insulation and a fully adhered single-ply roof membrane. A self-adhered rubberized asphalt membrane is installed over the plywood roof sheathing, serving as the vapor barrier at the roof assembly (and also functioning as a temporary roof during construction).



Typical Roof Assembly: R-81
- 80 mil TPO roof membrane (fully adhered, white)
- 1/2” coverboard
- 12” polyisocyanurate insulation
- Self-adhered rubberized asphalt membrane vapor barrier (serves also as temp. roof)
- 3/4” plywood
- Prefabricated wood truss framing (trusses @ 24”o.c.)
- 5/8” gypsum wall board (2 layers)



Typical Exterior Wall Assembly: R-39
- Fiber cement siding w/ treated 1x wood furring @ 24” o.c.
- 1-1/2” rigid mineral wool insulation (8 lb. density)
- Spun-bonded polyolefin sheet water-resistive barrier
- 1/2” plywood with air sealing tape at all seams
- 2x10 wood framing (studs at 24” o.c.)
- 9 1/4” blown fiberglass insulation at all framing cavities
- Polyamide sheet vapor barrier
- 5/8” gypsum wall board



Typical Slab Assembly: R-19
- 4” concrete slab
- 15 mil polymer sheet vapor barrier
- 4” Type II expanded polystyrene insulation
- Gravel base with radon mitigation system piping

Fig. 4 - Typical building enclosure assemblies Images courtesy of Ankrom Moisan Architects

All 57 apartments have balconies or patio spaces. The balconies help to shade the living room windows while providing more useable living space. Horizontal “balcony extensions” and eyebrows, both of which were conceived as design elements that help give the building articulation and character, further provide shading at bedroom windows.

Tilt-turn windows provide a high degree of thermal resistance and airtightness. The windows are fabricated with hybrid fiberglass-pvc frames and triple glazing, with argon fill and low emissivity coatings. Different coatings are utilized at the north and south facing windows compared to those at the east and west, to tailor the solar heat gain coefficient to the different exposures to enhance solar gain while mitigating the potential for overheating, particularly at west facing apartments. Exterior doors at the balconies and patios are of the same construction as the windows. Thermally broken aluminum frame doors with double glazing are used for the common area entry doors.

Important details for thermal and air barrier continuity have been encountered at the footings, windows and doors, parapets, decks/eyebrows, and interfaces between the conditioned (Passive House) and non-conditioned zones. The remainder of this paper will explore the enclosure design and construction process as well as the development and execution of the following five key detail conditions at the exterior wall assembly:

- Wall to Foundation
- Window Sill
- Window Jamb
- Window Head
- Wall to Roof

Enclosure Design and Construction Process

The challenges of meeting the performance requirements of the Passive House standard are considerable and it was clear to REACH and their owner's representative - Housing Development Center - that an integrated team was needed for the project. It was believed that an integrated approach to the design would help ensure forward thinking and ultimately result in fewer problems during the course of project delivery. The contractor - Walsh Construction Co. - was brought to the table at project inception. Soon after that the architect - William Wilson Architects - was selected and, following some initial conceptual design work, a project kick-off charrette was organized and attended by all team members as well as key stakeholders from the local community. This single act of getting all team players together at once, at the beginning of the project, set the course for the ongoing collaboration and teamwork that was to occur throughout the design process.

Early Concepts

At the charrette, the key tenets of the Passive House enclosure were reviewed: 1) high levels of thermal insulation, 2) minimal thermal bridging, 3) high degree of airtightness, and 4) highly-efficient windows and exterior doors. Following the charrette, the design process got underway. The contractor and the Passive House consultant - Green Hammer - provided input to the architect and structural engineer very early on. Since the project was pursuing Passive House certification, the entire team was aware out of the gate that the airtightness requirement (0.6 ACH50 max.) would require more design focus; this informed the team's thinking as the design was developed. For example, based on experience with previous projects, the team was aware that the joint between the wall and roof can be one of the most problematic areas to achieve air barrier continuity. A considerable amount of time was spent during the charrette to discuss this issue and a conceptual approach to the wall to roof joint was developed (Fig. 5). Typically, parapet walls on wood frame buildings are framed as an extension of the roof truss framing; however, this standard approach prohibits a simple, constructable and effective detail for transitioning the plane of airtightness from the wall sheathing to the roof sheathing. The team devised a concept where the parapet wall would be framed as a separate component placed on top of the roof sheathing and fastened to the roof framing, but this is done only after the air barrier has been transitioned from the wall to roof at the sheathing planes. With a commitment to integration and the challenges of designing an airtight and thermally efficient enclosure, the structural engineer participated actively in the kick-off charrette and let the team know he could work this alternate approach as he developed the structural detailing, so we proceeded in that direction. The final detail (Figs. 54 & 55) follows the initial concept very closely. (Note: as schematic design was completed and design development began a different architectural firm was engaged - Ankrom Moisan Architects - and they completed the design and developed the final details.)

At the kick-off charrette the team also established provisional target R-values for the various enclosure assemblies. These targets were then "tested" by the Passive House consultant by running them through the Passive House Planning Package ("PHPP") design tool as a starting point for what then became an ongoing and highly iterative

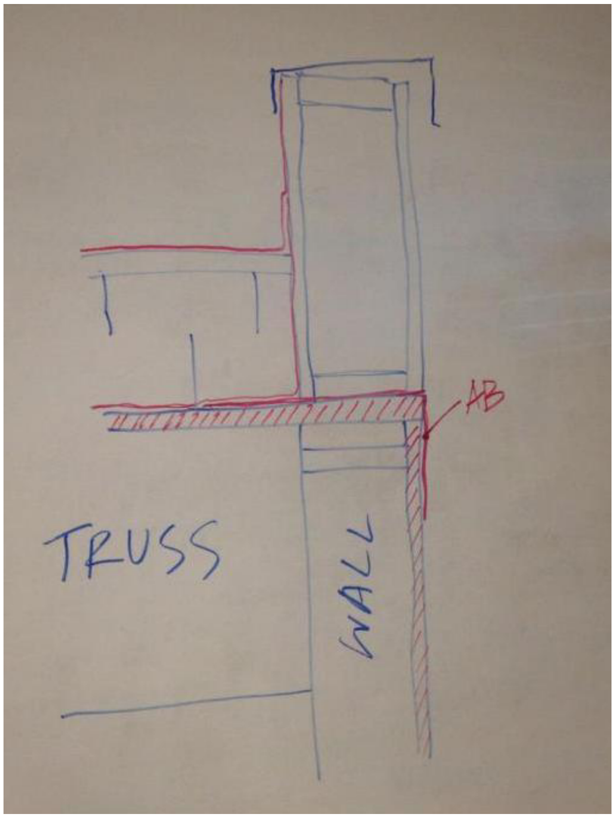


Fig. 5 - Concept detail developed at kickoff charrette to address need for air barrier continuity at the critical wall to roof joint.

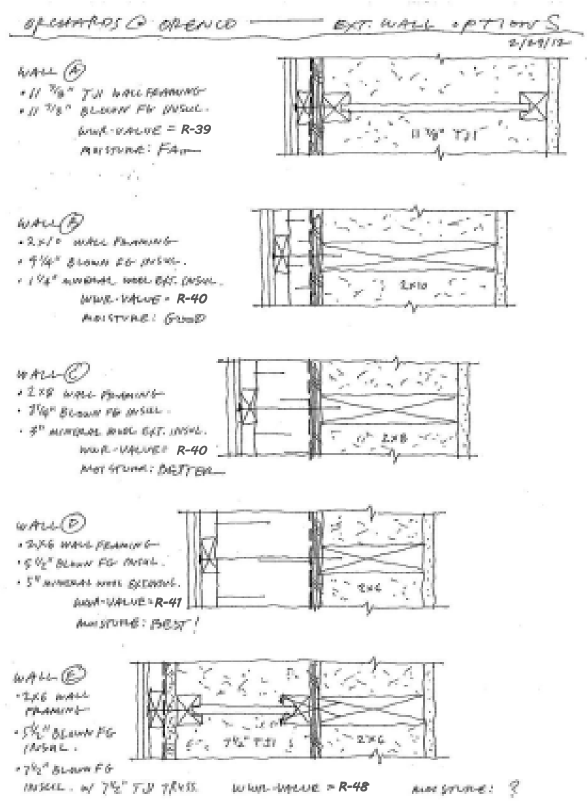


Fig. 6 - Wall design options investigated for cost and performance during schematic design phase.

process. For example, the team agreed that a whole wall R-value in the low to mid 40s would be the target for the exterior wall assembly as a starting point. A series of wall design options were developed (Fig. 6) and the contractor provided cost and constructability input on each. Specific R-values for each assembly were determined and used as inputs to subsequent PHPP analyses.

This was a process of iteratively analyzing the design to evaluate the performance and cost of the various components in an effort to achieve the most optimized balance. The process was not 100% objective or “scientific” as it involved a significant amount of subjective judgment by team members to assess non-measurable qualities of the various design options such as constructability, product familiarity, vendor reliability, etc.

Material and Product Selection

A key concern of all team members was the availability of the more specialized products needed to achieve Passive House certification, as well as the established track record of these products. The U.S. marketplace for products that provide Passive House levels of performance is still in the early stages of development. Additionally, the design, construction and operation of buildings are complex enterprises that entail numerous risks - including product reliability - and this becomes an important consideration in the design of any project.

The window and door selection process was particularly rigorous. The team researched window options extensively and looked at products available from local manufacturers (based in the Pacific Northwest) as well as several products manufactured in Europe. Based on early scoping and pricing exercises, the European products offered a higher level of performance, and at a lower estimated cost. However, the team collectively decided to move forward by specifying products produced locally by manufacturers with established track records for delivering high quality windows in a reliable manner on relatively large projects. With 322 high performance windows and balcony doors going into the project, the team did not feel comfortable specifying overseas suppliers.

The federal funds used to help finance the project also added accessibility requirements above and beyond the typical requirements of the Americans with Disabilities Act (ADA). This made finding commercial-grade doors with a robust air seal at the sill threshold quite challenging. At the doors occurring within the interior Passive House barrier interface between conditioned and non-conditioned zones, a 20-minute fire rating was also needed on top of the long list of other performance and accessibility criteria. The team had a difficult time sourcing products that fully met all the criteria. Ultimately it was agreed to use a custom fabricated insulated wood door with a drop-down seal at these locations, with plans to conduct quality control tests of the door seals to ensure adequate airtightness.

Coordinating the Work

To properly construct a Passive House design, diligent, proactive coordination of the work is required of the contractor. There is no substitute for diligence when it comes to this coordination. Even a highly developed and accurate set of design documents does not include all the information needed to build the project. Inevitably there will be some gaps in documentation or a need to modify a detail slightly or in a major way to achieve the design intent while accommodating construction variables such as sequencing of the work, tolerances, manufacturer's installation instructions, etc. This level of coordination is fundamental to all successful construction projects, but the need is heightened when executing a Passive House design, especially when it comes to detailing the airtight and thermal-bridge-free building envelope. For example, at some detail conditions there could be four or more trades that impact the airtightness of the building since they each supply and/or install components that are integral to the air barrier system.

Effective coordination can be understood to start early during the project, with the integration of construction thinking into the design process. Although this was not an issue on Orchards, on many projects it is not uncommon for a less experienced architect to develop a detail that indicates various components to be installed out of the normal sequence of trades. Perhaps this sequence can be accommodated if the indicated relationships are important to achieving performance; however, with a bit of dialogue it is usually possible to achieve the performance ends of the detail condition within the means of the normal construction sequence. In many ways, an active and ongoing dialogue between architect and contractor can uncover "issues" before they become "problems."

An important aspect of the contractor’s job is active communication with the entire group of subcontractors, to let them know about the Passive House goals and requirements, and to educate them about key issues that may impact their scopes of work and the overall Passive House certification. As the project moves into the bidding period, which is the threshold between design and construction, it is important for the contractor to coordinate the work in terms of packaging the various bid scopes. In this way, the scope of work for each trade is well defined and “grey areas” are eliminated or minimized. The contractor in some cases may interpret the design documents to clarify the scopes of the individual trades, especially where there is likelihood that one trade or other could miss some of the special requirements associated with the Passive House design.

Due to the intricacies involved with material specifications and detailing of the Passive House design, communication with subcontractors that impact the building envelope requires extra attention. On Orchards, a full-day Building Envelope Coordination (BEC) meeting was held on site during the first month of construction, gathering together all the enclosure-related subcontractors and key suppliers, to review project requirements including specifications, detailing, schedule, sequence of trades, etc. (Fig. 7). Scheduling this meeting early on during construction allowed the team to work through any gaps or inconsistencies in the scopes of work of various trades, as well as any issues related to the design documents. Upon completion of the BEC meeting, resolved issues were addressed readily and efficiently through the project submittal process.

Fig. 7 - Building Enclosure Coordination (BEC) Meeting

Issues that needed further examination or design work were addressed through the project Request for Information (RFI) process. Finally, the trades were brought together to execute a dry run of the enclosure construction on a free-standing exterior wall mockup (Fig. 8) where additional refinements were identified and reviewed by the team.

Fig. 8 - Exterior wall mockup

QA/QC / Commissioning

An effective quality process is essential to the delivery of any high performance building, whether seeking Passive House certification or not. At Orchards, quality assurance and quality control has been provided at three key levels: design, construction and commissioning. First, the project design - including specifications and detailing - has been extensively vetted through the architect's in-house quality review program. The contractor, the Passive House consultant and the third-party certification "rater" have also all reviewed the design for quality assurance. In fact, the pre-certification of the project under the PHIUS+ program was understood to be a critical quality assurance step in project development.

Secondly, the construction team has exercised a high level of internal quality control to assure installation of materials and components in accordance with the approved drawings and specifications as well as manufacturer's installation instructions. On Orchards, as is typical for all projects with significant scope of work on the building enclosure, the contractor has assigned a quality control specialist to work alongside the project superintendent to perform daily quality control review. This specialist, drawn from the contractor's crew of trained enclosure specialists (also known as "skin doctors"), has served as the project superintendent's eyes and ears on the work continuously during the months-long installation process. Inspections by the contractor's in-house quality director have occurred at regular intervals as well.

Quality control activities and methods are varied, and can be developed to suit the needs of the project. One issue that arose on Orchards was how to best inspect the blown fiberglass insulation in the exterior wall cavities. The material was specified to be installed at a certain density; however, it was difficult to inspect this visually. To some degree the density can be checked with a simple "mattress test" by placing one's hand on the netting and pushing on the installed insulation to "feel" the density, but this is a subjective assessment. The contractor developed a crude but effective measuring device to provide a more objective assessment: a sampling box constructed of sheet metal and tape that allowed for a number of random inspections of the installed density (Fig. 9). The box was pushed through the netting and insulation, and then pulled back out of the wall cavity, thereby removing one cubic foot of installed insulation (Fig. 10). The box was then weighed on a scale to determine the as-installed density (Fig. 11). A log was developed to record the sampling done during the course of the installation (Fig.12).

Lastly, the PHIUS+ rater has served as a commissioning agent for the project, inspecting all work critical to achieving Passive House certification and performance, including insulation below the foundation, insulation at walls and roofs, airtightness and thermal-bridge-free detailing at critical conditions, HVAC system installation, ductwork and piping. The rater has conducted duct leakage testing as well as whole building

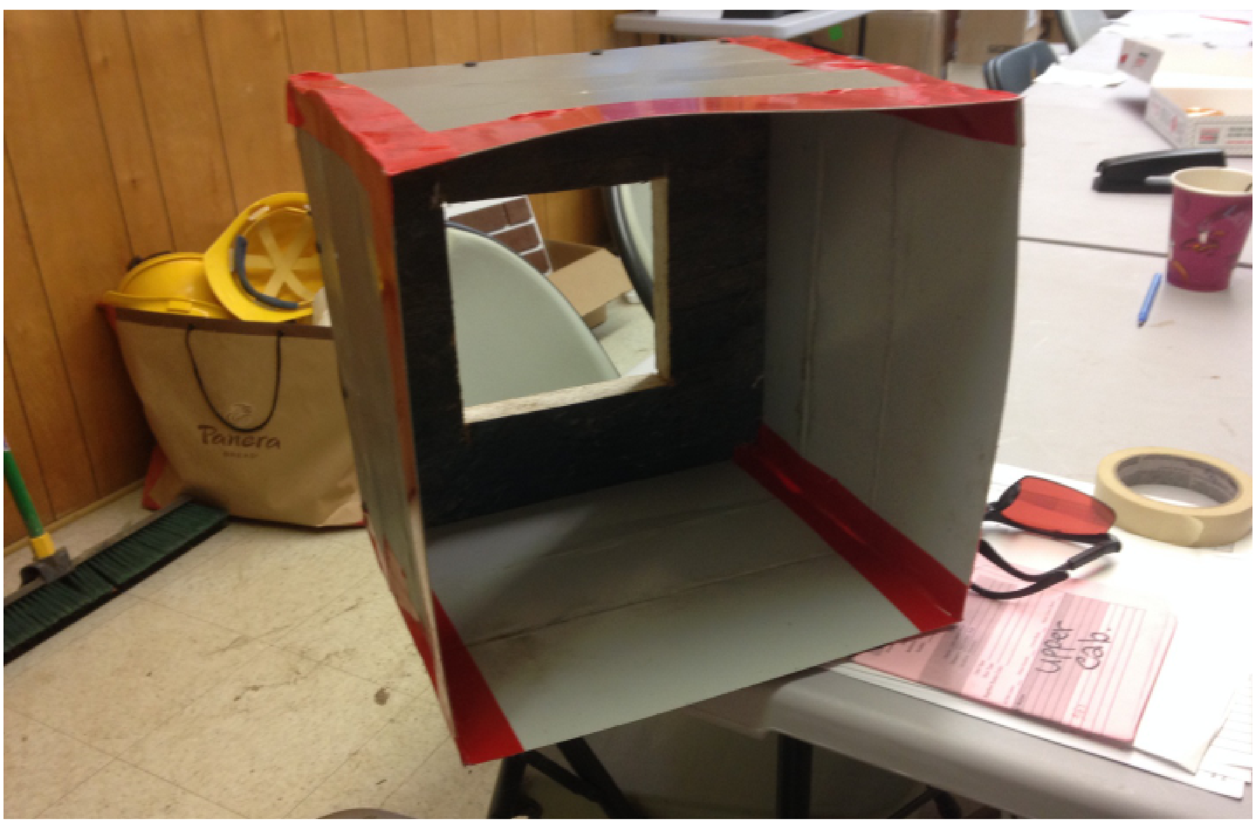


Fig. 9 - Insulation sampling box fabricated from sheet metal and construction tape

Fig. 10 - Insulation density test locations

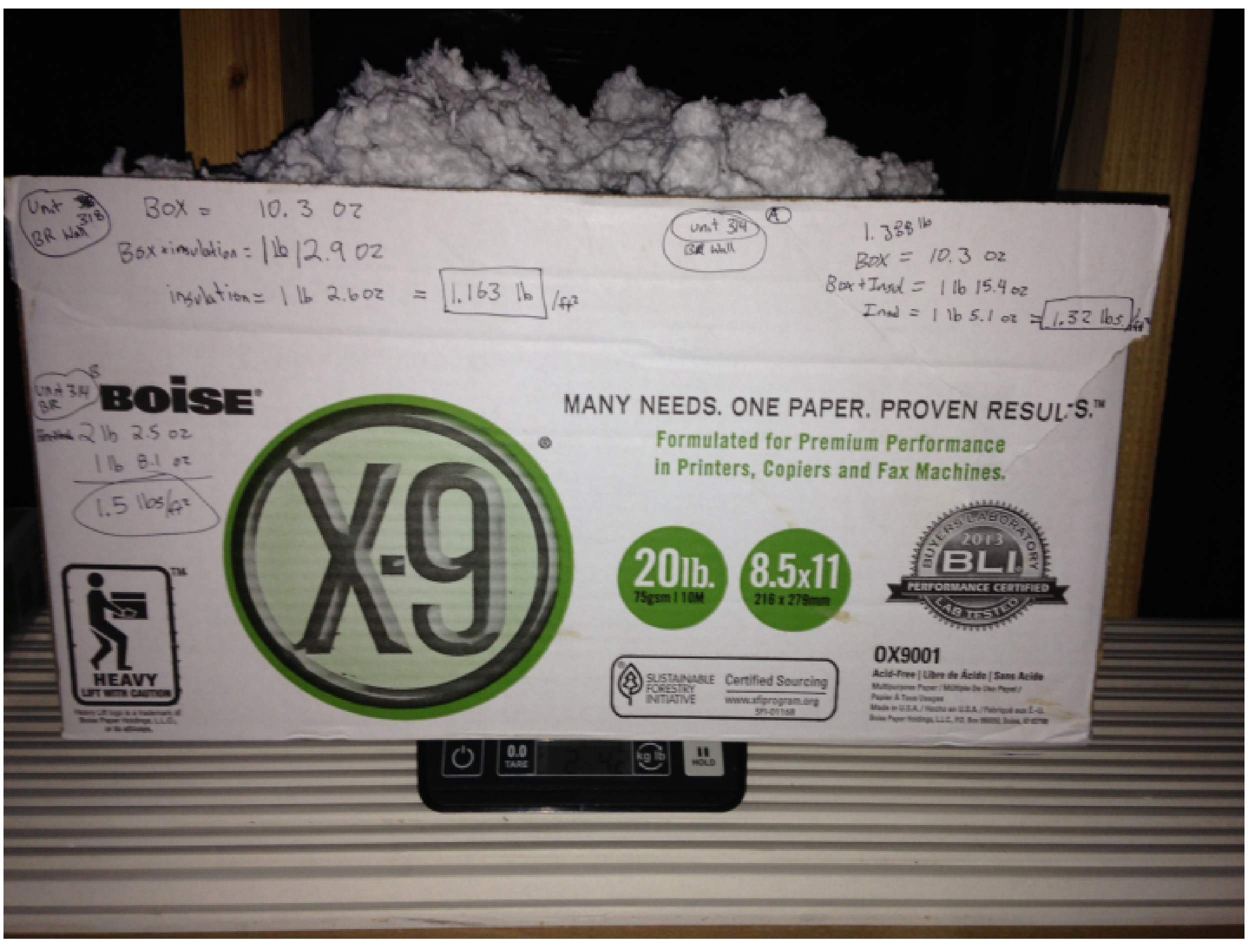


Fig. 11 - Quality control sample is weighed in specimen box

Orchards @ Orenco Station
Blown-in Fiberglass Insulation Density Check

Per submittal (07 21 26- 01 Blown-In Insulation) min density for a 2x10 stud wall = **1.388 lb/SF**

Floor	Zone	Date	Unit #	Tare Wt. (oz)	Box + Insulation (lbs. oz)	Insulation (lb/SF)	Notes
3rd FLOOR	Zone 1	12/3/2014	318	10.3 oz	1 lb 12.9oz	**1.16**	Adjacent to EA identified bays.
3rd FLOOR	Zone 1	12/3/2014	314	10.3 oz	1 lb 15.3oz	**1.32**	Adjacent to EA identified bays.
3rd FLOOR	Zone 1	12/3/2014	314	10.3 oz	2lb 2.5 oz	**1.51**	This is after Insulators added more blown-in per EA's direction.
3rd FLOOR	Zone 2	12/5/2014	303	10.4 oz	2lb 0.1 oz	**1.36**	
3rd FLOOR	Zone 2	12/5/2014	304	10.4 oz	2lb 7.9oz	**1.86**	(Miscalculated, Revised on 12/17 from 1.49 to 1.86)
2nd FLOOR	Zone 1	12/17/2014	205	10.4 oz	2lb 4.2oz	**1.62**	
2nd FLOOR	Zone 1	12/17/2014	201	10.4 oz	1lb 13.7oz	**1.21**	upper 1/4 of stud bay
2nd FLOOR	Zone 2	12/17/2014	208	10.4 oz	2lb 7.8oz	**1.84**	
2nd FLOOR	Zone 2	12/17/2014	213	10.4 oz	2lb 1.0oz	**1.41**	upper 1/4 of stud bay
			OVERALL AVERAGE:			**1.477**	

Fig. 12 - Insulation density test log

airtightness testing. A crucial step in the quality process occurred at roughly the midpoint of the 12-month construction schedule when trade work was halted for several days to conduct an interim whole building test to assess initial airtightness and the relative integrity of the air barrier system. Results from this testing were affirmative, with preliminary airtightness measured at 0.075 ACH50. Another airtightness test will occur upon the completion of construction to verify compliance with the Passive House requirement of 0.6 ACH50 maximum. Through the implementation of these various QA/QC activities and measures, the project team has worked effectively to ensure the building meets the performance targets established by the owner.

The Importance of Details

The design of the various enclosure assemblies is an important first step towards achieving high performance; however, success ultimately lies in the details. A knowledgeable and disciplined approach to enclosure detailing is required, or the actual performance of the building will likely be compromised. If water is not managed properly at the level of the details, water intrusion may occur, leading to durability problems. A lack of thermal insulation continuity, or airtightness, can lead to excessive heat loss and higher energy use, as well as problems with condensation within the hidden interstices of assemblies. Inadequate vapor control could lead to condensation problems as well.

To achieve effective hygrothermal performance at the level of the details, it is vitally important to establish continuity of the five critical barriers, and then to clearly indicate that continuity in the design drawings. On Orchards, the project team used *critical barrier analysis* during the design development process. This analysis methodology - and the terminology associated with it - has been developed by several building scientists over the past decade (Lstiburek 2007; Lawton, 2010; Finch et all 2013).

In terms of hygrothermal performance, the critical barriers of the building enclosure are:

1) the water-shedding surface
2) the water-resistive barrier
3) the air barrier
4) the vapor barrier
5) the thermal barrier

Design and construction team members can utilize a review/analysis exercise where one traces the barriers through the various drawings that describe the building enclosure. 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 assessed at the level of the wall section and enlarged plan, whereas each of the other barriers is best traced and assessed at the detail level, although indicating the general configuration at larger scale drawings is very helpful for communicating design intent.

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 remain misinformed of key materials and components, or sequencing requirements, needed to achieve the continuity of those barriers. As the project transitions into the construction phase, critical barrier analysis can be employed by the contractor also, to ensure continuity of the barriers is maintained. This is particularly important when detail adjustments are considered or implemented during the coordination process.

A discussion of five important interface details developed and implemented by the Orchards team will illustrate a number of the challenges encountered when designing and building the Passive House enclosure. The key to successful detailing at these interfaces has been providing continuity of the thermal barrier and air barrier, while managing water first at the water-shedding surface and then again at the water-resistive barrier level. The water-shedding surface and water resistive barrier, working together, provide two lines of defense against water intrusion at the exterior walls - a level of water management redundancy that is warranted at high R-value wall assemblies given the reduced heat flow through the assemblies and the high level of airtightness that is also essential to high performance enclosure design.

It is important that the architect clearly convey the design intent of the air barrier system in the individual details of the interface conditions of the building enclosure; however, at many buildings this intent can be more comprehensively described if the system design is called out at the enlarged scale wall sections or building sections and plans. On Orchards, the architect clearly indicated the configuration of the plane of airtightness at the wall sections and also the building sections (Fig. 13). By delineating the air barrier system configuration at these drawings, the design team helped the construction team develop a more complete understanding of the design intent, which ultimately led to successful implementation of the system during construction.

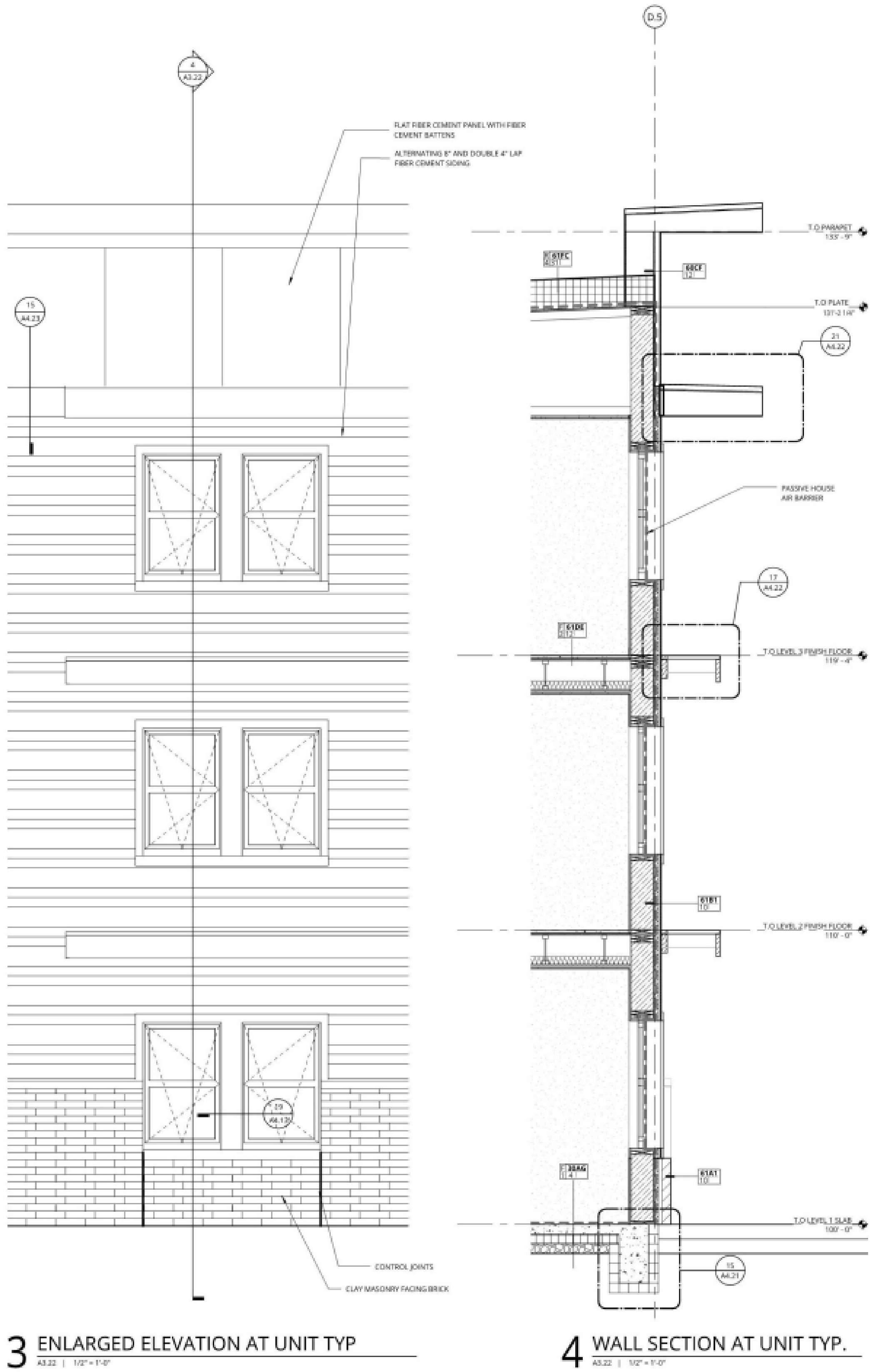


Fig. 13 - Architect’s wall section drawing indicating configuration of air barrier system and thermal barrier

Image courtesy of Ankrom Moisan Architects

Detail 1 - Wall to Foundation

The exterior wall to foundation condition provides an excellent example of the need to balance competing performance priorities when developing the Passive House enclosure design. This is the typical base of wall condition, with brick veneer used as a "wainscot" around most of the building base. From the architect's detail (Fig. 14) one can see that water resistive barrier continuity is provided, with the water resistive barrier ("WRB") shown lapping over the self-adhered membrane flashing ("SAM") which in turn laps over the stainless steel flashing at the base of the wall. The water-shedding surface is continuous, formed by the exterior face of the brick which at the base of wall ties in with the top of the concrete sidewalk which slopes away from the building. It can be seen that thermal barrier continuity has been provided through the detail condition for the most part. EPS insulation runs continuously for the most part from the sub-slab area, wrapping the concrete perimeter footing up to the top of the foundation, and then mineral wool insulation provides thermal barrier continuity upwards at the wood frame wall. One small discontinuity occurs at the steel brackets, which interrupt the continuous insulation layer at the exterior side of the foundation. These proprietary brackets are installed at 48 inches on center around the building foundation. Instead of using a "brick ledge" configuration on the footing as is typically used to support for brick veneer claddings, a steel ledger angle is used here. The ledger angle is connected to the intermittently installed brackets. This approach thermally isolates the ledger angle and the brick veneer from the concrete foundation, although there is a small amount of heat loss through the brackets. Air barrier continuity is provided by the SAM strip, which seals from the face of sheathing at the wall to the face of concrete at the footing. This SAM also provides a redundant layer of water management in the event any leakage occurs in the stainless steel flashing during the building's service life.

A number of adjustments and clarifications were made to the detail during the coordination process. Each of these adjustments can be seen in the contractor's coordination drawing (Fig. 15). The sub-slab vapor barrier had not been indicated in the architectural detail but it was important to determine configuration and termination details prior to installation. Additionally, the architect's drawing of the slab-on-grade assembly had called for the vapor barrier to be placed below the insulation. The contractor questioned if the vapor barrier could be relocated to the top of the insulation, to avoid the potential for problems with water collection in the insulation layer should it rain prior to the slab placement. The architect agreed to this revision. Due to constructability and sequencing considerations, the construction team also proposed to place the concrete in two lifts and this was agreed to by the architect as well; however, this change resulted in a horizontal cold joint in the foundation perimeter. Working with the vapor barrier installer, the contractor developed a proposal for terminating the vapor barrier within the cold joint, using an accessory seal product suited for this application (Fig. 17). Additionally, the SAM flashing and air seal was reconfigured to extend down the concrete further to seal over the cold joint. The coordination drawing was reviewed by the architect and approved for construction through the project RFI process.

During execution it was found that the cold joint on the outer face of the concrete was fairly rough and did not provide a smooth substrate for applying the SAM seal, so the contractor used a grinder to smooth out the substrate to receive the SAM (Fig. 19). Primer was applied to all surfaces prior to installing the SAM to facilitate a long-lasting bond (Fig. 20). When a significant amount of rainfall occurred prior to one of the slab pours, the team was relieved the vapor barrier had been moved to the top of the insulation (Fig. 18).

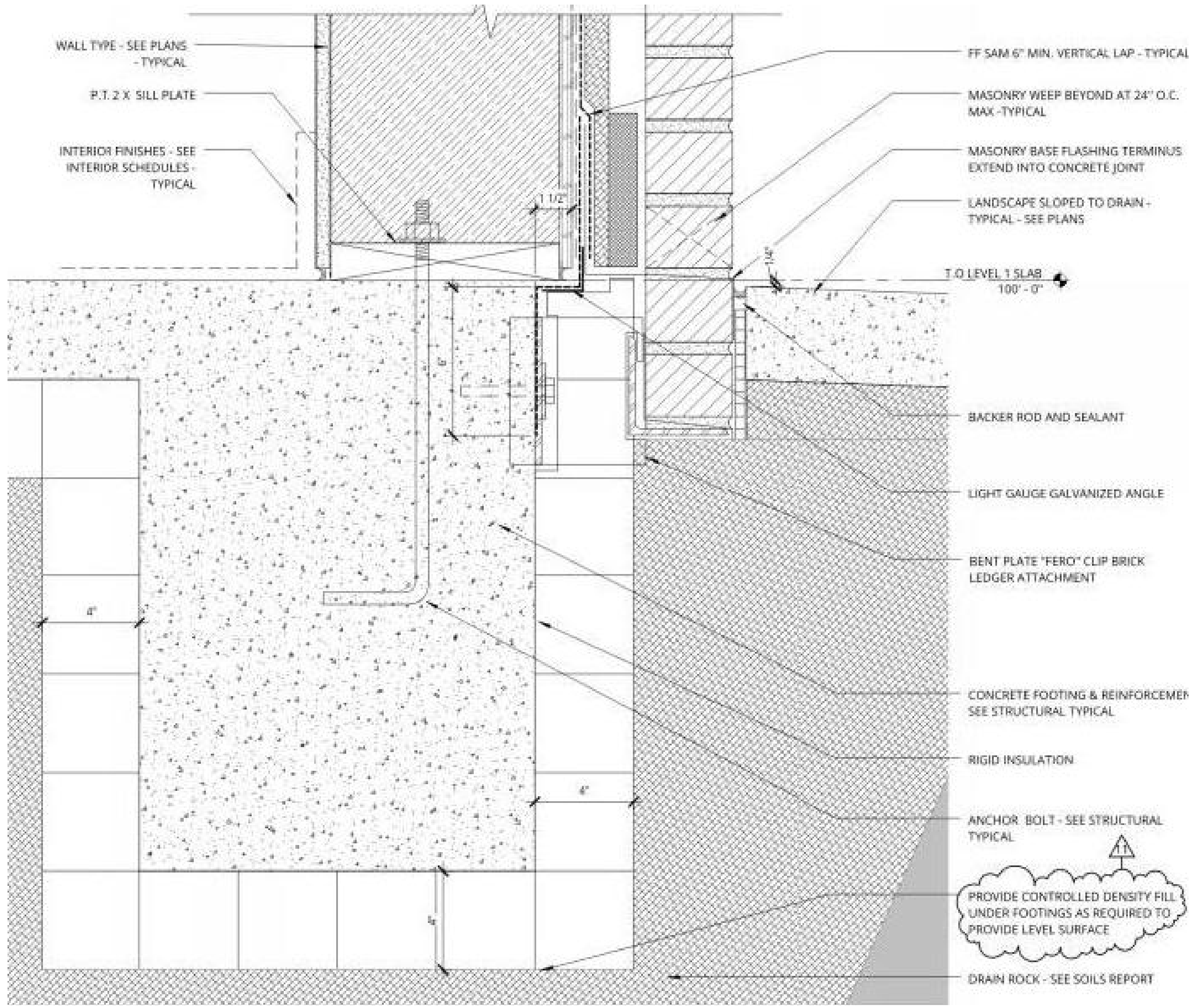


Fig. 14 - Architect's design detail at typical exterior wall to foundation condition

Image courtesy of Ankrom Moisan Architects

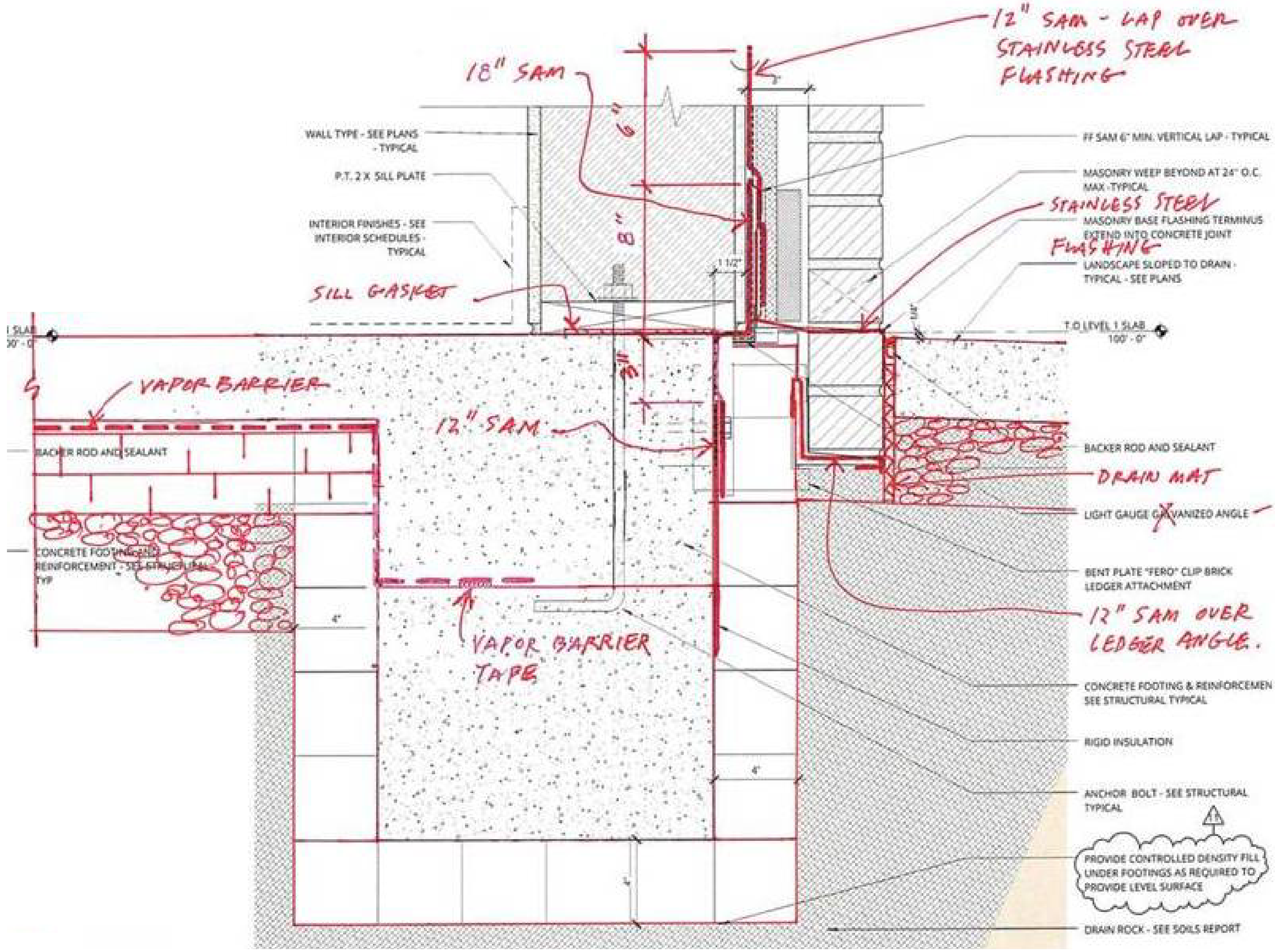


Fig. 15 - Contractor’s coordination drawing of typical exterior wall to foundation detail

Image courtesy of Walsh Construction Co.

Fig. 16 - Sub-slab insulation is installed over the gravel base. Vapor barrier installation follows.

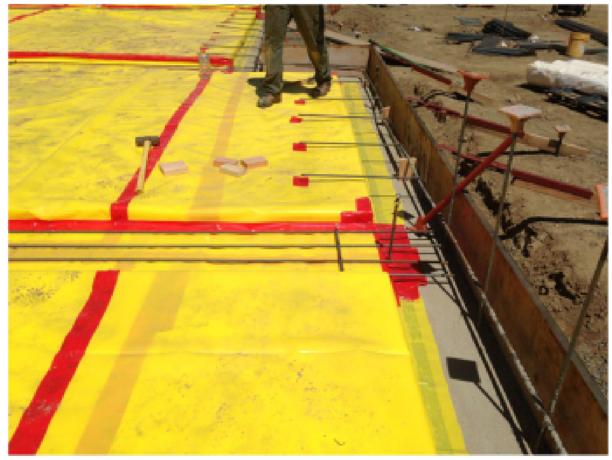


Fig. 17 - Vapor barrier termination seal at perimeter footing. An accessory product in the vapor barrier product line is used to seal the membrane to the green concrete.

Fig. 18 - When a significant amount of rainfall occurred just prior to one of the slab pours, the team was relieved the vapor barrier had been moved to the top of the Insulation.

Fig. 19 - Grinding the concrete footing edge to provide a smooth and consistent substrate for application of the SAM flashing and air seal at the typical base of wall condition.

Fig. 20 - Primer is applied to the concrete prior to installation of the SAM.

Fig. 21 - A laminate roller is used to apply pressure to the SAM to help ensure adhesion to the substrate and eliminate air pockets and pinhole leaks.

Detail 2 - Window Sill

The window to wall interface is among the most challenging detail conditions and that also proved to be the case on Orchards. Initially the design called for placing the face of the window frame approximately one inch outward from face of the wall sheathing. During design development, the Passive House consultant found that over-insulating the window frame (i.e. running exterior insulation over the exterior face of the frame) provided significant performance improvements based on the energy modeling results, so the team explored moving the window inward so that the face of the window frame was flush with the face of the sheathing. Though this improved energy performance, it created a challenge in terms of constructability. When the frame is placed outward from the face of sheathing, the cladding and flashings around the perimeter of the frame can be brought into close contact with the side of the frame while not interfering with or intruding upon the rough opening gap. The narrow gap (typically 3/8” - 1/2” wide) between the frame and the cladding/flashing is then closed with a flexible sealant. This approach accommodates construction tolerances very well as it allows a degree of flexibility in the exact dimensions of the joints/gaps between components. When the frame is placed flush with the sheathing, the cladding and flashings must be configured to enter the rough opening gap or must be applied to the face of the frame. From the architect’s typical window sill detail (Fig. 22) one can see the metal sill flashing indicated to enter the rough opening below the window sill, to provide an overlap that allows for a seal to be applied between the frame and flashing. At the sill, the flashing must be positioned below the frame since the weep openings for the window drainage cavity are located on the outer face of the frame. Furthermore, the window must be shimmed at its base and the flashing must be configured such that a 1/4” wide gap is maintained between the metal flashing and the SAM sub-sill flashing, to ensure that water can drain out of the sub-sill area.

From the detail one can see that water resistive barrier continuity is provided, with the SAM sub-sill flashing formed as a sill pan and turned down over the wall sheathing and then lapping over the WRB. The water-shedding surface is continuous, formed by the exterior face of the window (glazing, gaskets, frame) which at the base of window is sealed to the metal flashing which then laps over the fiber cement trim. Positive slope on the sill flashing and termination with projecting drip edge ensure the proper water-shedding function of the detail. One minor discontinuity exists where an unsealed gap occurs between the bottom of the trim and the top of the siding. This discontinuity is addressed in the contractor’s coordination drawing (Fig. 23). Thermal barrier continuity has been provided through the detail condition in large part; however, some minor discontinuities occur at the cavities in the window frame (these were subsequently addressed in the window manufacturer’s shop drawings). Another small discontinuity occurs where the wall cavity insulation is interrupted by the 2x10 rough sill framing; however, the continuous exterior insulation mitigates the thermal bridging impact here. An important detail for achieving airtightness occurs where the WRB is indicated to be held back two inches from the edge of the rough opening. In addition to its water-resistive barrier function, the SAM flashing serves a transition function for the air barrier system at this critical juncture. The SAM is sealed to the window frame at the back leg of the sill pan and then turns down and seals to the face of the sheathing before it laps over the WRB. The sheathing, with taped joints, serves as the primary air barrier material at the exterior walls.

Coordination of this detail was fairly straightforward. Several important dimensions were clarified in the coordination drawing. The exterior insulation is indicated to be placed 1/4" downward for the edge of the sill pan. This is to ensure positive drainage of water out of that sub-sill zone. Shims of varying lengths are called out to be used at the support points. This configuration of the shimming provided a cavity that the metal flashing could be inserted into, yet it also supported the metal flashing such that it does not interfere with the 1/4” gap needed to ensure drainage from the sub-sill zone (Fig. 34). Also, an elastomeric sealant was added at the narrow gap between trim and siding to provide WRB continuity as well as a substrate for exterior paint application.

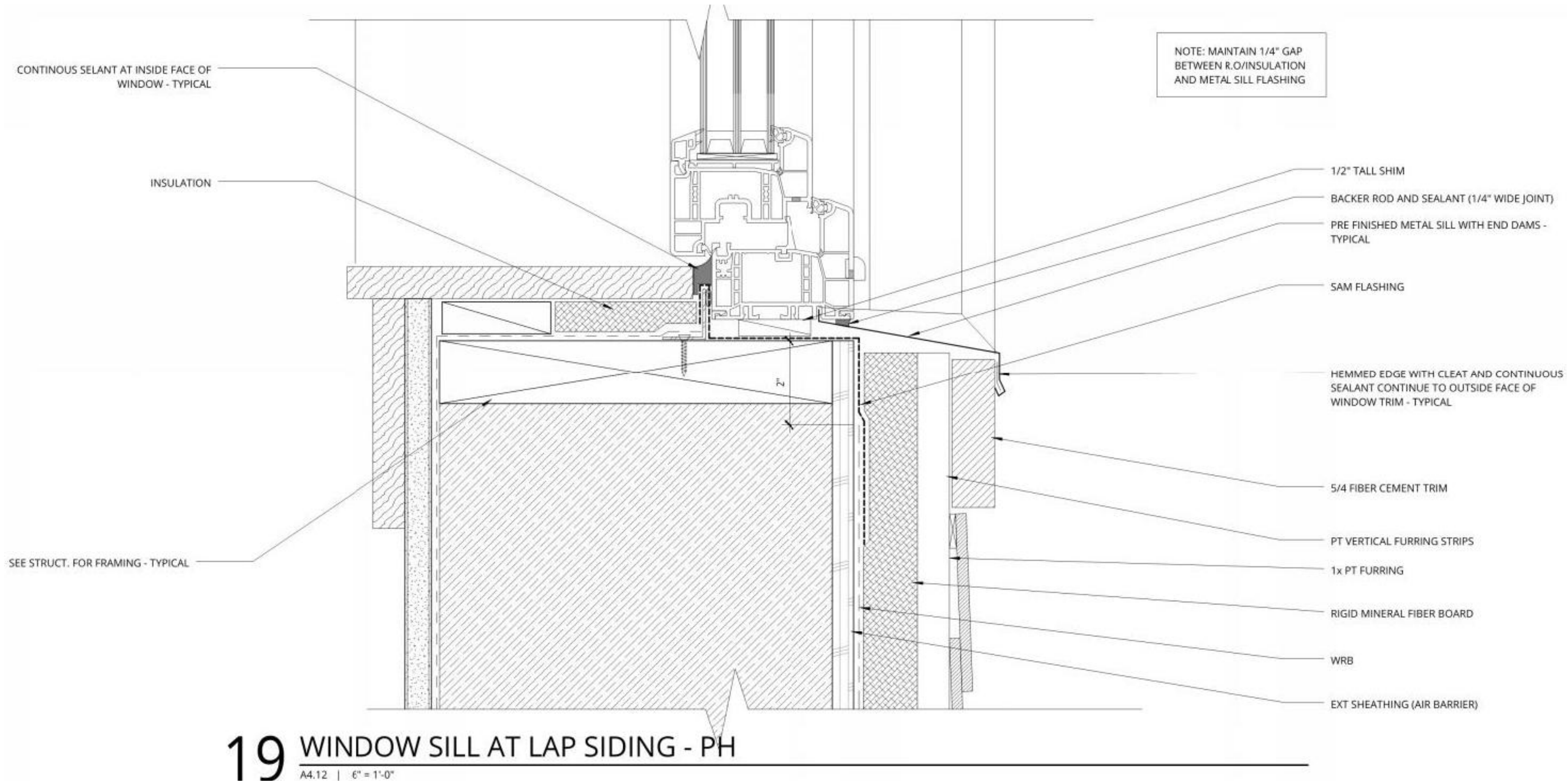


Fig. 22 - Architect's design detail at typical window sill condition

Image courtesy of Ankrom Moisan Architects

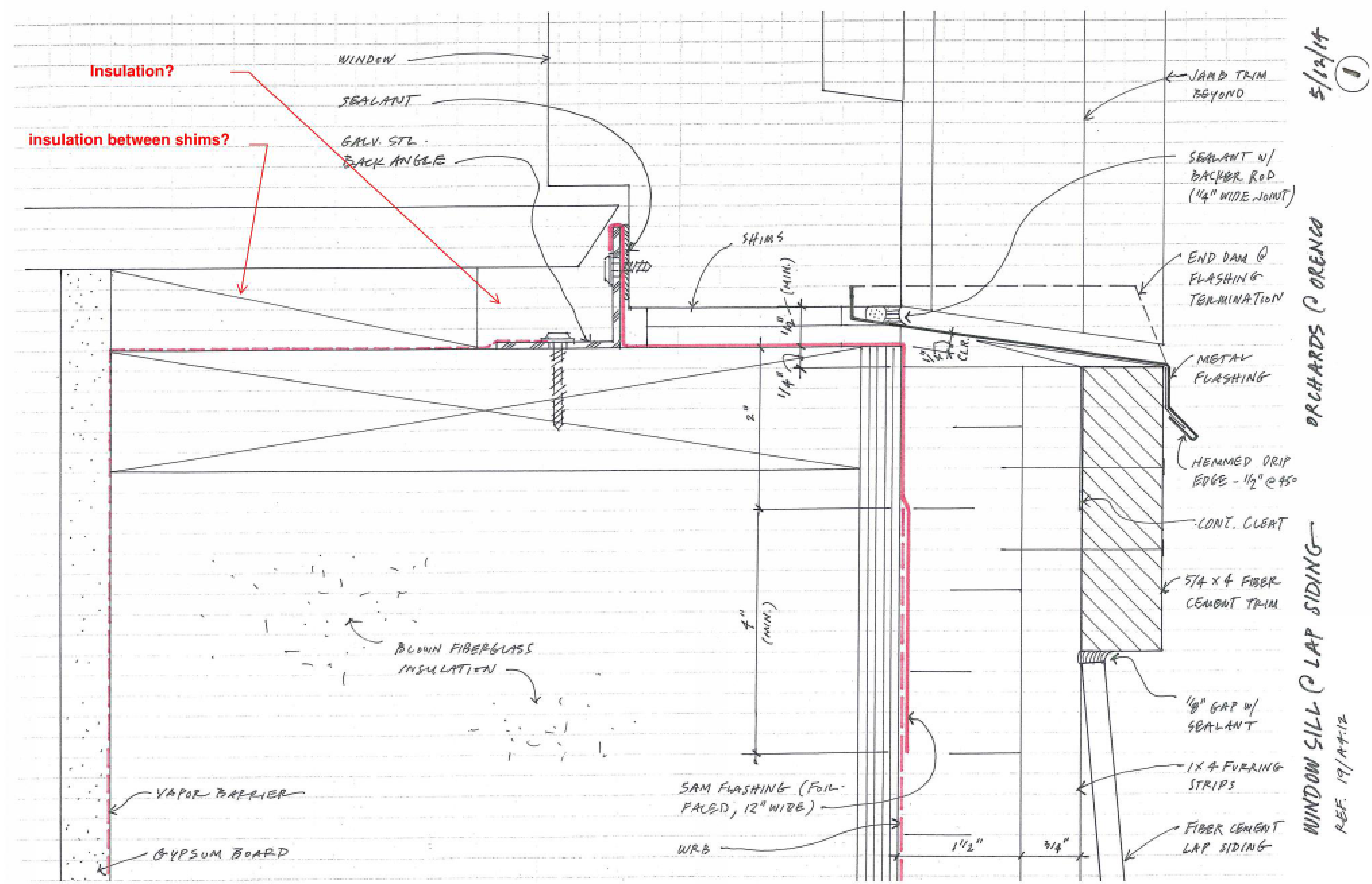


Fig. 23 - Contractor's coordination drawing of typical window sill detail. Notes in red are the architect's review comments.

Image courtesy of Walsh Construction Co.

Fig. 24 - View of exterior walls prior to preparation of the window openings. The plywood wall sheathing serves as the primary air barrier material at the walls. All joints in the sheathing are sealed with tape.

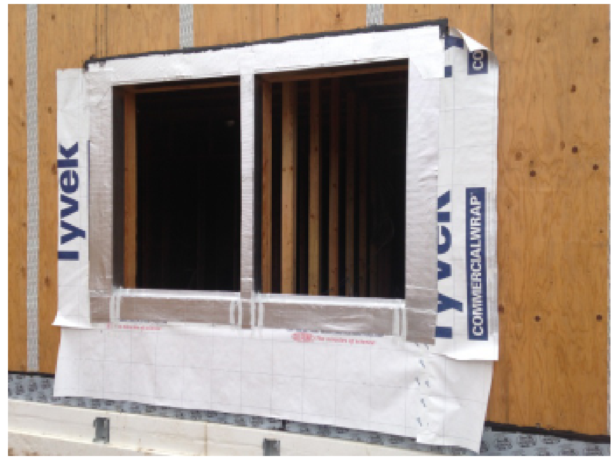


Fig. 25 - Typical rough opening preparation prior to window installation. Strips of WRB material are installed, then SAM flashing is used to wrap the openings for water management and airtightness at this crucial interface.

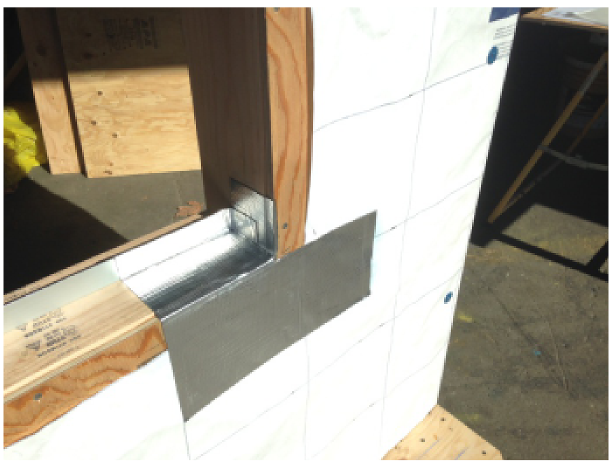


Fig. 26 - WRB material is held back 2” from the edge of the openings so that SAM is adhered to the sheathing prior to lapping the WRB. This provides for air barrier continuity. Note the SAM sill pan flashing in progress.

Fig. 27 - Sill pan flashing is complete. SAM flashing is applied to the jambs. SAM primer is applied to all substrate materials prior to adhering the SAM.

Fig. 28 - Detail view of sill pan flashing. The back leg of the pan is supported on the aluminum angle provided by the window manufacturer for attachment of the window sill.

Fig. 29 - Detail view of the SAM flashing wrap at jamb and head.

Detail 3 - Window Jamb

The architect's detail of the typical window jamb condition indicates the window frame to be positioned flush with the face of the sheathing (Fig. 30). The exterior insulation that covers the wall is shown extending over the frame approximately one inch. Two different wood furring strips (or "nailers) are indicated with the siding and trim fastened to these strips. Given the relatively compressible substrate of mineral wool exterior insulation, the configuration of these furring strips could be problematic. The 5/4 nailer is cantilevered off the wall and fastened with only one row of nails. After review during the BEC meeting, it was agreed that a single, wider furring strip could be used at this condition, which allowed for more robust attachment of the furring to the wall framing using two rows of screws, as is indicated in the contractor's coordination drawing (Fig. 31).

One can see that water resistive barrier continuity is clearly and simply provided at the window jamb, with the SAM flashing wrapping into the rough opening and turned out over the wall sheathing and then lapping over the WRB, similarly to the sill condition. A seal is applied between the SAM and the frame at the interior perimeter of the window to complete the WRB continuity. The water-shedding surface is continuous, formed by the exterior face of the window (glazing, gaskets, frame) which is sealed to the fiber cement trim. One minor discontinuity exists where an unsealed gap occurs between the trim and the siding. This discontinuity is addressed in the coordination drawing. Thermal barrier continuity has been provided through the detail condition in large part; however, some minor discontinuities occur at the cavities in the window frame. Another small discontinuity occurs where the wall cavity insulation is interrupted by the 2x10 rough jamb framing, but the continuous exterior insulation mitigates the thermal bridging impact here. Similarly to the sill, an important detail for airtightness occurs where the WRB is indicated to be held back two inches from the edge of the rough opening. In addition to its water-resistive barrier function, the SAM flashing serves a transition function for the air barrier system at this critical juncture. The SAM is sealed to the window frame at the interior perimeter of the window and then turns outward and seals to the face of the sheathing before it laps over the WRB. The sheathing - with taped joints - serves as the primary air barrier material at the exterior walls.

As with the sill condition, coordination of this detail was fairly straightforward. Several important dimensions were clarified in the coordination drawing. The two separate furring strips indicated in the architect's detail were replaced by a single 1x6, providing more robust attachment to the wall framing. An elastomeric sealant was added at the narrow gap between trim and siding to improve the continuity of the water-shedding surface. The contractor was concerned about the spray foam insulation indicated in the rough opening gap in the architect's detail due to its impacts on managing water in this window to wall interface. Typically that gap is utilized as a cavity to facilitate drainage of incidental moisture that potentially migrates into the opening. The window manufacturer also stated a concern about placing expanding foam in the rough opening gap. The contractor proposed adding a seal at the outer perimeter of the frame to mitigate the potential for water and air leakage by providing a redundant seal at the interface. The design team was concerned that removing the insulation could result in a reduction in energy performance; however, after modeling to predict the results of removing the insulation, it was agreed the insulation could be removed and replaced with the outer seal. Also, the coordination drawing clearly indicates how the trim is to be attached. Prior to installing the trim at the window, the face trim piece is nailed to the return piece. Then this prefabricated 90 degree trim is nailed to the furring strip at the window opening, leaving a 3/8" wide gap between the trim and the window frame. This gap is then sealed to provide water-shedding surface continuity.

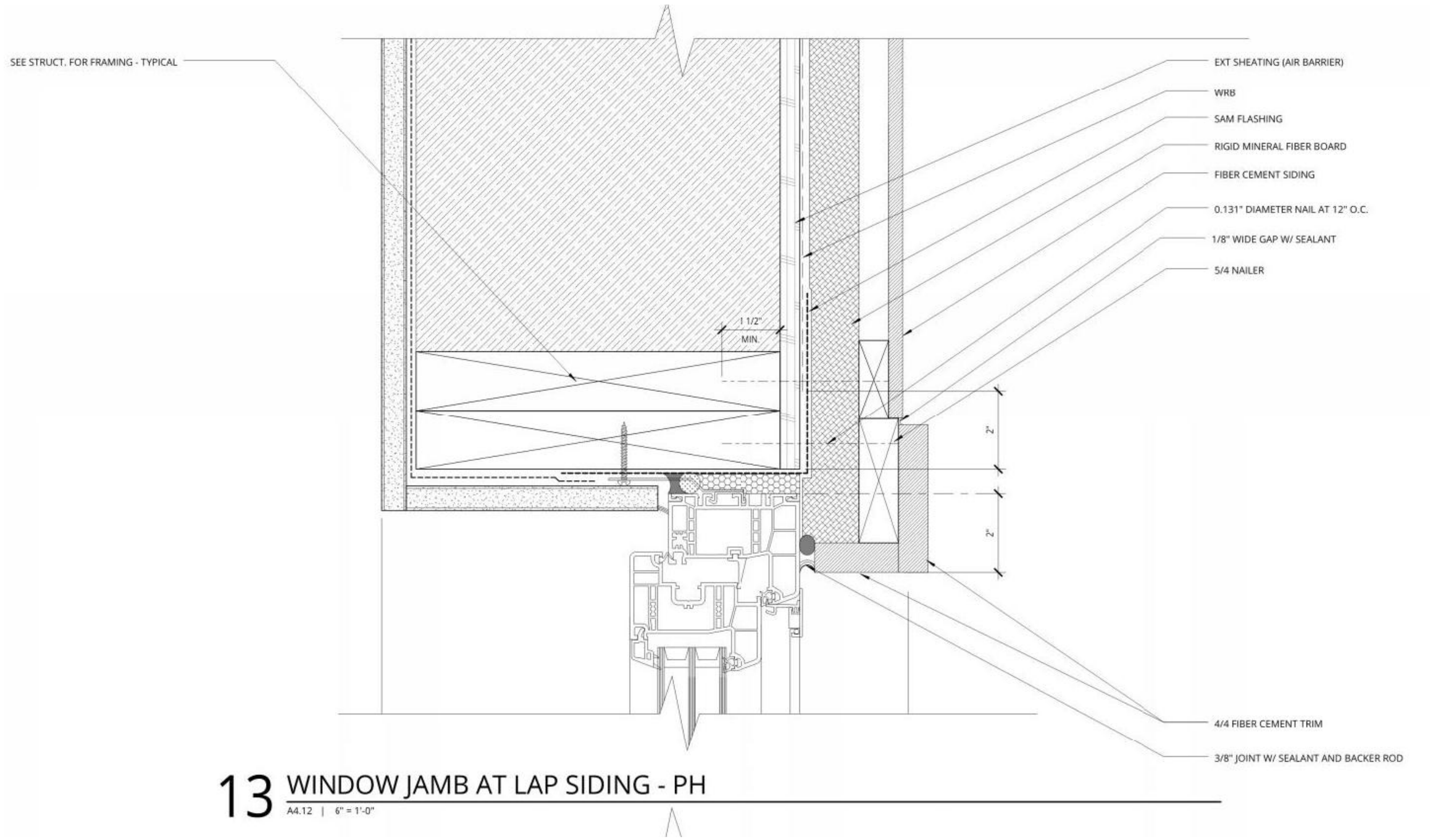


Fig. 30 - Architect’s design detail at typical window jamb condition

Image courtesy of Ankrom Moisan Architects

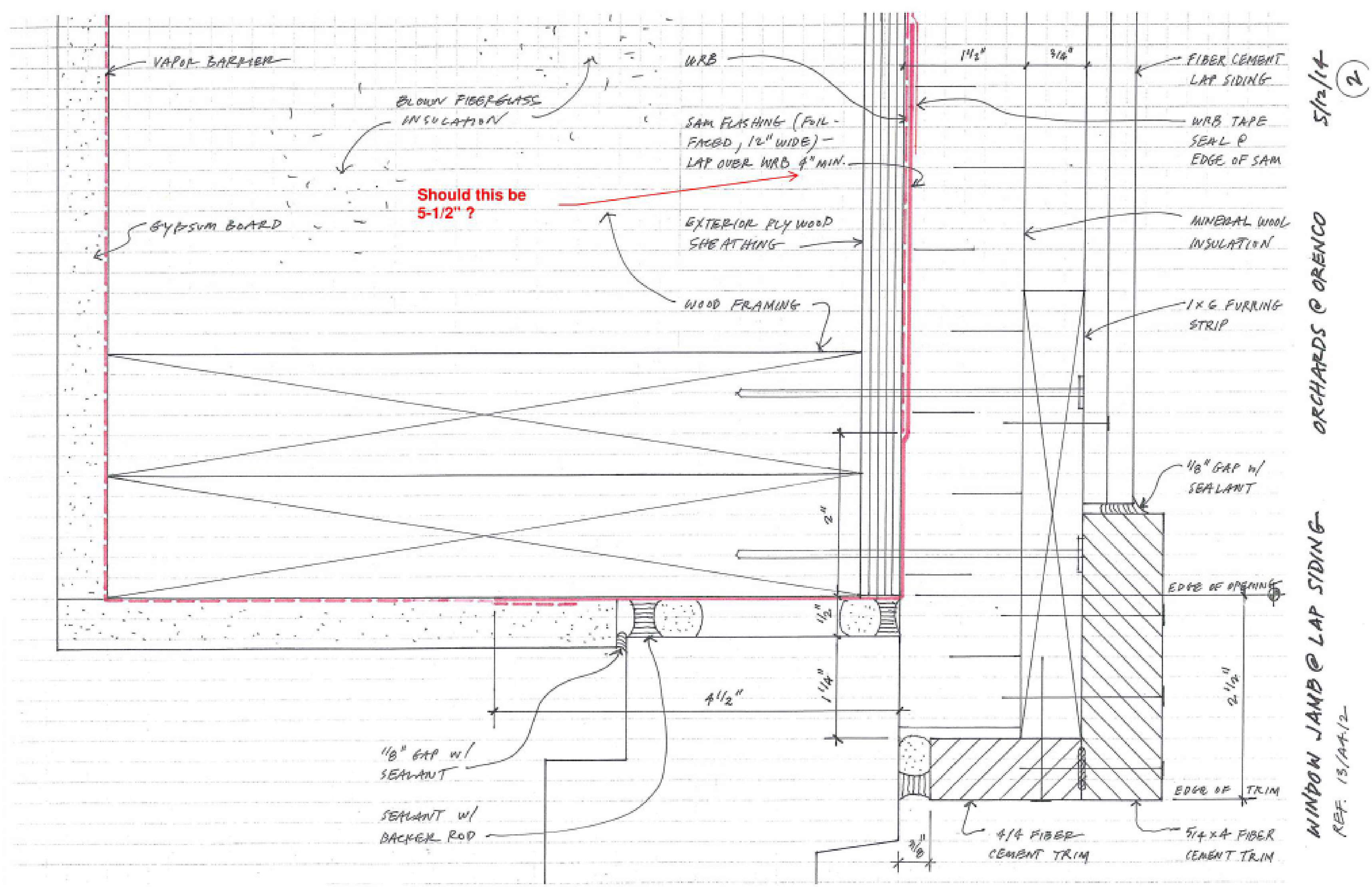


Fig. 31 - Contractor’s coordination drawing of typical window jamb detail. Notes in red are the architect’s review comments.

Image courtesy of Walsh Construction Co.

Fig. 32 - View of typical rough opening preparation at ground floor units, showing ganged windows and exterior door. This view also shows the SAM flashing and air seal applied at the base of wall.

Fig. 33 - View of rough opening prep at upper floor units where balconies occur. The water-resistive barrier system will be installed and completed in its entirety prior to installing the balcony structure.

Fig. 34 - View of sill pan showing two-stage shim. This set-up allows the metal sill flashing to enter the gap between the sill pan and the window frame.

Fig. 35 - Sealant is applied to the back leg of the sill pan prior to setting window into opening.

Fig. 36 - Window is fastened at the sill using an aluminum angle provided by the window manufactuer. The angle also serves as support for the SAM sill pan.

Fig. 37 - Window is fastened at the jambs and head using strap anchors provided by the window manufacturer.

Detail 4 - Window Head

A look at the architect's preliminary detail of the typical window head detail condition further illustrates how the enclosure design evolved (Fig. 38). This detail was presented at the design development (DD) stage and elicited a number of questions and comments from the contractor during the constructability/quality review process. Provisions for drainage were questioned, as was the positioning of the window frame and also the configuration of flashings and SAM/WRB materials to achieve continuity of the water-shedding surface, the water-resistive barrier and the air barrier. The architect also had an internal QA review process within their firm where many of the same questions were raised.

With each iteration of the design, the architect continued honing in on a set of well-conceived, better-coordinated details. Fig. 39 shows the final detail developed by the architect for the window head condition. Each of the issues raised in the contractor's review have been addressed, resulting in continuity of all the critical barriers, and improvements to constructability. The head flashing above the window was changed from metal to vinyl during the later stages of the design process, as the Passive House consultant raised concerns about thermal bridging caused by the metal flashing. The architect identified off-the-shelf PVC flashing that worked well with the proposed detail configuration.

Despite this well-conceived detail, the contractor found it important to propose several adjustments and clarifications to the detail during the construction phase coordination process (Fig. 40). The location of the trim and the head flashing were refined slightly by moving these components upward so the trim at the typical windows would align with the trim above exterior doors where those doors occur adjacent to windows at balconies. Moving the trim and flashing up also provided for more positive attachment of those components to the backup wall. During review of the proposed adjustments, the architect noted that this results in a lack of overinsulation at the window frame. The Passive House consultant reviewed the impacts of this in the PHPP results and confirmed the acceptability of no overinsulation at the window heads. The contractor also proposed removing the metal J-trim and this was accepted by the architect.

An important aspect of the construction management effort led by the contractor is the review and coordination of work indicated in the shop drawings developed by various suppliers or subcontractors. In the case of the window to wall interface details, the window manufacturer and the sheet metal fabrication/installation subcontractor both submitted shop drawings that had to be integrated with the contractor's coordination work. The window manufacturer's drawings were important for establishing additional dimensional coordination, particularly regarding the requirements for structural connection of the windows to the wall (Fig. 41). Other interface issues came to light during the shop drawing review process, most notably the manufacturer's persistent reluctance to allow spray foam insulation in the rough opening gap between the window frame and wall framing, out of a concern that structural loads would be placed on the window that it was not designed to accommodate. Upon review of this issue with the architect, the spray foam seal was allowed to be removed but also it was agreed that a flexible sealant would be applied between the SAM and the frame at the exterior perimeter of the window to provide redundant protection against water ingress into the rough opening gap and also to help minimize cold air flow into the gap. This seal is indicated in the contractor's coordination drawings for the jamb and head conditions. During execution, the window manufacturer's approved shop drawings were referenced for window frame dimensions and for attachment of the window to the wall, whereas the contractor's coordination drawings were referenced for the other aspects of the interface detailing.

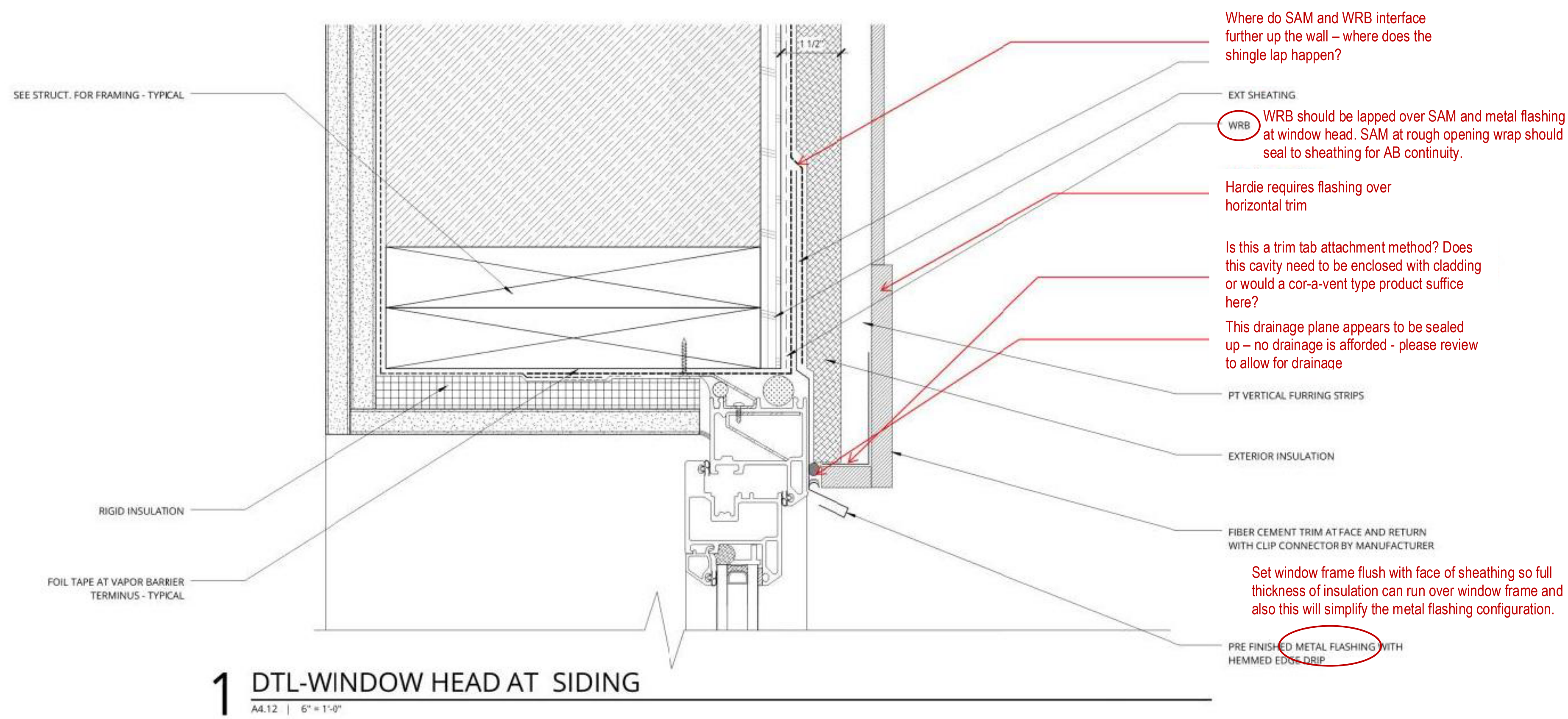


Fig. 38 - Architect's design detail of typical window head condition (at design development stage). Notes in red are the contractor's DD review comments.

Image courtesy of Ankrom Moisan Architects

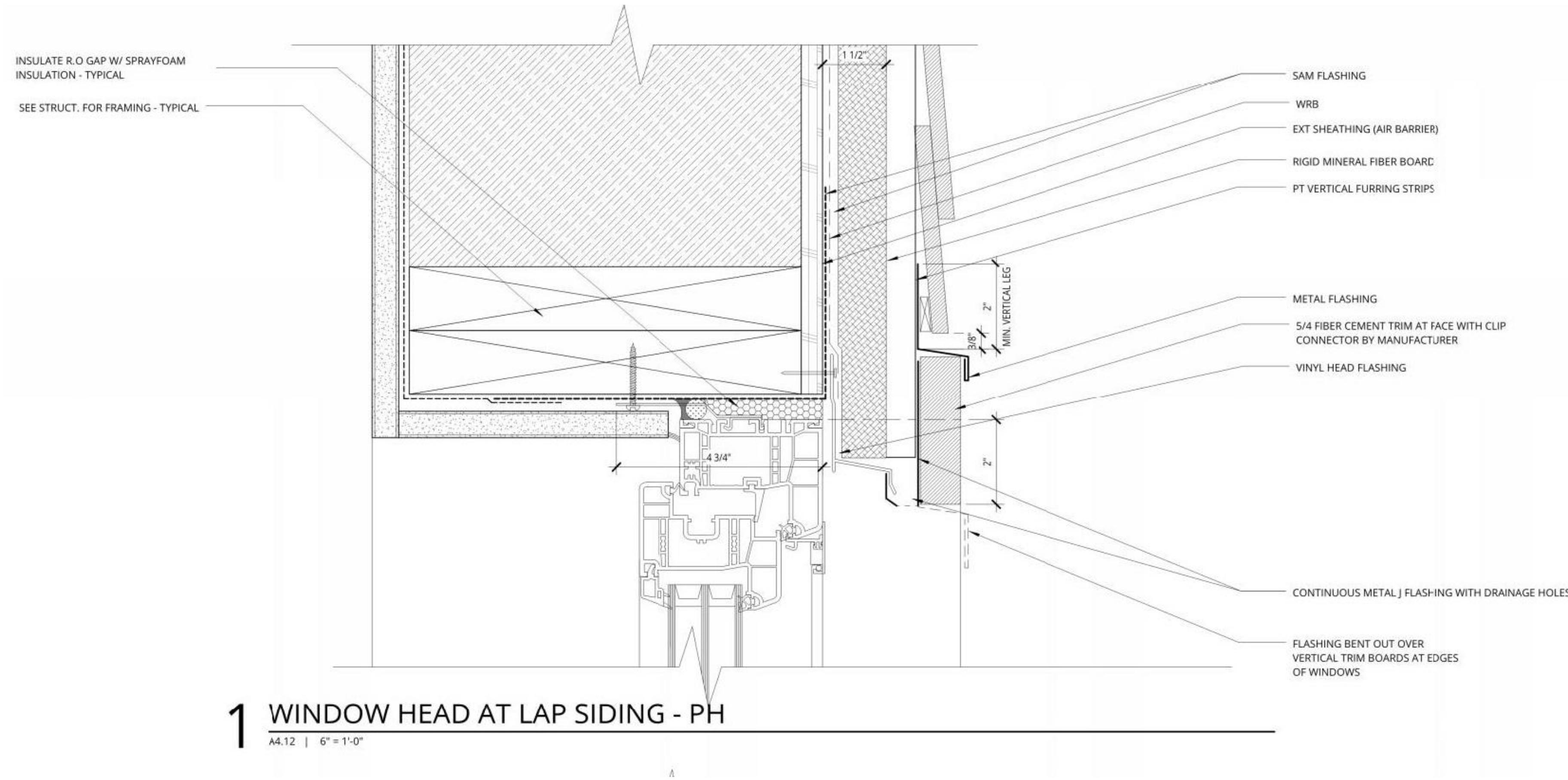


Fig. 39 - Architect’s design detail at typical window head condition

Image courtesy of Ankrom Moisan Architects

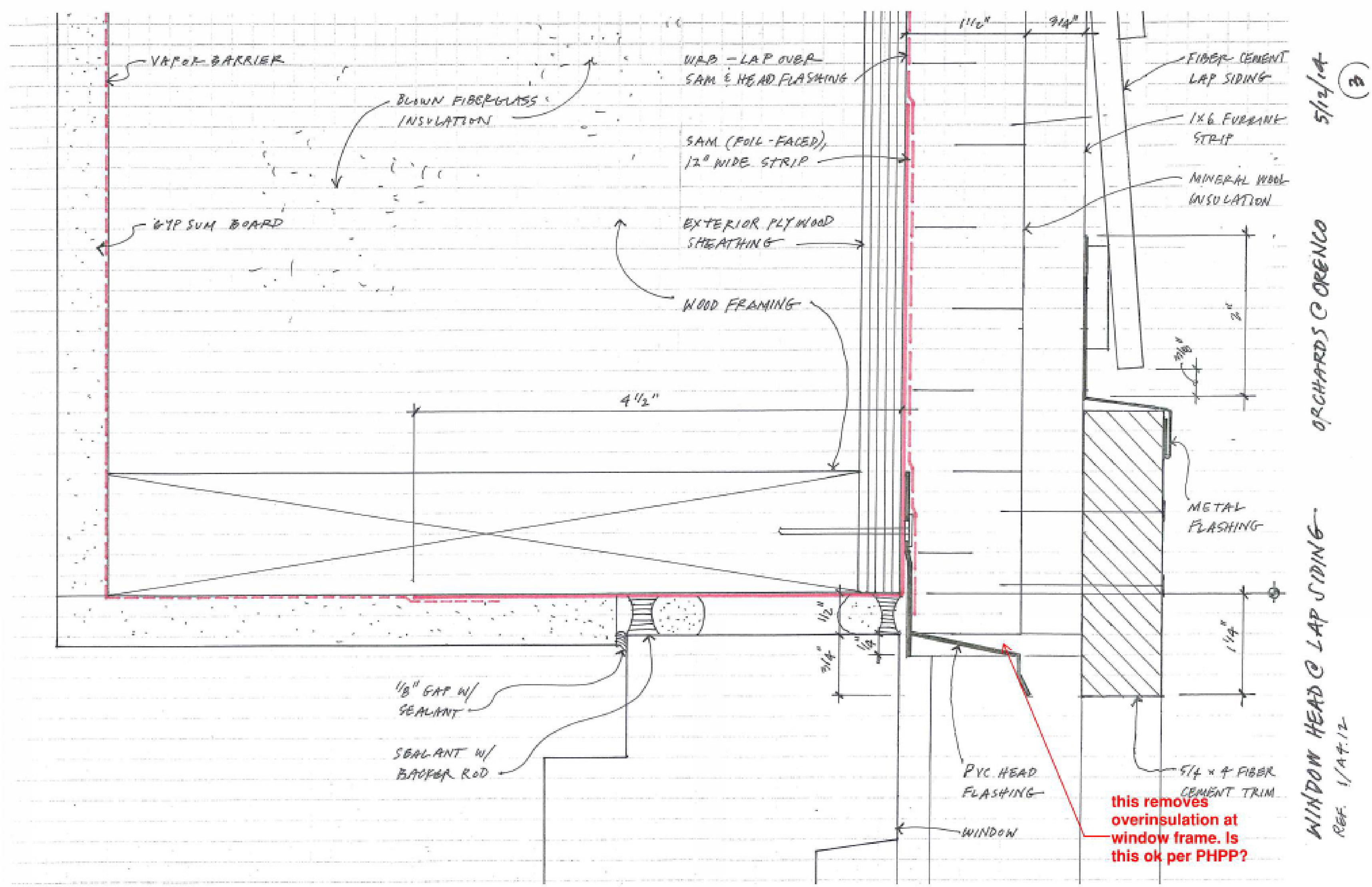


Fig. 40 - Contractor's coordination drawing of typical window head detail. Notes in red are the architect's review comments.

Image courtesy of Walsh Construction Co.

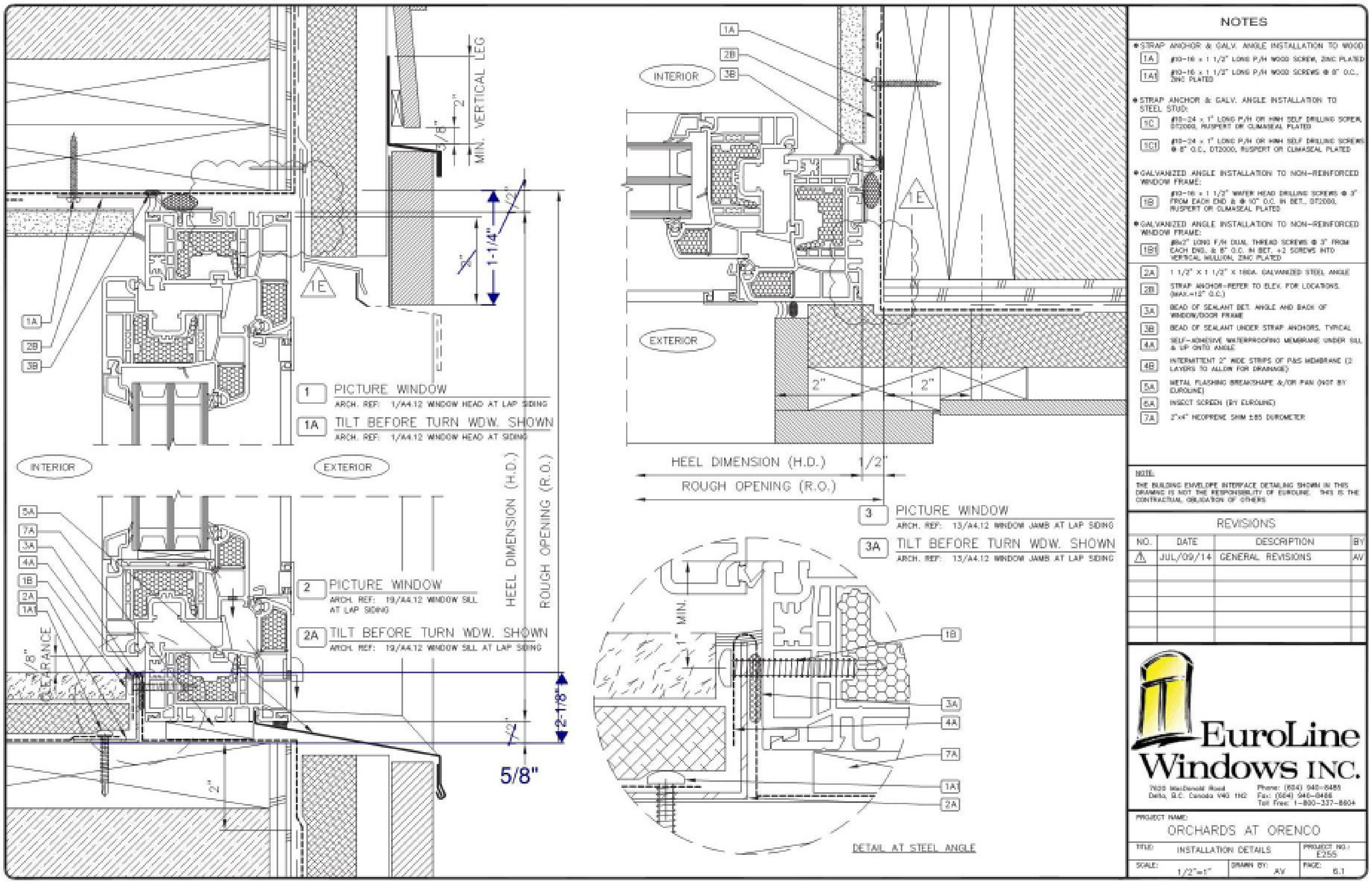


Fig. 41 - Window manufacturer's shop drawing of typical window details with dimensional coordination notes by the general contractor

Image courtesy of EuroLine Windows Inc.

Fig. 42 - Sealant applied to strap anchor location prior to fastening. This is an important detail to encapsulate the anchor in sealant to prevent air leakage.

Fig. 43 - Sealant applied to strap anchor after fastening. Backer rod and sealant is subsequently installed in the gap between SAM flashing and window frame.

Fig. 44 - Air and water seal at interior perimeter of window. This seal completes the air barrier continuity from the wall to the window.

Fig. 45 - Water seal at exterior perimeter of windows. These seals occur at the jambs and head of each window. The sill is left open to allow free drainage from the sill pan area.

Fig. 46 - Metal sill flashing (at mockup). The flashing is inserted into cavity at underside of window frame. Bond breaker tape and sealant is then applied at the gap. The flashing is placed on the lower of the two shims to provide support and maintain free drainage from the sill pan area.

Fig. 47 - Head flashing is installed directly above the window frame. WRB from the wall area above the window is then folded down to lap over the head flashing.

Fig. 48 - View of exterior walls after completion of the water-resistive barrier system. Treated wood blocks have been installed over the WRB at balcony ledger locations. Saddle flashing is to be installed over each block.

Fig. 49 - Mineral wool exterior insulation and treated wood furring installation in progress.

Fig. 50 - Fiber cement siding and trim installation in progress.

Fig. 51 - View showing trim installed prior to siding installation. Flashing and ventilation trim associated with the balcony ledger can be seen at the floor line area.

Fig. 52 - View showing similar balcony area with siding installed. Balcony ledgers will be attached to the intermittently placed wood blocks. This allows for thermal barrier continuity at the floor line area.

Fig. 53 - Metal sill flashing termination and fiber cement trim configuration at typical window.

Detail 5 - Wall to Roof

The typical detail where the exterior wall meets the roof exhibits good continuity of all the critical barriers with the exception of the vapor barrier (Fig. 54). The vapor barrier is not clearly indicated at either the wall assembly or the roof in this detail. Continuity of the thermal barrier is achieved by placing insulation in the parapet wall framing cavities. There is a minor amount of thermal bridging that will occur at each of the studs in the wall framing. The roof insulation is continuously installed over the roof sheathing. Prior to installing the insulation, a rubberized asphalt self-adhered membrane (SAM) is installed over the roof sheathing serving as the vapor barrier for the roof assembly. The SAM also functions as a temporary roof during construction until the insulation and roof membrane are installed. Although the vapor barrier had not been indicated in the detail, it had been indicated in the architect’s assembly drawing for the roof so it was clearly understood to be in the scope of work for the roofing subcontractor. The metal coping at the top of the wall, terminating on both edges with a drip edge, and lapping over the cladding on each side of the parapet, provides good continuity of the water-shedding surface. The high-temperature-rated SAM flashing that wraps the top of the parapet wall framing and laps over the WRB and the roof membrane provides water-resistive barrier continuity. Air barrier continuity is achieved with sealant applied in two beads at the roof truss framing and blocks that are to be installed between the trusses. By sealing both the exterior wall sheathing and the roof sheathing to the blocking, continuity appears to be provided; however, the gaps between the blocking and the truss members would likely allow some degree of air leakage such that the continuity is questionable. Vents are indicated at the parapet to allow airflow and thus facilitate the removal of moisture that could occur in the framing cavities. Since there is very little heat flow through the parapet wall, there is no drying mechanism other than ventilation.

During the coordination process the contractor proposed a different approach to achieving air barrier continuity at the wall to roof detail. First, the contractor had concerns about the airtightness of the design detail given the possible lack of continuity at the blocking and truss members. Also, to execute the design detail the framing subcontractor would be required to install the sealant beads during the framing process, or the contractor - who on Orchards had overall responsibility for the air barrier installation - would need to have personnel intermingling with the framers to get those seals installed. Neither option would be ideal, so the contractor proposed an alternate detail seen in the coordination drawing (Fig. 55). With this alternate approach, the roof trusses are set and the roof sheathing is installed and then strips of SAM flashing are installed to transition the air barrier from the wall sheathing to the roof sheathing. Then the parapet walls are framed on top of the SAM and roof sheathing, and fastened through to the roof trusses. Note that the SAM is extended 12” outward onto the roof deck, thus providing for a tie-in seal with the SAM vapor barrier to be applied later over the roof sheathing. The vapor barrier, which had not been clearly shown in the design detail, here is indicated to cover the roof sheathing and then turn up the side of the parapet wall, and extend up the inside of the wall to the height of the roof membrane. The vapor barrier also serves as the primary air barrier material at the roof assembly.

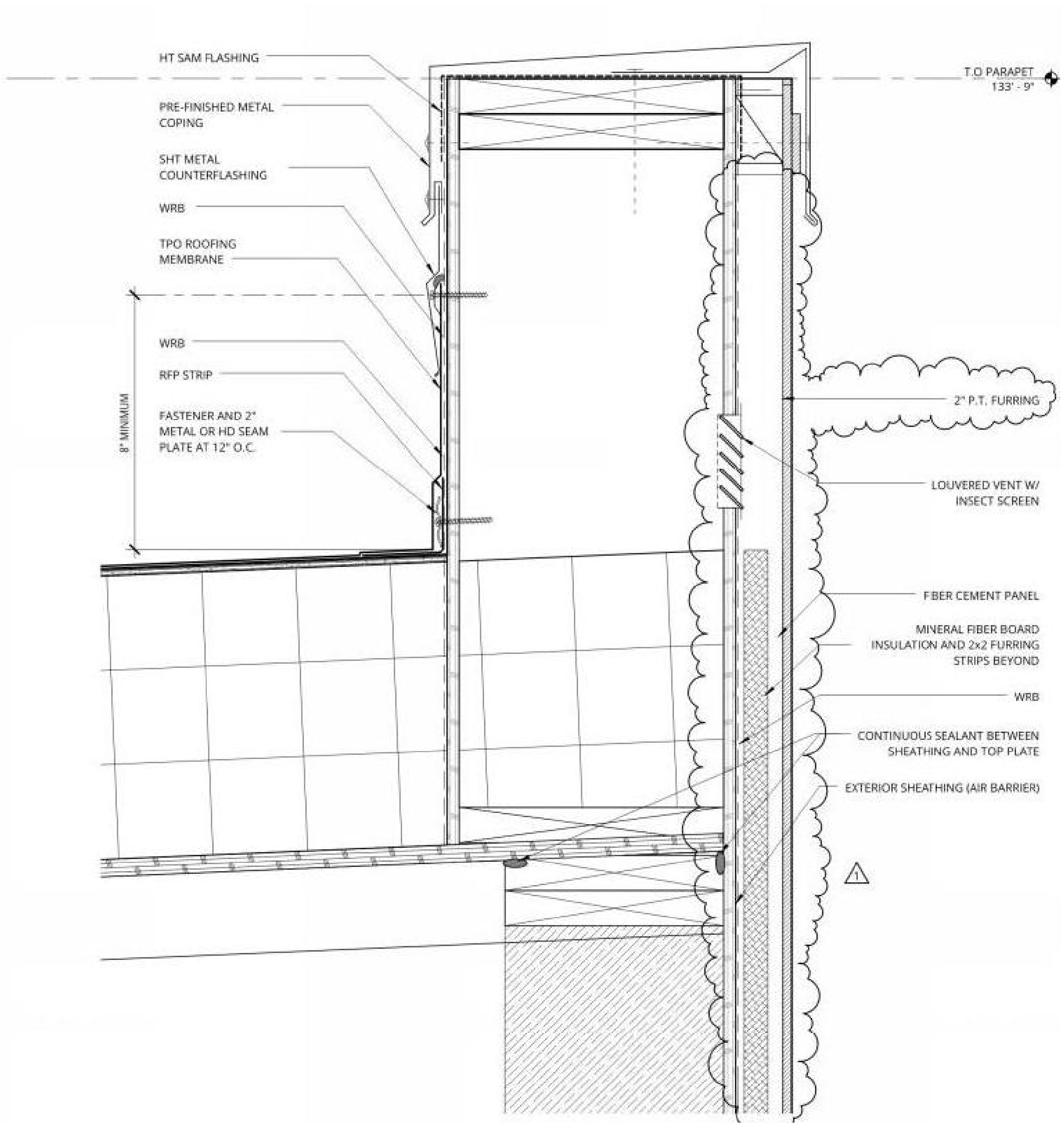


Fig. 54 - Architect's design detail at typical exterior wall to roof condition

Image courtesy of Ankrom Moisan Architects

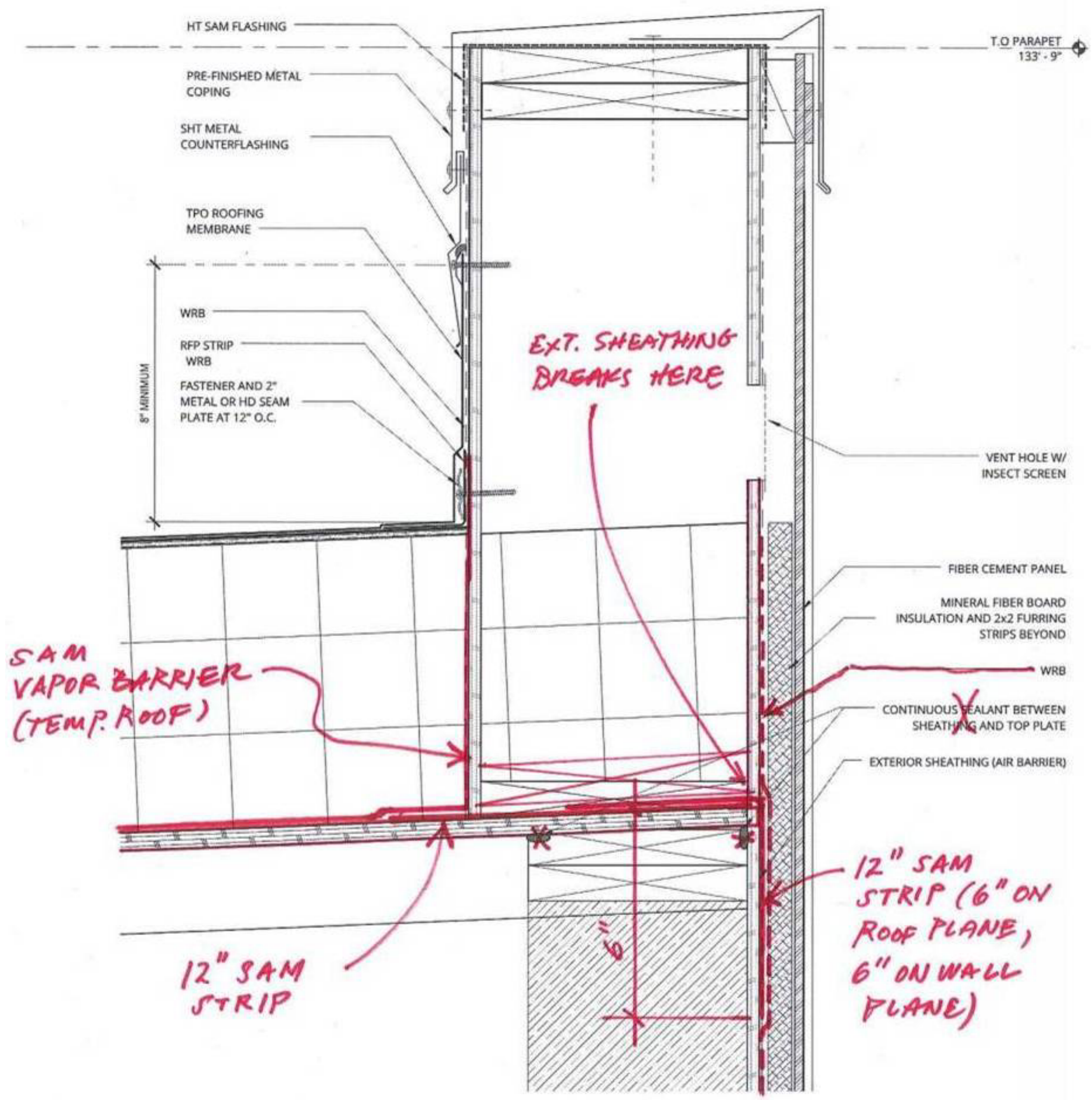


Fig. 55 - Contractor’s coordination drawing of typical exterior wall to roof detail

Image courtesy of Walsh Construction Co.

Fig. 56 - SAM is applied to interface between wall and roof. This essentially completes the seal of “the box” by connecting the wall sheathing to the roof sheathing.

Fig. 57 - SAM seal is applied to the top of “the box.” Note the poly sheeting to the right. It has been placed temporarily to keep the sheathing dry prior to installation of the membrane.

Fig. 58 - Parapet wall framing is installed over the SAM transition seal. SAM extends several inches outward from the inside of the parapet to facilitate the tie-in with the SAM vapor barrier / air barrier that will be installed later over the roof sheathing.

Fig. 59 - View of parapet walls framed on top of “the box.” Once the joints in the wall sheathing are taped, the windows are installed and sealed, and SAM is installed over the roof sheathing, the air barrier system will be largely complete.

Fig. 60 - SAM vapor barrier / air barrier installed over the roof sheathing. The SAM also serves as a temporary roof prior to placement of the roof insulation, coverboard and TPO roof membrane.

Fig. 61 - Steel strapping with large lag screws required to tie the parapet framing to the roof truss framing. These large penetrations are sealed to ensure air barrier continuity.

Concluding Remarks / Lessons Learned

As this paper is completed, construction is wrapping up on the Orchards at Orenco project. Final airtightness testing will take place in mid-April 2015, and the results of this testing will be essential to finalizing the Passive House certification. A number of conclusions and lessons learned can be derived from what appears to be the successful implementation of the Passive House enclosure on this project, regarding both technical aspects of the design and construction, as well as the process utilized to develop and implement the design.

It takes a team, working collaboratively and pushing in the same direction. A key element has been the commitment of all team members to meet the goals REACH established for the project. This has included not only members of the design and construction teams but also the broader network of consultants and funders involved. Throughout the project there has been a sense of everyone pulling in the same direction and thus, despite the challenges, there has been no sense of a tug-of-war or of obstacles that cannot be overcome. This is an important point, as it seems that where some other projects have run into problems during execution or certification, there may have been a lack of cooperation and collaboration amongst team members. While this project should serve as a case study for how Passive House can be applied to larger-scale projects in the United States, it is also an example of how early coordination, cooperation, and dedication to the Passive House standard can result in a successful implementation.

Early team integration pays off. The details developed on Orchards were relatively complex compared to standard construction; however, some degree of complexity was necessary to achieve the level of airtightness and thermal-bridge-free construction required by the standard. Passive House performance requirements have a tendency to drive design towards more complex solutions. Having the contractor and Passive House consultant involved very early in the design process fosters iterative analysis and dialogue amongst the team members in pursuit of an optimized balance of performance, cost and constructability. This level of integration is also likely to mitigate problems that could otherwise arise later during a different process when consultants and contractors unfamiliar with a design are brought into the picture. A relentless focus by the design team in keeping things as simple as possible is needed to ensure that an inordinate amount of complexity is not imposed on the construction team. Unnecessary complexity inevitably drives up costs and increases the chances for non-compliant construction and lower performance. The roof to wall detail at Orchards (Figs.5, 54 & 55) provides a good example of how detailing can be kept simple, leading to excellent results.

P**roactive coordination and quality control by the construction team is essential.** Diligent efforts to scope the work properly to the different trades, to identify gaps or inconsistencies in the drawings and specifications, to process submittals and shop drawings in a comprehensive and timely manner, are all needed to ensure successful implementation of the design. The contractor must provide effective leadership of a large group of subcontractors and suppliers that all contribute in substantial ways to the Passive House enclosure. Inspecting the work for quality control, and coordinating efforts with the commissioning agent, are also highly important in this regard.

Acknowledgments

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