The Ultimate Envelope – Honest, Effective AND Affordable

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Abstract
Thermal bridging is a term that we've been hearing more and more of over the years. However it is very rare that all the thermal bridges are accounted for when designing building envelopes and calculating the R-value for various assemblies. Recent studies have shown that even a very small percentage of uninsulated surface area can drastically decrease the overall R-value of a wall, roof or floor.

For some details careful planning ahead of time can eliminate thermal bridging all together, but others are intrinsic to building type. These often require a much larger effort and cost then they're worth to fix when compared to the energy savings that result. Then the goal becomes shrinking the uninsulated areas as much as feasibly possible.

Air barrier is another buzz word that has become more popular over the past decade. The newer multi component rubber and bituminous based systems have come a long way since their polyethylene predecessors. Now we have all sorts of lab tested performance data to compare products against each other and provide the basis for specification and code requirements. But are we actually achieving these leakage rates when installed in the field? How many projects are actually testing their wall assemblies on site, how many have the budget to do so?

Our experience with air barriers has been mostly with high-rise multifamily affordable housing, so budgets were tight. These buildings were shooting for a high performance certification where a continuous unbroken air barrier was a requirement, but it was up to the energy consult to define what this actually meant for each project.

First we tried following manufacturers requirements by the book. Often though, the details they provided did not match what we were seeing in drawings and in the field and had to be customized. This proved to be more difficult then anticipated because even though guidance was provided as to what products go where, very little information on sequencing was given.

When implementing via manufacturer methods it quickly became apparent that this was not going to work for these types of materials. Excessive use of materials, complexity of sequencing, and lack of compatibility with non-family products drove the cost of these systems higher then the market would bare. Alternative products and methods of achieving a continuous, unbroken air barrier is needed. This paper looks at these issues in more detail, providing first hand accounts of real problems and potential solutions found in the field.

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Introduction

Since 2004, SWA has been very active as a technical consultant in the development and implementation of the New York Energy Research and Development Authority's Multifamily Performance Program. The program provides whole building energy savings targets and financial incentives for developers to realize an ENERGY STAR label for new, high rise multifamily buildings. In our work with developers to improve building performance in over 3 million square feet of new construction at various stages of design and construction, we have identified many problems and some solutions for improving the air tightness and thermal performance of envelopes in masonry buildings.

Everyone talks a good game about how to deal with air barriers, insulation, vapor barriers and the like. But are some of the harder details being worked out during design or are they being left up to someone out in the field?

Thermal bridging and the correct detailing of installation and air barriers will be examined, especially in the envelope weak spots mentioned below. We will discuss current best practices, comparing some of the available products on the market and in field application.

- Exposed plank edges
- Shelf angles (even when insulated)
- Wall to window insulation/air barrier
- Connection between wall insulation and roof insulation at parapet

Guidelines for prioritizing envelope recommendations based on potential for energy savings and ease of implementation are presented. Typical and best practice whole wall R-values for various assemblies are discussed. For example, a 10,000 square foot roof with nominal R-40 insulation above the deck can have a true whole wall R-value of R-20 if there is a typical 1' insulated gap at the roof perimeter at the parapet! The contrast between these "honest" whole wall/roof R-values and the typical inputs used with whole building energy modeling software to meet various program requirements will be discussed.

While R-value issues lend themselves to quantification, understanding the impact of envelope details on infiltration is more challenging. A "trued up" whole building energy model based on actual utility bills from the first two ENERGY STAR high rise multifamily buildings in the country will be presented in order to estimate the impact of actual infiltration on building energy use compared to modeling assumptions.

Finally, pitfalls and sequencing issues associated with common air barrier systems will be discussed including liquid applied membrane for general coverage, peel and stick transition membranes at dissimilar materials and exterior grade building sealants for detailing.

Sequencing is extremely important as all transitional seams need to be sealed, and many of the components tied to the air barrier are installed at various stages throughout construction. Compatibility of all materials involved is also crucial to performance. Many conventional sealants are not made to work with the manufactured systems and can actually doo more harm then good.

Due to the complexity and added costs of a manufactured air barrier system, we look closely at the necessity and effectiveness of each component to determine the most cost effective solutions.

The Disconnect
Millions of square feet of multifamily new construction are being built in New York City every day. In most cases the architects, engineers, construction managers, owners, developers and future property managers all belong to different entities. This disconnects the designers and builders from those that will operate and occupy the building. There is little to no incentive to follow good practice other then fear of call backs and a damaged reputation. The school of thought being, if there are no complaints there are no problems. A portion of these projects proclaim they will rise above the rest in terms of energy efficiency, green components and best practice construction. Some pursue official status for their high performance endeavor through various rating systems.

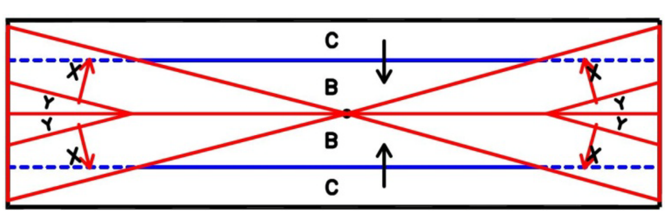
Most rating systems mandate design teams to work together to meet the requirements of the program, often under the guidance of a third party consultant. However, very few programs actually require inspections during construction, ensuring the as built resembles the design. Even then, most incentive monies are dispersed before the requirements have been met. Typically the third party consultant acts as the inspector, making the critical connection and closing the loop. They are there to communicate the goals of the program to the design team and then translate them into constructible systems.

This is especially true with air barriers. In new construction an air barrier is usually depicted as a single line on the drawings. It is often left to the builder to specify what the air barrier is comprised of and how to achieve continuity. Rarely are details included in the plans that clearly indicate specific types of products to be used, sequencing or compatibility issues to take note of. By the time the inspector gets to inspect the air barrier, installation has begun and appropriate corrections result in change orders from the builder. This is somewhat understandable when construction documents fail to provide a clear picture of what is involved.

In SWA's experience it is absolutely necessary to have a dedicated plan review for air and thermal barrier continuity.

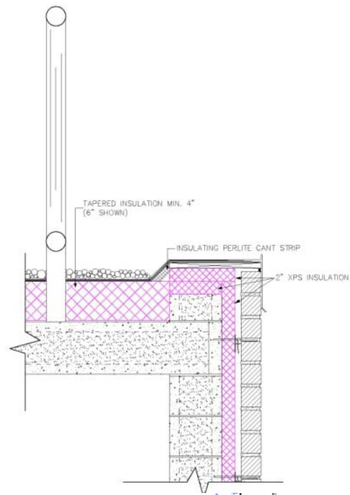
Raising the roof
In a typical specification, a built up roof is assigned an average R-value for heat loss calculations. With built-up roof insulation, this becomes challenging to verify in construction because thickness is dependent on location of the drains and the shape of the roof. The insulation on a flat roof is typically sloped towards the drains, with thickness increasing radially away from them.

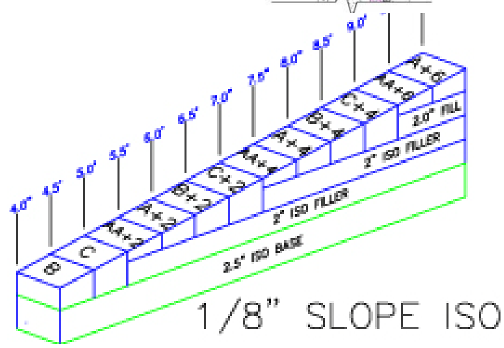
Some calculate the overall R value of a roof by averaging the R-values of the highest and lowest points. Since R-value is the reciprocal of a heat loss number, however, simple averaging does not work, for the same reason that you cannot simply add two fractions with different denominators. Figuring out the average R value of a typical sloped roof plan such as the one below requires somewhat complex math which is dependent on the shape of the roof, but the main trend is this: the average R value is often closer to the lower of the two thicknesses than it is to the upper, because lower R values tend to dominate assemblies thermally.



A highly simplified example illustrating this point is this: in a 100 square foot wall, R-10, an R-2 window occupies 10 square feet, or only 10%. However, because lower U values dominate the assembly thermally, the window represents 55% of the heat loss. Big difference.

What this means for roof insulation is that you get the most bang for your buck with the first few inches of thickness, after which we see diminishing returns. So given in-field installation methods, the minimum thickness becomes priority; all else is highly variable depending on the shape of the roof.



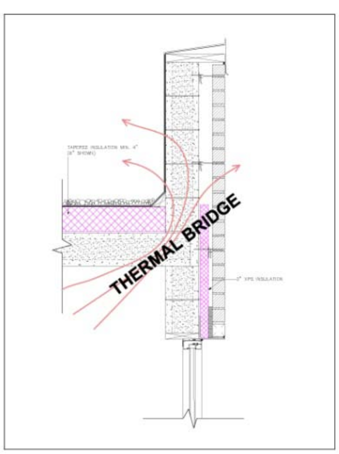


We find it helpful to recommend a minimum insulation value, such as 4 inches of polyisocyanurate (see attached graphic). That way, the entire roof will be at least R-26, but the average will be somewhat higher. Checking the roof slope plan carefully for minimum insulation values will aid in making sure you get the most energy-efficient roof for your money. Also it’s a good idea to require the roofing contractor to submit backup calculations from roofing insulation software such as Taper Plus or equivalent. This is common on bigger roof projects.

Another weak point in the roof assembly is the parapet, which are common in New York City's multifamily buildings.

We've all heard the thermal enclosure mantra, you should be able to trace the insulation around the entire building with picking your pen op off the plans. Parapets prevent the perimeter of the roof from having any insulation at all, breaking the continuous plane around the envelope.

To put it in perspective a 10,000 SF roof (100' x 100'), with a 1' uninsulated thermal bridge around the perimeter, de-rates an R-30 roof down to about R-20! The 1' thermal bridge is often made up an 8" CMU block, 1" air space and a 4" brick for cladding on the interior of the parapet.



Another interesting observation is a rectangular shaped building has a longer perimeter than a square of the same area. This means there is a longer parapet which creates more surface area for heat transfer. Additionally each setback creates the need for more parapets, again increasing surface areas for heat transfer.

The easiest and most cost effective solution is to get rid of the parapet. Most codes still require some sort of protection from water or objects falling off the building unexpectedly, but a gravel stop with a railing can satisfy both of these.

A gravel stop is short enough that the exterior cavity wall insulation can be wrapped up, around and down to meet the roof insulation. The insulation is still occasionally penetrated by the footers for the railing, but the overall thermal bridge area is drastically reduced.

The reduction in parapet materials means big first cost savings as well. Even if you only keep a full parapet at the front facade with a gravel stop elsewhere, you've taken care of 75% of the problem.

If the parapet has to stay for aesthetic reasons then there's a couple different options. One being a framed out parapet with an inch or two of rigid insulation under the bottom track, making sure to account for the extra length needed to fasten it to the roof deck.

When a masonry parapet is required, shrinking the size of the thermal bridge is the main goal. One easy way to do this is get rid of the brick on the interior and bring the roof insulation as close to the cavity wall insulation as possible. Install the cant strip on top of the insulation board, wood blocking is not needed underneath to ensure durability. Stucco and or metal panels are cost effective alternatives, especially if the material and trade is already being used on the jobsite. Decreasing the CMU block size shrinks the thermal bridge even further.

All of these things bring us closer to an honest R-value for the envelope. When your baseline at the thermal bridge is R-2, a little bit of insulation goes a long way.

View from Exterior
Rough opening: Air barrier (yellow), transition membrane (blue), sill stone and window frame installed.

Plank Edges

When left uninsulated and exposed plank edges greatly compromise a wall’s R-value. Even when the plank edge is in plane with the rest of the wall, often shelf angles are connected at every floor that penetrate the thermal barrier

After exploring different alternatives such as insulating overtop the angle or offsetting the angle and insulating between the angle and the wall, it became clear that the added cost and effort couldn’t be justified by the increase in R-value.

The easiest and least expensive solution is to only install continuous shelf angles at every other floor. Often structural engineers still want to install shelf angles above all window and door openings, so this allows approximately 25% of plank edges to be insulated. However if loose lintels were used above window and door openings at the floors without continuous shelf angles up to 50% of plank edges are able to be completely insulated.

This changes the approach to keeping water out of the building at those floors where shelf angles once directed water out the weep holes. Also this requires a closer look at the structural limitations of loose lintels for larger rough openings found in larger buildings. SWA was never able to convince a project team to evaluate the loose lintel approach, but most were comfortable installing non-continuous shelf angles at every other floor.

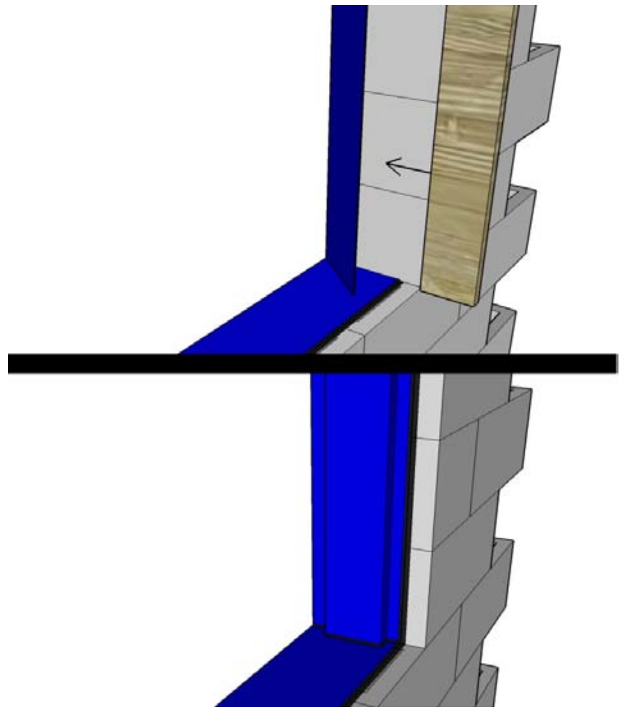
Air Barrier Sequencing in the Field

Recently, many building material manufacturers have started to provide specialized air barrier products in order to control air infiltration through the building envelope. These systems usually include a combination of sheet and liquid applied membranes. When these proprietary air barrier systems are detailed per manufacturer instructions, they can significantly reduce air leakage through porous CMU walls and joints. Rough openings that are made for windows and doors can create obstacles in maintaining air barrier continuity.

Manufacturers require expensive sheet-applied transition membranes for these rough openings and at joints of dissimilar materials (an example of such a joint is where concrete plank rests on a steel girder, each having different thermal expansion properties). In performing site inspections SWA has found this to be a problem area, particularly in large multi-family buildings. The involvement of multiple tradesmen and incompatible materials adds another layer of complexity.

First the surface must be prepped to receive the air barrier and insulation adds another layer to the process. The with CMU construction the joints squeeze mortar out from the weight of the blocks above. This means someone has to come through and "strike the joints" to make sure that the air barrier and insulation can fit tight against the wall. If air is able to move behind the insulation it becomes essentially ineffective.

When CMU is the chosen structural wall system, masons prefer a product that doubles as the air barrier as well as the insulation adhesive. Otherwise a separate adhesive or fastening system must be used, but a liquid adhesive applied around the perimeter of the insulation is preferred to get the tights seal against the wall.



View from Interior
Top: Wood blocking before transition membrane is wrapped.
Bottom: Transition membrane wrapped over wood blocking with compatible exterior grade sealant at all seams.

Per manufacturer requirements, when there is a window opening in the CMU wall, an asphalt-based polyethylene sheet membrane would be used to wrap the jambs, header and sill of the opening. A sequencing problem arises with the wood blocking which is typically installed over the jambs. Air barrier manufacturers specify that the sheet membrane should be wrapped over top of the wood blocking (see above). Also most "self-adhesive" sheets typically require a specialized primer in order for the membrane to properly adhere to the surface, again adding product and labor costs.

Another issue here is that the window installer will tell you he can't determine the size of the blocking until the brick is brought up to the same elevation as the window. However, once the brick is brought up, the transition membrane and the liquid air barrier membrane cannot be installed on the exterior face and the seams cannot be properly sealed. One approach in trying to resolve this issue is to use two transition membrane sheets installed at separate times. Another approach is to install one sheet adhered to the outside face and temporarily adhered on the inside edge until the brick is brought up to the proper elevation so the wood blocking can be slid underneath (see figure above). Similar sequencing troubles occur when using transition membranes at wall pipe penetrations, shelf angles and expansion joints.

Seeing the complexity of just reading these instructions, one can understand how difficult it is to get it right in the field. As a result, SWA has developed a simpler yet still effective method for achieving air barrier continuity. This approach uses several sealing products from different manufacturers and resolves most sequencing issues while also reducing the total cost of installation. Stay tuned for more information on how this is achieved.

Building Material Incompatibilities

The development of energy efficient building construction has required building material manufacturers to create high-performance hybrid plastic polymer materials which must be weatherproof, fireproof and long lasting. When new materials are introduced to a building system a significant amount of research about material compatibility is required before the new material can interact with the existing system materials. This article outlines several cases where common building materials show signs of compatibility issues when in contact with newer high-performing sealants.

The growing industry of building air sealing has created the need for a material capable of being relatively impermeable to air and water while maintaining adhesion over high movement joints. Research has led manufacturers in the industry to use flexible sheets made up of plastic polymers to block air infiltration in buildings. Many air barrier manufacturers are currently marketing a building wrap system using rubberized asphalt in combination with a polyethylene film and self adhesive layer as a sheet membrane. This material is generally used at rough openings where windows are installed. Plastic polymers are not compatible with many building materials and issues occur when a sealant is needed to seal the gap between the polyethylene membrane to the window frame. If a urethane-based sealant were to be used it would quickly delaminate from the polyethylene sheet. Often manufacturers provide a specialized high-priced sealant that adheres properly to the polyethylene surface, forcing builders to buy within the family but not without a significant cost.

Sometimes building designers will decide not to wrap polyethylene sheet in rough openings. In this case, manufacturers also market a fluid-applied air barrier that can be used instead of a sheet. These products are made primarily with high-performance asphalts that waterproof the enclosure and limit air infiltration.

As mentioned previously some of the liquid applied air barrier membranes act as the insulation adhesive. Some liquid membranes and insulation adhesives can react with polystyrene and or each other and deteriorate the insulation. In this case the liquid membrane must be allowed to cure per manufacturers requirements, which delays the installation of insulation and brickwork.

Another material incompatibility issue occurs when the window frame must be sealed to the asphalt covered substrate. The asphalt in the air barrier can contain plasticizers that dissolve urethane-based sealants over time and cause them to fail.

Another material incompatibility issue arises over time when the sealant between the window frame and rough opening has failed and must be resealed or replaced. One resealing option is to remove the old sealant from the window and reseal once the substrate and window frame joint has been primed to receive the new sealant. Another option is to simply reseal over the existing failed sealant. When resealing using this method and silicone is the base sealant, the only sealant that can be used to reseal over the existing sealant is silicone. Other sealants that are not made with silicone will quickly delaminate from the older base sealant and ultimately fail.

Sealants can potentially last 25 years if applied correctly and researched appropriately prior to application. When working with materials new to the building construction industry costly errors can be avoided by constructing system mock-ups and providing the appropriate performance reports and material data sheets.

Affordable and Effective Air Barriers

SWA received significant push back from the affordable housing market about the cost, level of effort and lack of clarity with following air barrier manufacturer guideline by the book. It was obvious that these projects could not support the attention these systems required, so an easier alternative was needed. So we began working with our pipeline of new construction projects to find less expensive generic products but that could still achieve a continuous, unbroken air barrier.

With both masonry and steel framed construction the most resistance we met in the field was how and where transition membranes were needed. There are two main types of movement in buildings are structural deflection which results from the building settling over time, and thermal expansion and contraction based on temperature fluctuations.

It was decided that transition membranes would only be used at high movement joints or where it was easier to use then other sealing methods.

- Steel/Concrete Junctions
- Exterior Sheathing Joints
- Expansion Joints
- Shelf Angles
- Steel Stud Construction Rough Opening

All other joints and surfaces could be sealed with the liquid membrane being used for general coverage in conjunction with a high grade 25 year sealant compatible with all surfaces. For example at masonry rough window openings, no transition membrane is used for air sealing, however a sill pan is used to protect from moisture intrusion. The liquid membrane wraps inside the full depth of the CMU back up wall and then sealant is used at all joints between the window frame and the previously sealed surface of the rough opening, thus creating an unbroken air barrier.

Even when following manufacturers' instructions to install the transition membrane overtop of wood blocking as discussed previously you are still left with a gap between the transition membrane and the window frame created by shims. Some manufacturers put a special coating on top of their transition membranes, making most generic sealants incompatible and forcing the market to only buy sealants within their product line which is often much more expensive then generic counterparts. So the alternative approach saves significant time and materials cost.

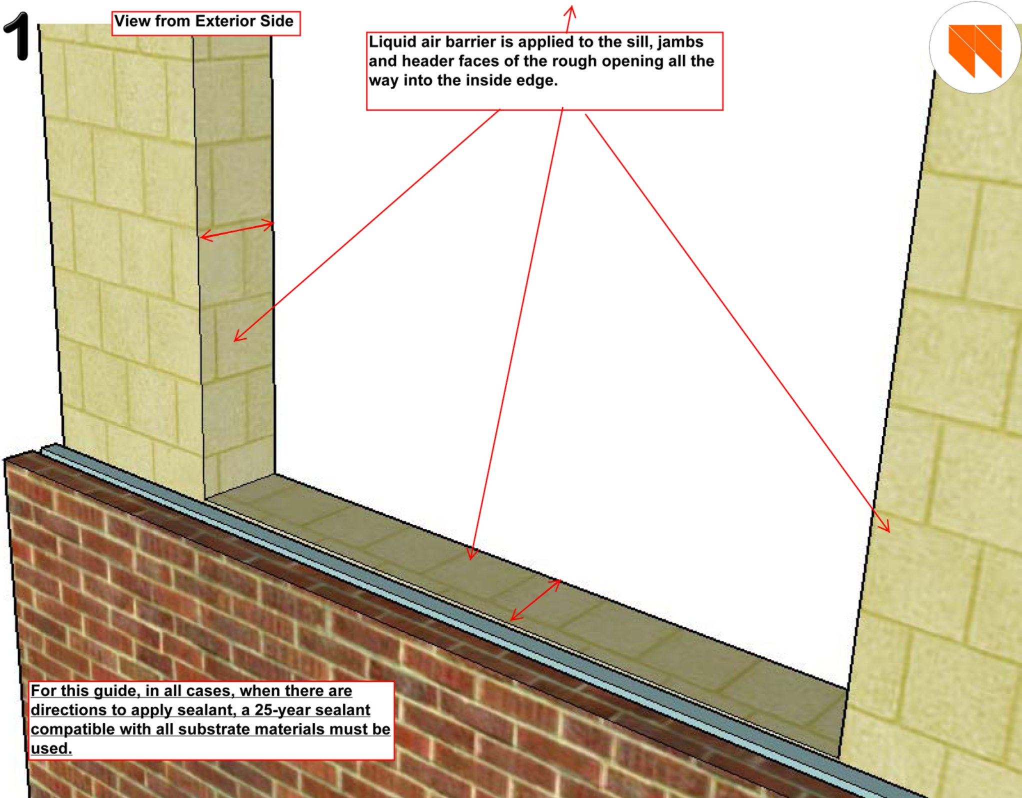
SWA found it very helpful to require wall mockups to be built to ensure the installers we're aware of the correct applications and sequences for each product. Additionally we designed flash cards to be laminated and clipped to the belts of the installer for quick reference. See the addendum for an example set of laminates to be used for sealing window rough openings in masonry construction. It should be noted however, that these details are building specific and should be customized for each specific project. Also the products being used on the job should be listed instead of generic terms to avoid confusion in the field.

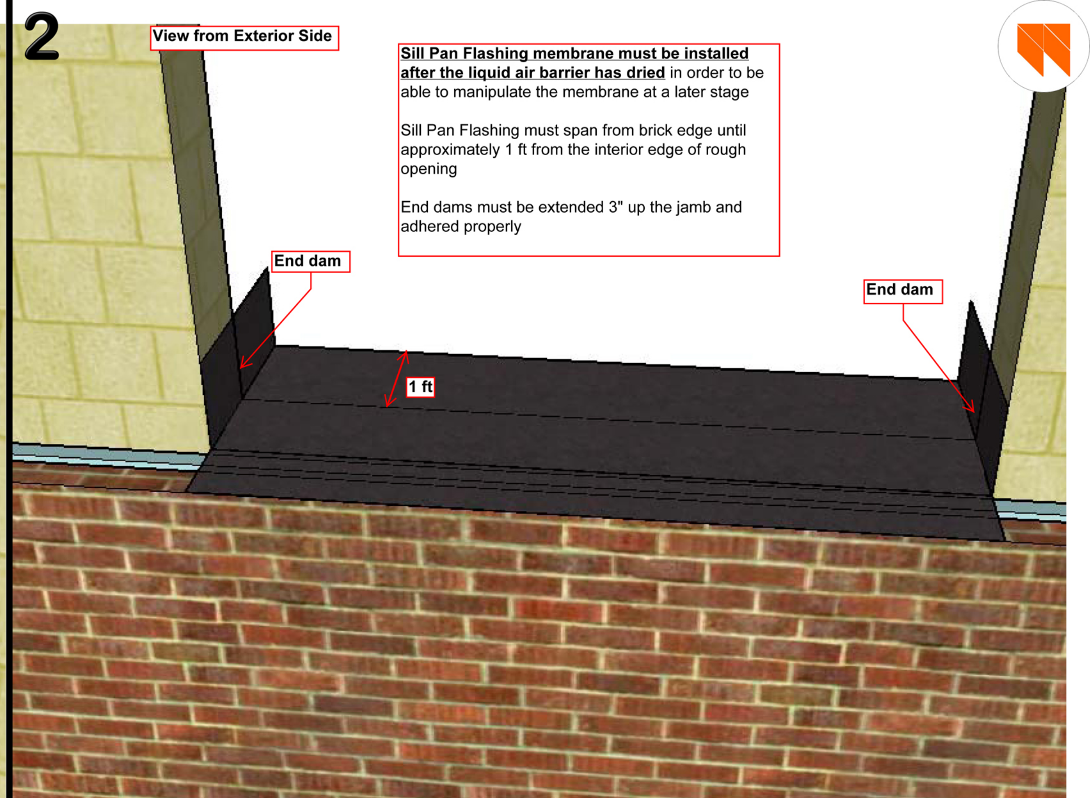
Selecting the products to be used for each component of the air barrier system is also a very important step. If a project team decides to source their products from different manufacturers it is extremely important to evaluate compatibility as previously mentioned. Air barrier manufacturers say that using products outside of the family will negate the warranty so this should be kept in mind. With affordable housing though, it is unlikely that air barrier failures would be highly noticeable unless was a result of a bigger structural failure which would not be covered by the air barrier manufacturers warranty anyways.

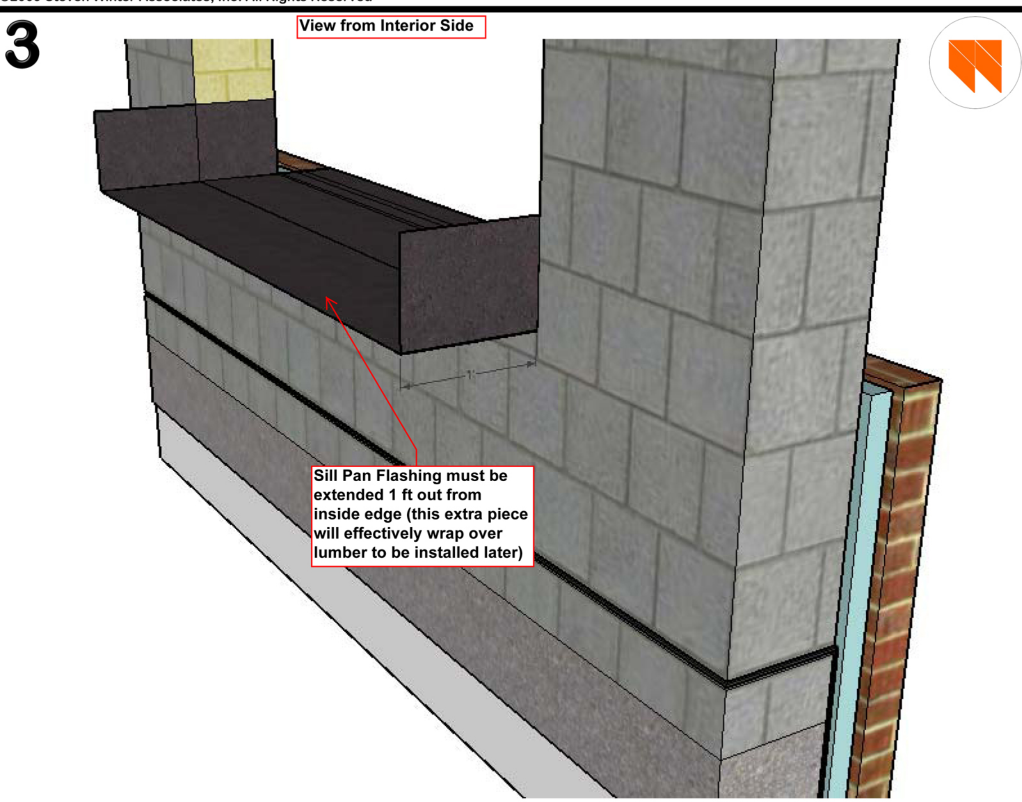
Below is an example of a table created for the liquid membrane component used for general coverage based on prices quoted in 2009. Note that these are products who have been lab tested for air leakage rates per ASTM standards. It is likely that there are many products on the market which effectively stop air leakage and are less expensive then these tested products.

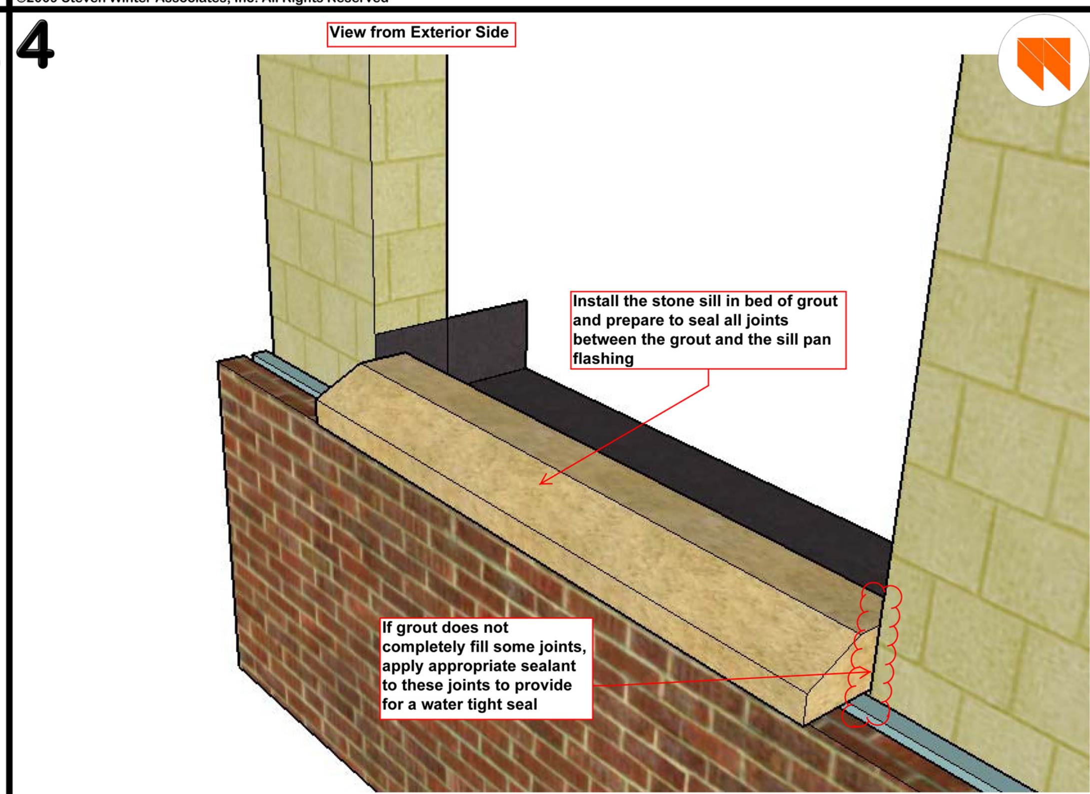
Manufacturer	**Product**	**Material Name**	**Air Leakage**	**Vapor Permeance****	**$/Gal**	**$/SF Covereage**	**Comments**
Prosoco	R-Guard	Asphalt Copolymer Emulsion	0.000195 CFM/ft^2 (ASTM 2178)	327 $ng/Pa.s.m^2$ (ASTM E-96)	$21.60	$0.86	Cannot be trowel applied, only roller / sprayed
Carlisle	Barritech VP	Latex modified asphalt emulsion	0.000195 CFM/ft^2 (ASTM 2178)	690 $ng/Pa.s.m^2$ (ASTM E-96)	$21.60	$0.86	Cannot be trowel applied, only roller / sprayed
Hohmann & Barnard	Textroflash Liquid	Latex modified asphalt emulsion	0.00159 CFM/ft^2 (ASTM 2178)	6 $ng/Pa.s.m^2$ (ASTM E-96)			Cannot be trowel applied, only roller / sprayed
Hohmann & Barnard	Textroflash Liquid VP	Latex modified asphalt emulsion	0.00159 CFM/ft^2 (ASTM 2178)	448 $ng/Pa.s.m^2$ (ASTM E-96)	$11.00	$0.28	Cannot be trowel applied, only roller / sprayed
Karnak	88R	Acrylate-Butadiene Rubber (ABR)	0.000195 CFM/ft^2 (ASTM 293)	1 $ng/Pa.s.m^2$ (ASTM E-96)	$18.07	$0.72	This product must be allowed to cure before adhering insulation
Henry	Air Bloc 21	Synthetic Rubber Based	0.0026 CFM/ft^2 (ASTM 2178)	1.7 $ng/Pa.s.m^2$ (ASTM E-96)	$28.00	$2.07	
Henry	Air Bloc 31	Elastomeric Emulsion	0.0005 CFM/ft^2 (ASTM 2178)	1201 $ng/Pa.s.m^2$ (ASTM E-96)	$26.00	$1.40	
Grace	Perm A Barrier	Synthetic Rubber Based	0.00012 CFM/ft^2 (ASTM 2178)	4.6 $ng/Pa.s.m^2$ (ASTM E-96)	$30.00	$1.20	
Grace	Perm A Barrier VP	Synthetic Rubber Based	0.0004 CFM/ft^2 (ASTM 2178)	644 $ng/Pa.s.m^2$ (ASTM E-96)	$34.95	$1.94	
Sto	Gold Coat	Silicon Dioxide Titanium Dioxide	0.002 CFM/ft^2 (ASTM 2178)	327 $ng/Pa.s.m^2$ (ASTM E-96)	$26.00	$1.30	

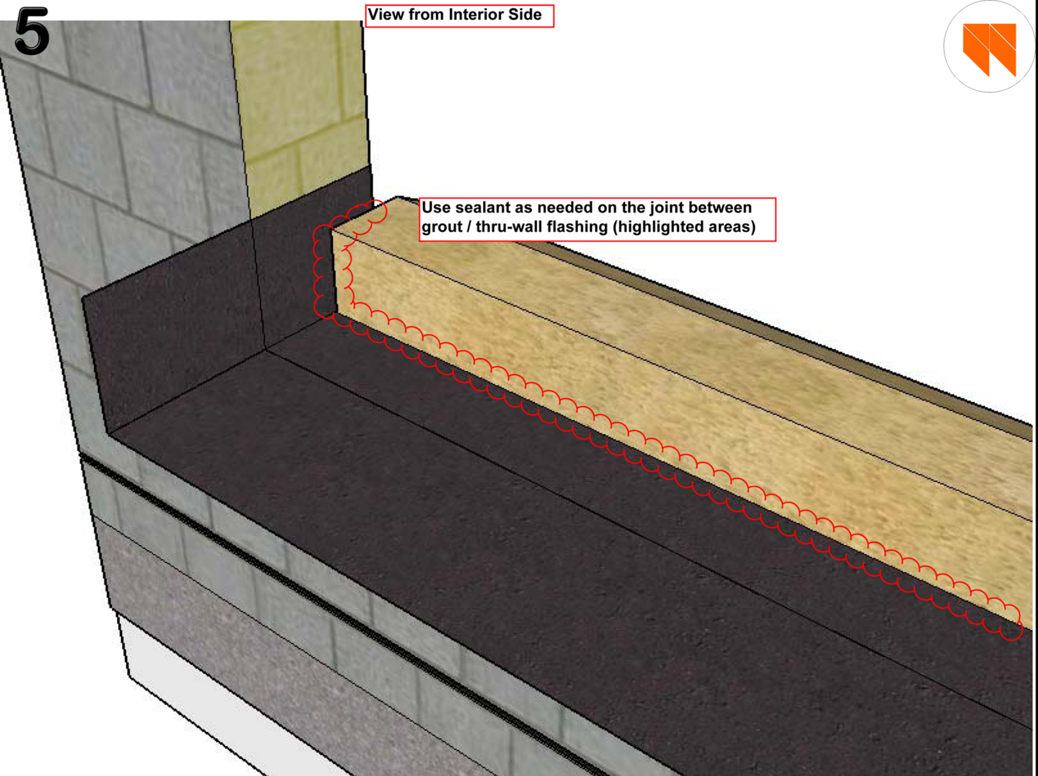
Conclusion
The building industry has started to pay closer attention to air and thermal barriers. However it still has a ways to go before proper, effective installation becomes common practice. There are critical steps that need to happen in order to make this a reality. Manufacturers should aim to simplify their system both from a sequencing standpoint and product compatibility. Inspections should happen as frequently as needed until installation the build team fully understands process and executes the installation correctly. Most importantly design teams need to fully develop all details to demonstrate continuity. Otherwise the installer will continue playing the guessing game.

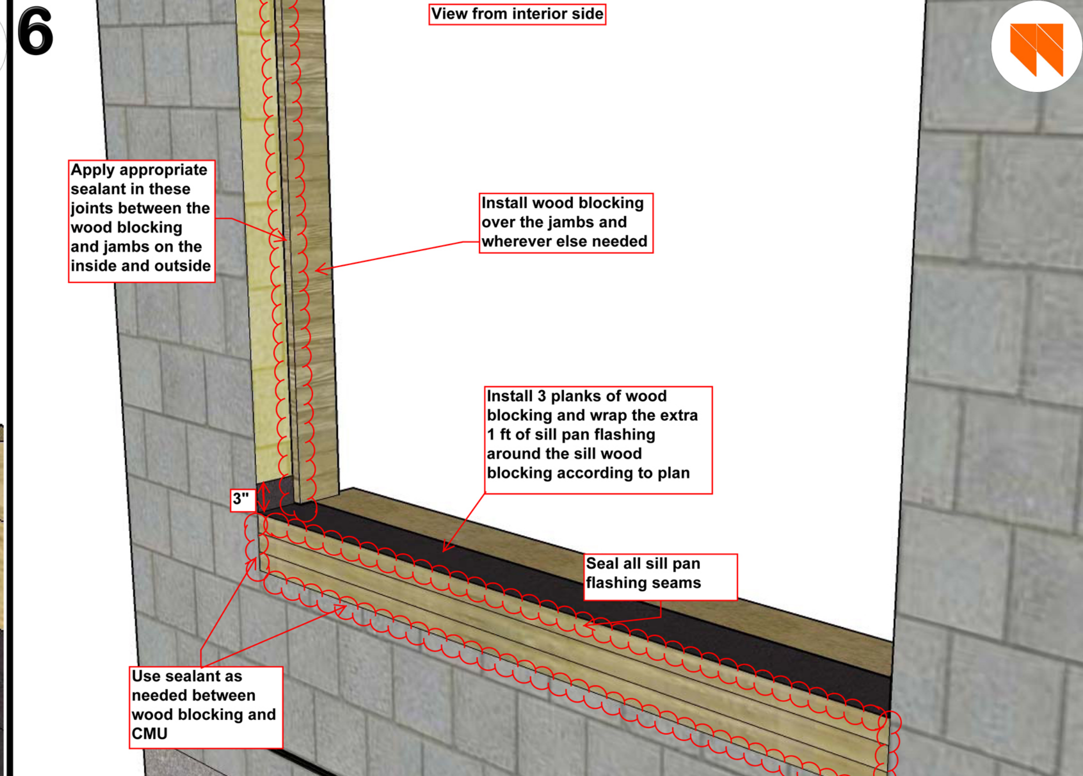

1
View from Exterior Side
Liquid air barrier is applied to the sill, jambs and header faces of the rough opening all the way into the inside edge.
For this guide, in all cases, when there are directions to apply sealant, a 25-year sealant compatible with all substrate materials must be used.

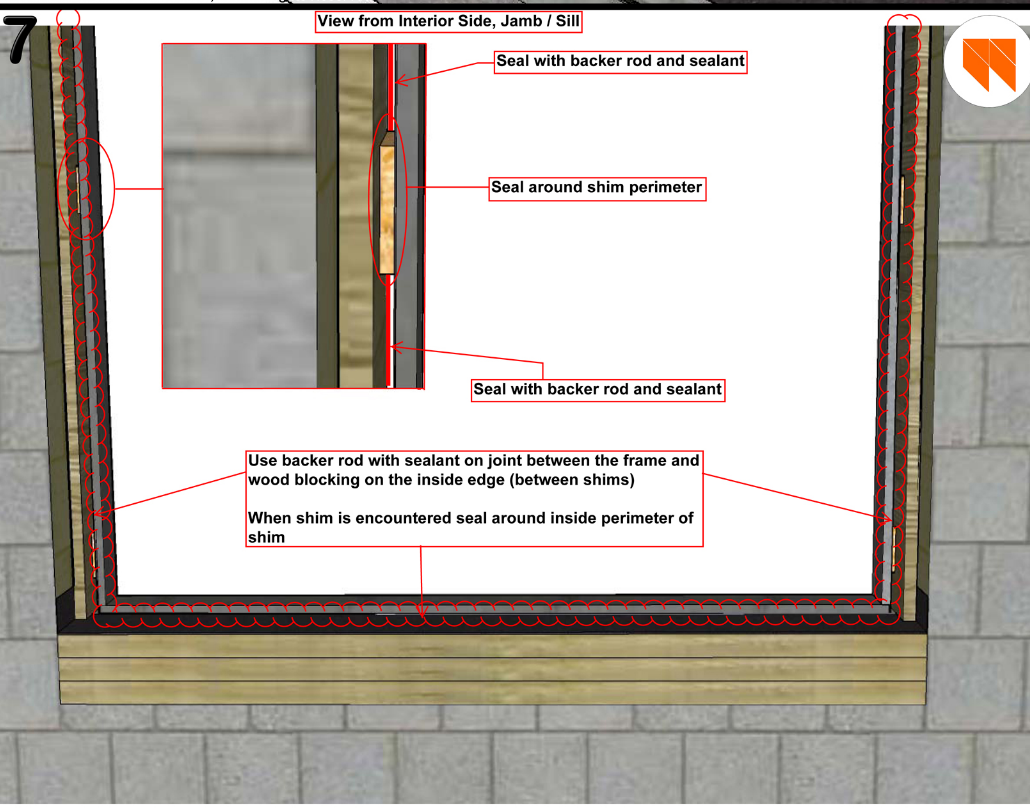

2
View from Exterior Side
Sill Pan Flashing membrane must be installed after the liquid air barrier has dried in order to be able to manipulate the membrane at a later stage
Sill Pan Flashing must span from brick edge until approximately 1 ft from the interior edge of rough opening
End dams must be extended 3" up the jamb and adhered properly
End dam
End dam
1 ft

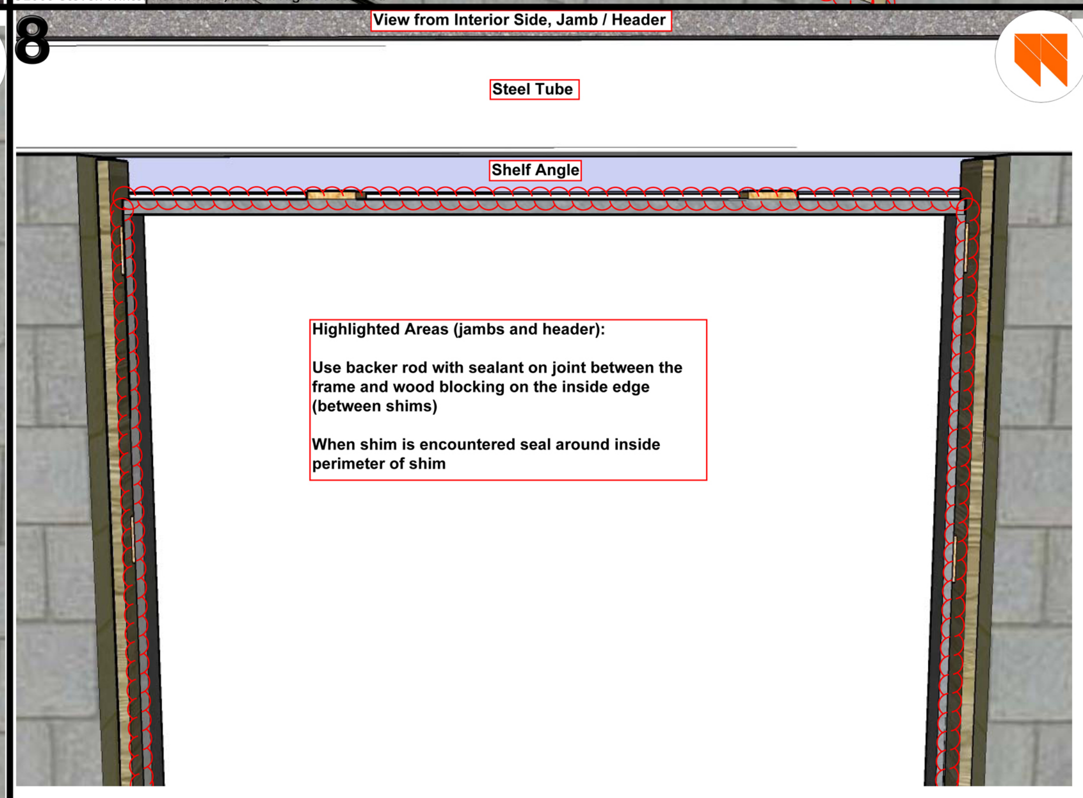

3
View from Interior Side
Sill Pan Flashing must be extended 1 ft out from inside edge (this extra piece will effectively wrap over lumber to be installed later)


4
View from Exterior Side
Install the stone sill in bed of grout and prepare to seal all joints between the grout and the sill pan flashing
If grout does not completely fill some joints, apply appropriate sealant to these joints to provide for a water tight seal


5
View from Interior Side
Use sealant as needed on the joint between grout / thru-wall flashing (highlighted areas)


6
View from interior side
Apply appropriate sealant in these joints between the wood blocking and jambs on the inside and outside
Install wood blocking over the jambs and wherever else needed
Install 3 planks of wood blocking and wrap the extra 1 ft of sill pan flashing around the sill wood blocking according to plan
3"
Seal all sill pan flashing seams
Use sealant as needed between wood blocking and CMU


7
View from Interior Side, Jamb / Sill
Seal with backer rod and sealant
Seal around shim perimeter
Seal with backer rod and sealant
Use backer rod with sealant on joint between the frame and wood blocking on the inside edge (between shims)
When shim is encountered seal around inside perimeter of shim


8
View from Interior Side, Jamb / Header
Steel Tube
Shelf Angle
Highlighted Areas (jambs and header):
Use backer rod with sealant on joint between the frame and wood blocking on the inside edge (between shims)
When shim is encountered seal around inside perimeter of shim