Adapting PERSIST for the Prevention of Water Accumulation in Residential Wood Frame Construction

Peter D. Baker **Chris B. Makepeace**

ABSTRACT

The purpose of this paper is to examine how the Pressure Equalized Rain Screen Insulated Structure Technique (PERSIST) can be applied to residential wood frame construction to provide an effective exterior envelope to prevent water accumulation in walls and roofs. Many residential buildings in North America are encountering problems of rot and mold growth related to water accumulation. These problems stretch further than only damage to the building materials. Issues of health, safety, accountability, and cost result as well. PERSIST is a technique that was developed by combining several concepts researched and developed by the National Research Council of Canada in the 1960s. In Alberta this technique of moving the air seal plane to the exterior of the structure has been used successfully for the past 20 years in commercial construction applications. The viability of PERSIST for residential applications is demonstrated through its ability to manage water penetration in the assembly, its ability to be applied to residential buildings, and by examining the cost considerations involved with damage caused by water accumulation.

INTRODUCTION

Wood frame residential construction includes all buildings from single-family houses to multi-family complexes, such as condominiums and high-rise apartment buildings, that are built using standard residential construction practices for the exterior wall and roof systems. In North America there have been reports of many of these wood-framed residential buildings experiencing problems caused by the intrusion of water in the exterior wall and roof assemblies. The problems stretch further than damage of building materials and property; issues of health, safety, and accountability have led and are still leading to litigation and large economic costs. The most widely reported Canadian case is the condominium crisis on the west coast.

Many condominiums in British Columbia that were damaged by water penetration have been renovated several times due to reoccurring problems (Figure 1). The immense cost associated with all of the renovations has resulted in numerous lawsuits being filed for compensation. The home warranty program developed to protect homeowners has gone bankrupt. Some insurance agencies are refusing to ensure designers for problems involving water accumulation in exterior wall assemblies. This has left many condo owners with no hope for any compensation and they have had to find their own means of financing the cost for the repairs. The Barrett Commission suggested that the cost to repair the problem facing residential homeowners is between \$500 million and \$800 million (1998). Since then, the figure has increased and has been estimated by many to now be in the billions of dollars, and yet the problems are still occurring.

This is not an isolated case nor is it simply a coastal problem. Failures are occurring all over North America in all kinds of climates. A study done by Canada Mortgage and Housing Corporation (CMHC) identified similar problems, although less severe, were occurring in Alberta (CMHC 2000). There are other media-reported cases of moisture-related problems in Florida and North Carolina, as well.

The problem is that moisture, which penetrates into the interior of a wall or roof, contributes to the promotion of rot and mold growth. Four conditions are required for the proliferation of rot and mold growth to occur: (1) the presence of

Peter D. Baker is a building science engineer and **Chris B. Makepeace** is the manager of the Walls and Windows Unit in the Building Sciences Section, Alberta Infrastructure, Edmonton, AB.

Figure 1 *Deteriorated wall of a B.C. condominium due to water penetration.*

Figure 2 *Air barrier membrane installed continuously over the entire structure.*

mold spores; (2) a food source; (3) an appropriate temperature; (4) and a source of moisture. The growth is often contained within the wall assemblies, leaving no visible signs of a problem. Once the mold colony has been established, it can become very durable. If the assembly dries out, the colony will become dormant until conditions become favorable again. Once the colony reaches maturity, it begins producing spores. These spores can then be spread by air movement or mechanical disturbance (Pearce 2000). The dangers of toxic mold spores are not well understood. Exposure to airborne mold spores can result in eye irritation, cough, congestion, aggravation of asthma, headache, and fatigue (NYC Department of Health 2000). The connection between mold exposure and some more severe symptoms is not confirmed; however, some speculate an association between airborne mold spores and cases of pulmonary hemorrhage, brain damage, and even death.

Many homeowners may not realize if the exterior walls of their homes are frequently getting wet. Signs of problems are often not visible on the exterior surfaces. Wetting of the construction in itself is no reason for concern; wood has the ability to absorb a lot of water and then dry out under more favorable conditions. It is the balancing act between the wetting and drying potential based on environment, design, and construction that has allowed many buildings to function without severe problems. Problems of rot and mold growth occur when the wetting load exceeds the drying capacity of the structure, allowing water to accumulate for a period of time.

Changes in the construction industry over the last 30 years have had an impact on this balance. Energy efficiency became very important in the 1970s. With this came some changes to construction standards and codes. Some municipalities implemented requirements for minimum insulation thickness in walls and ceilings. Vapor barriers and other water management materials and systems were added to building codes. The impact of these changes on the performance of the walls and roofs was not fully understood, and discussions still exists as to what real effects these changes have had. It can be seen that the changes have altered the dynamic of the construction assemblies, pushing the limits of the building envelope to manage the loads. Either the wetting potential has been increased, or the drying potential has been reduced, or both, causing failures to occur more rapidly.

The Pressure Equalized Rain Screen Insulated Structure Technique (PERSIST) is a building envelope approach that has been used successfully for many years in commercial construction. This is not saying that PERSIST should be used for all residential construction. Many homes function adequately in the environments in which they are placed. The approach would be justified for designs and locations that potentially run a higher risk for water accumulation. Adapting the principles of PERSIST to residential wood frame buildings would provide a reliable system to prevent water accumulation in a wood frame construction.

PERSIST

PERSIST is an approach that combines several building envelope concepts that were researched and developed by the National Research Council of Canada in the 1960s. The technique moves both the air barrier and insulation to the exterior of the structural components of the building. A cladding system that is held away from the insulation is provided to protect these components and to allow for drainage of the assembly to the exterior of the structure.

This technique considers the building envelope as a series of planes that all provide specific functions to resist the various loads imposed by the interior and exterior environments. These planes are arranged in such a way to maximize their own effectiveness in the assembly and to ensure the durability of the entire assembly.

The structure is designed to maintain, as much as possible, simple continuous planes from foundation to wall and from wall to roof. These planes minimize problems of maintaining continuity of the other envelope components and minimize problems that may arise due to spaces near the exterior walls that do not have adequate air movement to maintain an even temperature with the rest of the interior environment.

The air seal is fully adhered to the exterior sheathing of the structure (Figure 2). The air-sealing component is a continuous barrier that prevents the movement of air and water

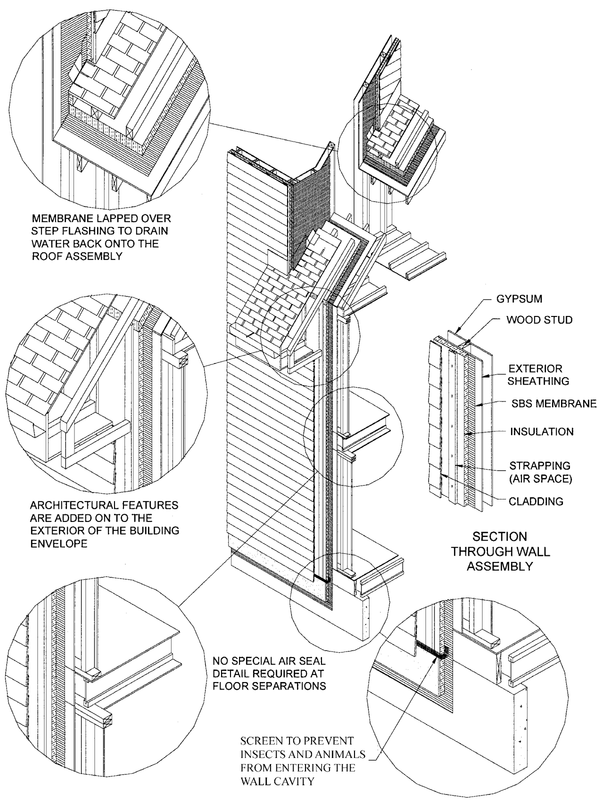

Figure 3 *Isometric of a PERSIST wood frame building.*

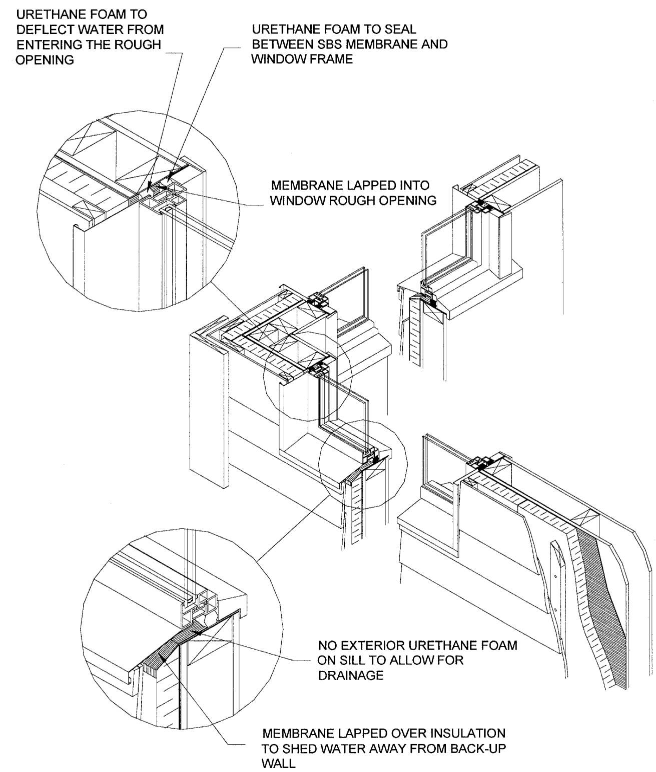

Figure 4 *Isometric of PERSIST window installation.*

through the envelope. In this way the structure is protected from any water that may penetrate from the exterior or from problems of condensation associated with air leakage. The air seal and structure work together to provide a continuous air barrier system for the building that is able to resist the air pressure loads caused by wind, stack effect and mechanical pressurization. This is the prime separator between the interior and exterior environment. All materials used exterior of the structure must be able to endure occasional wetting. Penetrations of the air seal by supports for the cladding or for mechanical and electrical requirements should be minimized and designed to allow for the air-sealing component to maintain a continuous seal.

Insulation is mechanically fastened tight to the air barrier system. The insulation keeps the temperature of both the air seal and the structure at or near the temperature of the interior environment. This prevents damage to these interior components from thermal cyclic loading. The insulation should be installed as continuously as possible over the entire structure so that problems of condensation and energy loss caused by thermal bridging are minimized. By installing the insulation to the exterior of the structure, the location at which the interior air reaches its dew point is moved to a location exterior of the waterproof air barrier plane and structure. Even if there are small imperfections in the air barrier, condensation due to air leakage will occur at a location exterior of the structure. The condensation is then drained out to the exterior of the cladding. The importance of ensuring that the insulation is kept tight to the exterior of the air barrier cannot be overstated. Air circling behind the insulation will reduce the insulation's effectiveness and increase the chance of condensation occurring in the structure.

The cladding is installed exterior of the insulation. The cladding protects all of the other envelope components from physical damage, damage due to radiation, and mass water penetration. An air space that is designed for pressure equalization is provided between the insulation and the cladding. Pressure equalization, though not instantaneous, is still effective in reducing the amount of water that is forced through the cladding by air pressure differences. The space also provides a capillary break that prevents direct transmission of water from the exterior of the cladding to the insulation and air barrier plane. Holes at the bottom of the cladding allow for any moisture that may penetrate the cavity to drain to the exterior, preventing water accumulation in the assembly. Air movements behind the cladding system increase the drying potential of the assembly.

ADAPTING PERSIST TO RESIDENTIAL CONSTRUCTION

The differences between a PERSIST building and a standard wood frame residential building are minimal, allowing for many existing construction practices to remain unchanged. The key points highlighting the differences are listed below and details are shown in Figure 3 and Figure 4.

Changes to the building assemblies:

- The structure and framing techniques, for the most part, remain the same. There are no additional special requirements for the exterior sheathing materials. The sizing of the structural members may be reduced because they are no longer governed by insulation thickness requirements between the studs.
- To date, the material usually used for the air seal component has been a styrene-butadiene-styrene modified bitumen membrane (SBS membrane) as it satisfies all of the requirements for the air barrier. Two types of SBS membranes are available, thermally fused or self-adhering. The self-adhering membrane is recommended due to the combustible nature of the construction. The membrane is installed vertically over the entire structure and all joints are shingled and sealed to form a continuous air/vapor barrier. By moving the plane of the air seal to the exterior of the structure, no special details are required to maintain an interior air seal. The polyethylene is no longer required behind the interior drywall and must be removed from the construction to prevent two possible air seal planes.
- Several different types of insulation can be used, such as glass batt, polystyrene, or isocyanurate. There are advantages and disadvantages associated with each insulation. While higher R-values can be achieved with rigid board insulations, semi-rigid and glass batts have the ability to conform to variances in the air barrier plane. For some wall applications, the type of insulation may be dependent on the requirements of the fastening system for the cladding. For roof application, the insulation may be required to satisfy structural loading. The choice is therefore left up to the designer to satisfy the specific requirements of each design.
- For brick veneer installations, thermal clips are used to mechanically fasten the insulation tight to the membrane. For most siding materials such as wood, metal, and vinyl, or stucco installations, wood strapping is used to fasten rigid insulation or z-bars for semi-rigid or batt insulation (a double z-bar system is preferred to further reduce thermal bridging through the insulating layer). The strapping can either be fastened back to the wood studs using nails or screws. For roof applications, strapping or z-bars are used to either support the second layer of sheathing for asphalt shingle application or to support the batons for wood shake and clay tile systems.
- The cladding and roof systems are installed as in a standard application.
- Architectural features such as eave overhangs and balconies are installed exterior of the rest of the structure. The connections depend on the structural requirements of the component. The fastening method is designed to minimize thermal bridging of the insulation.
- At roof to wall connections a membrane flashing is installed to shed any water at the membrane plane back out onto the shingles or out in front of the cladding.
- An insect screen is installed at the base of the cladding to prevent insects and animals from entering the cavity and burrowing into the insulation.
- A protective layer is installed over the exposed insulation between the base of the cladding and the grade. The protection should extend down below grade to a reasonable depth.
- Due to the residential window systems available in Canada it is often difficult to seal the membrane directly to the window frames to maintain the air seal. In this case, the membrane should be lapped into the rough opening to protect the head, jambs, and sill from damage caused by water penetrating from the joints around the window and frame. A bead of low expansion urethane foam is installed between the frame and the exterior head and jambs to limit water entry. The sill is open to provide drainage to the exterior of the structure. A second bead of foam is installed between the interior of the window frame and rough opening to complete the air seal. This way of sealing and protecting the structure around window openings is not ideal. Damage may still occur at these locations if care is not taken in construction to ensure proper sealing of the membrane and drainage of the sill to the exterior of the structure.

The PERSIST approach has proven to be effective in preventing water accumulation. The approach has often been applied as a retrofit for problem commercial buildings that were built using wood or metal stud infill wall construction. The same details that are presented in this paper have been applied to these buildings with few having any further problems.

The sequencing of the construction has proven to be beneficial to contractors. As soon as the air barrier is installed, other trades can begin work on the interior of the building as the interior is now protected from the weather. This can speed up the overall construction time of the project.

More freedom is also allotted to designers and architects. No special detailing is required to maintain an air seal on the interior of the structure. This allows for the structure to remain exposed, as in the case of cathedral ceilings. The junctions between exterior building elements become less critical. More exterior articulation can be installed with less concern over the prevention of water penetration. The system is flexible and the potential for design is now starting to be realized.

COST CONSIDERATIONS

The initial capital cost is the main consideration for most developers, designers, contractors, and new homebuyers. While it is important for a design to be cost-effective, lowest cost prices may have higher risks involved. The condominiums in British Columbia were designed to be viable in a market requiring aesthetic design at a reasonable price. The initial capital cost was the main concern, and the costs associated with maintenance of the structure over the life cycle of the building were not considered. The Barrett (1998) Commission stated that the cost to tear down and rebuild the exterior walls of certain condominiums represented an increase of 194% to as high as 288% over the original cost of construction.

As an example, an analysis was done using data for the Edmonton region to determine the difference in cost of material and labor between standard residential construction assemblies and ones adapted to the PERSIST system. The different materials used for the two approaches were applied to a simple house plan. The costs for standard residential construction practices and for the home adapted to PERSIST are shown in Table 1.

The 140 m^2 (1500 ft^2) model home had an approximate value of $155,000. The difference in cost of material and labor between the two systems was $4257, which accounts for approximately 2.7% of the initial capital cost. The example was used to illustrate the magnitude of the cost difference between initial capital costs and the potential costs associated with early renovation or replacement of a higher risk structure. The apparent slight premium to be paid when using the PERSIST approach can be justified when the two costs are compared.

The second consideration is the energy costs associated with operating a residence. When looking at energy loading, there are three methods by which thermal energy can be transferred: conduction, convection, and radiation. Of the three, conduction is the simplest to calculate and is therefore often used as the guide to measure the energy efficiency of the assembly. True energy load calculations are not nearly so simple.

TABLE 1
Differences in Construction Materials Between Standard Construction and PERSIST

Wall			
Standard		**PERSIST**	
Interior gypsum	$1194	Interior gypsum	$1194
Polyethylene	$204	-	$204
38 mm × 140 mm (2 × 6) wood studs	$1387	38 mm × 89 mm (2 × 4) wood studs	$1067
140 mm (6 in.) batt insulation	$752	-	
Exterior sheathing	$1175	Exterior sheathing	$1175
-		SBS air barrier membrane	$802
Building paper	$127	-	
-		63 mm (2 in.) rigid board insulation	$1829
-		19 mm × 75 mm (3/4 in. × 3 in.) plywood strapping	$771
Cladding	$2215	Cladding	$2215
Total	$7054		$9257

Roof			
Standard		**PERSIST**	
Interior gypsum	$724	Interior gypsum	$724
Polyethylene	$109	-	
Wood truss	$1639	Wood truss	$1639
300 mm (12 in.) batt insulation	$717	-	
Exterior sheathing	$718	Exterior sheathing	$718
-		SBS air barrier membrane	$454
-		75 mm (3 in.) rigid board insulation	$1192
-		38 mm × 89 mm (2 × 4) wood strapping	$516
-		Roof sheathing	$718
Shingles	$524	Shingles	$524
Total	$4431		$6485

Conductive losses can easily be calculated by using the thermal resistance of the various components of the construction assemblies. To illustrate this, the model home used in the first section for capital costs was used again as an example for energy calculations. The effective thermal resistance of each wall and roof assembly was calculated using the methods set out in Appendix C of the *Model National Energy Code of Canada for Houses* (CCBFC 1997). Using the new thermal resistance, the relative energy loss of the two approaches was calculated. The results showed an increase of 25% in conductive energy loss through the opaque part of the envelope with the PERSIST approach. This calculation did not consider the conductive losses due to windows. Since all homes have a certain percentage of window area, windows were added to complete the calculation. At 25% of the wall area taken up by windows, the total thermal loss difference through the assemblies was reduced to 10%; however, the total energy loss through the standard construction was increased by 157%. The actual insulation thickness used in the system can be increased to further reduce the conductive losses through the assembly; however, further insulation increases only provide marginal increases in savings.

Convective losses on the other hand are not very easy to determine. Actual air leakage impacts are variable and therefore difficult to estimate. A study done by CMHC reported that air leakage in a high-rise residential building in Ontario accounted for roughly 25% to 40% of the peak heating demand (CMHC 1991). From experience, the PERSIST approach has been reliable in minimizing air leakage through the building envelope and thus reducing the heating and air-conditioning load on the building.

Radiation energy is usually attributed to solar heating gains. The amount of solar gain is dependent on location, orientation, and size of the windows. Solar gain can be a major load on the cooling requirements of the building or an asset to the heating requirements of the building. In cold climates the quantity of conductive losses through the window area can often be offset by the energy gains from solar radiation. A good design approach would make use of size, orientation, and shading of windows to take full advantage of potential solar gain in a building.

Care must be taken when looking at standards for energy efficiency. The designer must look at all the variables and in what proportions they affect the efficiency of each design. Energy efficiency of a home can then be greatly improved by optimizing the efficiency of the governing variables while still maintaining sound design and construction practice for the rest. The 10% difference in conductive energy losses in many homes may be much less significant than the losses due to air leakage. The PERSIST approach takes into account the importance of an effective air seal and continuous insulation as a means of reducing energy losses in a building.

CONCLUSION

By providing an exterior air and moisture barrier, the PERSIST system provides the necessary protection for buildings with greater potential for water penetration. The prevention of water penetration into the structural assembly can effectively eliminate the risk of structural deterioration and mold growth.

The system can be adapted to residential buildings with only minor changes to current construction practices. These changes can be beneficial to the contractor by allowing other trades to work on the interior of the structure as soon as the air/moisture barrier is installed. More architectural freedom is gained in design. No special detailing is required on the interior of the building to maintain an air seal, allowing for the structure to remain exposed, and exterior junctions are less critical, allowing for more articulation of the exterior facade.

The additional cost for the system can be justified when compared to the possibly immense costs associated with repair and renovation of damaged buildings.

The PERSIST system may not be justifiable for all residential applications. Many homes function adequately in the environments in which they are placed. This approach should be applied for designs and locations that potentially run a higher risk for water accumulation.

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