GUIDELINES FOR DELIVERING EFFECTIVE AIR BARRIER SYSTEMS

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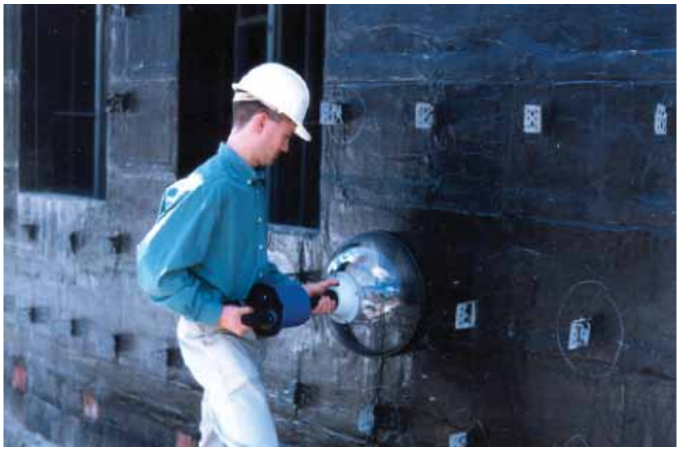
ABSTRACT



The negative impacts that can be attributed to air leakage through the building envelope are primarily threefold: (1) damage to the building envelope components; (2) increased heating and cooling loads resulting in excessive energy consumption and a subsequent increase in greenhouse gas emissions; and (3) occupant health and comfort issues caused by drafts, the entry of dust and pollution into residential living quarters, and wetting of materials which can stimulate the growth of mold and mildew. The growing North American concern in these regards is the driving force behind the development and implementation of more stringent government regulation for air barrier systems in buildings, including those buildings classified within Part 3 of the National Building Code of Canada.

As it is only recently that air barrier system technologies have begun being applied on a widespread basis in North American buildings, it can be reasonably expected that flaws would exist in the current 'process' of air barrier system design and installation. The prevalence of premature building envelope failures, increasing levels of energy consumption, and health concerns would suggest that the quality of air barrier installation is questionable. While air barrier system failures are most commonly the result of installation deficiencies, there are instances where material and/or design flaws are factors contributing to the system failure.

This article presents a methodology to help both designers and installers deliver an air barrier system that meets the requirements and recommendations of the National Building Code of Canada and any specifications particular to that project. Common design and installation flaws will be identified, and a protocol for the inspection and testing of the system, as it is being installed, will be documented.

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LEARNING OBJECTIVES

After reading this article, you should understand:

1. Problems resulting from inadequate control of airflow through the different building environments.
2. The functions and requirements of an air barrier system.
3. How to apply a protocol for the inspection and testing of air barrier systems prior to the commencement of installation, as the system is being installed, and once installation is complete.
4. Common flaws in air barrier system design.
5. Common problems that arise during air barrier system installation.
6. Visual inspection, and qualitative and quantitative test methods.

INTRODUCTION

Inadequate control of airflow through the building envelope is often a primary factor contributing to premature building envelope failures. If moisture-laden air is permitted to travel through the building envelope, the moisture may, under certain environmental conditions, condense within the walls of the structure. In above-freezing conditions, this may cause corrosion or rotting of the structural components, staining of the interior and/or exterior facade, and may stimulate the growth of mold and mildew. In cold climates, accumulated moisture may experience numerous freeze-thaw cycles, which can precipitate spalling (Figure 1) and the formation of icicles on the exterior façade (Figure 2).

Figure 1: Efflorescence and spalling of bricks and mortar.

Figure 2: Ice forming on exterior of building.

Air leakage is also a concern in areas where interior temperatures differ greatly from exterior temperatures, such as the Prairie Provinces, which can experience periods of extreme cold during the winter and extreme heat during the summer. The excessive heating and cooling loads placed upon buildings in this type of climate leads not only to an increase in space conditioning costs to the owner, but also has a negative impact upon the environment through increased energy consumption and the emission of greenhouse gases. In fact, studies conducted on high-rise residential and commercial buildings in cold climates have shown that anywhere from 20 to 50 percent of heat loss can be attributed to air leakage[*1,2,3*].

In Canada, building rehabilitation for roofing and wall system repairs and replacement cost an estimated $7.5 billion annually. A conservative estimate of the premature failure rate is 3 to 5 percent, or $225 to $375 million per year, with premature failure defined as any performance condition requiring repair or replacement of the system before the benchmark date. The building envelope has been identified as being particularly vulnerable to durability problems[*4*].

It is the growing global awareness of these air leakage-related problems that is driving the federal governments in Canada and the United States to introduce more stringent codes and regulations to govern building air permeance. In order to improve occupant health and safety, revisions were made to the National Building Code of Canada (NBCC) in 1995 designed to reduce air leakage in buildings, including those buildings classified within Part 3 of the Code[1]. Public Works Canada also recently revised their National Master Specification to include air barrier inspection and testing. In the United States, Persily's <u>Envelope Design Guidelines for Federal Office Buildings: Thermal Integrity and Airtightness</u> (1993) also documents the requirements as outlined in the NBCC. In addition, State Energy Codes are being adopted and/or revised, making air barriers a mandatory requirement in new construction and retrofits[*5*]. ASHRAE/IENSA Energy Standard for Buildings Except Low-Rise Residential Buildings (90.1-1999) also governs building envelope sealing.

Recently, air barrier trade associations have formed in Canada and the United States with the objective to improve the quality of air barrier system installations by providing education and training for the workforce. For an installer to become 'certified' through the association, an applicant must possess the required knowledge of air barrier material and system theory, and demonstrate sufficient skills in practical applications. In addition, through the associations' quality assurance programs,

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[1] Applies to (1) all buildings used for major occupancies classified as assembly occupancies (Group A), care or detention occupancies (Group B), or high hazard industrial occupancies (Group F, Division 1), and (2) all buildings exceeding 600 m^2 in building area or exceeding 3 storeys in building height used for major occupancies classified as residential occupancies (Group C), business or personal services occupancies (Group D), mercantile occupancies (Group E) or medium or low hazard industrial occupancies (Group F, Division 2 and 3).

documented self-testing and on-site third party audits are performed to verify the quality of the installation, and confirm the certified installers' ability to build to expected standards.

While there are numerous ASTM (American Society for Testing and Materials) methods for testing air barrier systems and/or components, there is no generic regimen for the application of these techniques being utilized on a widespread basis. The need for a complete design, inspection and testing protocol for air barrier systems cannot be understated. A recent study concluded that even *routine* testing can have a significant impact upon the airtightness of a building. Where air leakage testing was conducted, there was an overall reduction in air leakage for the system, a significant decrease in heating and cooling loads, a reduction in greenhouse gas emissions, and an increase in the life cycle of the building envelope[6].

With the growing use of inaccessible air barrier systems (such as bituminous membranes), on-site inspection and testing during installation is necessary to identify problems before the system is covered with finishing materials. The cost to repair an air barrier system after it has been covered can be conservatively estimated to be 50-60 times the cost of a correct first-time installation[7]. Hence, the need for inspection and testing is obvious.

WHAT ARE WE TESTING FOR?

The National Building Code of Canada (NBCC), Part 5, Section 5.4, Subsection 5.4.1.2., stipulates four key requirements for successful air barrier systems: airtightness, continuity, structural integrity and durability.

Airtightness - Subsection 5.4.1.2. Sentence 1 states that "**. . . sheet and panel type materials intended to provide the principal resistance to air leakage shall have an air leakage characteristic not greater than 0.02 L/(s·m^2) measured at an air pressure difference of 75 Pa.**" While there are many commercial *air barrier materials* that satisfy this requirement, these materials must be joined into a system so that the system is airtight under different indoor environmental conditions[8]. Recommended maximum leakage rates for *air barrier systems* in exterior envelopes are provided in Appendix A of the NBCC (Table 1).

Table 1.

Recommended Maximum Air Leakage Rates [9]

Warm side relative humidity at 21ºC	Recommended maximum system air leakage rate, L/(s•m^2) at 75 Pa
<27%	0.15
27 to 55%	0.10
>55%	0.05

<u>Continuity</u> - Subsection 5.4.1.2. Sentence 7 states that **"The air barrier system shall be continuous (a) across construction, control and expansion joints, (b) across junctions between different building assemblies, and (c) around penetrations through the building assembly."** That is to say that not only is it important that no gaps exist in the individual components that comprise the system, but the components must be joined such that there are no gaps in the system as a whole. It is air leakage at the connections between air barrier components, and at penetrations through it, that usually determine the overall effectiveness of the system[10].

<u>Structural Integrity</u> - Subsection 5.4.1.2. Sentences 8 and 9 state that **"An air barrier system installed in an assembly subject to wind load, and other elements of the separator that will be subject to wind load, shall transfer that load to the structure."** Specifically, it shall be "**. . . designed and constructed to resist 100% of the specified wind load as determined in subsection 4.1.8."** The air barrier system must be able to resist peak wind loads, stack pressure effects or sustained pressurization loads without exhibiting signs of detachment, rupturing or creep load failure.

<u>Durability</u> - Subsections 5.1.4.1 and 5.1.4.2. detail the requirements for resistance to environmental loads and resistance to deterioration. The air barrier system must be durable, meaning it must be able to perform its intended function, be compatible with adjoining materials and resistant to the mechanisms of deterioration that can be reasonably expected given the nature, function and exposure of the materials, over the life of the building envelope.

These four requirements represent the *minimum* performance requirements of an air barrier system. In some instances, for certain buildings, the specifications on the particular project will demand that the performance standards of the system exceed those contained in the NBCC. Note also that the air barrier system must not only meet the requirements of the national code, but any provincial/state or municipal codes as well.

WHY PROBLEMS OCCUR

The airtightness, continuity, structural integrity and durability of the air barrier system are dependant upon three factors; materials, design and installation practice. Flaws in any of these elements can have negative ramifications on the ability of the completed system to perform to specification in the short and/or long run.

Materials

When specifying air barrier materials, the designer must confirm that the material or materials chosen have an air permeance rating equal to or less than 0.02 $L/(s \cdot m^2)$ measured at an air pressure difference of 75 Pa. Many materials may meet this requirement, but care must be taken to ensure that the material will maintain its air permeance rating (and not have any adverse effect upon the system's ability to meet the other three requirements of continuity, structural integrity and durability) once it has been installed in the wall. For instance, two-part materials that are fabricated on site, such as some spray-applied materials, may be rendered ineffective if not mixed correctly. All relevant information regarding the material, including air permeance, fabrication instructions and material characteristics, can be found in the technical literature as supplied by the manufacturer.

Most commonly specified air barrier membrane materials demonstrate similar air and vapour permeance characteristics (in reference to their scope of use on a building). However, other performance characteristics, such as adhesion, elongation, puncture resistance and tensile strength may vary considerably and must be taken into consideration when specifying materials, especially when used around roof/wall junctions, wall/window junctions and control joints where movement is expected. The variance may be enough to compromise the ability of the system to function correctly. As an example, the elongation of regularly specified self-adhered air barrier membranes can range from 4% to 200%. Where movement between system components is expected, materials with greater elongation properties should be selected.

The installed materials must not react adversely to either other materials that comprise the air barrier system, or adjoining components within the building envelope. While it is beyond the scope of this paper to document every potential incompatibility, the designer must be aware that incompatibilities can occur, and should carefully consider the physical and chemical properties of the materials being specified.

Physical incompatibilities occur when the physical characteristics of different materials make them incompatible. A common example is where a hot-applied material is installed over heat-sensitive material. For instance, if torch-grade membrane is installed over self-adhered or spray-applied membrane, the excessive heat may cause the self-adhered or spray-applied membrane to melt (this may also occur if hot mopped asphalt is used around the roof/wall junction). However, specifications often allow for different trades to select between a range of acceptable materials, and a situation may occur where one trade has selected self-adhered membrane and a second trade chosen torch-grade. The general contractor should monitor the work of the sub-trades and identify any concerns regarding material compatibility or sequencing to the designer, who should be aware of the materials being used on the project.

Chemical incompatibilities occur when the chemical properties of different materials make them incompatible. Consider substrate preparation. If walls are not primed properly and in keeping with manufacturers' recommendations, or the incorrect primer is used, not only may the membrane not bond adequately to the substrate, but the chemical composition of the primer may damage the membrane itself. In fact, the chemical compositions of certain membranes may make it impractical to use them concurrently on a wall section. The chemical composition of asphalt membranes is such that it will cause certain rubber membrane to decompose. Similar results may be attained when a membrane of a particular makeup comes in contact with high solvent-based sealants or uncured solvent-based primers.

The Canadian Construction Materials Centre (CCMC) has published technical guides that detail specific structural, durability and air leakage test criteria for air barrier materials and systems. Air barrier materials can be tested both as stand-alone materials (tested for air permeance) and as part of a system (tested for air permeance, structural integrity and durability)[*11,12*]. For optimum results, all system materials should be evaluated under this protocol. However, while the results of evaluations like this can be used as a reference to provide assurance of the material's ability to perform as part of a system, the evaluations do not pre-approve the system. It is the responsibility of the designer and installer to bring the individual materials together as an effective system.

Design

Meeting specifications does not necessarily guarantee that the air barrier system will perform well. An incorrectly designed system will not function effectively regardless of how well it has been installed[*13*]. It is not uncommon for an air barrier system failure to be attributed to a flaw in design. Common examples are improperly locating the air barrier within the wall; discontinuity within the system (for instance, gaps in the system at major joints, such as roof/wall, wall/foundation, and window and door frames to wall junctions); sequencing of structural, mechanical and electrical systems which may make air barrier continuity impossible to achieve, and; failure to differentiate between air barriers, vapour barriers and/or materials that act as both[*14*].

In cold or severely cold climates[2], where a material is to act both as an air barrier and a vapour barrier, it should be placed on the warm side (or high-vapour pressure side) of the wall[3]. It should be placed at a sufficient depth within the building envelope so dew point temperature occurs to its exterior side. Where air barrier and vapour barrier functions are to be performed by *different* materials, the vapour barrier should be placed on the warm side of the wall. Again, it should be placed so dew point temperature occurs to its exterior side. In this instance, the air barrier may be placed anywhere within the wall provided it restricts the flow or movement of conditioned air, preventing this air from coming in contact with cool surfaces where temperature is below dew point. If the air barrier is placed outside the insulation plane, the air barrier material must have a vapour permeance characteristic, or the system be designed, such that water vapour will diffuse to the exterior of the building envelope, or a vapour barrier of lesser permeance is used on the inside[*16*].

In comparing warm and cold climates, the ‘science’ behind where the vapour barrier is placed within the wall does not change — it is always placed on the warm side of the wall. However, in warm climates, because the warm side of the wall will be closer to the exterior than in areas of cold climates, the vapour barrier will be placed closer to the exterior as well (and may even form part of the exterior wall).

In most instances, to best meet the requirement of durability, the air barrier should be placed within the exterior cladding and outward of the structural frame. This not only protects the air barrier from exterior environmental conditions, but by keeping the structural frame of the building within the air barrier, the system design is more straightforward in terms of maintaining continuity at penetrations associated with structural elements[*17*].

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[2] A cold climate can be defined as a region with approximately 4500 heating degree days or greater and less than approximately 6000 heating degree days. A severely cold climate can be defined as a region with approximately 6000 heating degree days or greater[*15*].

[3] For the purposes of this paper, when referring to the ‘warm side’ of the wall, unless specifically stating otherwise, this will be defined as the ‘warm or high-vapour pressure side’.

Problems may originate from both the type of materials chosen for various parts of the building envelope and in the way materials are specified to be put together, either from lack of information regarding construction sequencing or from incorrect assumptions of end performance. A common occurrence is where a system is designed and drawn such that, in theory, it will operate effectively but in practicality, site conditions prevent it from being constructed. Consider the examples shown in Figures 3 and 4:

Figure 3 represents a typical roof/wall junction, with brick veneer finishing and a curtain wall in-fill. As shown on the drawing, the air barrier runs along the roof deck and is joined onto the back pan of the curtain wall. When the roof deck and parapet are built, and the roofing membrane installed, a connection must be made underneath the parapet between the leading edge of the membrane and the back of the curtain wall back pan.However, once the curtain wall back pan is installed, it is impossible to work 'inside' the wall in order to make that connection, leaving a gap in the system. Blind junctions such as this must be avoided when designing construction details.

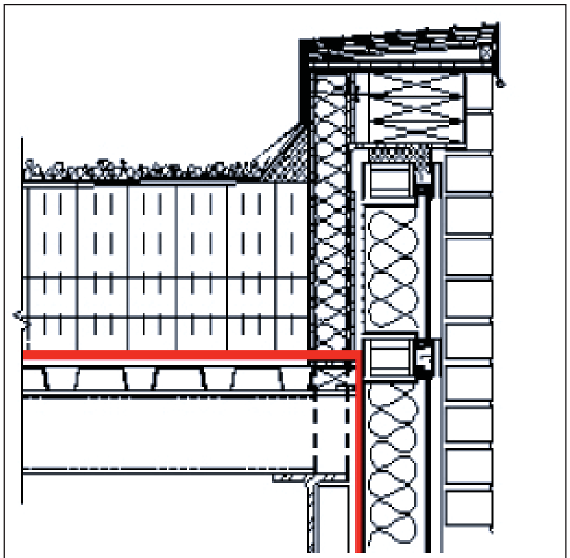

Figure 3: Roof/wall air barrier detail that cannot be built.

In some instances, the material specified is not suitable for the design as drawn. Figure 4 illustrates a typical window detail with a plywood rough buck installed into the window opening. The air barrier membrane, as installed along the interior stud wall, must be joined to the window frame as in the drawing. The designer appears to have drawn the membrane going around the rough buck, which is virtually impossible to do given the nature of the air barrier membrane material. The membrane is then joined onto the window frame, connected to the warm side of the thermal break. The membrane is installed in the right location, but again, this detail is physically impossible to construct.

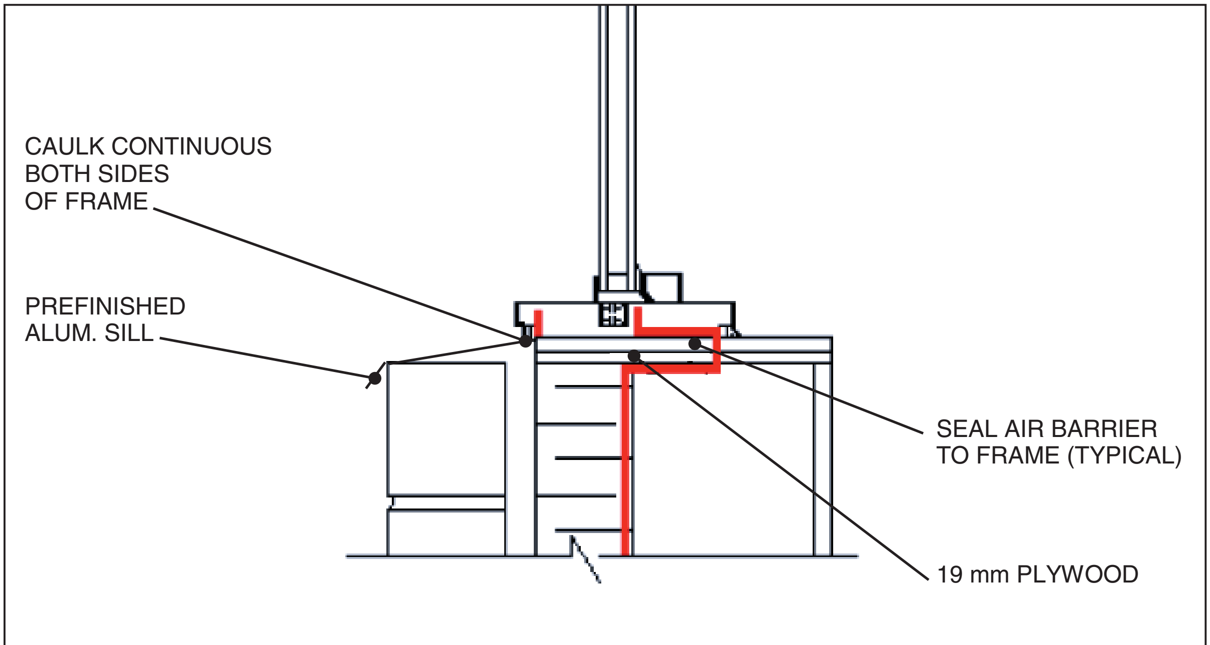

Figure 4: Window detail that cannot be built.

Figures 5 and 6 show correct window details. In Figure 5, a window with a flange is used. The plywood rough buck has been cut back so the insulation extends to the bottom of the frame. The air barrier runs along the wood blocking (to the warm side of the insulation) and is sealed to the flange, which has been seated in caulking (or some other sealant). Note that this detail can only be constructed prior to masonry having been installed. Where construction sequencing makes this impossible, the detail can be designed as in Figure 6. Here, the membrane runs along the wood blocking and under the frame. Another strip of membrane is then installed to overlap the initial strip, covering the remainder of the wood blocking and extending to the aluminum sill. This forms a 'T' junction. The frame is then installed over the wood blocking and urethane foam used to fill the void between the window frame and the rough opening, on the cold side of the frame. Care should be taken to ensure that the use of urethane foam between the window and rough opening does not compromise any drainage system built into the window, negatively affect the thermal performance of the window, or cause the frame to bend due to the expansion of the foam.

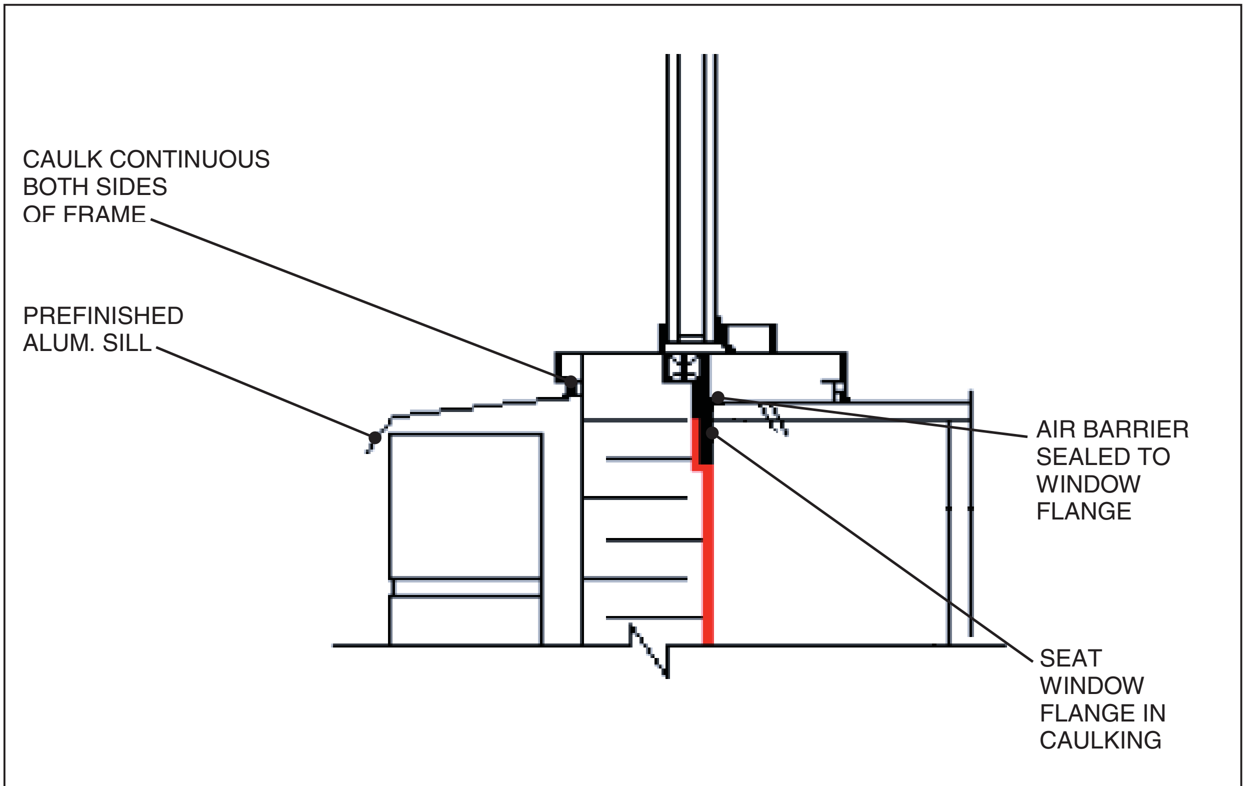

Figure 5: Correct window detail; air barrier is sealed to the window flange.

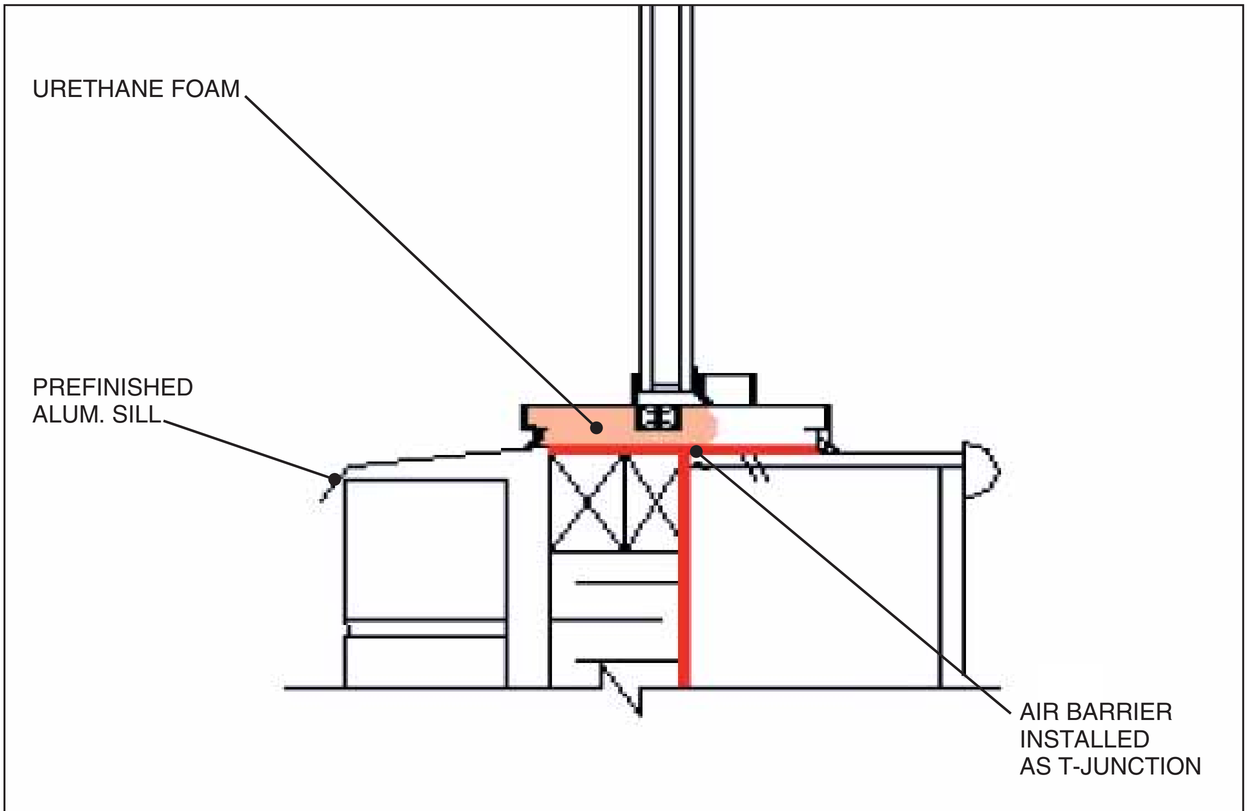

Figure 6: Correct window detail; air barrier installed as a T-junction.

Installation Practice

The critical element that determines whether the system will function as required is the quality of the installation. Air barriers can still be considered a 'new' technology, and therefore, it is no surprise that while there are some highly-skilled installers, the majority of installers lack the skills or training needed to perform a quality installation. While air barrier associations have been formed with the objective to develop a professional air barrier trade, air barrier installations are still being performed with different trades responsible for different components or sections of the air barrier (such as window-to-wall or wall-to-roof), many of whom do not have a satisfactory understanding of the functions and requirements of what they are installing. Whereas each trade may be responsible for a component or section, no one trade is responsible for ensuring continuity *between* the individual components or sections that form the 'system'.

Figure 7: Masonry being installed immediately after a section of air barrier.

It is this overlapping trade jurisdiction which can lead to many problems during an installation. Where communication between the trades is poor conflicts where it is not uncommon to find finishing materials being installed only minutes after a section of air barrier material, meaning that sections of the air barrier are being covered before the system is complete (Figure 7). Sometimes, the installation of finishing veneer may compromise the system if the veneer is fastened through the air barrier. Trades can frequently be seen drilling holes though the wall assembly and not repairing or resealing the air barrier.

Compounding the aforementioned situation is the fact that typically, details in specifications do not take into consideration the in-situ difficulties that may be prevalent. For example, the continuity of the air barrier system may be compromised by building services (such as electrical) or other wall components and structural elements. This point is clearly related to the idea of 'no-builds' and 'difficult to construct details' previously touched upon. Once again considering the window frame detail from the previous section (Figure 4), it can be assumed that several different trades, and in turn, several different materials were utilized within a confined space with many corners and other difficult details, making it hard to achieve continuity within the system or between different systems[18].

SPECIFICATIONS

Prior to designing the air barrier system, the designer should estimate, based upon available information, the expected performance levels of the building; specifically, interior temperature, relative humidity and pressurization. Climate, building use, and occupant lifestyle can all have a significant impact upon interior building conditions. Because different wall types have different air leakage characteristics, the wall type specified must be suitable for housing that type of environment. Also, a great deal of consideration must be given to the durability of materials over a period of time, for example, comparing drywall to masonry block. The designer can then reference Table 1 to specify the appropriate maximum allowable system air leakage rate.

Different systems within the building envelope have different leakage rates. For example, a fixed glazed window has a different air leakage rate than a horizontal sliding window. Appendix A of the NBCC recommends maximum system air leakage rates. Although these recommended rates are for the opaque wall, and do not include windows, doors or other fenestrations, Section 5.4.1.2. of the NBCC references numerous CAN/CGSB standards that govern the performance of these components. Because the Code states that the air barrier system must be continuous, joints and junctions between these components should meet the same air leakage criteria as recommended for the opaque wall.

Finally, the designer must specify the inspection and testing procedures to be used on the project. The section "The Design, Inspection and Testing Procedure" can be used as a reference to develop specifications for each individual project.

PROTOCOL FOR INSPECTION AND TESTING OF AIR BARRIERS

A proper and comprehensive inspection and testing regimen is the most powerful tool available to the building owner/designer that can be used to improve the quality of the air barrier installation. The potential budget for even the most comprehensive program represents only a small portion of the overall cost of the project and can save the owner from excessive future maintenance and repair costs. A complete inspection and testing program may also reduce the potential liabilities that designers and builders may face by preventing building failures which may be incorrectly attributed to them.

Ideally, there would be a formal process, specific to the construction industry, to identify problems, assign responsibility and resolve disputes. To this point, such a generic process does not exist. For this reason, the best way to solve disputes is to prevent what causes them. For example, if an air barrier membrane is poorly installed, it can often be determined who or what is at fault. However, if a window/wall junction has not been sealed correctly, who is at fault, the window trade or the wall trade? In most instances, disputes of this nature arise from a poorly defined scope of work in the specifications. Therefore, a more detailed definition of the scope of work within the air barrier specification can reduce the number of potential conflicts.

As there are many different air barrier materials, and an even wider range of air barrier system designs, an inspection and testing protocol must be comprehensive enough to encompass any type of system; that is, it must be ‘generic’ in order to be applied on a widespread basis. To illustrate this, consider maintainable (or serviceable) air barriers as compared to those which are non-maintainable. Maintainable air barriers are exactly that — they can be serviced throughout their life. Consequently, they are placed either on the exposed exterior or exposed interior of the building (drywall, for example). Because it is exposed, a system such as this can be tested once the entire system has been installed, and if testing were to indicate the presence of air leakage, it could be serviced relatively inexpensively and without a great deal of difficulty. However, it is often difficult to achieve continuity with this type of system, and system durability can be compromised when the air barrier is exposed to mechanisms of deterioration[19].

Now consider a non-maintainable air barrier, such as a single-ply membrane, located within the cavity wall. Once the air barrier has been covered, it is not practical to test the individual components in the system. While the whole building can be tested, it is virtually impossible to determine which components, if any, have failed. And even if the location of a deficiency could be pinpointed, repairing it would require disassembly of the wall in order to service it which can be expensive, time consuming and impractical (necessitating financial compensation).

Quality compliance testing, therefore, should apply inspection and testing procedures prior to construction commencing, during the installation process, and once the air barrier/building has been completed[20]. A combination of visual inspection, and qualitative and quantitative testing techniques conducted by both a third party testing agent/consultant and the workforce itself is recommended. Such a protocol should utilize several ASTM standard test methods which will be referenced at the beginning of each phase for which they are applicable.

<u>Factors Affecting the Inspection and Testing Protocol</u>

It is important to remember that a protocol is simply a guideline for how an air barrier system should be tested. It tells the designer how and in what capacity inspection and testing should be applied on a building, in general. In reality, not all projects will specify, nor require, all three phases of testing all of the time. The protocol is system specific, and the scope of inspection and testing on a particular project can be influenced by four other factors (although the scope is still firmly determined by the designer): geographic location, building use and occupancy, expected cost to repair, and budget[21].

Geographic location must be considered when evaluating the scope of inspection and testing to be specified on a project, as climactic conditions can be extremely varied throughout different areas. For example, in Canada, the west coast has a moist, relatively mild climate whereas the climate on the prairies is drier but has a much greater temperature range. This difference in climate can have a significant effect on the degree to which an air barrier is tested, and to what it is tested for.

To illustrate this point, a comparison can be made between buildings in Winnipeg and Vancouver. In Winnipeg, where the winter climate is cold and dry, the potential damage that can occur to a building envelope is primarily the result of freeze/thaw cycling of condensation (from the exfiltration of conditioned air) trapped within the walls. In Vancouver, where temperatures are much more mild and there is a high degree of precipitation, more often than not damage to the building envelope is caused by water leaking into the building envelope and the subsequent rotting and corroding of building components. As a result, the inspection and testing regimen for the building in Winnipeg may be more concentrated upon the air leakage characteristics of the air barrier, where for the building in Vancouver, a greater emphasis may be placed upon the design aspects of the air barrier and how it acts in conjunction with drainage planes and vapour retarders.

All buildings are and should be designed to serve the needs of the people occupying it, and be able to function as per its intended use. The lifestyles of the building occupants and the desired indoor conditions can have a profound effect upon the interior environmental conditions of the building. Buildings whose inhabitants' lifestyles generally produce a high temperature, high humidity environment (from, for example, hang-drying clothes and frequent cooking) may require a more comprehensive degree of inspection and testing because the potential damage resulting from air leakage is greater than it would be in a low temperature, low humidity environment. While the designer certainly cannot be expected to know the habits of all of the occupants in a building, a conservative approach should be taken when designing the system.

Similarly, where the intended function of the building stimulates extreme interior environmental conditions, or where the interior environment must be controlled, a greater degree of testing may be required. Some buildings, such as museums, art galleries, pools and hospitals require stable interior relative humidity and temperature levels, and would therefore undergo more rigorous testing. By comparison, a warehouse will generally have low humidity and average interior temperatures, reducing the transfer of air and vapour. Air leakage that does occur may not adversely affect the people working in the building and therefore may not affect the use of the building. In this instance, a lesser degree of testing may suffice.

The third factor that can influence the scope of an inspection and testing program is expected cost to repair. As touched upon earlier in this section, when an air barrier is non-maintainable, the cost to repair it can be high. In most cases, repair requires the removal of some or all of the exterior facade to make the air barrier accessible. This not only leads to high labour costs, but may also interrupt service within the building. Materials that cannot be reused will also have to be replaced.

There are a number of variables that can influence the cost of an inspection and testing program: location, building type, intended use of the building, inspector's rates, and so on, making it difficult to provide a gauge for the cost of a complete program. It can be said with confidence, however, that the cost of the program is small relative to the overall cost of the project, and it may be significantly less than costs associated with maintenance and repairs were a failure to occur in the system that could have been prevented by inspection and testing. Experience suggests that the cost of a complete inspection and testing program is between 0.1 and 0.3 percent of the total cost of the project. Keep in mind that this is only a rough guideline, and may be greatly influenced by the aforementioned factors.

Workforce Testing and Third Party Testing

The inspection and testing protocol which follows requires both workforce inspection and self-testing, and third party inspection and testing. While the methods and results may be similar, the rationale behind each is not.

Organizations such as the National Air Barrier Association (NABA) have developed quality assurance programs which require the workforce to not only test their installations, but also to provide written confirmation that testing was indeed performed and that the detail(s) tested met specification requirements[22]. Self-testing in this manner can be seen as a tool that the workforce can utilize to assist in providing a quality 'first-time' installation. By comparison, third party testing is an objective quality assurance mechanism used to determine whether the air barrier has been installed to specification and can be expected to function as intended by the designer. Both installers and third party testing agents can use visual inspection and qualitative and quantitative testing methods to evaluate certain details. Whereas the installer is simply testing the quality of the air barrier installation, third party inspection and testing is geared towards the entire building envelope, and how the air barrier functions both as a stand-alone component, and as a component within the building envelope system.

Workforce self-testing only has value if it can be confirmed that the testing is actually being done regularly and under a consistent protocol. Regular auditing from the governing association should be conducted, and stiff penalties levied against those not complying to the procedures of the quality assurance program. Third party inspection and testing only has value if the findings are considered, and subsequent recommendations enforceable. Inspectors should have the authority to halt construction, assign responsibility and then confirm compliance when corrections are complete. In most cases, however, it is only the designer who has the authority to make these decisions. Therefore, the job of the inspector is not to direct the trades on site, but rather provide recommendations, based upon site findings, to the designer who in turn gives instruction to the general contractor on what must be done to rectify the problem. In some instances, however, the inspector may be engaged directly by the owner, and may have been given the authority to make these decisions.

While visual inspection can identify obvious deficiencies, testing is required to confirm the performance of the air barrier system. Even the most experienced inspector does not have the ability to quantify the performance of the system by visual inspection alone.

THE DESIGN, INSPECTION AND TESTING PROCEDURE [*23,24*]

Phase 1: Design Stage

Standards utilized in Phase 1:
ASTM E 283, *Standard Test Method for Determining the Rate of Air Leakage Through Exterior Windows, Curtain Walls, and Doors Under Specified Pressure Differences Across the Specimen*

ASTM E 330, *Standard Test Method for Structural Performance of Exterior Windows, Curtain Walls, and Doors by Uniform Static Air Pressure Difference*

ASTM E 783, *Standard Test Method for Field Measurement of Air Leakage Through Installed Exterior Windows and Doors*

ASTM E 2099, *Standard Practice for the Specification and Evaluation of Pre-Construction Laboratory Mockups of Exterior Wall Systems*

Phase 1 consists of the following activities;

- review of plans and specifications as they are created
- review of trades' shop drawings
- orientation meeting
- construction of mockup
- testing of mockup

Prior to issuing construction drawings and bid documents, the designer and building envelope consultant should review the plans and specifications for the project to confirm that no problems are inherent in the design that may cause the system to not function as per NBCC requirements. Individual details, components and materials should be reviewed to determine whether they are compatible within the confines of the system, and to adjoining components or materials within the building envelope. The bid documents should make clear what will be required of the trades, and should inform them of the inspection and testing protocols to be utilized on the project. Once it is known what general contractor and sub-contractors will be working on the project, all shop drawings should be reviewed to determine whether the proposed details can be constructed in keeping with the general intent of the designer.

Before construction begins, an orientation meeting should be called by the building envelope consultant (it is often in the specifications) and is usually arranged by the general contractor. Present at the meeting should be the owner, designer, general contractor, trades, and third party testing agents/consultants. The purpose of this meeting is to reiterate to the contractor and trades exactly what will be required of them, and to allow them to voice any concerns prior to the commencement of work. All parties will be given a chance to review the plans, specifications, and shop drawings, and an appropriate sequencing of components and construction schedule is devised. Sub-contractors should declare their intentions as to the materials they will be using, so that compatibility issues can be discussed.

In order to evaluate the design aspects of the system as it is to be installed on site, a mockup of the key details of the system should be constructed by the general contractor, preferably by persons representative of the skill level that will be working on the project (construction and testing of a mockup should be included in the design specifications). ASTM E 2099 outlines construction and documentation procedures to assist in the specification and evaluation of pre-construction laboratory mockups.

When constructing the mockup, it is important to consider components or sections of the system where failure is most likely to occur. Improperly designed or installed window surrounds, unsealed fastener penetrations, and junctions between dissimilar components or materials are the most common causes or locations of air barrier system failure. In some cases, it may be impractical to build a mockup to test every type of detail in the system. However, the mockup must be representative of what will be constructed on site. The designer should specify which details should be included in the mockup. For some projects, several mockups may be required to include all of the details specified. The cost of building and testing the mockup is borne by the general contractor, although this cost should have been accounted for in the bid price. Once it has been built, the general contractor and consultant should coordinate the schedule for inspection and testing.

To determine the air leakage rate of the system, quantitative testing should be conducted in accordance with ASTM E 283. This test is performed under laboratory conditions and is only intended to measure leakage associated with the assembly, and not the site installation. To conduct the test, an airtight enclosure is constructed to the exterior of the sample area and attached to the plane of the air barrier. Air is supplied to the chamber within a range of pressure differentials, the reference point for the test procedure being taken at a pressure differential of 75 Pa as prescribed in the NBCC. The airflow required to maintain that pressure differential is equal to the air leakage out of the enclosure. If the air leakage rate of the system meets project specifications[4], the system passes. The test should also be conducted where air is exhausted from the chamber to create a range of negative pressure differentials. The additional air exhausted from the chamber to maintain that negative pressure differential is equal to the air leakage into the enclosure. It is important to run the test twice; once inducing a positive pressure differential within the enclosure and once inducing a negative pressure differential within the enclosure. Applying a pressure differential in one direction (positive or negative) may tighten the plane of air and provide a result not representative of the leakage rate if the pressure differential is reversed.

Several variations of the test can be conducted depending upon the details of the sample area. For example, where the sample area includes a combination of both fixed and operable window units, three variations of the test can be performed. First, a test can be conducted where the joints and junctions in the window or windows are masked with tape to eliminate air leakage through window assemblies; hence, the test results would indicate the amount of air leakage, if any, through the opaque wall section. For the second test, the masking can be removed from the fixed windows, where the difference in the results between tests 1 and 2 will represent the amount of leakage through the fixed units. Thirdly, the test is performed with masking completely removed from the

[4] The air leakage rate as specified in the project specifications should be equal to or less than that recommended in Appendix A of the NBCC.

window, where the difference in the results between tests 2 and 3 will represent the amount of leakage through the operable window. Regression analysis can then be performed on the test data to allow for a more precise determination of the air leakage characteristics of various wall and window components at the specified pressure differential.

Where the mockup has been constructed in a field setting, air leakage testing should be performed in keeping with ASTM E 783. The E 783 utilizes a similar test method as E 283, the only significant difference being that E 783 applies to field testing as opposed to laboratory testing.

By exposing the mockup to specified pressure differentials, it can be determined whether the structural ability of the system and the strength of the bond between the membrane and substrate are sufficient to withstand the loads likely to be placed against it. Testing can be performed in accordance with ASTM E 330 in this regard. Utilizing the sealed chamber used to conduct the E 283 or E 783 tests, the test area can be pressurized (or depressurized), and any deflections, deformations, and distress or failures in the specimen can be observed.

While these tests are useful in determining whether the system can 'work', it must be remembered that these tests do not take into account on-site variables that may have an effect on how the system performs, such as climate and environmental conditions, workforce skills, and materials (which may differ from those used on site). It should be noted, also, that in some cases, the mockup is eventually used in the actual building, at the discretion of the designer.

If the mockup does not meet project requirements of airtightness, structural integrity, durability or membrane-substrate adhesion, the system fails. It must then be determined whether the failure is a result of a material flaw, design error, unsatisfactory installation, or any combination of the three. Where the material has failed, it must be determined whether there was a manufacturer's defect in that particular sample of material, or whether the material itself is inadequate for that particular application. Where failure is attributed to a design flaw, the system must be redesigned and a new mockup constructed and tested, at the expense of the designer. If the failure is deemed to be the result of installation flaws, the mockup should be rebuilt and tested, at the expense of the contractor. If a second attempt also fails, the consultants and designer must decide whether the installer has the necessary knowledge and skill level to perform the work to specification.

Phase 2: Work-in-Progress

Standards utilized in Phase 2:

ASTM D 4541, *Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers*

ASTM E 783, *Standard Test Method for Field Measurement of Air Leakage Through Installed Exterior Windows and Doors*

ASTM E 1186, *Standard Practices for Air Leakage Site Detection in Building Envelopes and Air Retarder Systems*

4.2.6 *Chamber Pressurization or Depressurization in Conjunction With Smoke Tracers*

4.2.7 *Chamber Pressurization or Depressurization in Conjunction With Leak Detection Liquid*

Inspection and testing performed during this phase is a mixture of visual inspections, and qualitative and quantitative tests, conducted by both the workforce and third party testing agents/consultants. The mix will ultimately depend upon budget and application, although visual inspections should always be conducted. Ideally, quantitative and qualitative testing should be used to set project performance benchmarks, and a mixture of visual inspection and qualitative and quantitative testing methods used to test the installation for leaks, membrane-substrate bond adhesion, etc. Quantitative testing can then be used for code or specification compliance.

Visual Inspection

Visual inspections of the site conditions should be conducted by a certified installer prior to any membrane being installed. The installer should examine the substrate, ensuring that it is dry, clean and properly primed, and that substrate temperature is suitable for installation as per the type of material being applied. If the material is a 'two-part' material and is fabricated on site, the installer can and should ensure that it was done in accordance with manufacturer's recommendations, and that it is compatible with surrounding materials. As the air barrier is being installed, the installer should be aware of the construction schedule and how in-progress building conditions will affect the membrane, doing his best to avoid situations where the membrane is left exposed to conditions that may be potentially damaging, such as ultraviolet radiation. Visual inspection by the workforce should be an ongoing process throughout the installation, performed daily, to make sure proper installation practices are being adhered to. This should be assigned to the foreman, who is held accountable if these inspections are not performed.

As with the workforce, visual inspections should also be performed by the building envelope consultant throughout the construction process, with an emphasis on the initial installations. The inspector should look for such deficiencies as gaps in the system, damage to the air barrier from other trades, 'flutes', wrinkling, and unbonded areas of membrane especially around penetrations, window frames and other intricate or difficult to construct details.

'Flutes' are areas of the membrane where a seam has been left open and a passageway or tunnel has been created that moves from the seam opening through the midfield area of the membrane. This is usually a result of the membrane being applied to the wall when it is 'bunched up' rather than being pressed flat (Figure 8). Flutes can be repaired by re-rolling the affected area. Where flutes are in abundance or are too large, the affected area should be cut and removed, and the exposed area patched with a new strip of membrane.

Figure 8: Flutes in an air barrier membrane.

Figure 9: Membrane is not sealed at the penetration.

Similar to flutes is when the membrane appears wrinkled. While wrinkling may occur when the membrane is left exposed to extreme conditions, for example, direct sunlight, it may also be a result of poor installation practice; the membrane has either not been installed 'flat' or has not achieved a proper bond. The affected area should be tested for air leakage, the methods of which are discussed in the section 'Qualitative Testing'. If the area is airtight, no further measures need be taken. While the membrane may not be aesthetically pleasing, the wrinkling is not likely to compromise the performance of the system.

Penetrations through the membrane must be sealed and made airtight. Whereas examples such as seen in Figure 9 may be obvious to the eye, on many occasions, some form of airtightness testing will have to be conducted in order to determine whether or not the penetration has been sealed adequately. Some types of membranes are self-healing, meaning that they will seal around fasteners. These membranes should be tested to account for human errors such as over-drilling, or over-tightening of fasteners.

Figures 10 and 11 illustrate commonly found deficiencies in air barrier installations. Of particular interest is Figure 11, which encompasses several imperfections. The membrane is wrinkled and clearly not bonded to the wall, there are flutes in several areas, some of the structural steel hanger brackets are not sealed, and there are open seams where the membrane is joined onto the window frame. To make matters worse, the membrane is 'shingled' in the wrong direction, meaning water draining down the wall will drain into the seams instead of over them. This is of major concern when the air/vapour barrier acts as a drainage plane. There is even a trough forming behind the window head flashing which could cause water to drain back into the wall assembly.

Figure 10: Membrane is not sealed to the substrate.

Figure 11: Bad workmanship at window frame.

In summary, the purpose of third party visual inspection is twofold; (1) to identify the presence of obvious deficiencies that may be a clue that the workforce does not have the sufficient skill level and may have difficulty installing the membrane, and (2) to prevent having to use a large portion of the testing budget on samples that are obviously deficient and unacceptable.

Quantitative Testing

Third party quantitative testing should be performed on an installed sample area to determine whether or not the system, as installed, meets the requirements of the NBCC and/or prevailing project specifications. As with testing the mockup, ASTM E 783 can be used to test the sample (Figure 12). When used for this application, the test provides a measurement of the acceptable amount of air leakage for the system, which can then be used as a benchmark for the rest of the project.

Figure 12: Conducting an ASTM E 783 test.

Once the membrane has been applied to the substrate, membrane-substrate adhesion strength can be established by testing a sample area in keeping with ASTM D 4541, a test method applicable to any portable testing device which meets the basic requirements for determining bond-adhesion between a coating and the substrate. Test results can be used to determine whether the strength of adhesion between the membrane and the substrate is in keeping with manufacturer's recommendations. The D 4541 adhesion test is performed by selecting a sample area of installed membrane, approximately 4 inches in diameter, allowing for a test surface area of approximately 12 square inches. A loading fixture, commonly a metal test pad, is applied perpendicular to the test surface with an adhesive. Once the adhesive has cured, the area of the membrane covered by the adhesion pad is cut, separating the sample from the rest of the membrane (the test is destructive to the membrane, but the area damaged is small enough that it can be patched with little difficulty). A testing apparatus is then attached to the loading fixture, aligned to apply tension normal to the test surface. The load is increased until the membrane becomes detached or until a maximum load as specified either by the designer or within the manufacturers' technical literature is reached. If the membrane becomes detached before the specified load is attained, the bond strength between membrane and substrate is insufficient (see Figure 13).

Figure 13: ASTM D 4541 membrane-substrate adhesion test. Photo 1, installer makes a cut in the membrane by tracing around the adhesion pad. Photo 2, bond adhesion tester is used to place a load against the membrane. Photo 3, membrane becomes detached from the wall as a result of the load placed against it.

If the sample area fails, the inspector should examine the test sample and surface area, and ask the following questions: Has the substrate been cleaned prior to installation? Was the substrate primed properly? Was the correct primer used, and if so, was it applied and cured as to manufacturer's recommendations? If it appears that proper installation practices were observed when the membrane was installed, the inspector should test other areas of the membrane to determine whether the bond strength is unsatisfactory in several areas and needs to be re-applied, or whether the original test sample was simply not representative of the entire installation.

If testing determines that the membrane is not adequately bonded to the substrate, it is imperative that no materials be installed over the membrane. While stopping work is a very serious call, work should not be allowed to proceed that will make rectification or replacement of the membrane more difficult.

The procedure for fixing the membrane depends upon the material used. If the membrane is torch-applied, and the unbonded/unsatisfactorily bonded areas are small, the affected areas can be cut out and re-torched. If the affected areas are larger, then the membrane may need to be replaced. If the membrane is self-adhered, a simple re-rolling may suffice. If the wrong primer was used, or the substrate was not prepared properly, the membrane may have to be removed and replaced with new membrane. Where the unbonded area is small, it may be possible to cut out the unbonded area and patch it, rather than removing all of the membrane from the wall section.

Membrane-substrate adhesion strength should be tested frequently, especially around complex details, such as around windows and doors. In addition to random sampling, testing should be performed whenever installation conditions such as workforce, climate, site conditions or materials change. Because the test is easy to perform, and can be done quickly, installers can use this method to test random samples of their work to assess the quality of the installation.

Qualitative Testing

ASTM E 1186 has been revised, and includes new, simple test methods that can be performed quickly and without disrupting the critical path of construction. Installers are now able to test their work as it is being constructed. In order to identify problems or potential problems early in the construction process, a greater percentage of installer self-testing should be concentrated toward the front end of the project. Once it has been established that there are no fundamental problems with the installation, such as inadequately skilled labour, design flaws or materials concerns, the remaining testing can be performed randomly and on a frequency appropriate to the size of the project and dependant upon site variables such as installer skill level, materials, environmental or building conditions or when there is a change in any of these variables.

It is seldom the case where sheet membranes leak midfield, although some spray-applied membranes may. In most instances, air leakage will occur through seams at membrane laps and around penetrations through the membrane, which may be difficult to detect through visual inspections. Air leakage testing of seams and penetrations can be performed in accordance with ASTM E 1186 4.2.7. This provides a qualitative result which will indicate the presence of a leak (Figure 14). Test methodology proceeds as follows: a sample detail is selected. This detail can consist of either a membrane seam, or any penetration through the membrane. Leak detection liquid is applied generously over the detail. A clear, sealed chamber is placed over the detail, and a negative pressure differential applied to the detail within the chamber. The pressure differential gradually increases until it reaches a specified level. Bubbles forming in the test solution indicate the presence of a leak. Where no bubble forms, no leak is present. Once a sample size representative of the entire project has been built, seams and penetrations should be tested. Again, once it has been established that no major problems exist with the installation, random sample testing can be performed throughout the rest of the project.

Figure 14: ASTM E 4.2.7 test being performed on a masonry tie. Photo 1, leak detection solution is applied around the penetration. Photo 2, Leak Detector unit is placed over the detail and activated, creating a pressure differential within the clear test chamber. Photo 3, bubbles indicate the presence and location of a leak.

Third party testing agencies can provide quality assurance testing during this phase. The regimen is similar to that as utilized by the workforce, ASTM E 1186 4.2.7 and D 4541, although the third party agencies may make use of several alternative testing methods not applicable for workforce use. For example, aside from testing mockups, the ASTM E 1186 4.2.6 can also be used to provide a visual benchmark for the project as well as for testing the air leakage around window, wall and door details (Figure 15).

Figure 15: ASTM E 1186 4.2.6 smoke test being performed on a window.

For the on-site installer, where a 'number' for the acceptable rate of air leakage may have little relevance, the same benchmark can be expressed visually by testing the sample in accordance with ASTM E 1186 4.2.6. The test is conducted by the third party, and can utilize the same chamber as was used in the E 783 test. Air is exhausted from the chamber until a negative pressure differential of 75 Pa is reached. A smoke pencil is then moved along the interior of the sample area. Where leakage is present, smoke will be drawn through the leak area and into the chamber. The speed at which smoke enters the chamber, taken in combination with the amount of smoke that enters the chamber, can be used to visually assess the size and location of the leak(s).

To further elaborate on ASTM E 1186 4.2.6, the test can be performed several different ways depending upon the nature of the sample detail. While the methodology of the test was previously described where a smoke tracer was run along the interior surface of the detail with a negative pressure differential induced within the enclosure, the reverse is also applicable. Smoke tracers can be used to fill the enclosure with smoke and a *positive* pressure induced within the enclosure. Where leakage is present, smoke will be released into the interior of the room or test area. This provides an excellent visual picture of the amount and effect of air leakage.

In a situation where the exterior of the sample area cannot be reached, such as at an air barrier membrane/window section that has already been covered with finishing materials, the enclosure can be constructed to the *interior* of the detail. Here, the tester stands inside the enclosure and a positive pressure differential induced within. The tester then moves the smoke pencil along the test surface. Smoke drawn to the exterior indicates the presence of air leakage. It is also possible to seal and pressurize an entire room to conduct this test.

There are a couple of points to be noted regarding this test method. Firstly, the presence of smoke does indicate air leakage, but it only gives a visual 'approximation' as to the extent of the leakage. Therefore, the results are subjective. A smoke test performed under high pressure conditions often makes the leak look worse than it is. Also, it is easier to see leakage "in" that leakage "out". A qualified and experienced viewer should conduct the test in order to most accurately interpret test results. Whether or not the presence of a small, gradual flow of smoke into or away from the enclosure results in a 'failure' depends upon the project specifications which in turn depend upon the function of the building. Secondly, care should be taken when administering any type of smoke test as the fumes can be hazardous to the health of both the user and the building inhabitants.

<u>Phase 3: Post-Construction</u>

Standards utilized in Phase 3:

ASTM E 741, *Standard Test Method for Determining Air Change in a Single Zone by Means of a Tracer Gas Dilution*

ASTM E 779, *Standard Test Method for Determining Air Leakage Rate by Fan Pressurization*

ASTM E 1186, *Standard Practices for Air Leakage Site Detection in Building Envelopes and Air Retarder Systems*

- **4.2.1 *Building Depressurization with Infrared Scanning Techniques***
- **4.2.2 *Smoke Tracer in Conjunction With Building Pressurization or Depressurization***
- **4.2.3 *Building Depressurization (or Pressurization) in Conjunction With Airflow Measurement Devices, or Anemometers***
- **4.2.4 *Generated Sound in Conjunction With Sound Detection***
- **4.2.5 *Tracer Gas***

CAN/CGSB-149.10-M86, *Determination of the Airtightness of Building Envelopes by the Fan Depressurization Method*
CAN/CGSB-149.15-96, *Determination of the Overall Envelope Airtightness of Buildings by the Fan Pressurization Method Using the Building's Air Handling System*

Upon completion of the building, the overall airtightness of the building can be determined. There are many benefits to quantified testing of the completed building. Determining the air leakage rate for the entire building can be useful in estimating the overall air leakage related energy efficiency of the building, in addition to simply ascertaining whether or not the air barrier system is functional. Post-construction testing may not be necessary on all buildings however, and is usually only performed where one or more of the following conditions are present:

- the building is a ‘high-performance’ building, where the interior environment must be stable,
- it is required for specification or code compliance,
- it is required by the owner/designer to provide confirmation that the air barrier system is functional.

Post-construction testing provides its greatest benefits when utilized as a tool for monitoring/maintenance, retrofits, and diagnostic work. Whole buildings can be tested years after completion to determine whether the air permeance of the building still meets specifications, and if necessary, what preventative maintenance should be performed to ensure the building continues to function properly. For retrofits, testing can be utilized for ‘before and after’ analysis. The air leakage rate of the building can be determined prior to the retrofit, and again once the retrofit is complete. Thirdly, in situations where a building component has failed, post-construction testing can be used as a diagnostic tool to identify the probable causes of the failure.

Several different test methods can be applied in this regard[*25*]. ASTM E 779 consists of mechanically pressurizing or depressurizing a building to a specified level, and measuring the resulting air flow rates at given indoor-outdoor static pressure differences in order to evaluate the air permeance of the building envelope. The amount of additional airflow required to maintain that static pressure differential is equivalent to the amount of air leakage through the building envelope. Ideally, the test should be performed twice, once inducing a positive pressure into the building and once inducing an equal, negative pressure in order to account for airflow that passes though the building envelope in one direction only. This test should not be performed under conditions of high wind or large temperature differentials. Similar to this test, CAN/CGSB CAN/CGSB-149.10-M86 and CAN/CGSB-149.15-96 may also be used.

Whole building air leakage tests can also be conducted in accordance with ASTM E 741. Here, a tracer gas is introduced into the building, or into a part of the building (any structure or part of a structure that is enclosed), to determine how long it takes that gas to dissipate. By measuring the concentration of the gas that has been injected into the zone over time, the volume of airflow leaving the zone can be calculated and from this, the air leakage rate for the building or zone can be inferred.

ASTM E 1186 provides several alternative methods for determining the leakage rate of the air barrier system. Sections 4.2.1 *Building Depressurization (or Pressurization) with Infrared Scanning Techniques*, 4.2.2 *Smoke Tracer in Conjunction with Building Pressurization or Depressurization*, and

4.2.3 *Building Depressurization (or Pressurization) in Conjunction With Airflow Measurement Devices, or Anemometers* all involve inducing a pressure differential and/or temperature differential to the entire building, and in some cases, may require an engineer to interpret the results. These methods may prove infeasible for testing during the construction process and are more applicable to complete building tests. Section 4.2.4 *Generated Sound in Conjunction With Sound Detection* consists of locating a sound generator within the building and moving a sound detection device over the exterior of the building envelope, where increased sound intensity represents an air leakage location. The reverse methodology also applies, where the sound is generated to the exterior of the building and the detection device moved over the interior of the building envelope. Section 4.2.5 *Tracer Gas* can also be a used to detect building envelope air leakage. A tracer gas is released on one side of the building envelope and the concentration of the gas that flows to the other side of the building envelope is measured.

It should be noted that in each of the aforementioned test methods, caution should be taken when analyzing the results. While test results may indicate the presence of air leakage sites, they do not pinpoint the exact location where the leakage originates, or identify which component or components have failed. It is even possible for the numeric results generated through testing to indicate that the system has met air leakage requirements even though one or more components have failed. Therefore, when any of these tests do indicate that leakage is present, the inspector must ensure that the test results were not skewed by extraneous factors not representative of the test area. The inspector should investigate the following: (1) examine the site conditions to ensure that there were no abnormalities that may have influenced the test results (i.e. an open window), and (2) analyze the numerical results to ensure that they are correct and have been interpreted properly.

If it is determined that the test results are correct and have not been influenced by anomalous variables, the test should be conducted again. Test conditions for the second test should be the same as the first test in order to produce accurate results. If similar results occur on the second test, the consultant and designer should determine which components have failed. Where the air barrier is maintainable, this may be relatively simple. However, where the air barrier is non-maintainable, this may not only be difficult to determine, but also may be expensive to pursue. The final decision on how to proceed will be made by the owner, under the guidance of the designer and consultant.

The difficulty in post-construction testing is that many of the approved testing methods have inherent problems that may influence the results. Many of the qualitative methods contained in the ASTM E 1186 provide very subjective results, and do not test the individual components of the system. In addition, if often takes a great deal of time (a whole day or more) to prepare the test area and conduct the test, and where the building is under multi-ownership (as in a condominium complex), his may be difficult to coordinate. Finally, there are few firms qualified to perform this type of testing.

CONCLUSION

With the increasing incidence of premature building failures, and a growing global concern over greenhouse gas emissions, it is imperative that the construction industry respond to these concerns by reducing the amount of air leakage in buildings. Government has introduced more stringent regulations regarding building air permeance, and the formation of air barrier trade associations has given designers and owners the option to utilize association quality assurance programs. The development of an inspection and testing protocol that can be applied generically to any air barrier installation, and utilized on a widespread basis, is the missing piece of the puzzle to ensure that buildings meet the requirements and recommendations as set out in the National Building Code of Canada.

While the implementation of an inspection and testing protocol represents a giant leap forward in the goal of achieving airtight buildings, to realize the full benefit of the protocol requires the cooperation and commitment of all industry stakeholders. At the design level, architects must convince owners to provide realistic budgets for inspection and testing, and utilize the quality assurance programs that are available to them. When deficiencies are identified, the designer has to take steps to ensure that these deficiencies are rectified. At the contractor level, installers must take advantage of education and training opportunities, and ensure that self-testing is being performed on site. At the government level, codes and standards must be continuously upgraded to reflect the most recent technological advances. Finally, owners must be made aware of the serious problems attributable to building envelope air leakage, and the solutions available to prevent these problems from occurring.

QUESTIONS

1. Where should the following be placed within the wall — (a) air barrier (b) vapour barrier (c) air/vapour barrier?

2. Where an air barrier system is subject to a warm side relative humidity of 35% at a temperature of 21°C, what is the maximum leakage rate for the system as recommended in Appendix A of the National Building Code of Canada?

3. What are the four key requirements for an effective air barrier system?

4. What ASTM standard should be utilized to provide a quantitative figure for the air leakage rate of a section of air barrier that has been installed on site?

5. When designing the air barrier system, specifically at joints and junctions, what must the designer take into consideration to ensure system continuity?

6. What is the difference between and air barrier material and an air barrier system?

7. A random sample of masonry ties that penetrate the air barrier was tested for air leakage in accordance with ASTM E 1186 4.2.7. Test results showed that 80% of the ties tested exhibited signs of air leakage. This is the first sample that has been tested. What can be determined based upon these results?

8. Quantitative air leakage testing was performed on a sample area of wall (mockup). The sample met air leakage requirements. How are these results then applied over the rest of the project?

9. When finishing materials are installed immediately after the air barrier has been installed, how can this potentially compromise the performance of the air barrier?

10. Prior to an air barrier membrane being installed mid-wall, the installer should perform a visual inspection. What should he be looking for?

11. Consider the photograph in Figure 11. What deficiencies exist in the membrane installation?

12. A sample of air barrier was tested for adhesion strength in accordance with ASTM D 4541. Test results indicated that the test sample did not meet the membrane-substrate adhesion requirements as specified. What actions should be taken by the tester at this point?

13. Prior to commencement of construction, an orientation meeting should be held. Who should attend this meeting and what items should be up for discussion?

14. When specifying air barrier materials, the designer must ensure that the air permeance rating of the materials does not exceed what level? What other factors should the designer consider?

15. A sample area of wall has been completed by the trades. Prior to any testing, visual inspection by the tester identifies deficiencies in the sample. Should qualitative testing commence as scheduled? Explain rationale.

ANSWERS

1. (a) The air barrier can be placed anywhere in the wall provided it restricts the flow of conditioned air such that this air will not come into contact with cool surfaces where temperature is below dew point.
   (b) The vapour barrier should be placed on the high vapour pressure side of the wall.
   (c) The air/vapour barrier should be placed on the warm side of the building envelope.

2. 0.10 L/(s•m^2) at 75 Pa.

3. The four key requirements for an effective air barrier are airtightness, continuity, structural integrity and durability.

4. ASTM E 783 Standard Test Method for Field Measurement of Air Leakage Through Installed Exterior Windows and Doors.

5. The designer must consider the sequencing and scheduling of components.

6. Air barrier material is the stand-alone material that will be used as the air barrier or as a section of the air barrier system. The air barrier system is the group of components that, acting together, prevent the movement of air between the interior and the exterior, or between areas of dissimilar environments.

7. Three problems may exist: (1) installation flaw related to that particular installer, (2) a design flaw, and/or (3) material flaw, where the material may not be suited to that particular application

8. These results can be used as a benchmark for the rest of the project. Other details may be tested qualitatively to ensure they meet that benchmark.

9. Because the air barrier has been covered so quickly, it becomes more difficult to join to other sections or components, thereby compromising system continuity. In addition, it is unlikely that the system has been tested or inspected, therefore deficiencies that may exist in the installation will not have been seen nor rectified.

10. The installer should consider substrate condition (whether it been cleaned and properly primed), substrate temperature, environmental and climactic conditions that may inhibit installation (such

as temperature, the presence of rainfall, wind), materials (to ensure they have been fabricated properly), and construction schedule.

11. Deficiencies that exist are: structural steel hanger bracket furthest right in the photograph has not been sealed; the membrane is not bonded to the substrate; the membrane is not sealed to the window frame; flutes exist at the membrane seams; membrane is shingled in the wrong direction (water will drain into the seams); trough formed behind window head flashing.

12. The sample should be inspected. The tester should inspect the surface area to determine whether it has been properly cleaned and primed. Retests should be conducted to ensure that the sample chosen was representative of the entire installation.

13. Present at the meeting should be the owner, designer, general contractor, trades and consultants/testing agents. At the meeting, all parties are given a chance to voice concerns over the plans, specifications and shop drawings, and all parties are made aware what will be required of them. Trades will declare their intentions as to the materials they will be using, and compatibility issues will be discussed. In addition, the sequencing of components will be determined and a schedule for construction devised.

14. The material's air permeance should not exceed 0.02 $L/(s \cdot m^2)$ measured at an air pressure differential of 75 Pa. The designer should also be aware of the physical and chemical properties of the material to ensure that it is compatible to other materials or components within the system. The designer should review the technical literature as supplied by the manufacturer.

15. Qualitative testing at this point should not be performed. If deficiencies can be identified visually, there is no need to do any further testing until the deficiencies are corrected. Once deficiencies can no longer be identified visually, then testing can be performed in order to detect deficiencies that cannot be identified visually.

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