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Moisture Control For Buildings

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When designing a building's envelope and its interaction with the mechanical system, temperature, humidity, rain, and the interior climate often are ignored. The focus for the building may be more on aesthetics and cost than on performance.

The concept of limit states (limiting conditions) plays a key role in building durability. In structural engineering, loads and load resistance are considered and limiting states, such as deflection, are specified.

A similar approach is applied to moisture engineering. Rain, temperature, humidity and the interior climate are considered environmental loads with principal limiting conditions such as rot, decay, mold and corrosion. A damage function (damage process) analysis is then used to determine whether a limiting condition, such as mold growth, is achieved.

Moisture engineering uses an iterative and interdisciplinary systems approach to develop performance metrics to meet moisture-related objectives.

Environmental Loads

Hygro-thermal regions, rain exposure zones and interior climate classes are environmental loads used in applying moisture engineering to building envelopes and mechanical systems. *Figure 1* shows hygro-thermal regions and *Figure 2* shows rain exposure zones for North America. *Table 1* describes interior climate classes.

Moisture Balance

Moisture accumulates in the building envelope when the rate of moisture entry into an assembly exceeds the rate of moisture removal. When moisture accumulation exceeds the ability of the assembly materials to store the moisture without significantly degrading performance or long-term service life, moisture problems result. The moisture storage capacity of a material depends on time, temperature, and material properties.

This moisture storage capacity is significant in determining performance. Consider three examples: a wood frame wall, a steel stud wall and a masonry wall.

In an exterior wood frame wall with a wood-based sheathing, the wood can safely store moisture until the moisture content by weight exceeds 16% (the "surface mold limit for wood"). The equilibrium moisture content of wood exposed to a relative humidity of 80% is 16. In most climates, most wood materials come to equilibrium at around 5% to 6% moisture content by weight. The difference between the surface mold limit and the typical average condition in an exterior wood frame wall is approximately 10% moisture content by weight. In other words, the moisture storage capacity or hygric buffer capacity of most exterior wood frame walls with wood-based sheathings is approximately 10%. If moisture accumulates beyond about 16% by weight, wood surfaces are likely to develop mold.

Class I	Class II	Class III
• Temperature Moderated • Vapor Pressure Uncontrolled • Air Pressure Uncontrolled	• Temperature Controlled • Vapor Pressure Moderated • Air Pressure Moderated	• Temperature Controlled • Vapor Pressure Controlled • Air Pressure Controlled

Table 1: Interior climate classes.

In the average home approximately 4,000 to 5,000 lbs (1814 to 2267 kg) of wood are in the exterior walls. This yields a hygric buffer capacity of approximately 400 to 500 lbs (181 to 226 kg) of water or approximately 45 to 50 gallons (170 to 189 L). From a performance perspective, the average home can easily accommodate 45 to 50 gallons (170 to 189 L) of water via hygric redistribution. Most water leaks are not a problem because of this large capacity to store water.

About the Author

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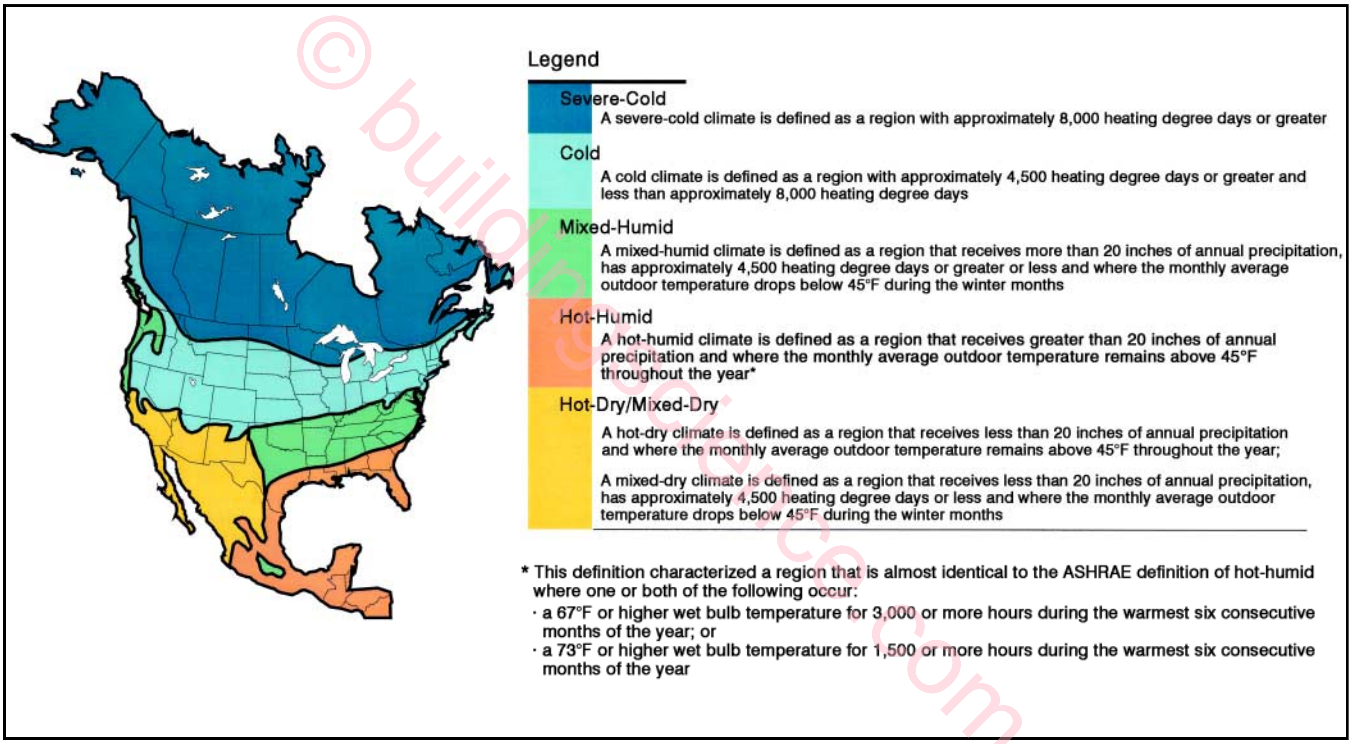


Legend

Severe-Cold
A severe-cold climate is defined as a region with approximately 8,000 heating degree days or greater

Cold
A cold climate is defined as a region with approximately 4,500 heating degree days or greater and less than approximately 8,000 heating degree days

Mixed-Humid
A mixed-humid climate is defined as a region that receives more than 20 inches of annual precipitation, has approximately 4,500 heating degree days or greater or less and where the monthly average outdoor temperature drops below 45°F during the winter months

Hot-Humid
A hot-humid climate is defined as a region that receives greater than 20 inches of annual precipitation and where the monthly average outdoor temperature remains above 45°F throughout the year*

Hot-Dry/Mixed-Dry
A hot-dry climate is defined as a region that receives less than 20 inches of annual precipitation and where the monthly average outdoor temperature remains above 45°F throughout the year;

A mixed-dry climate is defined as a region that receives less than 20 inches of annual precipitation, has approximately 4,500 heating degree days or less and where the monthly average outdoor temperature drops below 45°F during the winter months

* This definition characterized a region that is almost identical to the ASHRAE definition of hot-humid where one or both of the following occur:
- a 67°F or higher wet bulb temperature for 3,000 or more hours during the warmest six consecutive months of the year; or
- a 73°F or higher wet bulb temperature for 1,500 or more hours during the warmest six consecutive months of the year

Figure 1: Hygro-thermal regions in North America.

Matters are considerably different when the exterior walls are constructed with steel studs and gypsum sheathing. Steel studs have no water storage capacity. Gypsum sheathing can store approximately 1% moisture content by weight before mold colonization occurs. Constructing the average home with steel studs and gypsum sheathing yields a hygric buffer capacity of 5 gallons (19 L). In this type of assembly, even the smallest leak can lead to problems.

In contrast, consider a similar sized home built with masonry exterior walls and masonry cladding. That construction yields a hygric buffer capacity of approximately 500 gallons (1892 L).

Hygric Buffer Capacity for 2,000 ft^2 (186 m^2) Home

Steel Frame with Gypsum Sheathing	Approx. 5 gallons (19 L)
Wood Frame with Wood Sheathing	Approx. 50 gallons (189 L)
Masonry Wall	Approx. 500 gallons (1892 L)

The quantity of accumulated moisture in assemblies is affected by the energy flow through the assemblies. In general, more thermal insulation increases the dwell time of moisture in the assembly. Dwell time — or drying time — should be as short as possible to avoid moisture problems. Constructing highly insulated steel frame assemblies with gypsum sheathing is one of the significant challenges of moisture engineering. This assembly combines two perilous characteristics: low hygric buffer capacity (low safety margin) with slow drying times. So even small amounts of moisture will cause problems.

Moisture Control

Various strategies can be implemented to minimize the risk of moisture damage. The strategies fall into the following three groups:

1. Control of moisture entry,
2. Control of moisture accumulation, and
3. Removal of moisture.

These are best used in combination. Strategies effective in the control of moisture entry, however, often are not effective if building assemblies start out wet. In fact, these strategies can be detrimental. A technique that is effective at preventing moisture from entering an assembly is also likely to be effective at preventing moisture from leaving an assembly. Conversely, a technique effective at removing moisture also may allow moisture to enter. Balance between entry and removal is key in many assemblies.

The most significant wetting mechanisms are liquid flow and capillary suction. Groundwater and rain are the moisture sources. Controlling groundwater entry below grade and rain entry above grade has long preoccupied builders and designers. Air transport and vapor diffusion are less obvious contributions to the wetting of building assemblies. All of these mechanisms are capable of leading to moisture-related building problems.

All moisture movement, and any moisture-related problem, comes from one or more of these mechanisms.

Historically, successful approaches to moisture control usually follow this strategy: prevent building assemblies and surfaces from getting wet from the exterior; prevent building assemblies and surfaces from getting wet from the interior; and if building assemblies or surfaces get wet, or start out wet, allow them to dry to either the exterior or the interior.

Building assemblies, in all climates, can get wet from the exterior by both liquid flow and capillary suction (rain, dew and groundwater as moisture sources). Accordingly, techniques for the control of liquid flow and capillary suction are similar in all climates and are interchangeable.

However, building assemblies get wet by air movement and vapor diffusion in different manners depending on climate and time of year. Accordingly, techniques for the control of air movement and vapor diffusion are different for each climate and are seldom interchangeable between different geographical locations.

Both air movement and vapor diffusion move moisture from the interior and exterior of a building enclosure into the building envelope. The rates depend on both climactic and interior conditions. Designers and builders often overlook this fact. It is not unusual to find "cold" climate building envelope designs used in "warm" climate regions. Even more confusing to the builder and designer are conditions where both heating and cooling occur for extended periods of time.

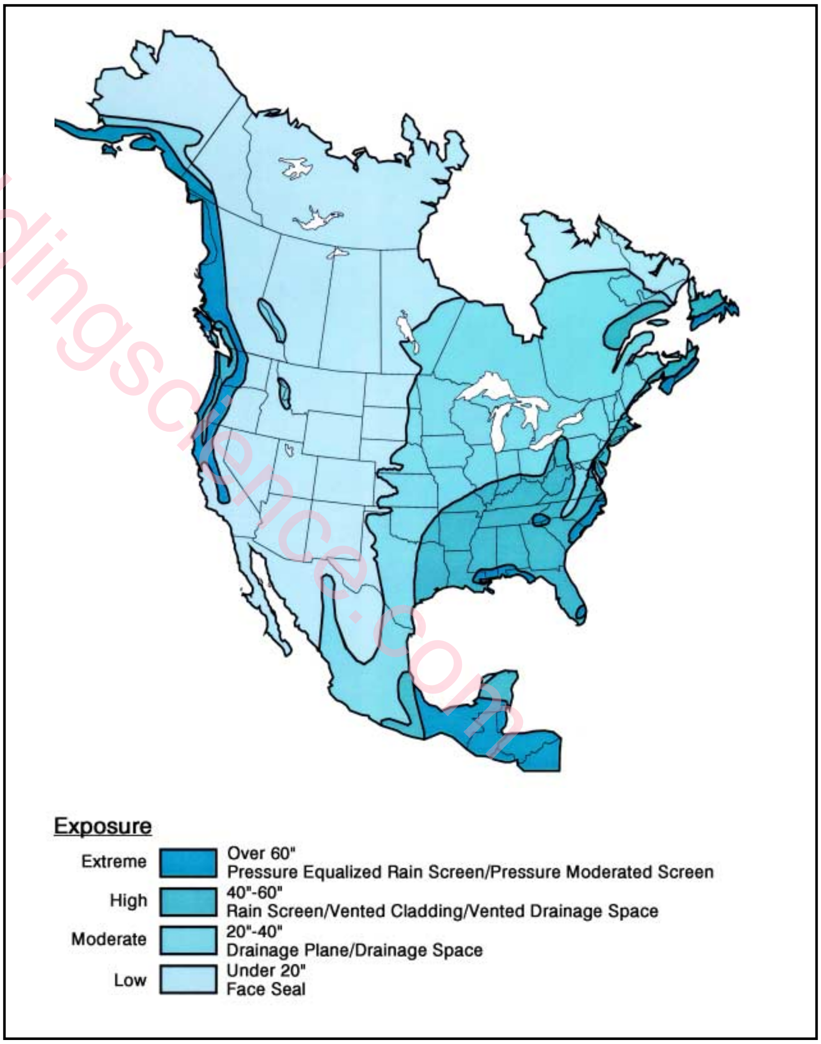


***Figure 2:** Annual precipitation in North America.*

General Strategy for All Climates

Building assemblies need to be protected from wetting via air transport and from vapor diffusion. The typical strategies use vapor barriers, air barriers, air pressure control, and control of interior moisture levels through ventilation and dehumidification. Climate location and season determine the location of air barriers and vapor barriers, pressurization vs. depressurization, and ventilation vs. dehumidification.

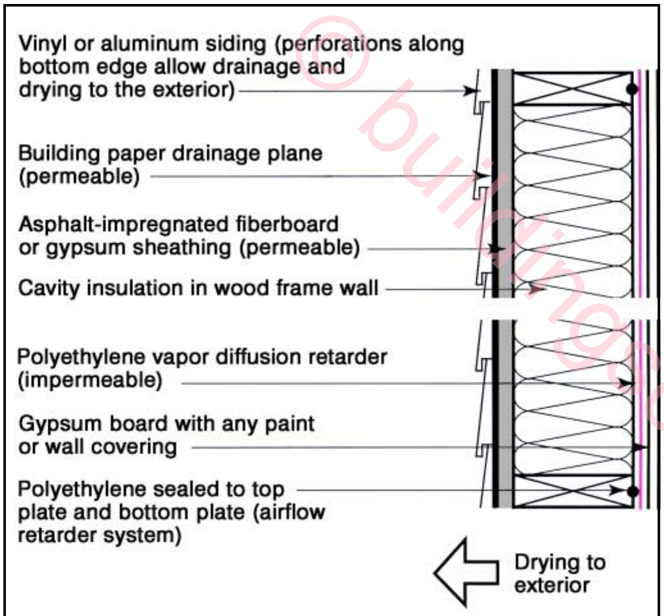
Moisture usually moves from warm to cold (driven by the thermal gradient) and from more to less (driven by the concentration gradient). In cold climates, moisture from the interior flows toward the exterior by passing through the building envelope. In hot climates, moisture from the exterior flows towards the cooled interior by passing through the building envelope.

Cold Climates

In cold climates and during heating periods, building assemblies need to be protected from getting wet from the interior. Therefore, air barriers and vapor barriers are installed towards the interior warm surfaces. Furthermore, conditioned spaces should be maintained at relatively low moisture levels through the use of controlled ventilation (dilution) and source control.

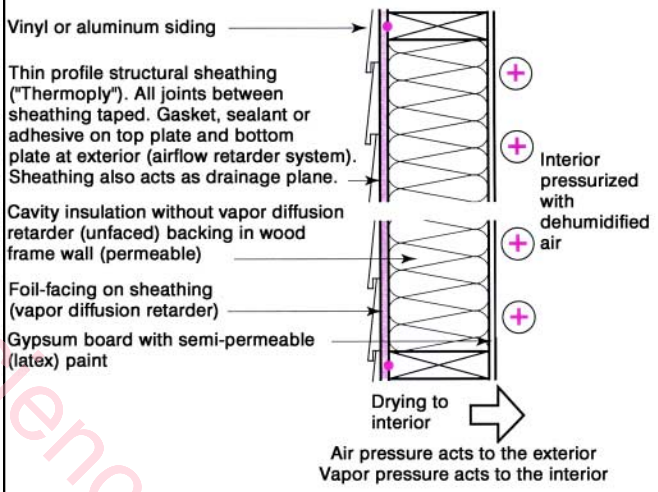
In cold climates, the goal is to make it as difficult as possible for the building assemblies to get wet from the interior. The first line of defense is the interior air barrier and the interior vapor barrier. Next comes ventilation (dilution with exterior air) and source control to limit interior moisture levels. Since it is likely that building assemblies will get wet, a degree of forgiveness should also be designed into building assemblies allowing them to dry if they get wet. In cold climates and during heating periods, building assemblies dry towards the outdoors. Therefore, permeable ("breathable") materials often are specified as exterior sheathings.

So, in cold climates, install air barriers and vapor barriers on the interior of building assemblies. Then, let the building assemblies dry to the exterior by installing vapor permeable materials towards the exterior.



- Vapor diffusion retarder to the interior
- Airflow retarder to the interior
- Permeable exterior sheathing and permeable building paper drainage plane
- Ventilation provides air change (dilution) and also limits the interior moisture levels

Figure 3: Classic severe-cold climate wall assembly.



- Vapor diffusion retarder to the exterior
- Airflow retarder to the exterior
- Pressurization of conditioned space
- Impermeable exterior sheathing also acts as drainage plane
- Permeable interior wall finish
- Interior conditioned space is maintained at a slight positive air pressure with respect to the exterior to limit infiltration of exterior, hot, humid air
- Air conditioning also provides dehumidification (moisture removal) from interior

Figure 4: Classic hot-humid climate wall assembly.

Hot Climates

Hot and humid climates, humid weather and cooling periods present the opposite challenge. Building assemblies need to be protected from getting wet from the exterior, and they must be allowed to dry towards the interior. Accordingly, air barriers and vapor barriers are installed on the exterior of building assemblies. Additionally, building assemblies must be allowed to dry towards the interior by using permeable interior wall finishes and installing cavity insulations without vapor barriers (unbacked fiberglass batts or blown cellulose or rock wool). Avoid any impermeable interior wall coverings such as vinyl wallpaper. Furthermore, conditioned spaces are maintained at a slight positive air pressure with conditioned (dehumidified) air to limit the infiltration of humid outdoor air.

Mixed Climates

In mixed climates, the situation becomes more complicated. Building assemblies need to be protected from getting wet from both interior and exterior moisture, and must be allowed to dry to the exterior and interior. Two general strategies are typically used:

1. Adopting a “flow-through” approach by using permeable building materials on both the interior and exterior surfaces of building assemblies to allow water vapor by diffusion to “flow-through” the building assembly without accumulating. Flow will be from the interior to exterior during heating periods, and from the exterior towards the interior during cooling periods. This approach requires both air pressure control and interior moisture control. The location of the air barrier can be towards the interior (sealed interior gypsum board), or towards the exterior (sealed exterior sheathings or building wraps).

2. Installing the vapor barrier roughly in the thermal “middle” of the assembly. This is typically accomplished by installing impermeable or semi-permeable insulating sheathing on the exterior of a frame cavity wall. For example, installing 1.5 in. (37 mm) of foil-faced insulating sheathing (approximately R 10) on the exterior of a 2 × 6 frame cavity wall insulated with unfaced fiberglass batt insulation (approximately R 19). The vapor barrier is the interior face of the exterior impermeable insulating sheathing. If the wall assembly total thermal resistance is R 29 (R 19 plus R 10), the location of the vapor barrier is 66% of the way (thermally) towards the exterior (19/29 = 0.66). In this approach air pressure control and using interior moisture control would also be used. The location of the air barrier can be towards the interior or exterior.

The advantage of this wall assembly is that an interior vapor barrier is not necessary. In fact, locating a vapor barrier there would be detrimental, as it would prevent the wall assembly from drying towards the interior during cooling periods. The wall assembly is more forgiving without the interior vapor barrier than if one were installed.

Suggestions for Moisture Engineering Specifications

General

- Soil surfaces shall be graded away from below-grade envelope surfaces.
- Materials next to below-grade envelope surfaces shall be free draining and shall connect to a subgrade drainage system through a filter media that will prevent fines buildup in the drainage system.
- A clay cap or other water-flow resistant surface layer shall be installed to prevent surface water from draining into the free-draining material next to below-grade envelope surfaces.
- Below-grade surfaces shall be provided with a damp-proofing layer or coating that will be effective as a capillary break.
- Surfaces subject to wind-driven rain or snow shall be provided with a drainage plane or layer that will prevent rain wetting of internal materials.
- Indoor dew point shall be maintained below the coldest surface temperature inside of the building envelope air barrier.
- Indoor relative humidity shall be maintained below 70% as measured at the coldest indoor surface.
- Building envelope assemblies should include at least one air barrier and one vapor retarder or vapor barrier surface.
- Crawl space assemblies should have a continuous impermeable ground cover that functions as both an air barrier and vapor barrier.

Cold-Climate Requirements

- Locate vapor barriers towards the interior of building assemblies. Avoid vapor barriers located towards the exterior.
- Where low permeance exterior sheathings are used, temperature of condensing surfaces under heating conditions should be controlled (use of insulating sheathings, external insulation) as well as by limiting the indoor vapor pressures.
- Provide air barrier systems that limit air movement from the interior into the exterior walls and roofs.
- Provide secondary air barriers that limit wind washing from the exterior.
- During the coldest portion of the heating season, keep the indoor dew point below 35°F (2°C).

Barriers and Retarders

Vapor Barriers and Vapor Retarders

The unit of measurement typically used in characterizing the water vapor permeability of materials is the "perm." Materials can be separated into three general classes based on their permeability:

Vapor Impermeable	Referred to as Vapor Barriers	1 perm or less
Semi-Vapor Permeable	Referred to as Vapor Retarders	more than 1 perm and less than 10 perms
Vapor Permeable	Referred to as Breathable	10 perms or more

Materials that are generally classed as impermeable to water vapor are: Rubber membranes, polyethylene film, glass, aluminum foil, sheet metal, oil-based paints, vinyl wall coverings, and foil-faced insulating sheathings.

Materials that are generally classed as semi-vapor permeable to water vapor are: plywood, OSB, unfaced expanded polystyrene (EPS), fiberfaced isocyanurate, heavy asphalt impregnated building papers, the paper and bitumen facing on most fiberglass batt insulation and most latex-based paints.

Materials that are generally classed as permeable to water vapor are: unpainted gypsum board and plaster, unfaced fiberglass insulation, cellulose insulation, unpainted stucco, lightweight asphalt impregnated building papers, asphalt impregnated fiberboard, exterior gypsum sheathings, cement sheathings, and "housewraps."

Air Barriers and Air Retarders

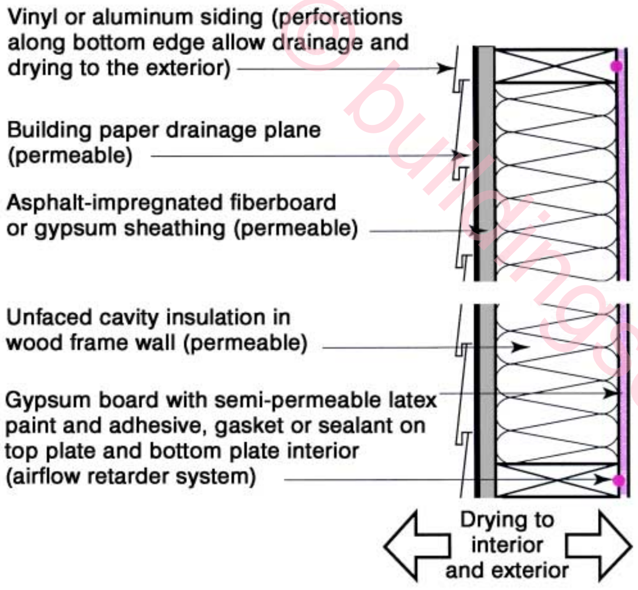
The physical properties that distinguish air barriers from other materials are the ability to resist airflow and air pressure. Air barriers are typically systems of materials that completely enclose the air within a building. Continuity of air barrier systems at holes, openings and penetrations of the building envelope is a key performance parameter.

Air barriers must resist the air pressure differences that act on them. Rigid materials such as gypsum board, exterior sheathing materials such as plywood and OSB and supported films such as "housewraps" installed over exterior sheathing are effective air barriers if their joints are sealed. Their rigidity aids their ability to resist air pressure differences. Often, rubber or bitumen-based membranes are adhered to masonry or sheathing materials to create an air barrier system. These rubber or bitumen-based membranes are also impermeable and are therefore also vapor barriers.

Not all air barriers are vapor barriers and not all vapor barriers are air barriers.

Air barriers typically define the location of the "pressure boundary" of the building envelope. The pressure boundary is defined as the location where 50% or more of the air pressure drop across an assembly occurs.

Materials or systems that reduce airflow or control airflow but do not resist 50% or more of the air pressure drop across an assembly are called air retarders.



- Permeable interior surface and finish and permeable exterior sheathing and permeable building paper drainage plane
- Interior conditioned space is maintained at a slight positive air pressure with respect to the exterior to limit the infiltration of exterior moisture-laden air during cooling
- Ventilation provides air change (dilution) and also limits the interior moisture levels during heating
- Air conditioning/dehumidification limits the interior moisture levels during cooling

Figure 5: Classic flow-through wall assembly.

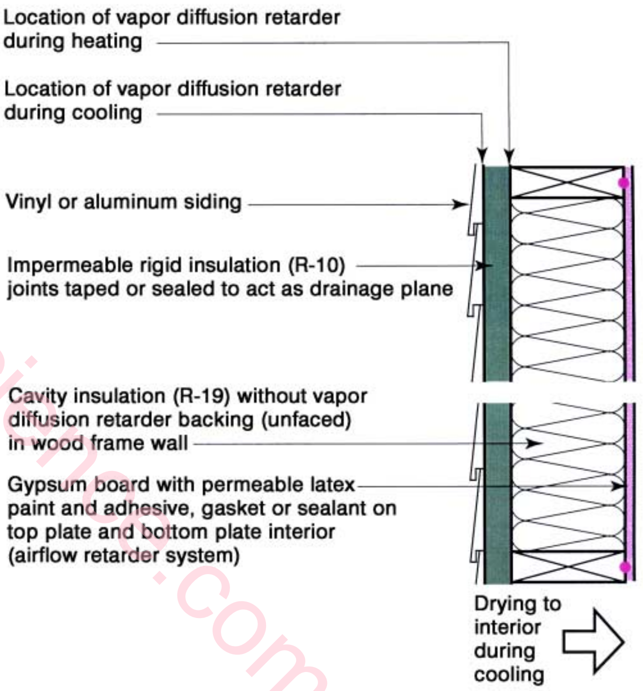
- Allow wet or moist materials used in construction to dry towards the outdoors.

Mixed-Climate Requirements

- Use a “flow-through” approach to vapor diffusion control.
- Where low permeance exterior sheathings are used, temperature of condensing surfaces under heating conditions should be controlled (use of insulating sheathings, external insulation) as well as interior vapor pressures.
- Provide air barrier systems that limit air movement from the interior.
- Provide air barrier systems that limit air movement from the exterior.
- During the coldest portion of the heating season, keep the indoor dew point below 40°F (4°C).
- During the cooling season, keep the indoor dew point below 55°F (13°C).

Hot, Humid Climate Requirements

- Pressurize conditioned and interstitial spaces with air dried below a dew point of 55°F (13°C).
- Locate vapor barriers toward the exterior of building assemblies. Avoid vapor barriers such as vinyl wall coverings toward the interior of building assemblies.



- Airflow retarder to the interior
- Permeable interior wall finish
- Interior conditioned space is maintained at a slight positive air pressure with respect to the exterior to limit the infiltration of exterior moisture-laden air during cooling
- Ventilation provides air change (dilution) and also limits the interior moisture levels during heating
- Air conditioning/dehumidification limits the interior moisture levels during cooling
- Impermeable exterior sheathing also acts as drainage plane

Figure 6: Vapor diffusion retarder in the middle of the wall.

- Provide air barrier systems that limit air infiltration and wind washing from the exterior.
- Provide adequate dehumidification capacity under part load conditions when sizing air-conditioning equipment.
- Dehumidify makeup air to a dew point of 55°F (13°C). before it is introduced.
- Keep the indoor dew point below 55°F (13°C).
- Insulate cold water piping and cold duct distribution systems.
- Do not overcool interior spaces.
- Design the exterior wall so that wet or moist materials used in construction can dry towards the interior.

Bibliography

Hutcheon, N.B. 1953. “Fundamental considerations in the design of exterior walls for buildings.” *Engineering Journal* 36(1):687–698.⬢