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With rising utility cost, concerns over availability of natural resources, and environmental impacts of our energy production and use, a push has been made to design buildings to minimize energy consumption in an attempt to work towards more sustainable communities. Creating more thermally efficient building enclosures is a necessary part of achieving this goal. The thermal resistance provided by insulating a stud cavity is limited by the standard framing sizes currently used in the United States and Canada. The options therefore are to either increase the depth of the studs used, add insulation to the interior of the wall assembly, or to add extra insulation to the exterior of the assembly. Providing rigid insulating sheathing to the exterior of a wall assembly is a technique that has been used in cold climates for more than 40 years. Recently it has begun to be integrated into enclosure designs in all climates. As with any newly adopted technology, there can be concerns for its proper application. This paper examines methods of incorporating insulating sheathing into the thermal and moisture management systems of the building enclosure in a variety of climate zones across North America. This is done through examining the material properties of the various products and how these properties can be used to achieve an energy efficient and durable building enclosure design, while avoiding problems relating moisture accumulation and degradation of materials.

Introduction and Background

The desire to design more sustainable buildings through increasing the energy efficiency of the enclosure can result in an increase in problems with moisture accumulation within building enclosure assemblies. These moisture problems (from issues such as an increase in the condensation potential within the assembly, or a reduction in the drying potential of the assemblies) lead to premature material degradation and large costs for renovations. Many enclosure failures occur due to the lack of understanding of energy and mass transfer through assemblies and through a lack of appreciation that products and materials have other properties than the ones that they are principally known for.

Though these lessons were hard learned, we can now use this knowledge for our benefit. Through examining and understanding materials based on all of their properties (not just what they were initially created for) and how they integrate to become a system, we can eliminate redundancies in enclosure design, making the systems simpler and more cost effective.

Insulating sheathing has been shown to be an effective method of reducing material use in a building, while increasing the energy efficiency of the thermal envelope, and if properly incorporated into the design of the moisture management system, can help in increasing the overall durability of the structure. In order to understand how to incorporate the materials into the design of the building enclosure, an understanding of the material properties themselves is important.

Material Properties

There are three main types of insulating sheathing currently being used in the industry: Expanded Polystyrene (EPS), Extruded Polystyrene (XPS), and Polyisocyanurate (Polyiso). Each of these products all has a different set of physical properties (**Table 1**) that will affect the dynamics of the wall assemblies in regards to the transmission and management of heat and moisture.

Table 1: Insulating Sheathing Material Properties

Insulating Sheathing Properties Table*					
	R-value/inch @ 75F ($F.ft^2.h/Btu$)	Density (pcf)	Permeance (perms)	Water Absorption (% by volume)	Compressive Strength (psi)
Expanded Polystyrene (EPS)					
unfaced	3.2	0.75	5.00	4.0	5
unfaced	3.9	1.00	5.00	4.0	10
unfaced	4.2	1.50	3.50	3.0	15
unfaced	4.4	2.00	2.00	2.0	25
Extruded Polystyrene (XPS)					
unfaced	4.6	1.20	1.10	0.3	15
unfaced	5.0	1.30	1.10	0.3	15
unfaced	5.0	1.60	1.10	0.3	25
unfaced	5.0	2.20	1.10	0.3	60
plastic film faced	5.0	1.20	0.3 - 0.8**	0.3	15
Polyisocyanurate					
foil faced	6.5	2.00	0.03**	1.0	25
glass fiber faced	5.0 - 6.0	2.00	1.0 - 3.0**	2.0	25

** The values used in this table are intended to be representative of common products. Specific properties of a manufactured product may vary from those listed above.*

*** Permeability is related to the properties of the facing material*

R-value

The thermal resistance of each of the products is different. In general, EPS foam has the lowest R-value per inch, with XPS being slightly more efficient, and with Polyisocyanurate having the best R-value per inch. The R-value of EPS foams can be increased by increasing the density of the product, however, the more dense expanded foams are less common in the market. Typically EPS foam has a rated value of approximately R-4 per inch. XPS foams are pretty consistent with an R-value of approximately R-5 per inch.

The thermal resistance of these EPS and XPS foams are generally stable over the long term and therefore the initial R-value at the time of manufacturing will not change over time. Polyisocyanurate foams are rated with a Long Term Thermal Resistance (LTTR) R-value representing a 15 year weighted R-value. This is in response to issues of thermal drift of the polyisocyanurate products. Thermal drift occurs due to the gasses produced during the forming of the foam. These gasses slowly diffuse out of the product over time and are replaced by air.

Since these gasses also have more thermal resistance than air, the R-value of polyisocyanurate diminishes over time as the gasses diffuse out of the product. Facings on the insulation board, such as aluminum foil, will slow this process down as the diffusion can only occur out the edges of the product and not through the front and back faces. Most polyisocyanurate products have an LTTR R-value of R-6.5 per inch.

Permeance

For unfaced insulating sheathing, the permeability is a function of the material thickness. In general most product manufacturers list the permeance of the material based on a thickness of 1 inch. Increasing or decreasing the thickness of the material will affect the permeance. As an example, 1 inch of XPS has a permeance of 1.1 perms. Increasing the thickness to 2 inches decreases the permeance to 0.55 perms.

For faced insulating sheathing boards (such as foil faced polyiso, glass fiber faced polyiso, and plastic film faced XPS), the permeance of the facing is often much lower than the permeance of the polyisocyanurate and will govern the overall permeability of the sheathing board. For these products, the permeance will not change with increasing thickness.

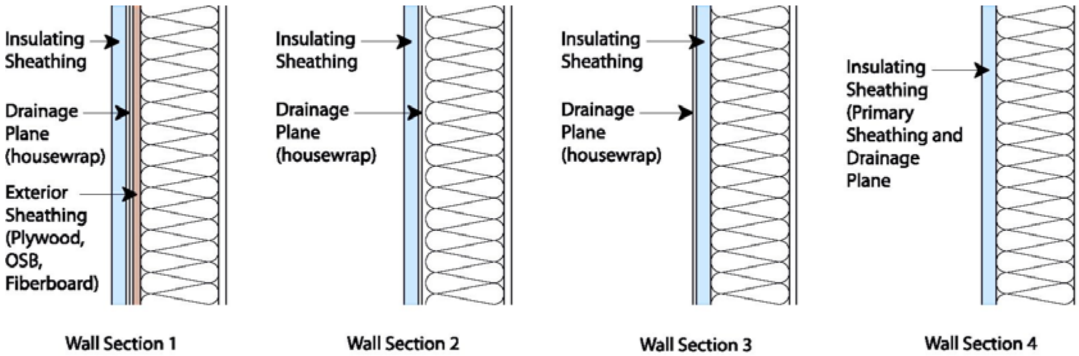
Rain Water Management

The choice of the how to integrate insulating sheathing into the enclosure water management system is based predominantly on the rainfall, exposure, and wind load potential of the area in which the house is being built. In areas of low rainfall, less than 20 inches per year, the risk of water damage due to exterior rain penetration is lower than in other areas where the rainfall is much higher, more than 40 inches per year. The risk also increases in areas that are more prone to short intense rainfall and high winds (such as coastal and hurricane zones) or areas that have little protection (such as areas with no trees or other structures close by) or are elevated (such as hilltops). How the water management system is designed and where the insulating sheathing is placed in the assembly will be affected by these considerations.

System Design Incorporating Insulating Sheathing

Since insulating sheathings are resistant to degradation due to moisture they can be placed exterior of the drainage plane of the assembly or in some cases can be used as the drainage plane of the assembly. This allows for several possible configurations of the rain water management system.

Figure 1. Rain Water Management Options



Wall Section 1 - Insulating Sheathing and Housewrap installed over Plywood or OSB. The first strategy involves installing the insulating sheathing over top of a layer of building paper or housewrap and wood sheathing. In this assembly, the insulating sheathing protects the housewrap drainage plane from exposure to wind and excessive heat. In addition, while it is not designed to be the drainage plane of the assembly, it will shed most of the water that penetrates past the cladding, minimizing the amount of water that actually penetrates back to the housewrap. In addition the backer layer of plywood sheathing also protects the wall from wind blown debris and projectiles during storm events. All water management details (flashing and window installation details) should be tied back to the plane of the housewrap. This type of assembly would be recommended in areas of high wind and rainfall exposure (hurricane and tornado prone zones).

Wall Section 2 - Insulation Sheathing and Housewrap installed over Wood Studs. The next proposed strategy is to install the insulating sheathing outside a housewrap that is stretched over wood studs. In this configuration, the housewrap drainage plane is protected from exterior elements (excessive wind loading, and rain exposure). All water management details (flashing and window installation details) should be tied back to the plane of the housewrap. The type of assembly would work effectively in most rainfall zones, though potentially not in high exposure locations. With the lack of wood sheathing support on the exterior of the framing more care is required during the installation of the housewrap and insulating sheathing.

Wall Section 3 - Housewrap installed over Insulating Sheathing and Wood Studs. The third strategy would be to install the housewrap to the exterior of the insulating sheathing, essentially replacing the plywood or OSB in a traditional wall assembly with insulating sheathing. The housewrap is more exposed to exterior elements such as wind loading and moisture and may not be as durable as the other approaches. In addition the fasteners used to install the housewrap must be able to penetrate all the way through the insulating sheathing and into the wood studs beyond. In this configuration the water management and window installation details are integrated into the housewrap at the exterior face of the insulating sheathing. Water management details would be the same as normal details of recommended good practice for wood sheathed house design. This wall approach would function adequately in most rainfall zones.

Wall Section 4 - Insulating Sheathing installed as the Drainage Plane. The final approach would be to use the insulating sheathing as the primary sheathing and drainage plane of the assembly. In order for the insulating sheathing to be used as a water resistive barrier, the vertical plane of the exterior face of the sheathing must be as continuous as possible. This is to prevent locations within the wall assembly where drainage could be blocked or where water might be held. In addition all the vertical joints must be taped or sealed and if possible, products that use shingle lapped or tongue and groove joints should be used. A polyethylene through wall flashing should be installed at all horizontal joints. Window head flashing and roof step flashings can be easily regletted into the face of the foam sheathing providing for better protection against flashing failure and reverse flashing problems. The reglette should only penetrate into the face of the sheathing and not all the way through the sheathing. Proper functioning of this system relies on the adhesion of membrane flashings and housewrap tapes to the face of the insulating sheathing. Membrane flashings and sheathing tapes are difficult to adhere to the surface of EPS and fiberglass faced polyisocyanurate. Foil faced polyisocyanurate and XPS would be more appropriate for this wall type. This is the least expensive system though it also has some increased risk associated with it. 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.

Installation

Insulating sheathing should be installed based on manufacturer's recommendations for fastener type and quantity. It is recommended to layout the insulating sheathing such that vertical joints do not occur at the corners of window and door openings or over window heads if possible.

For siding systems (wood, vinyl, and fiber cement) and masonry veneers, there is virtually no change from standard recommended practice for cladding attachment details. One of the only differences is that all fasteners must be installed through to the studs as insulating sheathing does not have adequate structural capacity in either shear or pull out strength.

For Wall Section 1 and Wall Section 2, cladding systems such as traditional hard coat stucco (including thin brick and cultured stone) and acrylic stucco can be directly applied to the insulation board. With these types of systems it is recommended to use drained insulation boards (ones with vertical grooves cut in the back) or to use a vertically textured (or profiled) housewrap, to ensure that there is a drainage space behind the rigid insulation board.

For Wall Section 3 and Wall Section 4, traditional hard coat stucco (including thin brick and cultured stone) should NOT be installed without the addition of at least one layer of building paper or house wrap between the stucco renderings and the housewrap or drainage plane sheathing to act as a bond break.

For thin layers of insulating sheathing, there is a concern of cracking of the stucco due to board flex. This issue can be minimized though the use of more rigid boards and by increasing the thickness of the insulating sheathing.

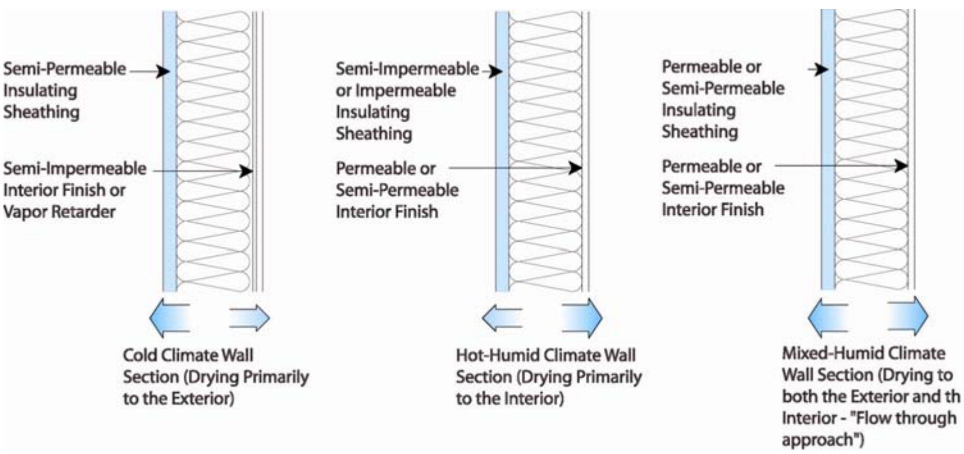
Vapor Management

The design of the vapor management system should attempt to allow maximum drying of the wall assembly by diffusion, while limiting the amount of moisture able to be driven into the assembly. Where possible, drying to both sides of the construction assembly should be encourage, however in some circumstances more stringent vapor control is required. As a general rule for standard framed construction, the vapor retarding layer should be placed to the interior of the assembly in cold climates (reducing the water vapor from the higher humidity interior air from diffusing into the assembly), while in hot humid climates, the vapor retarding layer should be placed to the exterior of the assembly (reducing the water vapor from the hot humid outside air from diffusing into the assembly).

Therefore, in a general sense, for cold climates it is preferable to use a more vapor permeable insulating sheathing (such as EPS and unfaced XPS) on the exterior and in hot humid climates, it is preferable to use a more vapor impermeable sheathing on the exterior of the assembly (such as foil faced polyisocyanurate and plastic film faced XPS). Examples of these strategies are illustrated in **Figure 2**.

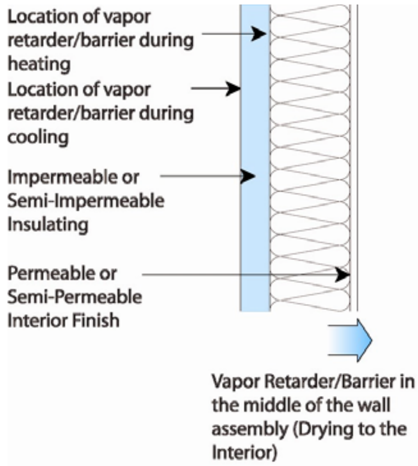
For mixed humid climates, the system choices become more difficult as the assembly needs to be protected from wetting from both the interior as well as the exterior. The drying can be predominantly to the exterior, the interior, or in both directions in a flow through type assembly. Often these strategies need to be combined with other vapor management strategies such as building pressurization (or depressurization) and supplemental dehumidification.

Figure 2. Vapor Diffusion Profiles



An additional vapor control strategy is to place the vapor control layer towards the middle of the assembly and control the condensing surface temperature (**Figure 3**). Using insulating sheathing materials of adequate thickness can ensure that the dewpoint temperature is not reached within the assembly. Using impermeable or semi-impermeable sheathing, the exterior face of the board would function as a vapor retarder during the cooling month, while the interior face of the insulating sheathing would function as a vapor retarder in the heating months. In order to determine the thickness needed to control the condensing surface temperature, the interior and exterior environmental conditions need to be considered and the thermal gradient across the assembly needs to be determined.

Figure 3. Vapor Control Layer in the Center of the Assembly



The thermal gradient can be predicted by examining the individual proportion of thermal resistance provided by each component. Each different component will provide a percentage of the total thermal resistance of the assembly. Therefore, the change in temperature of any component is based on the percentage of thermal resistance provided by that component multiplied by the overall temperature difference across the assembly.

$$\Delta T_{(comp)} = R_{(comp)} / R_{(total)} \times (T_{(in)} - T_{(out)})$$

Where:

$\Delta T_{(comp)}$	= temperature change across a component
$R_{(comp)}$	= thermal resistance of the component
$R_{(total)}$	= total thermal resistance of the assembly
$T_{(in)}$	= interior temperature
$T_{(out)}$	= exterior temperature

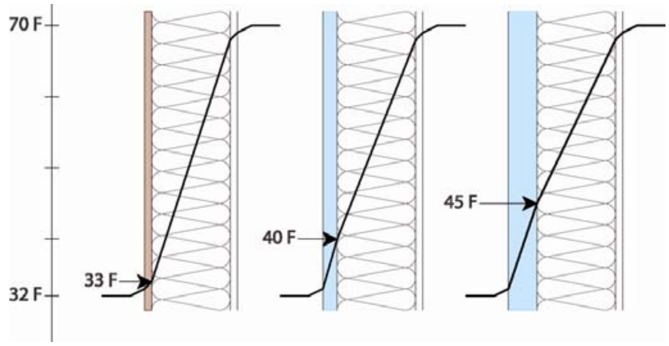
To determine the temperature at any given surface in the assembly, the individual temperature changes across each component in the assembly up to the desired surface is added to the exterior temperature.

$$T_{(surface)} = T_{(out)} + \Delta T_{(comp\ 1)} + \Delta T_{(comp\ 2)} + \ldots + \Delta T_{(comp\ n)}$$

The example below examines the temperature of the inside surface of the exterior sheathing (the surface of concern during heating seasons) with an exterior temperature of 32F and an interior temperature of 70F. For the first section below, the temperature at the inside surface of the exterior sheathing would be calculated as:

$$T_{(surface)} = T_{(out)} + \Delta T_{(exterior\ air\ film)} + \Delta T_{(plywood)}$$
$$T_{(surface)} = 32 + [0.17/20.92 \times (68\text{-}32)] + [0.62/20.92 \times (68\text{-}32)]$$
$$T_{(surface)} = 32 + [0.0081 \times 38] + [0.0296 \times 38]$$
$$T_{(surface)} = 32 + 0.31 + 1.13$$
$$T_{(surface)} = 33.44\ F$$

Figure 4. Thermal Gradient across Wall Assemblies

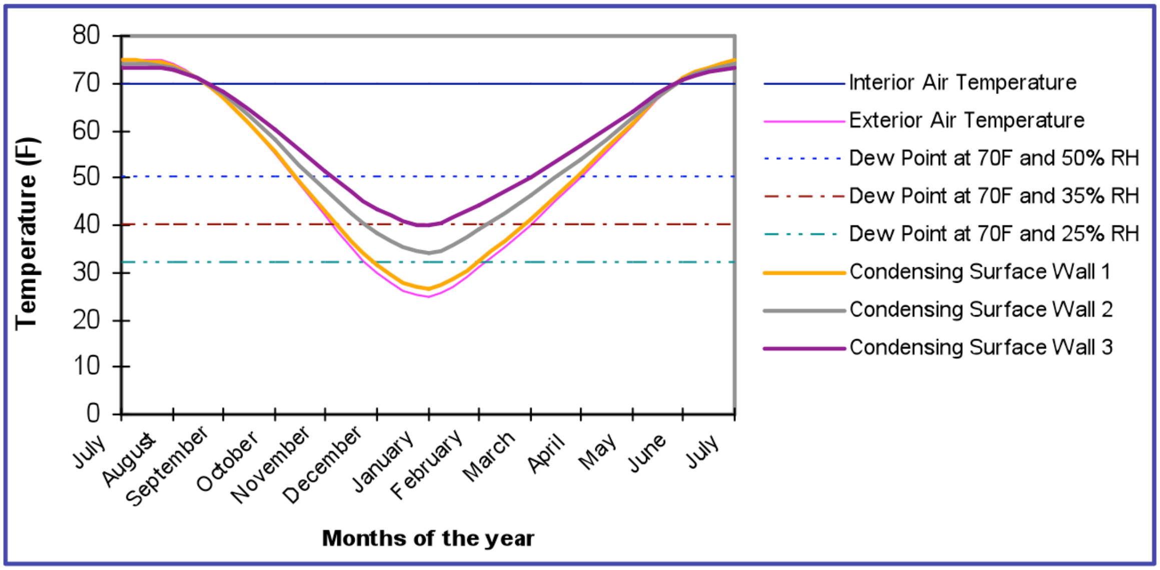


As it can be seen from **Figure 4**, with the additional thermal resistance of the rigid board insulation material, the temperature of the inside face of the sheathing will be warmer in the winter months than with traditional wood sheathing alone. Since the surface temperature is warmer, there is less of a risk of condensation forming on the inside face. If the exterior wood sheathing is eliminated, the system becomes even more durable as insulating sheathings are resistant to water and will not degrade if a small amount of condensation does occur.

For this to be applied effectively, understanding the climate zone and the interior environmental conditions in which the assembly is being designed is very important. As an example, the three wall sections were analyzed for the Chicago, IL area with the exterior conditions based on the average monthly temperatures for a one year cycle. Also, each assembly was assumed to have a vapor permeable interior finish or no effective interior air barrier layer allowing for the more humid interior air to come in contact with the interior face (condensing layer) of the exterior sheathing. The first wall section, designed under the traditional approach with wood sheathing, is at risk of condensation accumulation on the back of the wood sheathing from the middle of November to the middle of March (this is shown by the segment of the temperature profile that drops below the dewpoint of 40F for the interior air). With the addition of 1 inch of XPS insulating sheathing, the time period of condensation potential time is now from the middle of December to the middle of February. The addition of 2 inches of insulating sheathing the temperature profile does not drop below the dewpoint temperature, and therefore no longer at risk. Water vapor would not condense within the wall with 2" of XPS even with no vapor control layer or air sealing of the wall.

If the interior conditions change, the condensation potential will also change. As seen in **Figure 5**, varying the interior relative humidity demonstrates that 1 inch of insulating sheathing would be adequate if the relative humidity was kept below 25% (dewpoint of 32F), or that 2 inches of insulating sheathing would not be adequate if the interior relative humidity increases to 50% (dewpoint of 50F).

Figure 5. Condensing Surface Temperature Compared to Dew Point



In reality, the exterior temperature can vary quiet significantly from the monthly averages potentially leading to events of condensation occurrence.

While the use of insulating sheathing can help to reduce the condensation potential, it is only a component in the overall design of the building enclosure assembly. The example above was used to demonstrate how insulating sheathing can reduce the condensation potential in an assembly; however, design of the building enclosure will likely include other water, air, and vapor management strategies as well.

Thermal Management

There are several thermal benefits to installing the insulating sheathing on the exterior of the wall assembly. One benefit is that it brings the structure and other enclosure elements back further into the thermal envelope of the building. Keeping the structure and other enclosure elements at a more even temperature will increase their service life. The other and overriding benefit is the extra thermal resistance that the insulating sheathing adds to the wall assembly.

The thermal efficiency of the wall assembly is important for creating energy efficient building. Insulating sheathing is an easy way of adding significant additional thermal resistance without adding significant amount of additional wall thickness. In order to illustrate this, the overall thermal resistance of the wall assembly, or the effective R-value, must be considered. A simple method then can be used to estimate the effective R-value of the cavity space is through using the isothermal planes method set out in Chapter 25 of the ASHRAE Handbook - Fundamentals 2005 (ASHRAE 2005). While this method is not as accurate as some other more sophisticated computer simulation models, it is a means to get a rough idea of the effective insulating value of an assembly. With the isothermal method, the effective R-value of the cavity assembly is a proportional sum of the various U-values of the different components based on material fractions.

$$U_{(combined\ cavity)} = U_{(studs)} \cdot F_{(studs)} + U_{(insulation)} \cdot F_{(insulation)}$$

Where:		
	$U_{(cavity)}$	= average U value of the insulation and studs
	$U_{(studs)}$	= U value of wood framing
	$U_{(insulation)}$	= U value of cavity insulation
	$F_{(studs)}$	= fraction of area of studs, headers, and sill plates
	$F_{(insulation)}$	= fraction of area of insulation

$$R_{(combined\ cavity)} = 1/U_{(combined\ cavity)}$$

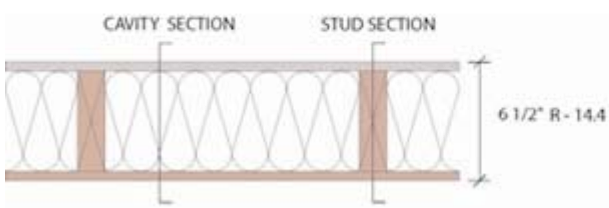
The overall R-value of the assembly is a sum of the thermal resistance of all of the components.

$$R_{(total)} = R_{(comp\ 1)} + R_{(comp\ 2)} + \ldots + R_{(comp\ n)}$$

Where:		
	$R_{(total)}$	= total R-value of the assembly
	$R_{(comp)}$	= individual effective R-value of each material layer

As an example the effective cavity insulation value and the total effective R-value for various assemblies were calculated. The fiberglass batt or blown cellulose may be rated as R-19, however due to the wood studs and other framing members comprising approximately 23% of the wall area, the effective thermal resistance may be as much as 35% less than the rated cavity insulation, leaving an effective value of only R-12.5 for the cavity as seen in the calculations in **Table 2** below.

Table 2. Effective Thermal Resistance of a Standard Wood Framed Wall



Element	Cavity Section (R-value)	Stud Section (R-value)
Outside Air Film	0.17	0.17
1/2" Plywood	0.62	0.62
2x6 Wood Stud	n/a	5.83
5.5" Fiberglass Batt	19.00	n/a
1/2" Interior Gypsum	0.45	0.45
Interior Air Film	0.68	0.68
Total	**20.92**	**7.75**

$F_{(studs)} = 0.23$

$F_{(insulation)} = 0.77$

$R_{(combined\ cavity)} = 1/[(0.77/19)+(0.23/5.83)]$

$R_{(combined\ cavity)} = 12.5$

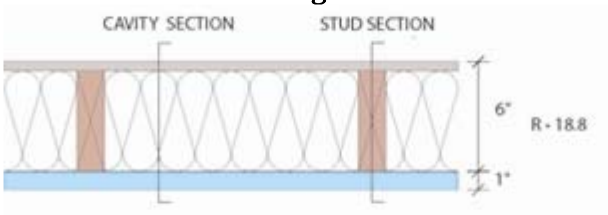
$R_{(total)} = 0.17+0.62+12.5+0.45+0.68$

$R_{(total)} = 14.42$

Insulating sheathing provides additional insulation to the house that is run continuous past the exterior face of the wood studs. Because of this the rated R-value for the insulating sheathing is very close to the effective R-value of the insulating sheathing in the assembly. With the lack of framing penetrating through the layer insulating sheathing, the whole R-value can be generally be used. This allows for large increases in the effective R-value of the assembly without substantially increasing the thickness of the wall.

If one inch insulating sheathing (R-5 for this example) is used as the primary sheathing (eliminating the plywood or OSB from the exterior), the thermal efficiency of the 2x6 stud wall will increase from an effective R-14.4 to an effective R-18.8 (**Table 3**). This represents an increase of 31% effective thermal resistance with only 8% increase in the overall wall thickness.

Table 3. Effective Thermal Resistance of a Wood Framed Wall with 1 Inch of Insulating Sheathing



Element	Cavity Section (R-value)	Stud Section (R-value)
Outside Air Film	0.17	0.17
1" Rigid Insulation	5	5
2x6 Wood Stud	n/a	5.83
5.5" Fiberglass Batt	19.00	n/a
1/2" Interior Gypsum	0.45	0.45
Interior Air Film	0.68	0.68
Total	**25.3**	**12.13**

$F_{(studs)} = 0.23$

$F_{(insulation)} = 0.77$

$R_{(combined\ cavity)} = 1/[(0.77/19)+(0.23/5.83)]$

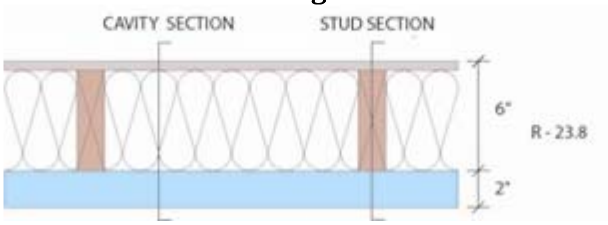
$R_{(combined\ cavity)} = 12.5$

$R_{(total)} = 0.17+5+12.5+0.45+0.68$

$R_{(total)} = 18.80$

Adding two inches of rigid insulation to the exterior (R-10) will increase the effective R-value from R-14.4 to R-23.8 (**Table 4**). This represents an increase of 65% over the original effective R-value.

Table 4. Effective Thermal Resistance of a Wood Framed Wall with 2 Inches of Insulating Sheathing



Element	Cavity Section (R-value)	Stud Section (R-value)
Outside Air Film	0.17	0.17
1" Rigid Insulation	10	10
2x6 Wood Stud	n/a	5.83
5.5" Fiberglass Batt	19.00	n/a
1/2" Interior Gypsum	0.45	0.45
Interior Air Film	0.68	0.68
Total	**30.3**	**17.13**

$F_{(studs)} = 0.23$

$F_{(insulation)} = 0.77$

$R_{(combined\ cavity)} = 1/[(0.77/19)+(0.23/5.83)]$

$R_{(combined\ cavity)} = 12.5$

$R_{(total)} = 0.17+10+12.5+0.45+0.68$

$R_{(total)} = 23.80$

Conclusion

Reducing energy consumption and material use is becoming increasingly important. The benefit of using insulating sheathing to increase the thermal performance of the building enclosure is an important factor in achieving this energy efficiency goal. Choosing which type and how much insulating sheathing used can affect the thermal and moisture management profile of the building. Understanding the material properties and ways that they can be applied for our benefit will help in choosing the appropriate rain water management strategy for the rain and wind exposure as well as the appropriate vapor control strategy for the climate zone.

References

ASHRAE. 2005. *2005 ASHRAE Handbook – Fundamentals.* P 25.2 - 25.3. Atlanta, GA: American Society of Heating, Refrigeration and Air Conditioning Engineers, Inc.

Blaga, A. 1974. "CBD 167 - Rigid Thermoplastic Foams" Canadian Building Digests 151 – 200. Ottawa, ON: National Research Council of Canada.

Blaga, A. 1974. "CBD 168 – Rigid Thermosetting Plastic Foams" Canadian Building Digests 151 – 200. Ottawa, ON: National Research Council of Canada.

Lstiburek, J.W. 2004. "Understanding Vapor Barriers" *ASHRAE Journal* 46(8):40-50.

[PIMA] Polyisocyanurate Insulation Manufacturers Association. 2004. "A Comparrison of Polyiso Insulation and Extruded Polystyrene Insulation." Technical Bulletin 201. Available online: http://www.pima.org/technical_bulletins/tb201.pdf

[PIMA] Polyisocyanurate Insulation Manufacturers Association. 2004. "Ployurethane and Polyiso: What is the Difference" Technical Bulletin 202. Available online: http://www.pima.org/technical_bulletins/tb201.pdf

[XPSA] Extruded Polystyrene Foam Association. 2005. "Physical Properties of XPS." Available online: http://www.xpsa.com/tech/physical.html

About this Paper

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