Vapour Diffusion for Residential Construction

Canada and Northern USA

Brookfield Homes, Niagara, Ontario

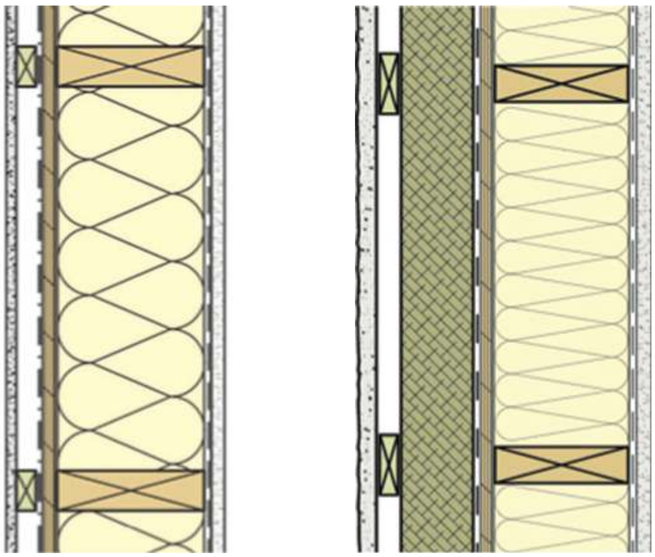
ROXUL®
The Better Insulation™

Vapour Diffusion and Condensation Control in Exterior and Split Insulated Wood-Frame Walls in Canada and Northern USA.

Adding exterior insulation to a wood-frame wall assembly to meet more stringent building and energy code standards requires a re-think about vapour diffusion and condensation control in wood-frame wall assemblies. These new insulation layers introduce complexity because of their varying vapour permeability – some are vapour permeable (mineral wool, stone wool), and others are relatively vapour impermeable (XPS, Polyiso, EPS, Spray foam).

Energy codes are silent on the issue, and Canadian building codes are somewhat confusing as it relates to exterior insulation selection and vapour diffusion control.

This bulletin clarifies and provides guidance on vapour diffusion and condensation control in these new wall assemblies.



Traditional stud insulated wall assembly (left) vs an improved R-value split-insulated (insulation outside the sheathing as well as in the stud space) wall assembly (right) – The selection of insulation type and vapour control strategy is different for each wall.

An exterior wall physically separates the outdoor and indoor environments. The differences in temperature, moisture, and air pressure between the outdoors and indoors result in loads that the wall must control or accommodate. Insulation is used to control heat flow, an air barrier is installed to control air flow, and the claddings, flashings and sheathing membranes are used to control water penetration. Selection of a particular arrangement of material layers, and the vapour permeance of those layers, will control vapour diffusion flow.

Vapour diffusion is the movement of water vapour molecules through porous materials (e,g. wood, insulation, drywall, concrete, paint, etc.) as a result of vapour pressure differences. Vapour pressure differences occur as the result of temperature and water vapour content differences in the air.

These vapour pressures can be looked up on a psychometric chart or calculated. Vapour diffusion flow always occurs through an assembly from the high to low vapour pressure side. For the majority of the year in Canada and Northern USA, this occurs from the warm side (heated indoors) to the cold side (winter outdoors) of a wall assembly. The direction of vapour diffusion flow will also reverse, particularly when the outdoors is hotter and more humid than the indoors (such as in the summer), and when the sun heats up damp, absorptive wall claddings (masonry), driving the water vapour inwards.

The process of vapour diffusion itself doesn't cause a problem. However, the moisture transported through this process can lead to elevated relative humidity levels within buildings and assemblies. It can also lead to condensation on colder surfaces within wall, roof and window assemblies and this can lead to damaged materials and fungal growth.

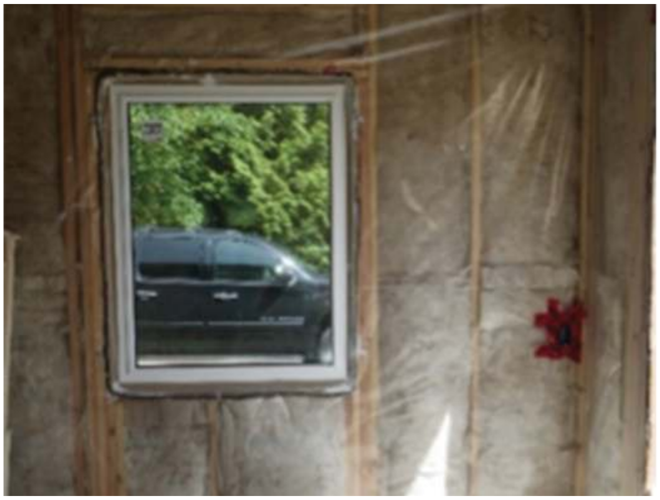
The process of vapour diffusion is relatively slow, and it can take several days to weeks to transport damaging amounts of water vapour into most wall assemblies. This is due to the resistance to flow provided by the building materials.

All building materials have a resistance to vapour flow that varies depending on the properties of the material. These properties can change with moisture content, age, temperature and other factors. Vapour resistance is commonly expressed using the inverse term "vapour permeance" which is the relative ease of vapour diffusion through a material. The metric units for vapour permeance are ng/Pa·s·m^2 or in IP units are grains/inHg·ft^2·hr. The latter is known more commonly as a "US perm." Both units are a measure of the mass flow over time per the vapour pressure difference and area of wall or other assembly. The conversion from IP to metric is to multiply the IP value by 57.4.

Building codes have grouped materials into classes (Classes I, II, III) depending on their vapour permeance values. Class I (<0.1 US perm), and Class II (0.1 to 1.0 US perm) vapour retarder materials are considered impermeable to near impermeable, respectively, and are known within the industry as "vapour barriers." Some materials that fall into this category include polyethylene sheet, sheet metal, aluminum foil, some foam plastic insulations (depending on thickness), self-adhered (peel-and-stick) bituminous membranes, and several other construction materials. Class III (1.0 to 10 US perm) vapour retarder materials are considered semi-permeable and typical materials that fall into this category include latex paints, wood sheathing, and some foam plastic insulations (depending on thickness).

The Class of vapour retarder (I, II, or III) is used within many building codes and building enclosure design publications to provide guidance for the selection of appropriate vapour control layers within wall assemblies in North American climate zones. This guidance is also based on the expected indoor conditions for certain building types, which is related to indoor moisture generation rates and natural and mechanical ventilation rates. This guidance is not reiterated here, and should be consulted for the selection of appropriate vapour retarder materials along with consideration for other issues as covered within this bulletin.

Vapour diffusion is typically perceived as a negative phenomenon, one that needs to be completely stopped, as is demonstrated by the widespread use of impermeable polyethylene vapour barriers on the interior side of most residential wall assemblies in Canada. However, vapour diffusion is also a positive benefit, and is a very important drying mechanism for a wall assembly. In fact, vapour diffusion is the only process in which most wall assemblies are able to dry out in service. The control of vapour diffusion within a wall assembly is therefore a **balance of minimizing or managing wetting sources** and **maximizing drying potential** should the wall be constructed wet, or be wetted by vapour diffusion, air leakage condensation or rainwater penetration while in service. This is particularly important with highly insulated wall assemblies as more insulation means less heat energy is available to dry out moisture from wall or roof assemblies.



Typical polyethylene plastic sheet (Class I vapour retarder) installed on the interior of a 2x6 insulated wall in Canada

Understanding Vapour Diffusion in Walls

Vapour diffusion is a physical process that is for the most part invisible to the naked eye, unless of course it leads to condensation, material damage, or fungal growth. The use of the simple schematics considered in the following sections helps to explain the process of vapour diffusion and the conditions leading to wetting and drying within different wall assemblies. The placement of vapour control layers and application of different types of exterior insulation are also explained.

Walls without Interior Vapour Control

First let's consider a conventional 2x6 insulated wood-frame wall assembly, where no vapour control layer has been installed to the interior side of the primary insulating layer (Figure 1). During wintertime, the temperature indoors is warmer than the outdoors as indicated by the coloured temperature gradient through the insulation. The vapour pressure here is also higher indoors than outdoors, as indicated by the density of dots, representing water vapour molecules in the air. Because of this vapour pressure difference, vapour diffusion will occur from the interior towards the exterior denoted by the arrows through the drywall. This scenario indicates what would happen in a wall if the interior vapour control layer was not installed.

As the temperature drops across the insulation, for the same absolute humidity level (moisture) within the air, the relative humidity (RH) will increase. This is a phenomenon that is typically explained using a psychrometric chart and is depicted graphically here by the water vapour molecules getting closer together. The relative humidity will continue to increase as the temperature drops through the wall. Condensation will only occur if the temperature of the sheathing is below the indoor air dewpoint temperature. Even where condensation does not form, high RH levels are conducive to fungal growth on building materials, so it is ideal to keep the RH below 80-90% if possible. In the case here, it is cold enough that condensation forms on the backside of the sheathing and this is depicted by the water droplets.

Note that if the indoor vapour pressure is lower (lower indoor RH), then condensation may not occur at the sheathing. This explains why in older homes with high air leakage rates and lower RH levels, vapour diffusion may not have caused wetting, though in a more airtight new home it can.

Vapour diffusion also aids in the drying-out of this assembly after it becomes wetted due to condensation. The more vapour permeable the sheathing, sheathing membrane and cladding layers, the faster this moisture can dry out, and reduce the risk of damage. This is why walls without vapour barriers can perform adequately – the drying ability exceeds the wetting.

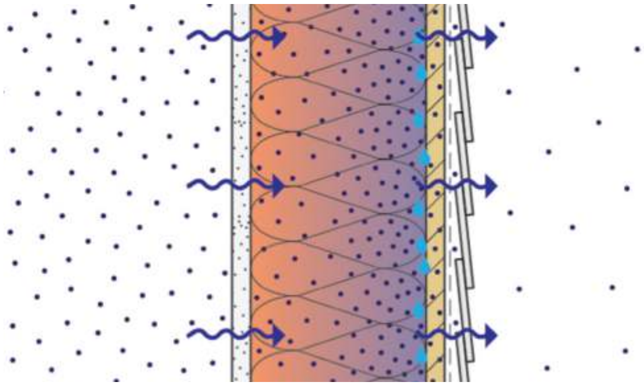


Figure 1: Vertical Section through Insulated 2x6 Wall without Interior Vapour Control

Walls with Interior Vapour Control

In the second scenario is a conventional 2x6 insulated wood-frame wall assembly with a polyethylene sheet vapour barrier installed on the interior side of the insulation (Figure 2). This schematic is also representative of a wall with vapour retarder paint applied to the exterior surface of the drywall, though the dashed line representing the vapour barrier would shift inwards accordingly.

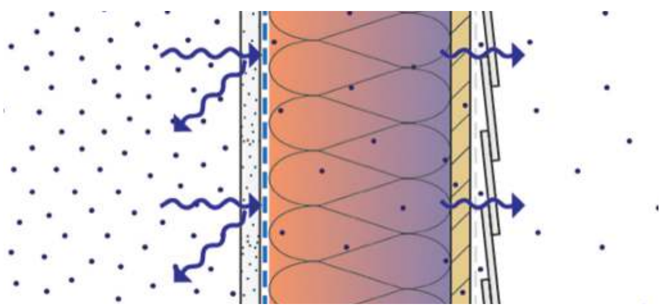


Figure 2: Vertical Section through Insulated 2x6 Wall with Interior Vapour Control (Polyethylene)

Similar to Figure 1, the temperature and vapour pressure indoors is higher than outdoors. As a result, vapour diffusion will occur from the interior towards the exterior, though it is essentially stopped by the sheet polyethylene (high resistance to vapour flow), as shown. The polyethylene sheet prevents water vapour from diffusing into the insulated stud cavity. Without this additional water vapour, the stud cavity remains at outdoor moisture levels and vapour pressure. Therefore as the temperature drops across the insulation for the same absolute humidity level within the air, the relative humidity (RH) will increase, but does not exceed the outdoor RH. This means that condensation will not occur. Outward vapour diffusion drying still occurs from the cavity through the sheathing, membrane and cladding, though there is little additional moisture to dry out.

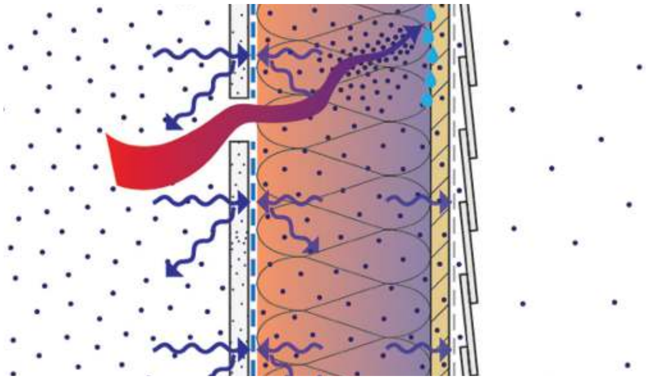


Figure 3: Vertical Section through Insulated 2x6 Wall with Air Leakage Condensation

If air leakage from the interior space into the wall cavity occurs, condensation would likely occur on the interior side of the sheathing. Drying would only be through the exterior side, since drying to the interior is limited by the sheet polyethylene (Figure 3). Similarly if this wall were to be wetted in service, drying could only occur to the exterior. Drying can be improved within this assembly by introducing a drained and ventilated cavity behind the cladding (rainscreen) as convective evaporation directly from the sheathing and sheathing membrane is increased and the influence of the cladding is eliminated.

Walls with a Vapour Barrier on the Wrong Side

For comparison with the previous scenario (Figure 2), consider a conventional 2x6 insulated wood-frame wall assembly with a vapour barrier material installed on the exterior side of the insulation (Figure 4) under wintertime conditions. The vapour barrier in this scenario could occur with the wrong type of sheathing membrane, or the use of excessive self-adhered bituminous membrane application at penetrations and details or, as in Figure 5, the installation of a vapour impermeable cladding (such as unvented asphalt shingles or metal siding). Vapour diffusion occurs from the interior to the exterior; however, moisture is prevented from diffusing outwards and will accumulate in the form of condensation, leading to damage. These schematics reinforce why the correct vapour barrier placement is important in walls under cold wintertime conditions.

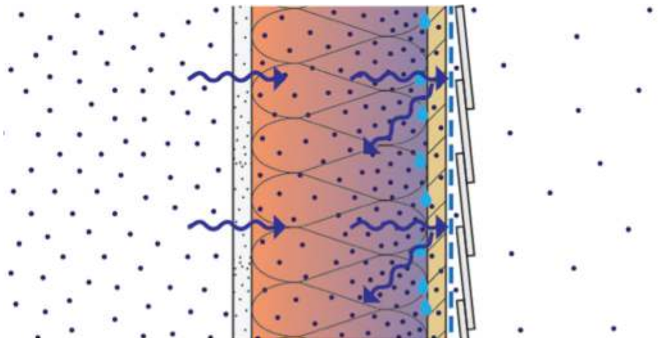


Figure 4: Vertical Section through Insulated 2x6 Wall with Vapour Barrier on Outside of Sheathing

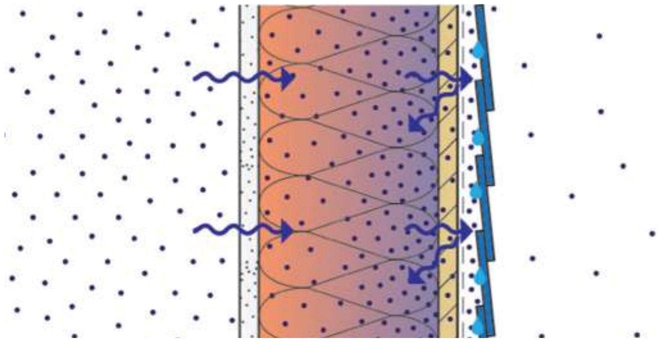


Figure 5: Vertical Section through Insulated 2x6 Wall with Vapour Impermeable Cladding

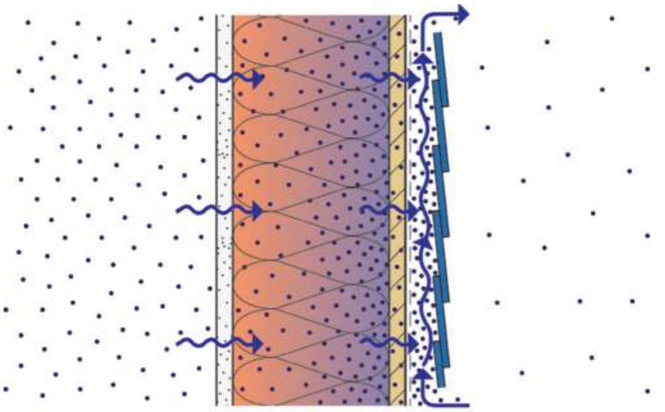


Figure 6: Vertical Section through Insulated 2x6 Wall with Ventilated Impermeable Cladding

The solution to address vapour impermeable claddings is to provide an airspace and ventilation behind the cladding, so that airflow from the outdoors will remove moisture deposited on the cladding by outward vapour diffusion. This is commonly achieved by the construction of a drained and ventilated rainscreen cavity (Figure 6). The requirement for venting behind impermeable claddings has existed within Canadian Building Codes since the introduction of requirements for interior vapour retarders.

Walls with Additional Insulation Installed Outside of the Sheathing

Split Insulated walls are those where additional rigid or semi-rigid insulation is placed outboard of the sheathing (or in some cases, the insulation is also the sheathing). Figure 7 shows this type of wall assembly. The addition of this insulation changes the temperature profile through the wall, and raises the temperature of the sheathing. The more insulation placed outboard of the sheathing compared to the insulation within the stud cavity, the warmer the sheathing. This is often expressed in terms of a nominal outboard to total insulation ratio. For example, if R-6 of rigid insulation is placed outboard of R-22 batt insulation within the stud space for a total insulation amount of R-28 nominal, the approximate ratio is 21% (or 1:5) of outboard insulation excluding other materials.

This increase in sheathing temperature keeps the sheathing above the dewpoint temperature of the indoor air with less risk of condensation due to either vapour diffusion or air leakage, and it also improves the drying ability of the sheathing – **warmer materials are drier materials.**

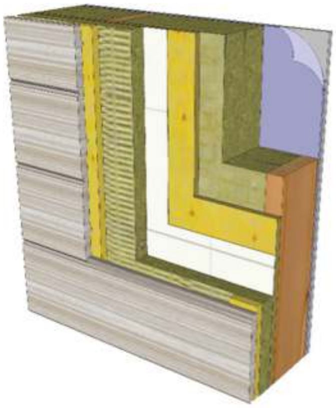


Figure 7: Split insulated wall assembly with mineral wool insulation installed over a 2x6 insulated wood-frame wall

Vapour Permeable Insulation

The split insulated wall scenario is shown in Figure 8 under wintertime conditions. Vapour permeable stone wool insulation has been placed outboard of the sheathing. This has the effect of warming the stud space and exterior sheathing – the more exterior insulation, the warmer the cavity and sheathing. No interior or exterior vapour barrier material has been used, though a Class II or III vapour retarder may be necessary to prevent condensation/high RH levels from occurring, depending on the thickness of exterior insulation and the vapour pressure gradient (expected interior and exterior conditions). For most Canadian and Northern US climate zones and indoor conditions, the installation of a few inches of mineral wool outboard of an insulated 2x6 wall is sufficient to ensure good performance when a Class III vapour retarder (latex paint) is used on the interior of the drywall.

The vapour pressure difference from interior to exterior within this scenario is the same as the previous cases, and is not affected by the exterior insulation; however, the temperature within the stud cavity is warmer, and consequently the RH does not increase as much. As a result, condensation does not form within the cavity and the vapour passes through the sheathing and vapour permeable insulation without harm. The RH within the cavity behind the sheathing will depend on the insulation ratio and on the rate at which drying occurs through the sheathing – therefore the more vapour permeable the sheathing and insulation, the lower the RH within the cavity.

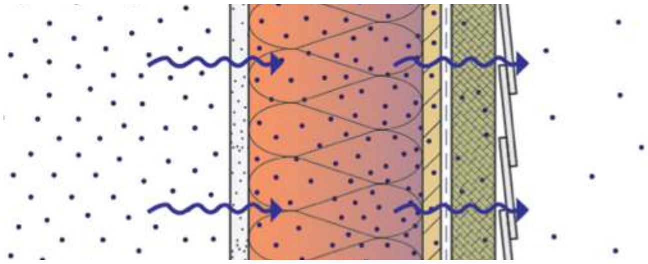


Figure 8: Vertical Section through Insulated 2x6 Wall with Vapour Permeable Exterior Rigid Insulation

As long as the sheathing is warmed up above the indoor air dewpoint temperature, air leakage condensation risk is less, further improving the durability of this wall. With vapour diffusion and air leakage wetting addressed, the only risk to moisture damage is from an external leak. However, because the sheathing is kept warmer by the insulation, it is able to dry out faster, and in this wall assembly moisture will dry both inwards and outwards by vapour diffusion through the relatively vapour permeable materials.

Vapour Impermeable Insulation

Consider the same wall assembly as in the previous scenario but with vapour impermeable foam insulation (XPS, polyiso) used on the exterior of the sheathing (Figure 9). These insulation materials can be considered a Class I or II vapour retarder depending on type, density, thickness and facings. Installation details for the exterior foam insulation (i.e. tight to sheathing membrane or over a drainage membrane, joints are taped or sealed) will also affect the effective vapour permeance of the insulation.

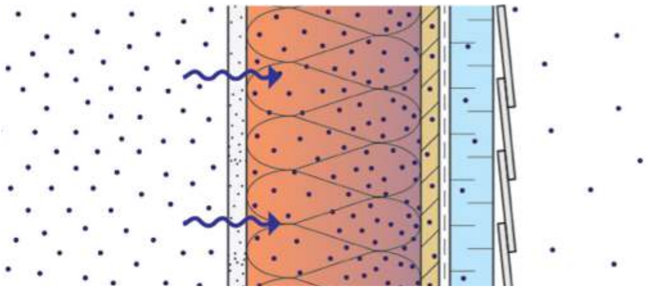


Figure 9: Vertical Section through Insulated 2x6 Wall with Vapour Impermeable Exterior Rigid Insulation

Vapour impermeable foam insulation with the same R-value as in the previous scenario has been placed outboard of the sheathing. This has the effect of warming up the rest of cavity – the more exterior insulation the warmer the cavity and sheathing. No interior vapour barrier has been installed in this scenario, nor would it be recommended, as the inclusion of a vapour barrier (Class I or II) at the interior in conjunction with the exterior foam is considered bad building practice; moisture that is built in or leaks into the wall cannot readily dry. This wall, therefore, relies on vapour diffusion drying towards the interior, as vapour diffusion drying through the exterior insulation is limited. In terms of balancing wetting sources and drying ability, this is a more sensitive wall than the previous scenario as a result of this insulation selection. This is particularly important if the indoor humidity is elevated within the building, or the outdoor climate is wet. Even higher indoor wintertime RH levels of 40-60% (such as in coastal climates or in homes where ventilation levels are low) can create a challenge for this assembly due to the increased outward vapour diffusion and reduced drying potential.

The vapour pressure difference from interior to exterior within this scenario is the same as in the previous scenarios; it hasn't been affected by the presence of the exterior insulation. While vapour diffusion outwards is significantly slowed, or stopped, condensation does not occur within the wall cavity because the temperature is warm enough to keep the RH below 100%. While condensation does not form within the cavity of this assembly, moisture is prevented from travelling through the exterior insulation, which can be an issue in the event of a leak or if there is not enough insulation outboard to prevent air leakage condensation. The RH within the cavity behind the sheathing will depend on the insulation ratio and the effective vapour permeance of the foam insulation. With this assembly, it is generally safer to have more exterior insulation (or a higher insulation ratio) than with vapour permeable insulation so that the RH is kept below 80%.

As long as the sheathing is warmed up above the indoor air dewpoint temperature, air leakage condensation is prevented, improving the durability over a non-exterior insulated 2x6 wall. If vapour diffusion and air leakage wetting are addressed by placement of sufficient exterior insulation, the only risk of moisture damage is from an external leak. In the event of a leak, drying outwards by vapour diffusion is restricted by the foam, and drying can only occur in the inward direction. Solutions to improve outward drying are to provide a small drainage layer behind the foam or to use more vapour permeable insulation. The relative tightness in which the rigid foam board insulation is installed and how the joints are sealed will also affect the outward drying ability.

Summary

The control of vapour diffusion within walls is a balance between minimizing wetting and maximizing drying ability. Correctly placed vapour control layers prevent excessive moisture from diffusing into wall assemblies and potentially condensing, while vapour permeable materials allow moisture to diffuse out and are beneficial to drying performance. In the design and construction of traditional stud insulated wood-frame walls in Canada and the Northern USA, it has been common practice to install a polyethylene sheet vapour barrier at the interior of the insulation to control vapour flow (and often air flow) and therefore limit vapour diffusion wetting while using vapour permeable materials on the exterior to encourage drying.

When insulation is added to the exterior of the stud insulation as in the case of a split-insulated or insulated sheathing, this insulation increases the temperature of the stud cavity and exterior sheathing, reducing the potential for vapour diffusion (and air leakage) condensation to occur within the cavity. The more insulation that is installed outboard of the sheathing, the warmer and drier the stud cavity will be. Wherever possible, the exterior insulation ratio should be maximized. This can mean the use of thicker exterior insulation over an insulated 2x4 wall instead of a thinner insulation over an insulated 2x6 wall.

The change in temperature profile due to the addition of exterior insulation means that a vapour barrier may no longer be needed at the interior, and alternate strategies such as a latex paint may be used instead of polyethylene. Where the exterior insulation is vapour impermeable, an interior vapour retarder must be avoided to prevent trapping moisture within the wall assembly.

The type of insulation installed outboard of the sheathing (or as the sheathing) has an important impact in the vapour diffusion drying capability of the wall. Vapour permeable insulation such as mineral wool or stone wool will result in a greater outward drying than can be achieved with vapour impermeable insulation such as foam plastics; XPS, polyiso, or EPS. This greater drying ability generally results in improved durability of the wall assembly.

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ROXUL Inc. is part of ROCKWOOL International, the largest producer of stone wool insulation, which is made from natural basalt rock and recycled material.

ROCKWOOL International was founded in 1909 and today operates worldwide with more than 9,300 employees, with 27 factories across three continents.

ROXUL manufactures a range of premium insulation products for multiple Residential, Commercial, Industrial and OEM applications.

3) Environmentally Sustainable

Our stone wool production process utilizes some of the most advanced technology available. The ROXUL facility is designed to capture and recycle rainwater, reduce energy consumption, and create zero waste to landfill by recycling raw materials back into the production process.

ROXUL insulations are created using naturally occuring, inorganic raw materials and materials with a high-recycled content. Stone wool insulation is noncombustible and achieves its thermal performance without the use of blowing agents. The products do not off-gas and are fully recyclable, therefore contributing to a sustainable environment.

ROXUL is pleased to have third-party certification of our products' recycled content for our Milton facility completed by **ICC-ES SAVE**™. All ROXUL products produced in the Milton facility contain a minimum of 40% recycled content. ROXUL products produced in our Grand Forks facility are currently awaiting ICC-ES Save™ certification.

ROXUL demonstrates its commitment to the environment through eco-friendly insulation products and green manufacturing processes.

Please visit **roxul.com** for the latest information. For more information, contact ROXUL to determine your specific product needs.

The content of this paper is primarily based on research and guideline development work undertaken for Roxul by RDH Building Engineering Ltd. and RDH Building Sciences Inc. www.rdh.com

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