5.3.6.4 Condensation within walls and use of vapor retarders

Although condensation due to air movement is usually much greater than that due to vapor diffusion for most buildings, the contribution from water vapor diffusion can still be significant. In a well-designed building, the effects of air movement and water vapor diffusion in walls and roofs are considered.

Vapor retarders. Air barriers (also called air retarders) and vapor retarders (also called vapor barriers) are often confused. An air barrier is used to reduce the amount of infiltration (or leakage) or exfiltration of air into a conditioned space. A vapor retarder is used to prevent, or more correctly greatly reduce, water vapor (moisture) from moving through building materials. A vapor retarder can be used as an air barrier. An air barrier on the outside of a building in a cold climate generally needs to let moisture escape, so should not function as a vapor retarder. If the air barrier will also be serving as a vapor retarder, or if it has a low permeance to vapor diffusion, then its position within the building envelope must be carefully considered in relation to the other envelope components.

The principal function of a vapor retarder is to impede the passage of moisture as it diffuses through the assembly of materials in a building envelope, to control the location of the dew point in the assembly and to ensure there is a manageable flow of moisture across the assembly. The basic principles, simply stated are:

- Moisture migrates through building materials due to a difference in temperature or RH or both between the inside and outside.
- Sometimes this moisture migration will cause condensation. The correct type and placement of insulation and a vapor retarder will prevent condensation on cold portions within a wall.
- The vapor retarder or vapor retarding materials are generally placed on the side of the wall that is warm most of the year.
- If a vapor retarder with low permeance is selected, the materials on the opposite side should have higher permeance so the wall is able to dry to that side, if necessary.

These principles are covered in depth in the sections that follow.

Most codes and references consider a material or membrane with a permeance of 1 perm or less a vapor retarder; less than 0.1 perms is considered vapor impermeable and between 0.1 and 1 perm is considered semi-impermeable. Materials or membranes with a permeance greater than 10 are considered permeable. In the range of 1 to 10 perms, materials are considered semi-permeable.

Concrete as a vapor retarder. Normalweight, quality concrete can be considered a semi-impermeable vapor retarder in thicknesses of 3 in. or more. Published values of concrete permeability are approximately 3 perm·in., so that 3 in. of concrete has a permeance of approximately 1 perm, provided it remains relatively crack-free. Permeance is a function of the water-cement ratio of the concrete. A low water-cement ratio, such as that used in most precast concrete members, results in concrete with low permeance.

Where climatic conditions demand, insulation, sufficient concrete, or the addition of a vapor retarder is generally necessary in order to prevent condensation. Thicknesses of 1 in. or more of rigid extruded polystyrene board (XPS) or 2 to 3 in. of expanded polystyrene (EPS), if properly applied, will serve as its own vapor retarder. In such cases, for cold climates, the insulation can be installed on a complete bed of adhesive applied to the interior of the inner wythe of the wall with joints fully sealed with adhesive, to provide a complete barrier to both air and vapor movement.

Codes. The International Energy Conservation Code (IECC)[1] requires a vapor retarder with of 1 perm or less on the inside of insulation in cold climates. However it allows for an exception where moisture or its freezing will not damage the materials, or where other means are provided to prevent condensation. This requirement is workable for concrete since 3 in. of concrete has a perm of approximately 1 perm. The important concepts are whether condensation will occur and, if it does, will it damage the materials.

At present, the Massachusetts energy code is more restrictive that the IECC.[2] This code requires a vapor retarder of 0.1 perms on the indoor side of the insulation. Concrete wall systems can generally meet the code under the exceptions that require calculations because the condensing surface is the warm side of the insulation, and the temperature at that surface is kept above the dew point of the indoor air. This code also requires that the materials and finishes on the outdoor side of the insulation have permeances at least 10 times greater than that on the inside. This requirement is needed to allow the wall to dry to the outdoor side since the low permeance will not allow it to dry to the indoor side. Codes that have blanket requirements such as these for all wall systems may cause more moisture problems since low permeance materials sometimes prevent walls

1 International Energy Conservation Code (IECC), International Code Council, Inc., Country Club Hills, IL, www.ICCsafe.org

2 Massachusetts Energy Code. www.mass.gov/bbrs/780 CMR Chapter 13.pdf.

from drying.

Other materials. Building materials have water vapor permeances from very low to very high, see Table 5.3.13. Actual values for a given material vary depending on the moisture content of the material. Two commonly used test methods are the water method (wet cup) and desiccant method (dry cup) methods in ASTM E96, "Standard Test Methods for Water Vapor Transmission of Materials." Specimens are sealed over the tops of cups containing either water or desiccant, placed in a controlled atmosphere usually at 50% relative humidity, and weight changes measured. The change in weight represents the rate of moisture passing through the specimen.

When properly used, low permeance materials keep moisture from entering a wall assembly. Materials with higher permeance allow construction moisture and moisture which enters inadvertently, or by design, to escape.

When a material such as plaster or gypsum board has a permeance which is too high for the intended use, a vapor retarder can be used directly behind such products. Polyethylene sheet, aluminum foil and building paper with various coatings are commonly used. Proprietary vapor retarders, usually combinations of foil and polyethylene or asphalt, are frequently used in freezer and cold storage construction. When vapor retarders are added sheets or coatings, they should be clearly identified by the designer and be clearly identifiable by the general contractor.

Water vapor diffusion occurs when water vapor molecules diffuse through solid interior materials. The passage of water vapor through material is in itself generally not harmful. It becomes of consequence when, at some point along the vapor flow path, a temperature level is encountered that is below the dew-point temperature and condensate accumulates. The rate of vapor movement is dependent on the permeability of the materials, the vapor pressure, and temperature differentials. Generally, the greater the temperature difference between inside and outside and the more permeable the materials, the more vapor will travel through the wall. Vapor pressures increase with temperature even if the relative humidities stay the same. So, generally, the colder the outside temperature, the greater the pressure of the water vapor in the warm inside air compared to the cooler outside air. Water vapor pressures at saturation (100%RH) are provided in Table 5.3.14. Leakage of moist air through small cracks may be a greater problem than vapor diffusion.

Application. The location of the vapor retarder is dependent on the wall construction and climate. A solid precast concrete wall with appropriate joint sealant will act as a semi-impermeable vapor retarder in many climates. If a separate air barrier membrane is used, it should be clearly identified in the construction documents, preferably on the drawings. While a vapor retarder does not need to be perfectly continuous, care should be taken to minimize the occurrence of small discontinuities or imperfections such as unsealed laps, cuts, and pin holes. The vapor retarder in a wall system should be continuous from the floor to the underside of the ceiling slab to prevent moisture from bypassing the vapor retarder. Wall penetration such as outlets and window frames, should also be sealed.

Low-permeance paints, vinyl wall paper, or other similar materials that act as vapor retarders should not be placed on the interior surface of concrete walls. Since concrete acts also as a vapor retarder, an additional vapor retarder prevents moisture within the wall from evaporating.

Three common precast concrete systems and their applicability for use in various climate zones (see Fig. 5.3.19) are presented in Fig. 5.3.20. These walls allow concrete to dry without accumulating moisture within the wall. The traditional practice for frame walls of placing a vapor retarder behind gypsum wallboard in cold climates is *not* recommended for these walls. The recommendations were developed using typical indoor relative humidities during winter for all building types. Indoor relative humidities greater than these during December, January, and February have the potential to cause condensation within these or any wall/HVAC system not properly designed.

The three walls in Fig. 5.3.20 are insulated to meet the requirements of the 2004 International Energy Conservation Code (IECC).[3] The total wall including the concrete, insulation, and interior finishes are considered in the design of a wall with low potential for moisture problems. Providing insulation as required by codes such as ASHRAE 90.1 or the IECC generally provides cost effective levels of insulation for precast concrete walls. Insulation requirements are dependent on climate. The map in Fig. 5.3.19 is used to determine the climate zone number and letter required for determining compliance with the IECC. The amount of insulation required for the three walls is shown in Fig. 5.3.20. For international locations, Appendix B of ASHRAE 90.1-2004 provides tables with climate zone numbers and letters. This appendix also provides the climate zones in tabular form by U.S. county.

A precast concrete sandwich panel wall with concrete on both sides of rigid insulation, Fig. 5.3.20(a), is recommended for Climate Zones 1 through 7 (all except subarctic climates). Expanded polystyrene (EPS) or extruded expanded polystyrene insulation (XPS) may be used. The insulation board shown in the wall details is placed within the concrete during the precasting

3 International Energy Conservation Code (IECC), International Code Council, Inc., Country Club Hills, IL, www.ICCsafe.org

process prior to building construction. The overall thermal resistance of a sandwich panel is greater (more energy saving) if the ties connecting the concrete wythes are plastic, composite fiberglass or epoxy coated carbon grid rather than metal.

A precast concrete wall with continuous rigid insulation, Fig. 5.3.20(b), is recommended for Climate Zones 1 through 7 (all except subarctic climates). XPS insulation may be used in Climate Zones 1 through 7 and EPS insulation may be used in Climate Zones 1 through 5. The lower permeance of the XPS is recommended for the colder climates, Zones 6 and 7. The insulation board should be applied continuously and in direct contact with the precast concrete. This can be done using adhesive, stick pins, or mechanical fasteners.

Continuous insulation uninterrupted by metal framing is beneficial because metal framing reduces the effectiveness of fiberglass batt insulation and other insulation by more than half. For example, R13 insulation has an effective R-value of 6 when placed between steel frame members spaced 16 in. on center. The continuous insulation also reduces the potential for cold spots on the interior and exterior surfaces caused by metal framing. These can sometimes lead to condensation and shadowing or other unsightly moisture problems on the inside and outside surfaces of buildings. The potential for shadowing in a sandwich panel wall is less if the ties connecting the concrete wythes are plastic, fiberglass composite, or epoxy coated carbon grid rather than metal.

Wood and steel frame walls have cavities where moisture can accumulate, causing wood to rot and metal to corrode. The sandwich panel wall and concrete wall with rigid insulation have no wall cavities within the structural portion of the wall, thus reducing the possibility of unnoticed moisture accumulation and related damage. The only cavity is the air space between the insulation and gypsum wallboard, if wallboard is desired. This cavity is designed to keep the wallboard dry. XPS insulation is particularly moisture resistant and has low water absorption compared to other insulation materials while EPS has lower moisture absorption compared to non-foam insulation materials.

A precast concrete wall with batt insulation (and kraft paper where appropriate), Fig. 5.3.20(c), is recommended for Climate Zones 1 through 5. To prevent potential moisture accumulation within the wall and related problems, this type of wall construction is not recommended for the colder climates, Zones 6, 7, and 8. The fiberglass insulation is installed between metal framing. A 1-in. minimum air space is required between the batts and the concrete to prevent the potential for moisture to accumulate in the batt insulation. The air space between the metal framing and the precast concrete reduces the potential for cold spots on the interior and exterior surfaces caused by the framing. These can sometimes lead to condensation and shadowing or other unsightly moisture problems on the inside and outside surfaces of buildings. In Climate Zones 3A (above the warm humid line), 4, and 5, kraft-faced batts are required to prevent condensation within the walls during the winter.

The three walls in Fig. 5.3.20, with appropriate joint sealant, will act as semi-impermeable vapor retarders and allow concrete to dry without moisture accumulating within the walls. These constructions allow the outside layer of concrete to dry to the outside and the rest of the wall to dry to the inside. Latex paint with a permeance of 5 to 10 perms on the drywall is generally adequate. The sandwich panel wall and wall with rigid insulation are assumed to have $1^1/_2$ to 2 in. of insulation in Zone 4, 2 in. in Zone 5, 2 to $2^1/_2$ in. in Zone 6, and $2^1/_2$ to 3 in. in Zone 7. The wall with batt insulation is assumed to have R13 fiberglass batts.

The location of the cold surfaces within a wall depends on the climate. Moisture generally moves into wall systems from indoors when it is cold outside, and into wall systems from outdoors when it is warm outside. Actual water vapor and moisture-laden air movement depends on the temperature and relative humidity indoors and outdoors, the moisture content of the materials, and their absorption properties.

Cold Climates (Zones 5, 6, and 7). In these climates the vapor retarding surface should be applied on or near the warm side (inner surface) of assemblies. For the concrete sandwich panel wall, the insulation, inside concrete wythe and painted gypsum wallboard, if used, act as the semi-impermeable vapor retarder during the winter. For the precast concrete wall with rigid insulation, the insulation and painted gypsum wallboard on the inside act as a semi-permeable vapor retarder during the winter. For the precast concrete wall with batt insulation, the kraft paper and painted gypsum wallboard act as a semi-permeable vapor retarder during the winter. For all three walls, the exterior concrete wythe acts as a semi-impermeable vapor retarder during the summer. Providing an additional low permeance vapor retarder on the inside of the wall would create a "double vapor retarder" and prevent moisture that accumulates within the wall from leakage or condensation from drying to the inside. For this reason, a low permeance vapor retarder on the inside of this wall system is not recommended.

For the sandwich panel wall and the precast concrete wall with rigid insulation, the relative humidity of the indoor space in the coldest winter months is assumed to be not more than 25% in Zone 5, 20% in Zone 6, and 10% in Zone 7. For the precast concrete wall with batt insulation, the relative humidity of the indoor space in the coldest winter months is assumed to be not more than 25% in Zone 5. The recommendations were developed using these typical indoor relative humidities during winter. Indoor relative humidities greater than these during December, January, and February have the potential to cause condensation within these or any wall system not properly designed. Calculations may be required when exterior sheathing is used on the cold outdoor side since it may act as a vapor retarder on the cold side of the wall.

Fittings installed in outer walls, such as electrical boxes without holes and conduits, should be completely sealed against moisture and air passage, and they should be installed on the warm side insulation. Also, high thermal conductance paths such as at connections inward from or near the colder surfaces may cause condensation within the construction.

Warm Humid Climates (1A, 2A, 3A south of the humid line). In these climates, the exterior surface should have a lower vapor permeance than the interior surface. For all three walls, the exterior concrete acts as a semi-impermeable vapor retarder during the warm humid months. For the concrete sandwich panel wall, the inside concrete wythe and painted gypsum wallboard, if used, act as the semi-permeable vapor retarder during the cool months. For the precast concrete wall with rigid insulation, the insulation and painted gypsum wallboard on the inside act as a semi-permeable vapor retarder during the cool months. For the precast concrete wall with batt insulation, the painted gypsum wallboard acts as a semi-permeable vapor retarder during the cool months. Low permeance paints, vinyl wallpaper, or other materials that act as vapor retarders should not be placed on the interior surface of the wall. Moisture from outdoors often accumulates behind these materials when used in these climates. Kraft paper is not recommended on the insulation in these climates because it also prevents the wall from drying.

In warm humid climates during rainy periods, exterior walls can absorb large quantities of moisture that are later driven inward by warm temperatures and solar effects. The concrete and rigid insulation (where provided) each have a moderately low permeance that helps prevent this moisture from moving inward. Some exterior paints and finishes can also provide an adequate level of resistance to moisture intrusion. The concrete and rigid insulation should be continuous and sealed to prevent the moisture from moving inward.

The operation of the cooling system is more important in warm and humid climates than any other climate. Since the latent load (that required to remove moisture) is often greater than the sensible load (that required to bring down the temperature), the system needs to be designed to remove the latent load without cycling off because it has reached the desired temperature set point. Oversized air-conditioners may cycle off before the latent load is removed. Setting the chilled water supply temperature too high will have the same effect of not being able to remove the latent load. Also, many people erroneously think that setting the thermostat lower will remove moisture problems. Low thermostat settings on hot humid days has the opposite effect; they make surfaces colder and more prone to condensation.

Warm Dry, Mixed, and Marine Climates (1B, 2B, 3A north of the humid line, 3B, 3C, 4). The need for vapor retarders and low permeance materials is less in these climates than in cold or warm humid climates. Condensation can occur by the mechanisms discussed for cold climates, but the duration of these conditions is usually short enough that the materials subsequently dry without problems if surfaces are semi-permeable or semi-impermeable. The strategy for these climates is to allow the wall system to dry either to the outside or inside, or preferably, to both sides, since more damage is caused by improperly placed vapor retarders than by omitting one. The three precast concrete walls allow this drying to either side. The exterior concrete wythe acts as a semi-impermeable vapor retarder during the warm months. For the concrete sandwich panel wall, the inside concrete wythe and painted gypsum wallboard, if used, act as the semi-permeable vapor retarder during the cool months. For the precast concrete wall with rigid insulation, the insulation and painted gypsum wallboard on the inside act as a semi-permeable vapor retarder during the cool months. For the precast concrete wall with batt insulation, the painted gypsum wallboard acts as a semi-permeable vapor retarder during the cool months.

For the sandwich panel wall and the precast concrete wall with XPS insulation, the relative humidity of the indoor space in the coldest winter months is assumed to be not more than 40% in Zone 4. For the precast concrete wall with EPS insulation, the relative humidity of the indoor space in the coldest winter months is assumed to be not more than 30% in Zones 4A and 4B and 35% in Zone 4C. For the precast concrete wall with batt insulation, the relative humidity of the indoor space in the coldest winter months is assumed to be not more than 30% in Zone 4A and 35% in Zones 4B and 4C. The recommendations were developed using these typical indoor relative humidities during winter. Indoor relative humidities greater than these during December, January, and February have the potential to cause condensation within these or any wall system not properly designed.

These recommendations are for general use under normal building operating conditions.

Table 5.3.13 Typical Permeance (M) and Permeability (μ) Values[1].

Material	M Perms	μ Perm-in.
Concrete (1:2:4 mixture)[2]	—	3.2
Wood (sugar pine)	—	0.4 – 5.4
Extruded polystyrene (XPS)		1.2
Expanded polystyrene, bead (EPS)	—	2.0 – 5.8
Polyisocyanurate	—	4.0 – 6.6
Polyicynene		50
Glass fiber batt		120
Kraft paper	1	
Plaster on gypsum lath (with studs)	20	
Gypsum wallboard, 0.375 in.	50	
Polyethylene, 2 mil	0.16	
Polyethylene, 4 mil	0.08	
Polyethylene, 6 mil	0.06	
Aluminum foil, 0.35 mil	0.05	
Aluminum foil, 1 mil	0.00	
Built-up roofing (hot mopped)	0.00	
Duplex sheet, asphalt laminated, aluminum foil one side	0.0023	
Paint 1 coat primer plus 2 coats latex on gypsum wallboard	3 to 20	
1 coat primer plus 2 coats acrylic on gypsum wallboard	7	
1 coat primer plus 2 coats synthetic on gypsum wallboard	3	
1 coat primer plus 2 coats oil on gypsum wallboard	5	
2 coats asphalt paint on plywood	0.4 [3]	
2 coats enamel on smooth plaster	0.5 – 1.5	
Various primers plus 1 coat flat oil paint on plaster	1.6 – 3.0	
Breather type membrane	3 – 25	

1 *ASHRAE Handbook of Fundamentals and other sources*. Values vary depending on the moisture content of the material.

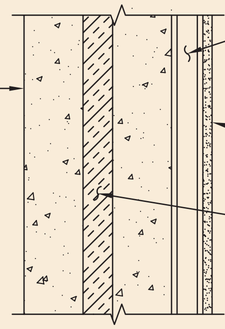
2 Permeances for concrete vary on the concrete's water-cement ratio and other factors.

3 Dry-cup (ASTM E 96).

Table 5.3.14 Water Vapor Pressures at Saturation (SVP) for Various Temperatures.

Temp., °F	SVP, in. Hg	Temp., °F	SVP, in. Hg	Temp., °F	SVP, in. Hg	Temp., °F	SVP, In. Hg
-30	0.007	17	0.089	38	0.229	59	0.504
-20	0.013	18	0.093	39	0.238	60	0.522
-10	0.022	19	0.098	40	0.248	61	0.541
-5	0.029	20	0.103	41	0.258	62	0.560
0	0.038	21	0.108	42	0.268	63	0.580
1	0.040	22	0.113	43	0.278	64	0.601
2	0.042	23	0.118	44	0.289	65	0.622
3	0.044	24	0.124	45	0.300	66	0.644
4	0.046	25	0.130	46	0.312	67	0.667
5	0.049	26	0.136	47	0.324	68	0.691
6	0.051	27	0.143	48	0.336	69	0.715
7	0.054	28	0.150	49	0.349	70	0.739
8	0.057	29	0.157	50	0.363	71	0.765
9	0.060	30	0.164	51	0.376	72	0.791
10	0.063	31	0.172	52	0.391	73	0.819
11	0.066	32	0.180	53	0.405	74	0.847
12	0.069	33	0.188	54	0.420	75	0.875
13	0.073	34	0.195	55	0.436	76	0.905
14	0.077	35	0.203	56	0.452	77	0.935
15	0.081	36	0.212	57	0.469	78	0.967
16	0.085	37	0.220	58	0.486	79	0.999
						80	1.032

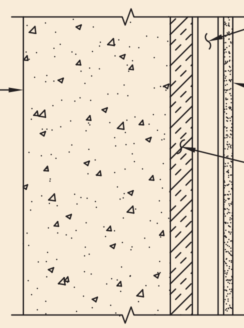
Note: 1 in. Hg = 0.491 psi. Actual vapor pressure = SVP x (%RH).



"A" Precast Sandwich Panel Wall
Not to scale

Extruded or Expanded Polystyrene Insulation, Continous

IECC Zone	Min. R-Value of Added Insulation
1, 2	None
3B	None
3A (Below "Warm Humid Line")	None
3A (Above "Warm Humid Line")	R7.5
3C, 4A, 4B	R7.5
4C, 5, 6	R10
7	R12.5

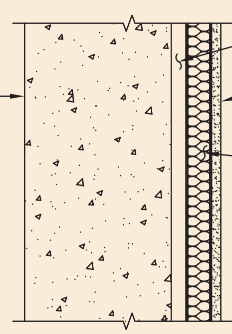


"B" Precast Concrete with Rigid Insulation
Not to scale

Extruded or Expanded Polystyrene Insulation*, Continous and Taped at Joints

IECC Zone	Min. R-Value of Added Insulation
1, 2	None
3B	None
3A (Below "Warm Humid Line")	None
3A (Above "Warm Humid Line")	R7.5
3C, 4A, 4B	R7.5
4C, 5, 6	R10
7	R12.5

*Expanded polystyrene insulation acceptable in climate zones 1-5



"C" Precast Concrete with Batt Insulation
Not to scale

Batt Insulation with Kraft Paper on Inside Face, in Zones 3, 4 and 5, in Metal Frame

IECC Zone	Min. R-Value of Added Insulation
1*, 2*	None
3B*	None
3A* (Below "Warm Humid Line")	None
3A (Above "Warm Humid Line")	R13
3C*, 4, 5	R13

*If insulation is used, kraft paper not recommended.
Only applicable for IECC zones 1-5

Fig. 5.3.20 Typical wall details.