Innovating Continuous Exterior Insulation

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ABSTRACT

As the need to reduce energy usage and carbon consumption has increased, the need for energy efficient building envelopes has increased. The application of continuous exterior insulation in frame construction is a key technology to achieving an energy efficient building envelope. Continuous exterior insulation includes a variety of products, including insulating sheathing and insulated claddings and while these products have long been available, recent advances in the energy codes have spurred innovation in products and application techniques. This paper reviews the benefits of exterior continuous insulation, including the increase in wall effective R-value, reduction of thermal bridging, and reduction of potential for vapor condensation. The challenges of integrating exterior insulation into a wall system, including the complications of interfaces with other building components and the reduction in wall drying potential and water management will also be reviewed. Finally, this paper will describe recently introduced continuous insulation products and explore how they meet these challenges.

INTRODUCTION

Energy codes and certification have increased the interest in increasing the insulation level of opaque building envelope assemblies and spurred the development of new insulation materials and systems. One key building block in the design of energy efficient wall systems is incorporating exterior continuous insulation. Polystyrene and poly-isocyanurate foam boards have traditionally been used to provide continuous insulation, but because of their low vapor permeability they can present challenges to water management of wall systems. Integration with other building components such as windows and siding can also be an issue. As the drive to become more energy efficient increases, new insulation products have been brought to the market to address some of the deficiencies in the traditional products.

ENERGY CODE EVOLUTION

The challenges of diminishing resources and the need to reduce global climate change have led to an increased desire for energy efficiency. When residential and commercial occupancies are combined, the building sector comprises about 41% of the U.S. Energy consumption [U. S. Department of Energy].

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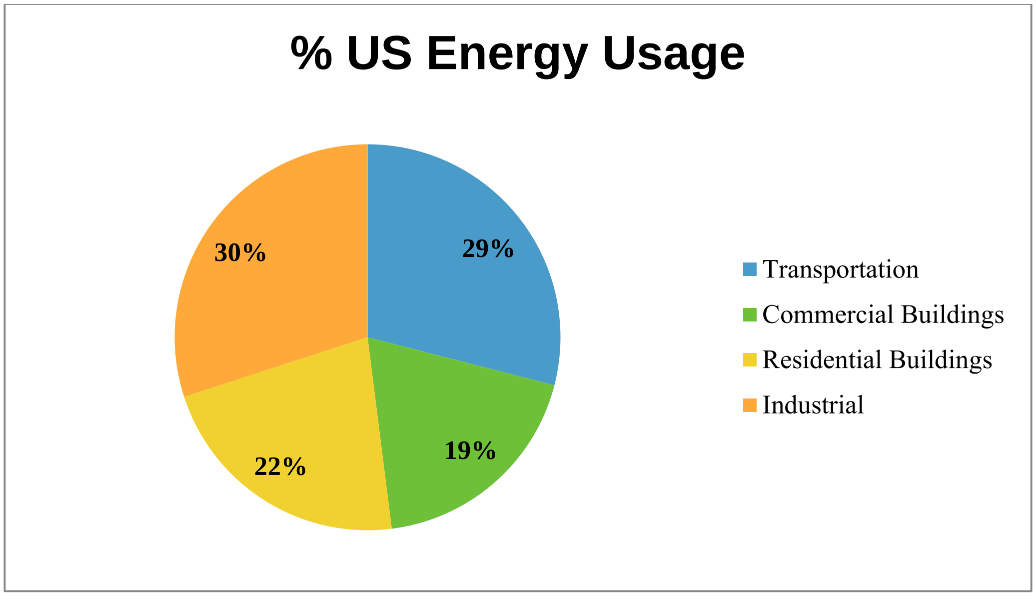

Figure 1. U. S. Energy Usage by Sector

Early energy efficiency gains had been made through utility and green building programs, most notably through the EPA's Energy Star for New Homes Program. Over the last 5 to 10 years, energy codes have picked up momentum, following the U.S. Federal government's setting of goals for improvements in both the residential and commercial energy codes. The actual energy efficiency determinations for residential energy codes versus the federal goal are shown in Table 1.

Table 1. Energy Code Determinations vs. Federal Goals

	IECC 2006	IECC 2009	IECC 2012	IECC 2015
US DOE Goal Improvement	Baseline	17%	30%	50%
US DOE Actual Determination	Baseline	14%	32%	34%

Key components in the advancement of the energy codes, have been an increase in the insulation required in opaque wall assemblies and more stringent air leakage requirements. As an example, the increase in R-value requirements in the Residential wood frame wall prescriptive path is shown in Table 2. [ICC 2006, ICC 2009, ICC 2012, ICC 2015-2] The increase in overall minimum R-values, as well as the increase in continuous insulation use, is evident.

Table 2. IECC Residential Wood Frame Wall R-value Requirements

CLIMATE ZONE	2006 IECC	2009 IECC	2012 & 2015 IECC
1	13	13	13
2	13	13	13
3	13	13	20 or 13+5
4 X-MARINE	13	13	20 or 13+5
4 MARINE	19 or 13+5	20 or 13+5	20 or 13+5
5	19 or 13+5	20 or 13+5	20 or 13+5
6	19 or 13+5	20 or 13+5	20+5 or 13+10
7	21	21	20+5 or 13+10
8	21	21	20+5 or 13+10

The development of residential air leakage requirements in the IECC provisions is shown in Figure 2. In 2006, air leakage requirements were vague and difficult to demonstrate compliance and enforce. In 2009, methods of demonstrating compliance were detailed with options for visual inspection or whole-building air leakage testing. The whole-building air leakage maximum at 7 ACH_{50}, was quite modest. In 2012 and upheld in 2015 was mandatory visual inspection and whole-building air leakage testing. The whole-building leakage maximum was reduced to much more challenging 5 ACH_{50} in climate zones 1 and 2, and 3 ACH_{50} in climate zones 3 through 8. Air leakage reduction is not only important to meet code, but it also improves the performance of insulation. The standard test method to determine R-value is conducted with no air pressure difference across the sample. In real conditions, air pressures differences from wind, mechanical systems or stack pressure can induce airflow through the insulation, resulting in reduced effective R-value. As shown in Figure 3, testing of thermal performance of wall assemblies with and without air flow demonstrates effective R-value can be reduced by more than 50% under low to moderate wind loads, especially when an air barrier is included in the wall system [Jones, 1995].

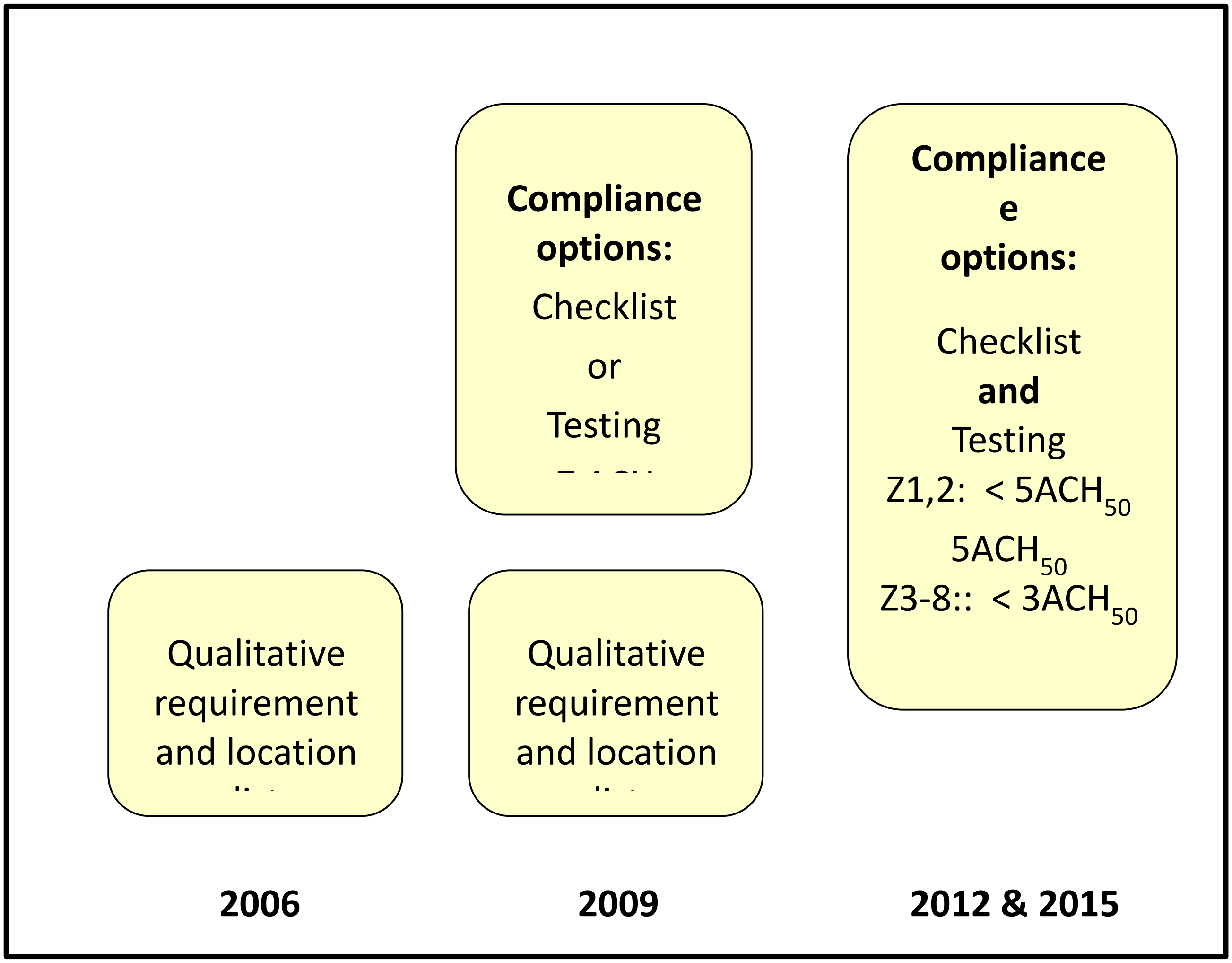

Figure 2. IECC Residential Air Leakage Requirements

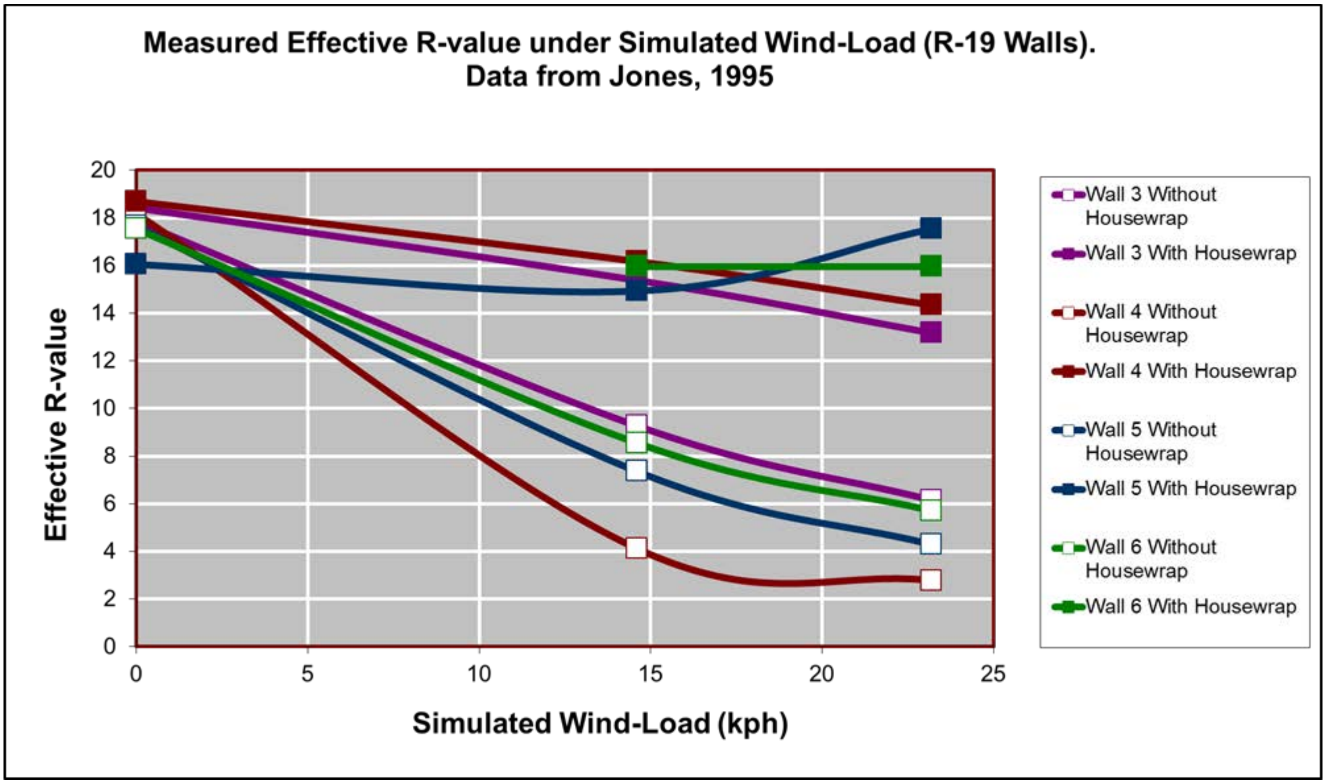

Figure 3. Wall Assembly Effective R-value as a Function of Simulated Wind Load

INSULATION DEVELOPMENT CRITERIA

Analysis of the energy code evolution showed that there was opportunity for new product development in insulation products. Key desired attributes include:

- Insulating performance: impact increased with continuous insulation performance
- Air barrier performance: provide a continuous and durable air barrier for the wall system which can be integrated with other building envelope assemblies
- Water management performance: include both the ability to be detailed and perform as a water-resistive barrier and providing forgiveness (drying) in the event of incidental water entry.

Each of these performance requirements is described in more detail in the following sections.

Insulating Performance: Benefits of Continuous Insulation. The primary benefit of continuous insulation is the reduction in thermal bridging at the studs leading to a more uniform and higher thermal resistance for the wall system. The results can easily be seen when houses with and without exterior insulation are compared using infrared (IR) photography as can be seen in Figures 4 and 5. These figures show two houses in the Columbus, OH region. The only difference in the wall system design is the inclusion of continuous exterior insulation in the house in Figure 5. Thermal bridging reduces the overall R-value of the wall system, as is quantified in the calculations shown in Table 3.

An additional benefit of exterior continuous insulation is the warming of the interior sheathing surface. This surface is a potential plane of winter-time condensation if vapor intrudes past the interior vapor/air barrier. Its warming reduces the potential for water condensing within the wall assembly.

Because of the various benefits provided by exterior continuous insulation, it should be a focus of product innovation.

Figure 4. IR Photography of house in Columbus, OH with no exterior insulation.

Figure 5. IR Photography of house in Columbus, OH with exterior continuous insulation.

Table 3. Total Calculated Wall R-value for Different Wall Assemblies

Wall Assembly Component	2x4		2x6		2x4 + c.i.	
	Studs	Cavity	Studs	Cavity	Studs	Cavity
Outside Air Film	0.17	0.17	0.17	0.17	0.17	0.17
Exterior Insulation	n/a	n/a	n/a	n/a	5	5
½" OSB	0.62	0.62	0.62	0.62	0.62	0.62
Stud Wood	3.71	n/a	5.83	n/a	3.71	n/a
Cavity Insulation	n/a	13	n/a	20	n/a	13
½" Gypsum Wallboard	0.45	0.45	0.45	0.45	0.45	0.45
Interior Air Film	0.68	0.68	0.68	0.68	0.68	0.68
Total	**5.6**	**14.9**	**7.75**	**21.9**	**10.6**	**19.9**
Total Wall (Standard Framing - 23%)	**10.8**		**15.4**		**16.6**	
Total Wall (Advanced Framing – 17%)			**16.7**			

Air Barrier Performance. Many materials have been used to reduce air leakage in buildings. For residential wall systems, the most common air barrier material is a continuous sheet material, sometimes referred to as a "house wrap", which is detailed as an air barrier at interfaces and connections. Performance of house wraps to provide air leakage protection was reviewed in 2006 [Weston, 2006]. This study concluded that *"Significant research has been conducted to characterize the performance of house wrap materials and their ability to control air leakage in residential construction. The research clearly shows that house wraps if installed correctly can* *significantly reduce air leakage and provide the associated energy savings."* The performance of house wraps to control air leakage was also documented in a field study on a high performance home showed that with correct detailing and installation a house wrap can provide the air barrier performance sufficient to meet the 2012 and 2015 air leakage requirements [Oberg, 2011] . Taping the seams of board products has been proposed to provide air barrier performance. However, taping of board products, such as foam sheathing, may not provide a durable air barrier. Figure 6 shows the results of air leakage testing of taped foam board and typical house wrap wall assemblies. Both assemblies were tested as built and after thermal cycling. While both assemblies met assembly air barrier requirements as-built, after thermal cycling the foam sheathing wall exhibited air leakage in excess of the maximum allowable air leakage while the house wrap wall continued to meet requirements. The data can indicate that exterior insulation wall assembly innovation should focus on insulation systems that either include a separate air barrier layer, or incorporate an air barrier layer that be integrated to provide air barrier continuity as part of the insulation product.

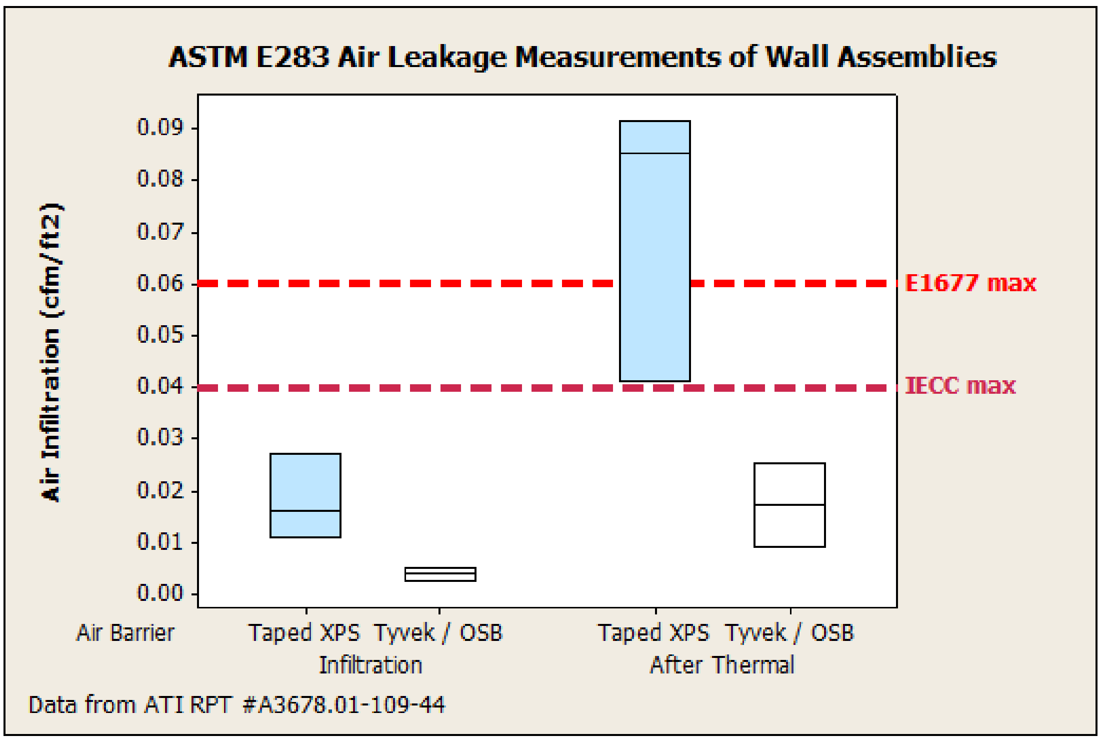

Figure 6. Air Leakage of Wall Assemblies As-Built and after Thermal Cycling

Water Management Performance. To manage water properly, a wall system must not only resist wetting it must also allow drying if there is any incidental moisture entry. The building code requirements focus on four areas of water management of wall assemblies:

- Flashing at intersections
- Water-resistive barrier

- Means of draining water
- Protection against condensation

The first three items deal with prevention of bulk water intrusion, such as from precipitation. "Protection against condensation" will be increased to some extent by any exterior insulation because the warming of the exterior sheathing surface and will be increased by air barrier incorporation.

Performance of a water-resistive barrier is dependent on both material and installation. The International Residential Code provides the basic requirements for both materials and installation [ICC 2015-3]:

> *"One layer of No. 15 asphalt felt, free from holes and breaks, complying with ASTM D226 for Type 1 felt or other approved water-resistive barrier shall be applied over studs or sheathing of all exterior walls. Such felt or material shall be applied horizontally, with the upper layer lapped over the lower layer not less than 2 inches (51 mm). Where joints occur, felt shall be lapped not less than 6 inches (152 mm). The felt or other approved material shall be continuous to the top of walls and terminated at penetrations and building appendages in a manner to meet the requirements of the exterior wall envelope as described in Section R703.1."*

The requirements invoke shingling as a traditional method of water management. Taped board products have been proposed to perform as a water-resistive barrier. These systems do not utilize shingling to allow water to drain off the assembly, but rely on the tape adhesion to prevent water entry. The tape joint is very dependent on installation conditions to perform. For examples, poor adhesion can result if the substrate surface is cold, wet, or dirty during installation. Additionally, for board products that have significant thermal expansion and contraction, the tape joint will be stressed as the assembly is subjected to normal temperature cycles. This has been noted in past studies, "*With some question as to the long term dimensional stability of insulating sheathing products, this should only be used in areas with limited rainfall and exposure, where rain water management is not as critical*" [Baker, 2006] .

To examine the performance of taped seams of foam sheathing for water intrusion, wall assemblies were tested before and after thermal cycling using ASTM E331 [ASTM, 2009] . Figure 7 shows water (dyed red) has intruded at taped foam-board interfaces.

To best prevent water intrusion, an exterior continuous insulation product would need to be flexible enough to be installed and integrated with flashings in shingled manner or to be installed with a separate water resistive barrier. For wall systems involving rigid board exterior insulation a separate water-resistive barrier is advisable.

Figure 7. Wall Specimen after Testing with E331 showing water intrusion at foam insulation board taped seams.

The second key to good water management is to allow for drying. The ability for a wall to dry will help provide for durability whether the source is bulk water, condensation from air leakage or vapor diffusion, or built-in construction moisture. The codes require interior vapor retarders in cold climates to reduce winter-time moisture condensation. Problems may occur, however, if exterior insulation has low vapor permeability. In this case, there is restricted drying at both the exterior and interior boundaries of the wall assembly. In a modeling study of different wall assemblies subjected to small amounts to water intrusion concluded that this wall assembly condition was at increased risk of moisture accumulation [Weston 2012]. Figure 8 shows the results of 3-year moisture simulations in Minneapolis climate zone with either no water intrusion, or with intrusion of 1% of the water that impacts the exterior wall surface. The results compare walls with exterior foam sheathing (vapor retarder) with walls with a vapor permeable exterior insulation. Both walls had kraft paper vapor retarder to meet the minimum code requirement. The results show year-over-year accumulation in wall total water content in the wall with foam sheathing, while the vapor permeable exterior insulation was able to manage the water intrusion with no total water content accumulation. These results indicate that a vapor permeable exterior insulation would be preferred to effectively manage water.

The need for a vapor open exterior insulation has begun to be included in code provisions. In 2015, the International Building Code included restrictions on interior vapor retarders when walls incorporate vapor impermeable exterior insulation: [ICC 2015-1]

> *" 1405.3.12 Class III vapor retarders…. Only Class III vapor retarders shall be used on the interior side of frame walls where foam plastic insulating sheathing with perm rating of less than 1 perm is applied in accordance with Table 1405.3.1 on the exterior side of the frame wall."*

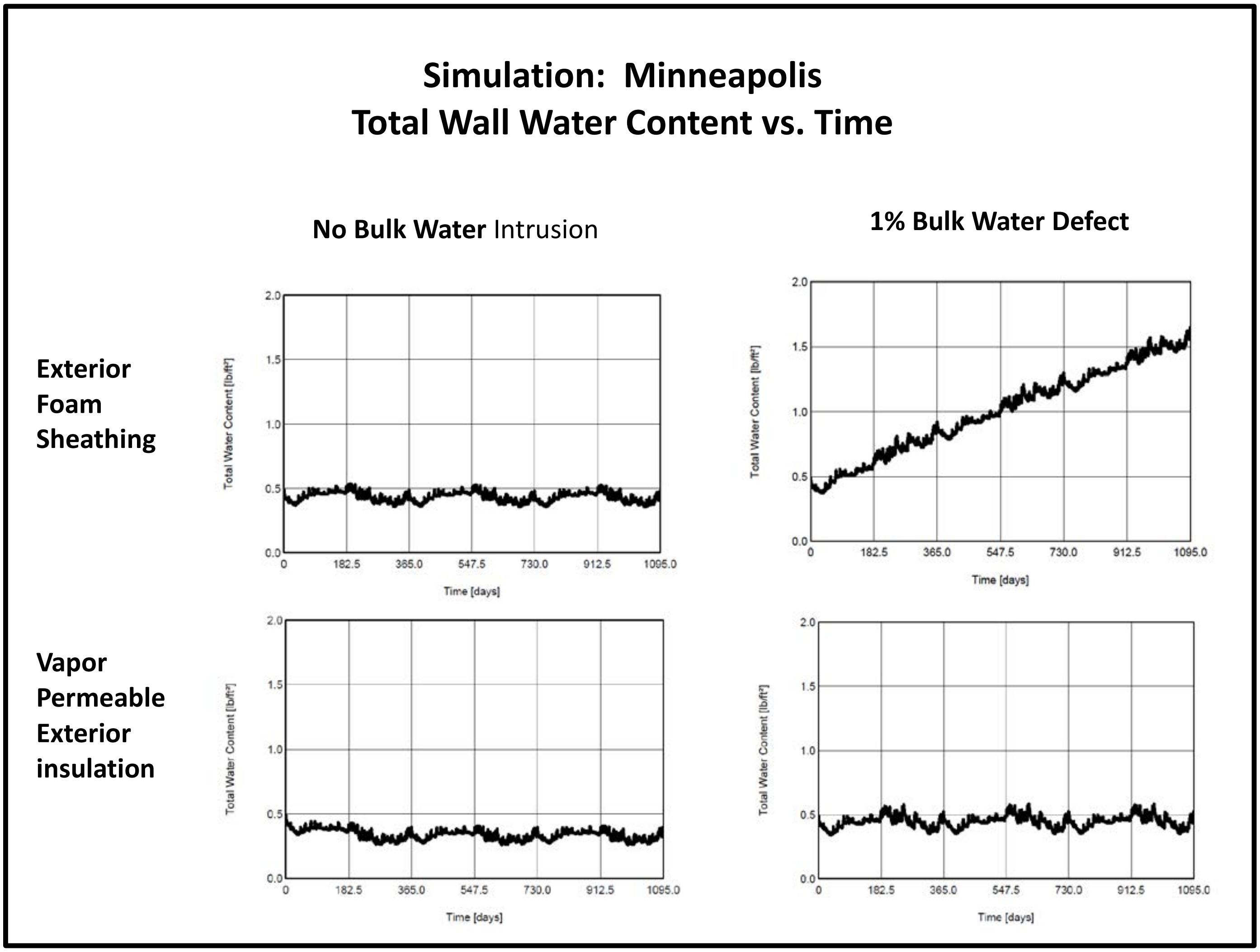

Figure 8. Moisture Simulations indicating higher moisture accumulation risk with both exterior and interior vapor barriers.

PRODUCT DEVELOPMENT RECOMMENDATIONS

Weighing the factors of thermal performance, air leakage reduction and water management, an insulation product was developed. It was a 1 ¼″ polymer fibrous batt that was faced with vapor permeable air and water-resistive barrier sheet. The product is provided in roll form with flaps of the facing that can be used to shingle over previously installed layers. This is just one possible insulation solution. Many other products of systems could be designed. The criteria described in this paper is a starting point but the choice of specific solution need to respond to constructability and cost concerns of a specific project. Constructability concerns include:

- Safety & ergonomics during the construction process
- Job-site storage requirements
- Installation dependence on environmental conditions
- Ease of installation
    - Is the new system installed in a similar way to existing products?
    - Can it be installed by existing trades?
    - Does it require a high level of specialization to install?
- Reliability & repeatability of the installation.
- Integration with other products (Can the next group of laborers work easily on top of it?)

Finally cost assessment should not be confined to first material cost. Also included should be costs of implementing a new product including costs associated with design changes and required contractor training or re-training. Installation costs should include any required environmental conditions required by the system and any adaptation needed by adjacent components. Finally, the costs associated with call-backs and long term moisture intrusion should be assessed.

SUMMARY AND CONCLUSIONS

The increasing stringency in energy and building codes is stirring interest in innovation of insulating products and systems. Product innovation should not focus on the single attribute of material R-value, but should evaluate durability and insulation effectiveness of the entire wall system. Water resistance concerns in existing systems were discussed. Product development recommendations include energy efficiency performance, moisture management performance and constructability of the system.

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