Vapor Barriers and Air Barriers

By: John Straube

The single most common building science question I get from builders, engineers, code officials and architects is "Do I need a vapor barrier?". The queries come from all corners of the continent, and from people involved in all kinds of buildings. The answer is usually simple to give, but first one has to know more about the question and the specific situation.

Remarkably, the decision of where and what kind of a vapor retarder to use depends on scientific principles. In my work as a structural engineer, I have never been asked "Do I need an 8" deep I-beam?" Everyone in the building business accepts that such a question is naïve, and impossible to answer without more information. The same is true about vapor barriers.

The most important fact to recognize is that an air barrier and a vapor barrier perform different functions.

- Both control the movement of water vapor into enclosures, and hence both aim to control excessive (i.e., damaging) condensation from occurring.
- **Vapor barriers or retarders** control water vapor transport driven by diffusion. Diffusion is simply the movement of water vapor from regions of more to less vapor (without the movement of air).
- **Air barriers** control the moisture that is transported along with airflow. Airflow is driven by air pressure differences, and it moves water vapor in the direction that the air pressure drives it.
- Air barrier systems are needed in just about every type of building, whereas specific vapor retarding layers are not needed in many situations.
- Air barriers must be sealed, continuous, strong, air impermeable, and stiff.
- Vapor barriers need only be vapor impermeable, and sealing joints, small punctures, and cracks is not usually necessary.

The widespread confusion between air barriers and vapor barriers has perhaps arisen because some materials, such as glass, and sheet metal, can be used as part of an air barrier system while at the same time acting as a vapor barrier. An example does not prove the rule of course, and materials like unpainted gypsum board can be excellent air barrier materials while providing little vapor diffusion control. Add to this mix materials like unsealed or torn polyethylene sheets, which act as a vapor barrier but not as part of an effective air barrier system, and the confusion becomes understandable.

Building codes historically added to the mess by requiring vapor barriers (arbitrarily defined as materials with a permeance of the conveniently round number of 1 US perm) while remaining mute on the much greater need for air barrier systems. The codes are slowly being fixed, with air barriers called out independently of vapor control, and vapor control requirements increasingly nuanced (the International Residential Code is the most sophisticated, but does not address many commercial enclosure assemblies).

Manufacturers and others often use the term *air-vapor retarders* to effectively limit the whole discussion to only one limited choice -- that of a system which combines the material and location of both airflow and vapor diffusion control functions.

Why not just place a vapor barrier on both sides of an enclosure all the time and stop worrying? Because this is the surest way to rot, corrode, and otherwise destroy your building in record time. Vapor barriers stop drying, and so we must be sure that we do not use a vapor barrier on the wrong side, or, even worse on both sides, since they will practically stop drying out any moisture that might (will!) get in. To avoid vapor barriers on both sides we sometimes use ventilated cladding systems that would otherwise be vapor barriers (e.g., metal and vinyl siding, asphalt shingle roofs). In systems with two vapor barriers (e.g., a low-slope exposed membrane roof with a deck level vapor barrier) we accept the risk, and acknowledge that a small rain leak or construction moisture condems us to replacing the roof system.

To decide how to control vapor diffusion properly you must have information about three different aspects of your specific situation: the exterior climate, interior conditions, and the properties and arrangements of the enclosure assembly. Lets consider each.

Exterior Climate

As mentioned above, vapor diffusion moves from more to less. The ASHRAE and DOE climate classifications (Zone 1-8, and Humid, Dry, and mixed) are very helpful in assessing what type of climate we have. For a climate with more vapor (meaning hot *and* humid) outdoors almost all the time than indoors (e.g. Miami), it stands to reason that one should place a vapor barrier on the exterior side of the assembly. Not everyone recognizes this yet, but it is a fact. Similarly, for a climate with less moisture outside all the time (e.g., severe cold northern Alaska) a vapor barrier should usually be placed near the interior. For all other situations, we need to know more before we decide.

It must also be remembered that the outside could also mean the conditions created behind rain wetted, absorbent cladding (like brick, cedar shakes, stucco, wood, cement board) exposed to sunshine. This creates a "climate" outside of the wall or roof similar to a sauna (i.e., even worse than Houston summers), and hence drives moisture inward. For enclosures with absorbent claddings in rainy temperate climates, this effect can become quite important.

Interior Conditions

If you are building a swimming pool, you can be quite sure that it will be very humid and warm inside all year long. Thus, a vapor barrier on the inside is practically mandatory in all but the hottest and most humid climates. On the other hand, if the enclosure is being built around a deep-freeze storage facility or ice rink, there will be more moisture in the outside air than the inside most of the time, and the vapor barrier goes on the outside, even in a climate like Pittsburgh. Houses should typically be maintained at a moderate interior humidity level by using ventilation in cold weather and dehumidification in hot humid.

Wall Assembly

The wall assembly used plays a very significant role in deciding on your vapor diffusion control needs. Although designers tend to be fixated on the need to label vapor barriers, the fact is many materials in an assembly may control vapor diffusion. While batt insulation (permeable: 20 perms) has practically no vapor resistance, 8" of concrete is a pretty good barrier (impermeable: 0.5 perms) and latex paint on gypsum board is semi-permeable (about 3 perms).

Thus, a wall with painted gypsum already has some pretty good vapor control, and would not need an additional layer if used to separate a moderate exterior climate (e.g., Boston) from a moderate interior climate (say a house with good ventilation). For a colder climate (say Minneapolis), an 8" structural concrete wall, or 6" of EPS (about 0.75 perms), would be sufficient for all but very humid interior conditions.

The arrangement of the layers is also critically important. Using an unventilated low-permeance layer on the exterior (such as a sealed roofing membrane, precast concrete, etc.) in a cold climate will prevent water vapor from escaping to the exterior (this slows drying to the outside). The permeance of the interior layers must be considerably less than the permeance of outer layers (various rules place the ratio at 3:1 to as much as 10:1) in such cold climate situations. Using insulating sheathing also changes the behavior drastically. The rules are reversed for hot climates. Increasing the temperature inboard of the insulated sheathing essentially transports the wall to a warmer and more temperate climate zone, thereby also reducing the need for low-permeance vapor barriers. For example, an R12 wood frame house wall with R7.5 insulated sheathing in Nebraska would not require a sheet vapor barrier, but would require a normal latex paint layer.

Figure it out

Given the kind of information described above, it is reasonably easy to decide if, where, and what kind of vapor barrier you need. The ASHRAE *Handbook of Fundamentals* describes the procedure as do. The analyst then needs to decide on what kind of interior and exterior conditions to apply, the properties of the materials, and the capacity for wetting that materials can withstand. Detailed hourly simulations can be performed with the aid of easy-to-use but sophisticated hygrothermal simulation programs. WUFI (www.wufi.de) is one of the best and most widely used. However, such detailed models are not often necessary, and should only be operated by people with experience from the field and other methods of analysis.

Conclusions

If you learn anything from this article, learn this: air barriers are important and necessary components of almost all building enclosures in all climates, whereas vapor barriers are typically less important components that may or may not be needed.

How do you answer the question "Do I need a vapor barrier?". Figure it out. And while you do your figuring remember that you must include the exterior climate, interior conditions, and the properties and arrangements of the enclosure assembly.

Appendix A: Guidance for the Selection of Vapor Control

Vapour control layers of some type are often required in enclosure designs. A vapour impermeable material (i.e., a barrier) can be used to block most vapour flow by diffusion. However, in most cases allowing a vapour permeable path is desirable to allow drying of construction moisture and any accidental wetting that might occur. The direction of vapour flow will often change between summer (inward) and winter (outward). Hence, the location of any low vapour permeance layer must be carefully considered, and it is often best to avoid low permeance layers in assemblies, especially in climate zones with hot humid summers.

To specify what level of vapour permeance is acceptable, it is useful to describe three levels, or classes, of vapour control depending on the ASTM E96 dry-cup vapour permeance of the vapour control layer:

- Class I - less than 0.1 perms
  - e.g., polyethylene sheet, sheet metal, aluminum or polyethylene facing on any product.
  - virtually vapour impermeable, a vapour barrier. A Class I vapour control layer divides the wall assembly into interior and exterior zones with regard to vapour diffusion. Vapour diffusion wetting and drying can occur on both sides of the Class I vapour control layer, but not across the vapour control layer.
  - Required or desirable only in extreme climates and extreme occupancies. Useful for special applications such as ground covers.
- Class II - 0.1 to 1.0 perms
  - e.g., the kraft facing on fibreglass batts, some vapour control paints, 2" of extruded polystyrene foam (XPS), over 2-3" of medium-density closed-cell spray polyurethane foam, and 3 to 5 inches of EPS
  - vapour semi-impermeable. A Class II vapour control layer throttles or limits diffusion wetting but allows a small amount of diffusion to help dry an accidentally-wetted assembly.
  - Class II vapour control layer provides sufficient vapour diffusion control to avoid condensation for most climates and occupancies.
- Class III - 1.0 - 10 perms
  - e.g., latex or enamel paints on drywall/gypsum board, more than about 6" to 8" (150-200 mm) of open-cell spray polyurethane foam

- vapour semi-permeable. A Class III vapour control layer restricts vapour diffusion, but allows significantly greater vapour diffusion wetting and drying than a Class II vapour control layer.
- Although Class III vapour control layers allow significant drying assemblies will often require insulated sheathing in cold climates to control diffusion wetting.

Class	Permeance (US perms)	(Metric perms)	Description
I	Less than 0.1	Less than 6	Impermeable
II	0.1 to 1.0	6-60	Semi-impermeable
III	1 to 10	60-600	Semi-permeable
none	Over 10	Over 600	Permeable

Tested by ASTM E96 dry-cup (Method A).

Vapour Control Layer Classification

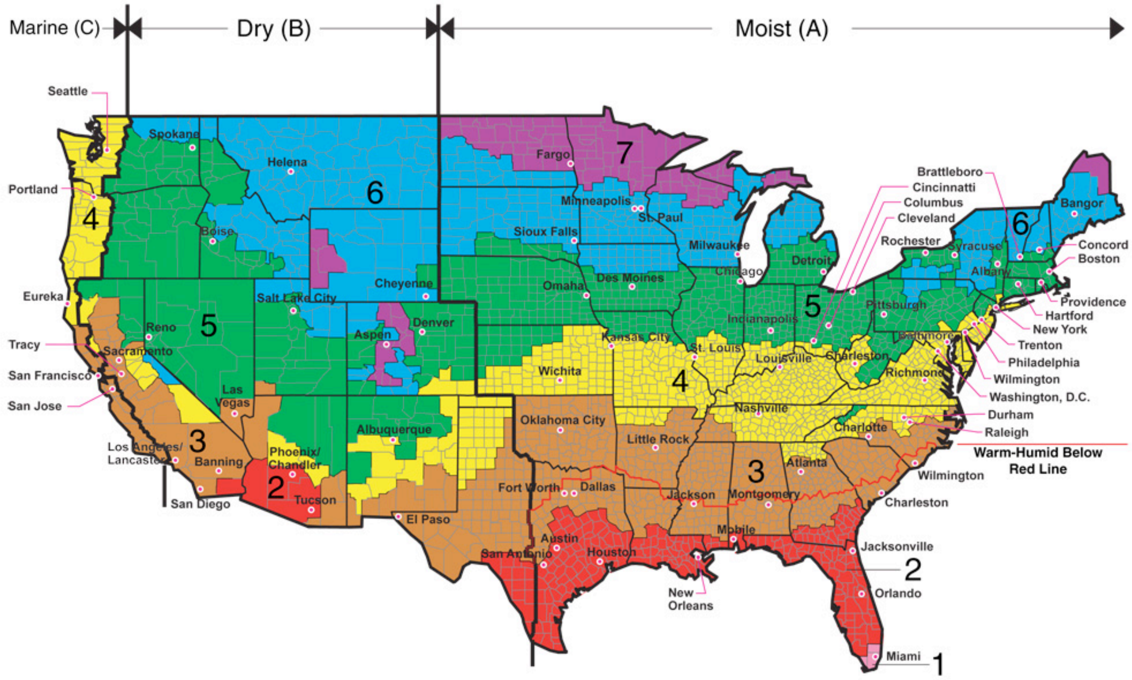
The need for a vapour control layer, and which class, depends strongly on the enclosure design, the air permeance of the insulation layers[1], the interior conditions, and the exterior climate.

The exterior climate is divided into Zones from 1 to 8 by the US DOE based on heating degree days (HDD). The zones are further sub-divided into different exterior humidity levels, indicated by appending the letters A to C (e.g., Zone 6C).

The class of vapour control required can be prescribed for many common wall or roof assemblies for interior conditions of normal residential, school, retail, and office occupancy. This means indoor temperatures of around 72 °F (21°C) and indoor winter time relative humidity of less than 40% (less than 35% in Zones 7 and

[1] Air permeable for an insulation layer is defined as having a permeance of less than 0.04 cfm/ft^2 @ 0.3 in wc (0.2 l/s/m^2 @75 Pa) when tested to ASTM E283 or similar.

8).



All of Alaska in Zone 7 except for the following Boroughs in Zone 8: Bethel, Dellingham, Fairbanks, N. Star, Nome North Slope, Northwest Arctic, Southeast Fairbanks, Wade Hampton, and Yukon-Koyukuk

Zone 1 includes: Hawaii, Guam, Puerto Rico, and the Virgin Islands

Zone	Description	City
1A, 2A, 3A south of warm-humid line	Hot humid	Oahu, Miami, Houston
1B, 2B	Hot dry	Phoenix, Austin
3A north of warm-humid line, 4A	Mixed humid	Atlanta, Richmond
3B, 3C, 4B	Mixed dry	Los Angeles, Albuquerque
4C	Cool, marine	Vancouver, Seattle
5A,6A	Cold humid	Toronto, Chicago, Halifax
5B, 6B	Cold dry	Lethbridge, Helena
7	Very cold	Edmonton, Anchorage
8	Subarctic	Whitehorse, Fairbanks

Climate Zone Descriptions

Different types of assemblies also have different vapour control requirements, even in the same climate zone. Although the requirements for vapour control can be developed through rational engineering analysis, a simplified summary of recommendations, many from the "I" codes, is presented below.

Above-Grade Wall Assemblies

Four categories of above-grade wall assemblies include most of the possible enclosures:

a) framed assemblies with all or most of the insulation inside of the sheathing and between the framing members;

b) framed assemblies with some insulation outboard of the framing and some insulation between the framing members;

c) assemblies with all or most of the insulation outboard of the structure (framed or solid); and

d) assemblies with insulation comprised of only air impermeable and Class II vapour control insulation between, within, or outside the structure.

a) Framed wall assemblies with all or most of the insulation value installed between the framing or structure (e.g., wood or steel stud) as vapour permeable (more than 10 perm) insulation (e.g., fibreglass, rockwool, cellulose, or open cell foam)

The goal of the vapour control design is to prevent vapour diffusing easily and condensing on either the cold sheathing in cold weather or the cold interior finish during warm weather.

- No vapour control layer is needed in Climate Zones 1,2,3,4a or 4 b.
- A Class I or Class II vapour control layer is required on the interior side of framed walls in Zones 4c, 5, 6, 7, and 8, with the exceptions of basement walls, below grade portion of any wall, and wall construction that is not sensitive to moisture or freezing (e.g. concrete).
- Class I vapour control layers, including non-perforated vinyl wallpaper, reflective foil, glass, epoxy paint, white boards, melamine, etc. are not recommended and *should be avoided* on the interior of air-conditioned building occupancies in climates with humid summers in Zones 1-6. The dividing line between Dry (B) and Moist (A) can be found in ASHRAE 90.1. Enclosures clad with unvented water absorbent claddings (e.g., stucco, masonry, fibre cement, wood) are at especially high risk of summer condensation.
- A Class III vapour retarder can be used instead of a Class I or Class II when
    - in Zones 4c, or 5, vented cladding is used over sheathing with a perm rating of more than 1 (wet-cup), i.e., OSB, plywood, or exterior gypsum sheathing, OR
    - in Zone 6, vented cladding is used over high permeance (more than 10 perm) sheathings such as fiberboard and exterior gypsum

Vented claddings include vinyl siding, metal panels, terra cotta, wood or fibre cement siding on air gaps, and masonry veneers with clear airspaces and vent openings top and bottom. A clear gap of around 3/8” (10 mm) will generally provide sufficient airflow to allow for ventilation, but at least 1" (25 mm) should be specified for masonry walls.

b) Framed assemblies with some insulation value outside of the framing or structure.

The recommendations in the previous assembly category may be used, but it is usually desirable to design for more drying, especially in warmer climate zones (4 and 5 especially). The use of insulation on the exterior of the sheathing increases its temperature in cold weather, thereby relaxing the need to control cold-weather vapour diffusion. Exterior insulation made of foamed plastic has the benefit that ut also tends to reduce inward vapour drives during warm weather. MFI insulation work differently in that they allow more outward drying.[2]

A Class III vapour retarder can be used instead of a Class I or Class II in zones 4c, 5, 6, 7, or 8 where any of the criteria for the specific zone from the list below is met. These criteria may depend upon the climate zone and the ratio of the insulation value in the stud space to insulation value installed outboard of the sheathing[3].

A Class III vapour control layer may be used on the interior of framed walls in Zone 4c and higher, if the any of the following criteria are met:

Zone 4c (e.g. Vancouver, Seattle or Portland)

- Sheathing-to-cavity R-value ratio of >0.20
- Insulated sheathing with an R-value ≥ 2.5 on a 2x4 framed wall
- Insulated sheathing with an R-value ≥ 3.75 on a 2x6 framed wall.

Zone 5 (e.g. Chicago, Windsor, Boston)

- Sheathing-to-cavity R-value ratio of >0.35
- Insulated sheathing with an R-value ≥ 5 (e.g. 1" XPS) on a 2x4 framed wall

[2] Exterior insulation made of mineral fibers is highly vapour permeable and when combined with vapour permeable sheathing and membrane layers, enclosures will behave differently than less permeable sheathings/membranes: less R-value of such products are needed to perform well than the rules in this category.

[3] The insulation value in the stud space is often a function of whether 3.5", 5.5", 6" or 8" framing is filled with insulation. Self-supporting spray-applied insulations such as glass-fiber and foam products, or batt products well supported on the open side DO NOT need to fill the whole studspace, and thereby reduce the required insulation value of the exterior continuous insulation layer. Cavity insulations need to be in tight contact on five surfaces: the sixth surface can be open to the interior.

- Insulated sheathing with an R-value ≥ 7.5 (e.g. 1.5" XPS) on a 2x6 framed wall.

Zone 6 (e.g., Toronto, Ottawa, Helena, Montreal, Halifax, Minneapolis)

- Sheathing-to-cavity R-value ratio of >0.50
- Insulated sheathing with an R-value ≥ 7.5 (e.g. 1.5" XPS) on a 2x4 framed wall
- Insulated sheathing with an R-value ≥ 11.25 (e.g. 2" PIC) on a 2x6 framed wall.

Zones 7 and 8 (e.g. Calgary, Edmonton, Whitehorse, Anchorage, Fairbanks)

- Sheathing-to-cavity R-value ratio of >0.70
- Insulated sheathing with an R value ≥ 10 (e.g. 2" XPS) on a 2x4 framed wall
- Insulated sheathing with an R-value ≥ 15 (e.g. 3" XPS) on a 2x6 framed wall.

Insulated sheathing can be installed in the form of Expanded Polystyrene (EPS) or semi-rigid glassfiber and rockwool with approximately R-4 per inch, Extruded Polystyrene (XPS) with R-5 per inch, Polyisocyanurate (PIC) with approximately R-6 per inch, or closed-cell spray foam (usually around R6/inch).

c) Assemblies with all or most (more than 75% of the total) of the insulation value located outboard of the structure (framing or solid)

This is the simplest and most robust wall to design with respect to vapour control. Such walls should ideally have all moisture sensitive components and materials located on the inside of the insulation. In this location, a Class I or II layer on the inside of all or most of the insulation value is acceptable and recommended if all outboard components are moisture tolerant[4]. A Class III layer on the interface of a high permeance (more than 10 perms) insulation layer outboard of a moisture-sensitive structure should only be used if warm weather and inward vapour drive condensation are not an issue or are controlled by other means.

d) Assemblies comprised of only air impermeable and Class II vapour control insulation between, within, or outside the structure.

[4] Condensation during warm weather and condensation caused by vapour driven inward from wetted cladding heated by the sun will occur on the exterior of the vapour control layer: hence it is best detailed as a drainage plane water control layer.

The EPS and urethane foam cores of wood or metal SIPS, board foams, and medium density closed cell spray foam (between wood or steel studs), if installed as continuous layers, all provide their own vapour control layers and require no additional vapour-diffusion control in any climate. Wood studs themselves and small cracks between steel or wood studs do not allow significant vapour to flow by diffusion. Their use does not change the recommendations.

Cracks between framing members and insulation boards are often significant for airflow control and must be addressed in all of the systems described in the previous paragraph.

Below-Grade Wall Assemblies

Below-grade spaces, such as basements, are of particular concern with respect to improperly located Class I vapour control layers. Because the moisture drive in below-grade walls is always from the exterior to the interior in Zones 6 and lower, installing a low-permeance layer on the interior side of insulation wall will cause moisture related durability issues by trapping moisture in the enclosure (see *BSD-103: Understanding Basements*). A Class I vapour control layer outside a concrete or masonry basement wall is recommended to control the flow of vapour from damp soil into the assembly. Installing a Class II vapour control layer on the inside of below-grade framed assemblies is recommended for Zones 7 and higher.

In cold climates (Zone 5 and higher), condensation may occur on the interior side of concrete/masonry structure of a below-grade wall assembly if insulated on the inside with an air and vapour permeable (Class III or more, e.g., fibrous insulation) layer. To control both inward and outward drives, it is recommended that a Class II or III insulation product (e.g. most foams) be used in contact with the interior face of the concrete/masonry, and any insulation installed between interior framing follow the rules of "Framed assemblies with some insulation value outside of the framing or structure".

Below-Grade Floor Assemblies

Locating all of the insulation below the structure (concrete slab, or framed) with a Class I vapour control layer between the structure and the is the practical and economical manifestation of the perfect enclosure. Some insulations provide the same level of vapour control (foil-faced polyiso or EPS, plastic-faced XPS) but many products will require a special low-permeance layer (polyethylene sheet is commonly used, inexpensive, and effective).

If no impermeable floor finishes are likely to be used during the life of the structure, the vapour control class requirement can be relaxed to a Class II. See also *BSI-003 Concrete Floor Problems* and *BSI-009 New Light in Crawlspaces* online at www.buildingscience.com for more discussion of vapour control and flooring.

Roof Assemblies

Roofing behaves differently than walls from a vapour control point of view for a number of reasons: most roof membranes are located on the exterior and provide Class I vapour control. Roof membranes, shingles, metal roofing are all vapour impermeable. Only back-ventilated roofing such as concrete tiles perform in a similar manner to walls.

Assuming a vapour impermeable roofing membrane, four categories of roof assemblies will include most practical roofing systems:

a) unvented roof assemblies with all or most of the insulation outboard of the structure (framed or solid).

b) vented, framed roof assemblies with all or most of the insulation inside of the sheathing and between the framing members

c) unvented, framed roof assemblies with either some insulation outboard of the framing and some insulation between the framing members, or some air impermeable insulation outboard or air impermeable insulation, and

d) unvented roof assemblies with insulation comprised of air impermeable and Class II vapour control insulation between, within, or outside the structure.

a) unvented roof assemblies with all or most (>75%) of the insulation outboard of the structure (framed or solid)

These types of roofs comprise most of the low-slope, rigid board insulated, commercial roof systems installed over metal and concrete decks. However, there is no technical difference between a low-slope roof built in this manner and a sloped roof. This type of roof has very little need for additional vapour control as all of the common board foam roofing insulations (PIC, EPS, XPS) provide sufficient vapour control for most climate zones.

- No additional vapour control layer is needed if a Class II vapour control insulation layer is used (>2" of XPS, PIC, >3" of EPS).
- To control diffusion at joints in board foam, all board insulation should be installed in two layers or more, with joints offset vertically and horizontally. This is especially important in Zones 5 and higher.

Such roofs should ideally have all moisture sensitive components and materials located to the inside of the insulation. In this location a Class I or II layer on the inside of all or most of the insulation value (e.g. 75%) is acceptable but will restrict desirable and effective inward drying. For Zones 5 and lower, a vapour control layer of Class III or higher is recommended to allow for inward drying of incidental moisture due to solar heating of roof membranes (e.g., gypsum board on metal deck).

b) Vented, framed roof assemblies with all or most of the insulation value installed between the framing (e.g., wood/steel stud, metal buildings) as vapour permeable (more than 10 perm) insulation (e.g., fibreglass, rockwool, cellulose, or open cell foam)

If a compact roof is well-vented above the insulation (i.e., with soffit and ridge vents connected by an open air-space of 1.5" or more / 38 or more),

- no vapour control layer is required in Zones 1 through 3.
- Class III vapour control in Zones 4 through 6.
- Class II vapour control in Zones 7 and higher.

If a roof is sloped over a well-vented attic (i.e., with soffit and ridge vents connected by an open air volume of at least 12" (300 mm) average height, and no less than 1.5"(38 mm) anywhere),

- no vapour control layer is required in Zones 1 through 4,
- Class III vapour control layer is recommended for Zones 5 through 6,
- Class II vapour control layer is recommended in Zones 7 and higher.

Unvented, framed assemblies with all the insulation value comprised of air permeable insulation (fiberglass, rockwool, cellulose) between the framing are *not* recommended due to the potential for air leakage condensation.

c) Unvented framed roof assemblies with some insulation provided by air impermeable insulation.

Roofs need not be vented if diffusion and air leakage related wetting can be strictly limited. To accomplish this, some air impermeable, some Class II insulation can be located outside of air and vapour permeable (more than 10 perm) insulation (e.g., fibreglass, rockwool, cellulose are both).

The ratio of the insulation value of the exterior air- and vapour-control insulation to the insulation value of the interior air- and vapour-permeable insulation increases as the climate becomes colder, and the interior more humid. For normal commercial and residential occupancies the following recommendations can be made (Note: painted drywall or more than about 150 mm / 6" of open cell foam are Class III retarder).

For Zones 1 through 3A, 3B

- Outer air impermeable insulation value >15% of total
- No vapour control layer required.

For Zones 3c/4c (e.g. Vancouver, Seattle, Portland, San Francisco)

- Outer air impermeable insulation value >25% of total
- Class III vapour control

Zone 4A, 4B, 5 (e.g. Windsor, Kansas City, Boston)

- Outer air impermeable insulation value >35% of total
- Class III vapour control in Zone 5

Zone 6 (e.g. Toronto, Ottawa, Montreal, Halifax, St Johns, Minneapolis)

- Outer, air impermeable insulation value >50% of total
- Class III vapour control

Zones 7 and 8 (e.g. Edmonton, Calgary, Winnipeg, Whitehorse, Fairbanks)

- Outer, air impermeable insulation value >65%
- Class III vapour control

- Air-impermeable insulation can be in the form of Expanded Polystyrene (EPS) with approximately R4 per inch, Extruded Polystyrene (XPS) with R5 per inch, Polyisocyanurate (PIC) with approximately R6 per inch, 2 pcf (32 kg/m^3) closed-cell spray foam (usually around R6 per inch), or 0.5 pcf (8 kg/m^3) open-cell spray foam (usually around R4 per inch). All of these products, other than open-cell spray foam and EPS, provide a Class II vapour control layer in thicknesses of 1.5" or more. EPS of 1 pcf density (16 kg/m^3) which requires between 3" and 5" (depending on density) to reach Class II performance, and open-cell foam requires a special vapor control coating.

d) unvented roof assemblies with insulation comprised of only air impermeable and Class II vapour control insulation between, within, or outside the structure.

The EPS and urethane foam cores of wood or metal SIPS, board foams, and medium density closed cell spray foam (between wood or steel studs), if installed as continuous layers, all provide their own vapour control layers and require no additional vapour diffusion control in any climate with normal residential and commercial interior humidity conditions. Wood studs and cracks between steel or wood studs do not allow significant vapour to flow by diffusion and hence do not change the recommendations.

Cracks between framing members and panels are significant for airflow control and must be addressed in all of the systems described above. A very effective airflow control layer is required on the inside of the insulation and/or framing for all unvented roof assemblies.