CITY OF BELLAIRE TEXAS

MAYOR AND COUNCIL

JULY 21, 2014

Council Chamber	**Joint Workshop Session**	**6:00 PM**

7008 S. RICE AVENUE
BELLAIRE, TX 77401

Mayor

Dr. Philip L. Nauert

Mayor Pro Tem	**Councilman**	**Councilman**
Amanda B. Nathan	James P. Avioli Sr.	Pat B. McLaughlan
Councilman	**Councilman**	**Councilman**
Roman F. Reed	Gus E. Pappas	Andrew S. Friedberg

Mission Statement:
The City of Bellaire is dedicated to outstanding quality service and facilities to ensure an open, progressive, and secure community.

JOINT WORKSHOP SESSION - BELLAIRE CITY COUNCIL AND BELLAIRE BUILDING AND STANDARDS COMMISSION - 6:00 P.M.

A. Call to Order and Announcement of a Quorum of Members of City Council - Dr. Philip L. Nauert, Mayor.

B. Call to Order and Announcement of a Quorum of Members of the Building and Standards Commission - Kristin Schuster, Chair.

C. Code Amendment to Chapter 9, Buildings, of the Code of Ordinances of the City of Bellaire, Texas:

Discussion regarding a report and recommendation from the Building and Standards Commission of the City of Bellaire, Texas, related to the installation of a water vapor control barrier in residential crawlspace construction in preparation of an amendment to the applicable article(s) and section(s) in Chapter 9, Buildings, of the Code of Ordinances of the City of Bellaire, Texas.

(Requested by John McDonald, Community Development)

D. Adjournment of City Council - Dr. Philip L. Nauert, Mayor.

E. Adjournment of Building and Standards Commission - Kristin Schuster, Chair.

Mayor and Council
7008 S. Rice Avenue
Bellaire, TX 77401

SCHEDULED
ACTION ITEM (ID # 1293)

Meeting: 07/21/14 06:00 PM
Department: Community Development
Category: Discussion
Department Head: John McDonald
DOC ID: 1293

Item Title:

Discussion regarding a report and recommendation from the Building and Standards Commission of the City of Bellaire, Texas, related to the installation of a water vapor control barrier in residential crawlspace construction in preparation of an amendment to the applicable article(s) and section(s) in Chapter 9, Buildings, of the Code of Ordinances of the City of Bellaire, Texas.

Background/Summary:

On June 2, 2014, the Building and Standards Commission presented a report and recommendation to the City Council addressing the installation of water vapor control barriers in residential crawlspace construction. Their report included a proposed amendment to the *Code of Ordinances, Chapter 9, Buildings*, which would require the application of an air and vapor retardant as a local amendment to the 2012 International Residential Code. A local amendment is change to the building codes adopted by a local jurisdiction that applies only within that jurisdiction's boundaries.

At the conclusion of the presentation and after some dialogue between members of Council and members of the BSC, Council moved to schedule a workshop to allow for a fuller discussion of the subject matter. This workshop is scheduled for 6:00 P.M. on Monday, prior to the regular Council meeting.

During their presentation to Council on June 2, the BSC modified their recommendation from the one that was submitted for inclusion in the Council packets. The Commission subsequently amended their initial recommendation to bring it in line with the one presented. The updated report along with the original attachments is included in your packet.

The BSC Chairman has also asked that additional materials be included in this packet (last 3 attachments).

ATTACHMENTS:

- BSC Updated Report 20June2014 (PDF)
- BSC Appendix I (PDF)
- BSC Appendix II (PDF)
- BSC Appendix III (PDF)
- Insulations, Sheathings, and Vapor Retarders J. Lsitburek Nov 2004 (PDF)
- High-Performance Wall Assemblies Handouts (PDF)
- BSI-009_Crawlspace_2010r2 Article (PDF)
- Location of vapor retarder (PDF)

City of Bellaire Building and Standards Commission

Final Report to City Council regarding a recommendation for water vapor control in crawlspace construction

Introduction

This report and recommendation have developed over the course of nine months of work by the Building and Standards Commission of the City of Bellaire. During this time period 12 meetings and workshops were held to discuss the topic, including a workshop with local builders to collect information and feedback.

The intent of this recommendation by the Building and Standards Commission is to prevent mold, mildew and wood rot caused by the trapping of excessive moisture that has condensed out of hot humid air onto wood within the crawlspaces of homes in Bellaire. After significant study, the Commission recognizes that such problems may be exacerbated as the energy efficiency measures mandated by the 2012 IECC/IRC are implemented in our community.

The International Energy Conservation Code (IECC) and International Residential Code (IRC) are model codes ratified by the City of Bellaire to govern construction within the City of Bellaire. In September of 2013 the city ratified the 2012 edition of these codes, moving from the 2009 version previously ratified.

Recommendation

The Building and Standards Commission of the City of Bellaire respectfully recommends that City Council direct City Staff to work with the Commission to develop a revision to the City of Bellaire Code of Ordinances, Chapter 9, Buildings, Article II, Building Codes, Division I, Generally, Section 9.17, Amendments to the Building Code for the purpose of mandating the installation of a vapor retarder over all surfaces of the insulation facing the crawlspace in all new residential construction, and to develop a process for verifying compliance with this requirement.

Refer to **Exhibit I** for suggested language, provided by the Commission for the consideration of City Staff and City Attorneys in drafting a revision to the City Code of Ordinances, for a future recommendation to City Council.

Water vapor control in crawlspace construction

The energy efficiency measures in the recently ratified 2012 IRC and IECC, which mandate Air Barrier and Insulation requirements, will result in new houses that are built to be significantly more air-tight than homes built in previous years. With minimal air leaks in the building envelope, the HVAC (Heating, Ventilation and Air Conditioning) system will be more effective at removing humidity from the air inside of the house. As a result, the moisture in the warm humid air in the crawl space will want to migrate to the dryer environment created inside the house, in an effort to equalize vapor pressure. This is known as vapor drive. While the 2012 codes address Air Barrier (air-tightness) and Insulation (heat transfer) requirements, vapor drive through the crawlspace is not addressed.

Vapor will move from an area of high vapor pressure to low vapor pressure along the path of least resistance. The codes mandate the installation of a vapor retarder in exterior wall assemblies, but not in the floor assembly above the crawlspace. As a result, vapor will migrate through this unprotected floor assembly. In summer conditions the floor assembly will be kept cool by the AC, and when moisture begins to migrate into the dry environment inside the house it will form condensation on the floor joists. The relatively limited air circulation in the crawl space area allows the condensation to linger, which can lead to mold, mildew and wood rot. Installing a vapor retarder in the appropriate place within the floor assembly (as is required within exterior wall assemblies) will slow the rate of vapor transfer and will reduce the amount of condensation being formed to an amount that can be drawn out through evaporation.

Increasingly stringent energy codes, the hot-humid climate and flood management practices particular to Bellaire come together to set Bellaire homes up for future moisture and mold issues. This is a problem that develops over time. The decision whether or not to install a vapor retarder in the floor assembly above the crawlspace should not be left up to the builder or even the first home owner because a problem may not be recognized for many years. The burden may only fall on future owners of the building.

It is the responsibility of local jurisdictions to modify Model Codes to local conditions.

Confluence of factors in Bellaire

Energy Code Requirements: The state of Texas mandates energy code requirements and sets minimum energy efficiency standards in construction. These requirements are becoming more stringent with each update of the code. Increasing energy efficiency standards are driving rapid changes in construction practices. Per the recently ratified 2012 IECC and IRC, houses must be visually inspected and tested for air-tightness. Air leakage now must not exceed 5 air changes per hour (ACH). This is a significant decrease from the 7 ACH allowed under the 2009 codes, and an increase in the verification requirements.

Refer to **Appendix I** "Building Technologies Program Air Leakage Guide" by the United States Department of Energy for information about the Air Leakage and Insulation requirements in the 2012 IECC and IRC, including a description of the blower door test.

Specific Climate Conditions: Humidity and heat are the primary climate specific factors affecting energy efficiency in buildings. Here in Bellaire, our hot/humid climate puts significant demand on building systems relative to other parts of the country. Publishers of models codes are challenged with developing standards that can address and be adapted to multiple climate zones across the country. Building and Standards Commission's recommendation is intended to tailor the code requirements to Bellaire's specific climate conditions by mandating certain additional measurements.

Refer to **Appendix II** "Insulating Raised Floors in Hot Humid Climates" by the Louisiana State University Agricultural Center for information and empirical data about crawlspace insulation and moisture management practicies in hot/humid climates.

Flood management: The Federal Emergency Management Agency (FEMA) requires the finished floor of a newly constructed or substantially remodeled structure located in the flood plain to be at or above base flood elevation (BFE). The City of Bellaire goes beyond this and requires the finished floor to be a minimum of 1' above BFE. This additional local requirement contributes to a flood insurance rate reduction all Bellaire homeowners receive through the NFIP's Community Rating System.

The city of Bellaire has adopted a 'no net-fill' ordinance in order to prevent overall fill in floodplain, and to prevent conveyance of water in neighboring properties. Bellaire does not allow lots to be filled with dirt to raise the finished floor. As a result, most homes must be built with a crawl space in order to raise the floor to an adequate height.

The preferred method nation-wide for controlling air and moisture in a crawlspace is to seal it entirely at the dirt and all walls. If a home is built in the 100 year flood plain however, crawlspaces are required to be vented for flood waters. Because the majority of Bellaire is within the flood plain, sealed crawlspaces are not a viable option in the majority of our city.

Refer to **Appendix III** for sections of the City of Bellaire Code of Ordinances pertaining to flood hazard mitigation and residential drainage requirements.

Summary

Current building science indicates that inaction by the City of Bellaire on the matter of water vapor control in crawlspace construction has the potential to set Bellaire homeowners up for long term problems in the future due to the confluence of code factors, climate conditions and flood control requirements. While there are Bellaire homeowners who have encountered mold in the crawlspace and deteriorated framing, City Staff has heard few complaints. The Building and Standards Commission recognizes that such problems may be exacerbated as energy efficiency requirements continue to increase, and cautions that a lack of reporting does not mean problems are not occurring. Crawlspace moisture problems are hidden conditions. They may exist undiscovered until a homeowner uncovers them in the course of some other investigation or there is a building system failure.

The proposed requirement for a vapor retarder sets performance criteria only. It does not mandate the use of specific building products or systems. There are in multiple low-cost ways builders can comply with the requirement if they are not already doing so. Many of the established builders in Bellaire recognize the need for water vapor control in crawlspace construction and already use construction methods that would meet the requirements of an ordinance change in keeping with the Commission's recommendation. The Building and Standards Commission found this to be the case while conducting interviews with local builders during a Workshop Session held in Council Chambers in August of 2013. The intent of the Commission's recommendation is to protect residents of homes constructed by builders who are not currently meeting the proposed standard.

The requirement of a vapor retarder in the crawlspace will raise the minimum quality of construction in the City of Bellaire and in turn contribute to the reputation of our city as a premier community in which to build and live.

Exhibit I

Building and Standards Commission suggest the following language, for the consideration of City Staff and the City Attorney in developing a revision to the City of Bellaire Code of Ordinances, Chapter 9, Buildings, Article II, Building Codes, Division I, Generally, Section 9.17, Amendments to the Building Code.

Crawl Space Air Barrier, Insulation and Moisture Control

In addition to the requirements of Sections R402.1 and R402.2 of the 2012 IECC, an air barrier and Class III Vapor Retarder shall be applied over all surfaces of the insulation facing the crawlspace, if the insulation does not effectively provide the same. No Class I or Class II Vapor Retarders shall be applied over the interior surface of the floor assembly above a crawlspace, except at shower pans and areas intended to hold water.

U.S. DEPARTMENT OF ENERGY
Energy Efficiency & Renewable Energy

BUILDING TECHNOLOGIES PROGRAM

Air Leakage GUIDE

Building Energy Codes

Meeting the Air Leakage Requirements of the 2012 IECC

The U.S. Department of Energy (DOE) recognizes the enormous potential that exists for improving the energy efficiency, safety and comfort of homes. The newest edition of the International Energy Conservation Code® (IECC) (2012) sets the bar higher for energy efficiency, and new air sealing requirements are one of the key new provisions.

This guide is a resource for understanding the new air leakage requirements in the 2012 IECC and suggestions on how these new measures can be met. It also provides information from Building America's Air Sealing Guide, Best Practices and case studies on homes that are currently meeting the provisions. The 2012 IECC and a few International Residential Code (IRC) requirements are referenced throughout the guide.

Building Energy Code Resource Guide:

Air Leakage Guide

PREPARED BY

Building Energy Codes

DOE's Building Energy Codes Program (BECP) is an information resource on national energy codes. BECP works with other government agencies, state and local jurisdictions, national code organizations, and industry to promote stronger building energy codes and help states adopt, implement, and enforce those codes.

September 2011

Prepared for the U.S. Department of Energy under Contract DE-AC05-76RLO 1830

PNNL-SA-82900

WHAT'S INSIDE

1 INTRODUCTION: Basics of Air Leakage

Air leakage control is an important but commonly misunderstood component of the energy efficient house. Tightening the structure with caulking and sealants has several positive impacts.

A tight house will:

- Have lower heating bills due to less heat loss
- Have fewer drafts and be more comfortable
- Reduce the chance of mold and rot because moisture is less likely to enter and become trapped in cavities
- Have a better performing ventilation system
- Potentially require smaller heating and cooling equipment capacities.

Air leakage is sometimes called infiltration, which is the unintentional or accidental introduction of outside air into a building, typically through cracks in the building envelope and through use of doors for passage. In the summer, infiltration can bring humid outdoor air into the building. Whenever there is infiltration, there is corresponding exfiltration elsewhere in the building. In the winter, this can result in warm, moist indoor air moving into cold envelope cavities. In either case, condensation can occur in the structure, resulting in mold or rot. Infiltration is caused by wind, stack effect, and mechanical equipment in the building (see Figure 1).

Wind creates a positive pressure on the windward face and negative pressure on the non-windward (leeward) facing walls, which pulls the air out of the building. Wind causes infiltration on one side of a building and exfiltration on the other. Wind effects can vary by surrounding terrain, shrubs, and trees.

The "stack effect" is when warm air moves upward in a building. This happens in summer and winter, but is most pronounced in the winter because indoor-outdoor temperature differences are the greatest. Warm air rises because it's lighter than cold air. So when indoor air is warmer than the outdoor air, it escapes out of the upper levels of the building, through open windows, ventilation openings, or penetrations and cracks in the building envelope. The rising warm air reduces the pressure in the base of the building, forcing cold air to infiltrate through open doors, windows, or other openings. The stack effect basically causes air infiltration on the lower portion of a building and exfiltration on the upper part.

Mechanical equipment such as fans and blowers causes the movement of air within buildings and through enclosures, which can generate pressure differences. If more air is exhausted from a building than is supplied, a net negative pressure is generated, which can induce unwanted airflow through the building envelope.

Bathroom exhaust fans, clothes dryers, built-in vacuum cleaners, dust collection systems, and range hoods all exhaust air from a building. This creates a negative pressure inside the building. If the enclosure is airtight or the exhaust flow rate high, large negative pressures can be generated.

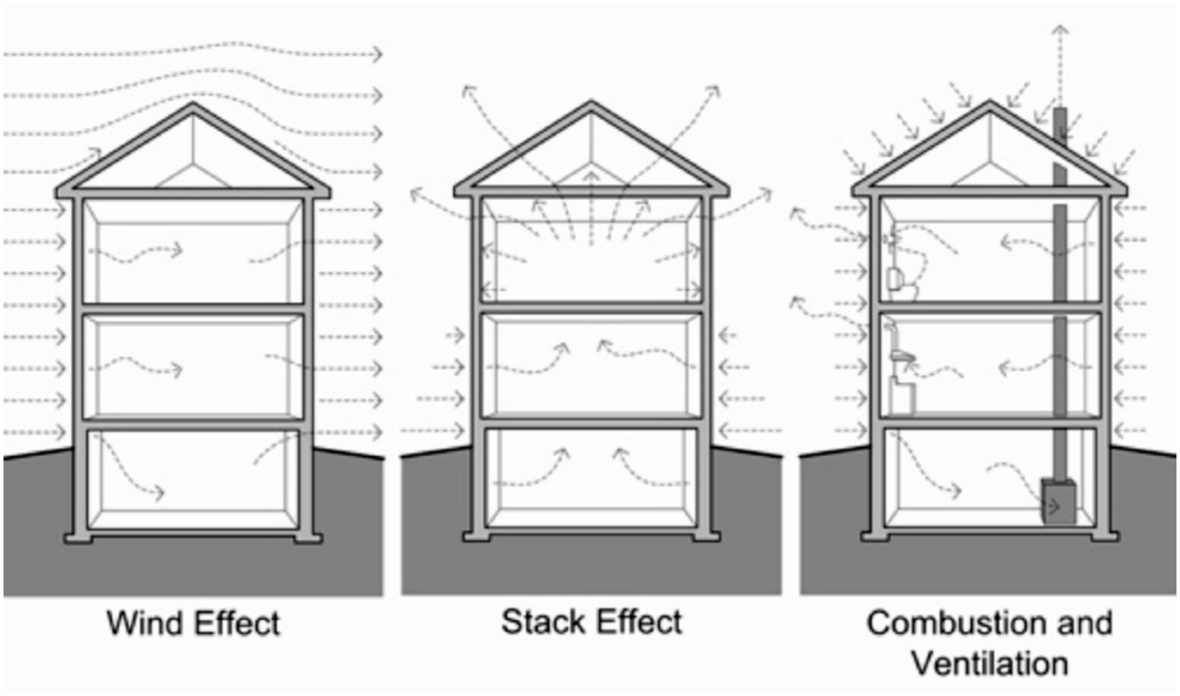


Figure 1: Examples of infiltration. Image courtesy: Building Science Corporation, www.buildingscience.com

2 CODES: New Code Air Leakage Requirements

The 2012 IECC has several new requirements for verification of air sealing in new construction and additions. **These new requirements apply to new construction, additions, and alterations where adopted by states and local jurisdictions.** Furthermore, additional language was added to clarify that where there are conflicts or differences between provisions of the IECC and referenced codes, the IECC provisions must apply (Section R106, 2012 IECC).

For more information on the status of state code adoption, visit **http://www.energycodes.gov/states/**

R106.1.2 Provisions in Referenced Codes and Standards

Where the extent of the reference to a referenced code or standard includes subject matter that is within the scope of this code, the provisions of this code, as applicable, shall take precedence over the provisions in the referenced code or standard.

Sealing the building thermal envelope has been required by the energy code for many years (editions of the IECC). However, in years past the provisions were somewhat vague and only required that areas of potential air leakage such as joints, seams, and utility penetrations be sealed with a durable material such as caulking, gasketing, or weather stripping. The 2009 IECC required verification of air sealing by either a visual inspection against a detailed checklist or a whole-house pressure test. The 2012 IECC ***NOW*** requires all new construction and additions be both visually inspected and pressure tested as mandatory requirements. There have been some slight changes to the visual inspection checklist and ratcheting down of the testing parameters, requiring houses to be much tighter than the previous edition of the code (see Figure 2 and Table 1).

DEFINITIONS

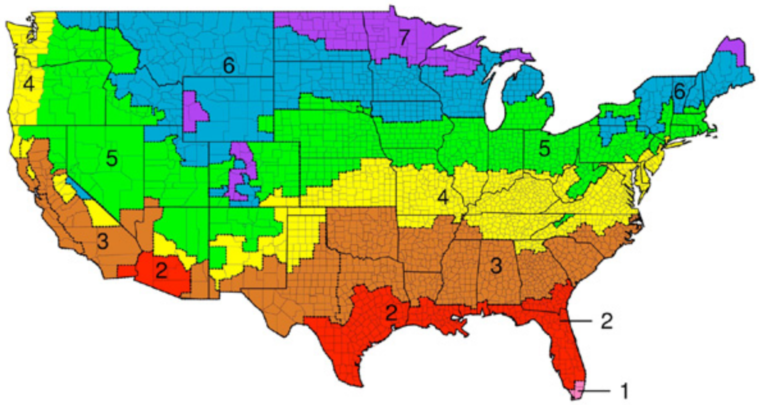
As defined according to 2012 IECC:

BUILDING

Any structure used or intended for supporting or sheltering any use or occupancy, including any mechanical systems, service water heating systems and electric power and lighting systems located on the building site and supporting the building.

BUILDING THERMAL ENVELOPE

The basement walls, exterior walls, floor, roof, and any other building elements that enclose *conditioned space* or provide a boundary between *conditioned space* and exempt or unconditioned space.



All of Alaska in Zone 7
except for the following buroughs in Zone 8:

- Bethel
- Dellingham
- Fairbanks N.Star
- Nome
- North Slope
- Northwest Arctic
- Southeast Fairbanks
- Wade Hampton
- Yukon-Koyukuk

Zone 1 includes:

- Hawaii
- Guam
- Puerto Rico
- Virgin Islands

Figure 2: Climate zones (by county) for the 2012 IECC

Climate Zone	2009 IECC	2012 IECC
1 - 2	< 7 ACH	≤ 5 ACH @ 50 pascals
3 - 8	< 7 ACH @ 50 pascals	≤ 3 ACH @ 50 pascals

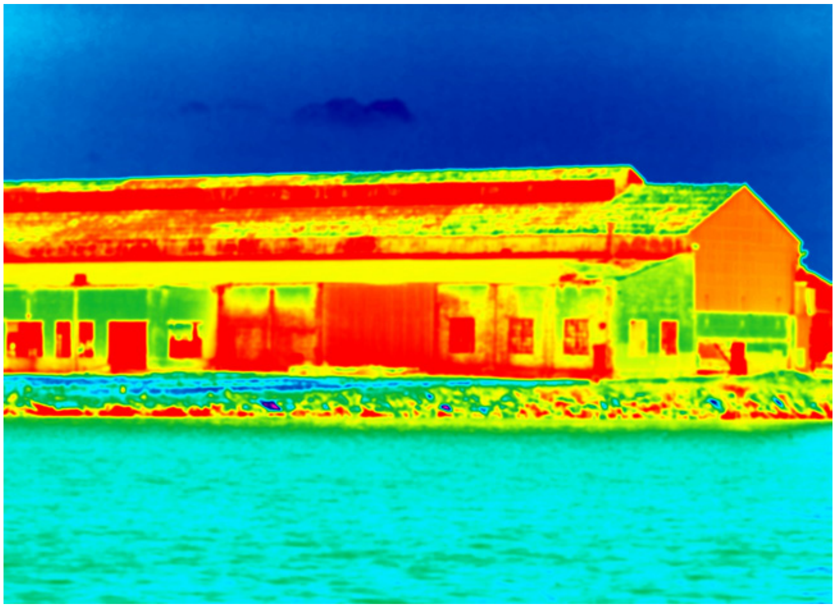
Table 1: 2009 vs. 2012 IECC Comparisons

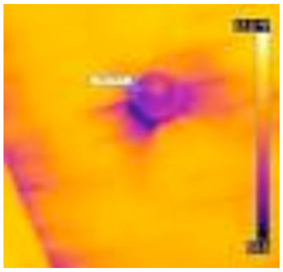
R402.4 Air leakage (Mandatory)

The building thermal envelope shall be constructed to limit air leakage in accordance with the requirements of Sections R402.4.1 through R402.4.4.

3 PLANNING: Air Sealing Measures and Checklists

The 2012 IECC provides a comprehensive list of components that must be sealed and inspected. However, unless the components are installed properly, passing the inspection and meeting the tested air leakage rate requirements may not be achievable without rebuilding some construction assemblies (such as gypsum board) that were previously installed. A good example is the air barrier between the ceiling (unconditioned attic) and conditioned space (living area). Since air leakage paths are driven by the fact that warm air rises, the attic is the largest area (square footage) of potential heat loss. Areas in the ceiling that might not have been sealed properly could include recessed cans, wires, pipes, attic access panels, drop down stair or knee wall doors and more. Figure 3 is a picture taken with an infrared camera illustrating where the temperature difference is and potential heat loss. The reds and purples indicate higher heat loss areas.





Recessed Can

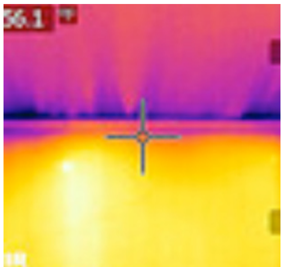


Figure 3: Air Leakage Test Results

Ceiling Plane

DEFINITIONS

As defined according to 2012 IECC:

AIR BARRIER

Material(s) assembled and joined together to provide a barrier to air leakage through the building envelope. An air barrier may be a single material or combination of materials.

CONTINUOUS AIR BARRIER

A combination of materials and assemblies that restrict or prevent the passage of air through the building thermal envelope.

R402.4.1.1 Installation

The components of the building thermal envelope as listed in Table R402.4.1.1 shall be installed in accordance with the manufacturer's instructions and the criteria listed in Table R402.4.1.1, as applicable to the method of construction. Where required by the code official an approved third party shall inspect all components and verify compliance.

The IECC's checklist covers not only air barriers but proper installation of insulation and other elements. **In Table 402.4.1.1, items that are directly related to air leakage and proper air barriers are highlighted in yellow.**

Even though the IECC checklist lists 14 specific components that are directly related to air barriers, more attention must be focused on all areas that have potential for air leakage. A good understanding of building science can facilitate proper air sealing. For example, Building America research identifies 19 key areas where air sealing can improve a home's energy efficiency, comfort, and building durability.

Common air sealing trouble spots are shown in Figure 4 on page 8 and listed in the following table. Several of these trouble spots are described in more detail as highlighted in the Building America Air Sealing Checklist.

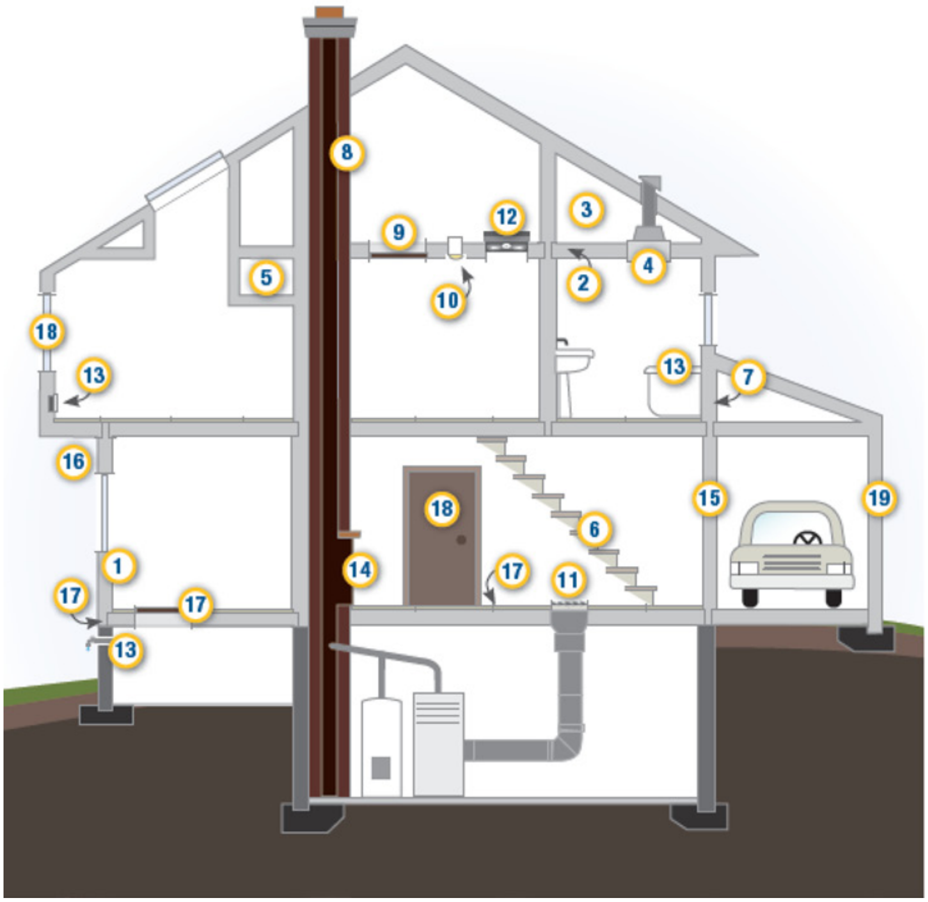
Additional information on other trouble spots and other building science information can be found in the Building America Best Practices guides and Air Leakage guide available for free download at **www.buildingamerica.gov**.

Builders, contractors, and/or designers should develop an air sealing strategy beginning with reviewing the building plans and identifying potential areas of air leakage. These checklists can be used to help identify the areas. The strategy also needs to include the types of materials that will be used to create an air barrier and seal the building envelope. The IECC does not identify specific products that must be used to create air barriers and seal the building envelope, but does require that the materials allow for expansion and contraction.

Table R402.4.1.1 (2012 IECC). Air Barrier and Insulation Installation*

COMPONENT	CRITERIA*
Air barrier and thermal barrier	A continuous air barrier shall be installed in the building envelope. Exterior thermal envelope contains a continuous air barrier. Breaks or joints in the air barrier shall be sealed. Air-permeable insulation shall not be used as a sealing material.
Ceiling/attic	The air barrier in any dropped ceiling/soffit shall be aligned with the insulation and any gaps in the air barrier sealed. Access openings, drop down stair or knee wall doors to unconditioned attic spaces shall be sealed.
Walls	Corners and headers shall be insulated and the junction of the foundation and sill plate shall be sealed. The junction of the top plate and top of exterior walls shall be sealed. Exterior thermal envelope insulation for framed walls shall be installed in substantial contact and continuous alignment with the air barrier. Knee walls shall be sealed.
Windows, skylights and doors	The space between window/door jambs and framing and skylights and framing shall be sealed.
Rim joists	Rim joists shall be insulated and include the air barrier.
Floors (including above-garage and cantilevered floors)	Insulation shall be installed to maintain permanent contact with underside of subfloor decking. The air barrier shall be installed at any exposed edge of insulation.
Crawl space walls	Where provided in lieu of floor insulation, insulation shall be permanently attached to the crawl space walls. Exposed earth in unvented crawl spaces shall be covered with a Class I vapor retarder with overlapping joints taped.
Shafts, penetration	Duct shafts, utility penetrations and flue shafts opening to exterior or unconditioned space shall be sealed.
Narrow cavities	Batts in narrow cavities shall be cut to fit, or narrow cavities shall be filled by insulation that on installation readily conforms to the available cavity space.
Garage separation	Air sealing shall be provided between the garage and conditioned spaces.
Recessed lighting	Recessed light fixtures installed in the building thermal envelope shall be air tight, IC rated, and sealed to the drywall.
Plumbing and wiring	Batt insulation shall be cut neatly to fit around wiring and plumbing in exterior walls, or insulation that on installation readily conforms to available space shall extend behind piping and wiring.
Shower/tub on exterior wall	Exterior walls adjacent to showers and tubs shall be insulated and the air barrier installed separating them from the showers and tubs.
Electrical/phone box on exterior walls	The air barrier shall be installed behind electrical or communication boxes or air sealed boxes shall be installed.
HVAC register boots	HVAC register boots that penetrate building thermal envelope shall be sealed to the subfloor or drywall.
Fireplace	An air barrier shall be installed on fireplace walls. Fireplaces shall have gasketed doors.

*In addition, inspection of log walls shall be in accordance with the provisions of ICC-400.



Air Sealing Trouble Spots

1. Air Barrier and Thermal Barrier Alignment
2. Attic Air Sealing
3. Attic Kneewalls
4. Shaft for Piping or Ducts
5. Dropped Ceiling/Soffit
6. Staircase Framing at Exterior Wall
7. Porch Roof
8. Flue or Chimney Shaft
9. Attic Access
10. Recessed Lighting
11. Ducts
12. Whole-House Fan
13. Exterior Wall Penetrations
14. Fireplace Wall
15. Garage/Living Space Walls
16. Cantilevered Floor
17. Rim Joists, Sill Plate, Foundation, Floor
18. Windows & Doors
19. Common Walls Between Attached Dwelling Units

Figure 4: Building America—air sealing trouble spots

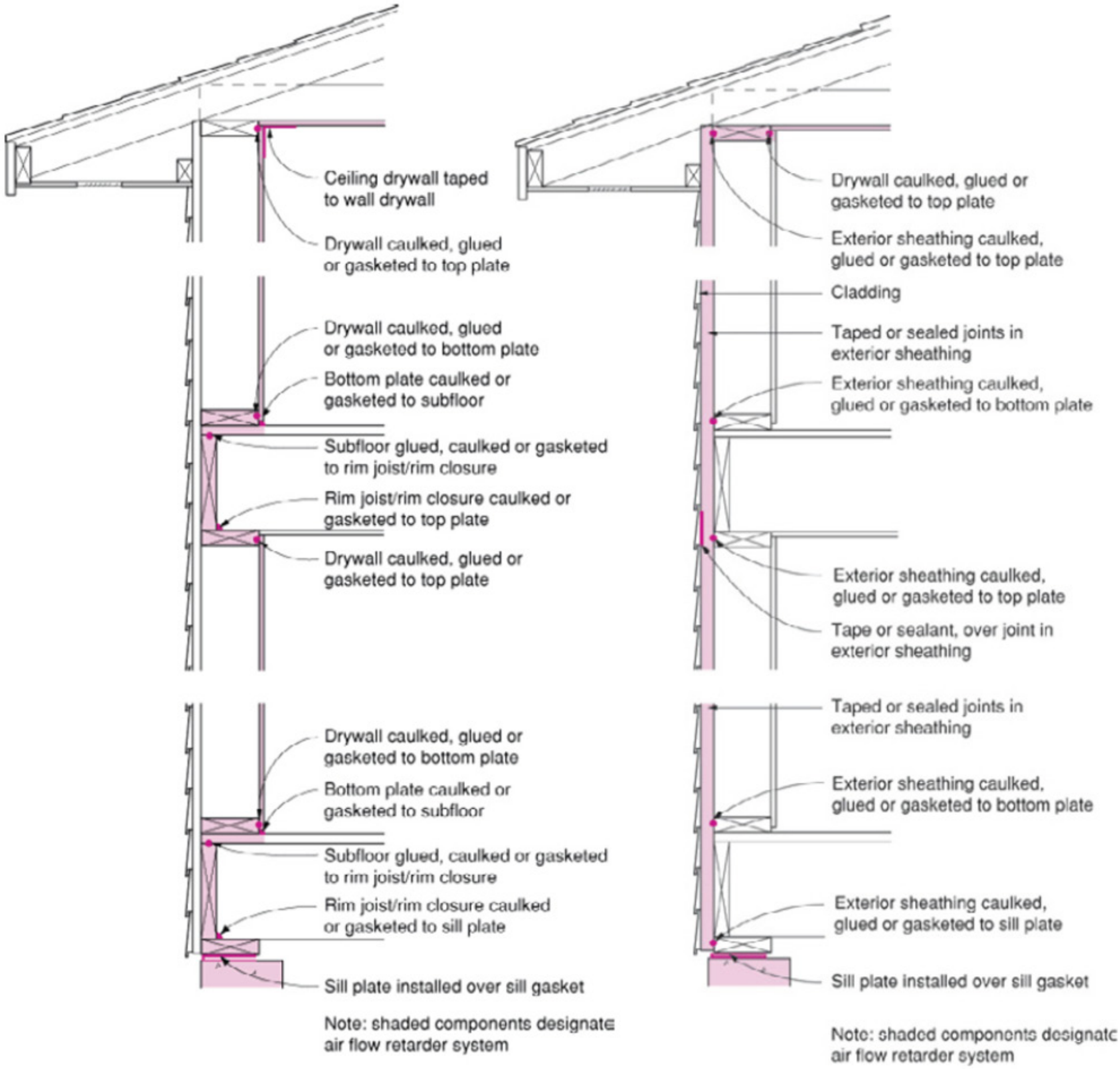
Table 2. Building America Air Sealing Checklist

Air Barrier	Completion Guidelines
1. Air Barrier and Thermal Barrier Alignment	Air Barrier is in alignment with the thermal barrier (insulation).
2. Attic Air Sealing	Top plates and wall-to-ceiling connections are sealed.
3. Attic Kneewalls	Air barrier is installed at the insulated boundary (kneewall transition or roof, as appropriate).
4. Duct Shaft/Piping Shaft and Penetrations	Openings from attic to conditioned space are sealed.
5. Dropped Ceiling/Soffit	Air barrier is fully aligned with insulation; all gaps are fully sealed.
6. Staircase Framing at Exterior Wall/Attic	Air barrier is fully aligned with insulation; all gaps are fully sealed.
7. Porch Roof	Air barrier is installed at the intersection of the porch roof and exterior wall.
8. Flue or Chimney Shaft	Opening around flue is closed with flashing, and any remaining gaps are sealed with fire-rated caulk or sealant.
9. Attic Access/Pull-Down Stair	Attic access panel or drop-down stair is fully gasketed for an air-tight fit.
10. Recessed Lighting	Fixtures are provided with air-tight assembly or covering.
11. Ducts	All ducts should be sealed, especially in attics, vented crawlspaces, and rim areas.
12. Whole-House Fan Penetration at Attic	An insulated cover is provided that is gasketed or sealed to the opening from either the attic side or ceiling side of the fan.
13. Exterior Walls	Service penetrations are sealed and air sealing is in place behind or around shower/tub enclosures, electrical boxes, switches, and outlets on exterior walls.
14. Fireplace Wall	Air sealing is completed in framed shaft behind the fireplace or at fireplace surround.
15. Garage/Living Space Walls	Air sealing is completed between garage and living space. Pass-through door is weather stripped.
16. Cantilevered Floor	Cantilevered floors are air sealed and insulated at perimeter or joist transition.
17. Rim Joists, Seal Plate, Foundation, and Floor	Rim joists are insulated and include an air barrier. Junction of foundation and sill plate is sealed. Penetrations through the bottom plate are sealed. All leaks at foundations, floor joists, and floor penetrations are sealed. Exposed earth in crawlspace is covered with Class I vapor retarder overlapped and taped at seams.
18. Windows and Doors	Space between window/door jambs and framing is sealed.
19. Common Walls Between Attached Dwelling Units	The gap between a gypsum shaft wall (i.e., common wall) and the structural framing between units is sealed.

Items highlighted in yellow will be discussed in more detail.

Air Barrier and Thermal Barrier Alignment

Envelope Air Sealing



Source: Building Science Corporation

Attic Kneewalls

Air barrier is installed at the insulated boundary (kneewall transition or roof, as appropriate)

Kneewalls, the sidewalls of finished rooms in attics, are often leaky and uninsulated. A contractor can insulate and air seal these walls in one step by covering them from the attic side with sealed rigid foam insulation. A contractor can plug the open cavities between joists beneath the kneewall with plastic bags filled with insulation or with pieces of rigid foam. Another option is to apply rigid foam to the underside of the rafters along the sloped roof line and air seal at the top of the kneewall and the top of the sidewall, which provides the benefit of both insulating the kneewall and providing insulated attic storage space.

Doors cut into kneewalls should also be insulated and air sealed by attaching rigid foam to the attic side of the door, and using a latch that pulls the door tightly to a weather-stripped frame.

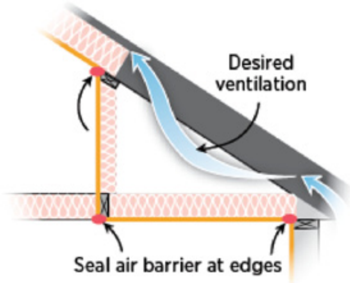


Figure 5. Insulate and air seal the kneewall itself, as shown, or along the roof line (Source: DOE 2000a).

Figure 6. Air seal floor joist cavities under kneewalls by filling cavities with fiberglass batts that are rolled and stuffed in plastic bags (as shown here) or use rigid foam, Oriented Strand Board (OSB), or other air barrier board cut to fit and sealed at the edges with caulk.

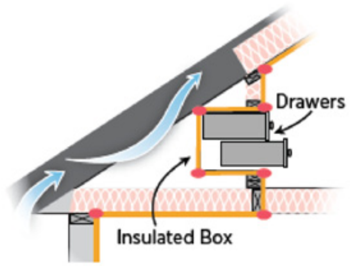


Figure 7. Build an airtight insulated box around any drawers or closets built into attic kneewalls that extend into uninsulated attic space. Insulate along air barrier (shown in yellow on drawing) or along roof line with rigid foam (Source: Iowa Energy Center 2008).

Dropped Ceiling/Soffit

Air barrier is fully aligned with insulation; all gaps are fully sealed

Soffits (dropped ceilings) found over kitchen cabinets or sometimes running along hallways or room ceilings as duct or piping chases are often culprits for air leakage. A contractor will push aside the attic insulation to see if an air barrier is in place over the dropped area. If none exists, the contractor will cover the area with a piece of rigid foam board, sheet goods, or reflective foil insulation that is glued in place and sealed along all edges with caulk or spray foam, then covered with attic insulation. If the soffit is on an exterior wall, sheet goods or rigid foam board should be sealed along the exterior wall as well. If the soffit contains recessed can lights, they should be rated for insulation contact and airtight or a dam should be built around them to prevent insulation contact.

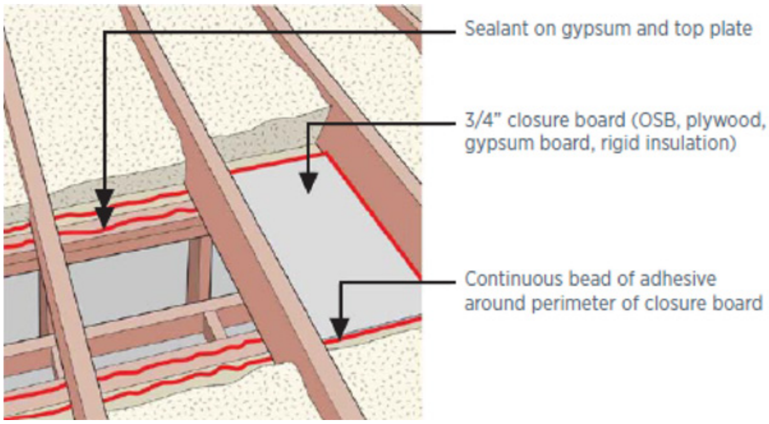


Figure 8. Place a solid air barrier over soffits as follows: pull back existing insulation; cover area with air barrier material (gypsum, plywood, OSB, rigid foam, etc.); seal edges with caulk; cover with insulation (Lstiburek 2010).

Staircase Framing at Exterior Wall/Attic

Air barrier is fully aligned with insulation; all gaps are fully sealed

If the area under the stairs is accessible, look to see if the inside wall is finished. If not, have your contractor insulate it, if needed, and cover it with a solid sheet product like drywall, plywood, OSB, or rigid foam insulation. Then, your contractor can caulk the edges and tape the seams to form an air-tight barrier. Stairs should be caulked where they meet the wall.

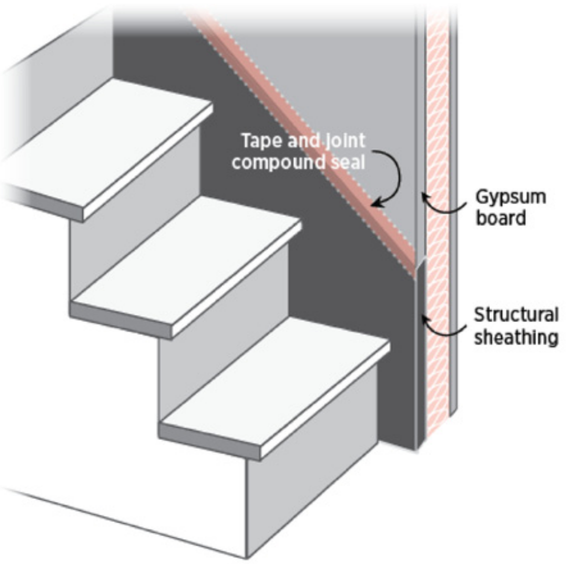


Figure 9. Install an air barrier and air sealing on exterior walls behind stairs. If the area behind the stairs is inaccessible, caulk stairs where they meet the wall. Use caulk if the area is already painted; use tape and joint compound if area will be painted.

Porch Roof

Air barrier is installed at the intersection of the porch roof and exterior wall

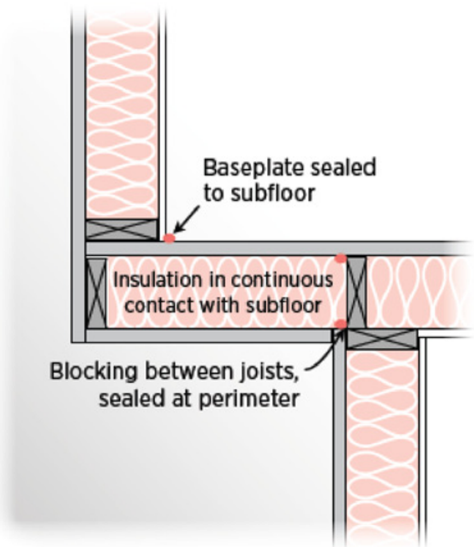
If a test-in inspection identifies air leakage at the wall separating the porch from the living space, the contractor will investigate to see if the wall board is missing or unsealed. If this is the case, the contractor will install some type of wall sheathing (oriented strand board, plywood, rigid foam board) cut to fit and sealed at the edges with spray foam. A contractor will also make sure this wall separating the attic from the porch is fully insulated.

Figure 10. When researchers pulled back the porch ceiling, they found the wall board was missing so nothing was covering the insulation on this exterior wall. An air barrier of rigid foam board was put in place with spray foam (Image: Moriarta 2008).

Studies Show

Steven Winter Associates, a Building America research team lead, used a blower door test and infrared cameras to investigate high-energy bill complaints at a 360-unit affordable housing development and found nearly twice the expected air leakage. Infrared scanning revealed an air leakage path on an exterior second-story wall above a front porch. Steven Winter Associates found that, while the wall between the porch and the attic had been insulated with unfaced fiberglass batts, wall board had never been installed. The insulation was dirty from years of windwashing as wind carried dust up through the perforated porch ceiling, through the insulation, into the attic and into the wall above. Crews used rigid foam cut to fit and glued in place with expandable spray foam to seal each area. Blower door tests showed the change reduced overall envelope leakage by 200 CFM_{50}. At a cost of $267 per unit, this fix resulted in savings of $200 per year per unit, for a payback of less than two years.

Cantilevered Floor



Cantilevered floors are air sealed and insulated at perimeter or joist transitions

Cantilevered floors, second-story bump-outs, and bay windows are another area in the home that often lacks proper air sealing. The floor cavity must be filled with insulation with good alignment (i.e., that is completely touching) the underside of the floor. The interior and exterior sheathing needs to be sealed at the framing edges. Blocking between floor joists should form a consistent air barrier between the cantilever and the rest of the house. Continuous sheathing, such as insulating foam sheathing, should cover the underside of the cantilever and be air sealed at the edges with caulk.

Figure 11. Block and air seal both the floor-to-upper wall junction and the floor-to-lower wall junction.

R402.4.1 Building thermal envelope

The building thermal envelope shall comply with Sections R402.4.1.1 and R402.4.1.2. The sealing methods between dissimilar materials shall allow for differential expansion and contraction.

The most common products for creating an airtight barrier are tapes, gaskets, caulks, and spray foam materials.

Tapes

To limit air leakage, builders use tapes to seal the seams of a variety of membranes and buildings products, including housewrap, polyethylene, OSB, and plywood. Tapes are also used to seal duct seams; seal leaks around penetrations through air barriers, for example, around plumbing vents, and sheet goods to a variety of materials, including concrete. No single tape works well in all of these applications, so builders, general contractors and trades need to familiarize themselves with the range of products and what will work best (time tested) and include these materials in the overall air barrier strategy.

Image: GreenBuildingAdvisor.com

Gaskets can be Better than Caulk

When builders first learn about air sealing, they often depend heavily on caulk. After inspecting a home for leaks during a blower-door test, however, they learn that caulk has a few downsides. That's when they usually graduate to gaskets.

Typical locations for gaskets include between the:

- Top of the foundation and the mudsill;
- Subfloor and the bottom plate;
- Window frame and the rough opening;
- Bottom plate and the drywall; and
- Top plate and the drywall.

Spray Foams

Spray foams are available in a variety of different forms, from small cans to larger industrial gallon sizes. Special care needs to be taken when using these products, as some expand more than others and some can exert significant pressure on the surrounding structure during expansion.

Image: Sprayfoam.com

Who is Responsible for Air Sealing?

The IECC does not specify who is responsible for air sealing; it states that the building envelope shall be sealed in accordance with manufacturers' instructions and the provisions (checklist) of the IECC. The construction documents for permitting to begin construction are typically submitted by the person in charge of the project and responsible for making sure all measures are installed properly and meet the provisions of the code. The inspector is responsible for making sure those measures meet code by verifying through on-site inspections.

Since so many different areas of the building envelope must be sealed, the responsibility will not always be on one person, installer, or trade. For example, the mechanical contractor who installs the heating and cooling equipment most likely will not be installing an air barrier between the attic and conditioned space, as that is usually the responsibility of the insulation contractor.

However, general contractors typically assume that the insulation and air sealing contractors seal and fill the holes, including filling any unintended holes that other subs leave behind. An air sealing strategy can include identifying who is responsible for sealing which building components, including unintended cracks or holes in the building thermal envelope.

The following table is an example of building components to be sealed and who might be responsible for sealing those components.

Table 3. Building components to be sealed and who might be responsible for sealing those components

Building Components	Contractor/Trade
Ceiling/attic, kneewalls, attic access, recessed lighting, walls, floors, garage separation, electrical and service penetrations in ceiling, floors, and walls	• Insulation/air sealing installers • Gypsum board contractors • Foundation contractors • Electricians • Roofers • Framers • General contractors
Service water piping, penetrations for water supply and demand	• Plumbers • Electricians
Rim joists, sill plates, windows, skylights, doors, porch roof, shower/tub on exterior wall, electrical box on exterior wall, fireplace	• Framers • Roofers • Plumbers • Electricians • Insulation/air sealing installers • Window and door installers • General contractors
Ducts, piping, shafts, penetrations, register boots	• HVAC installers
All of the above	• Inspectors • General contractors

4 TESTING: Requirements

The specific test requirements are based on the flow rate of air produced by a blower door at a specified pressure (50 pascals or 0.2 inches of water) when exterior doors are closed, dampers are closed but not otherwise sealed, exterior openings for continuous ventilation systems and heat recovery ventilators are closed but not sealed, HVAC systems are turned off, and duct supply and return registers are not covered or sealed.

The infiltration rate is the volumetric flow rate of outside air into a building, typically in cubic feet per minute (CFM) or liters per second (LPS). The air exchange rate, (I), is the number of interior volume air changes that occur per hour, and has units of 1/h. The air exchange rate is also known as air changes per hour (ACH).

ACH can be calculated by multiplying the building's CFM by 60, then dividing by the building volume in cubic feet. (CFM x 60)/volume. The requirement is expressed in ACH, which takes account of the overall size (volume) of the home:

Total air leakage < 3-5 ACH (air changes per hour)

What is a blower door? It is a powerful fan that attaches and seals to a door (typically the entrance door to the home) and blows air into or out of the house to pressurize or depressurize the home. The inside-outside pressure difference will cause air to force its way through any cracks in the building thermal envelope. Measuring the flow rate at the specified test pressure indicates the leakiness of the envelope.

Figure 12. Blower door

Who Performs the Test and is Certification Required?

The IECC does not specifically address who should perform the test. Builders, contractors, tradesmen, or code officials can perform the test. Code officials can also request the test be performed by an independent third party. The IECC does not require the person performing the test to be certified. However, it is recommended that the person be knowledgeable and have experience in using the equipment.

RESNET and BPI provide certifications for whole-house testing. For more information go to **www.resnet.org** or **www.bpi.org**.

R402.4.1.2 Testing

The building or dwelling unit shall be tested and verified as having an air leakage rate not exceeding 5 air changes per hour in Climate Zones 1 and 2, and 3 air changes per hour in Climate Zones 3 through 8. Testing shall be conducted with a blower door at a pressure of 0.2 inches w.g. (50 pascals). Where required by the code official, testing shall be conducted by an approved third party. A written report of the results of the test shall be signed by the party conducting the test and provided to the code official. Testing shall be performed at any time after creation of all penetrations of the building thermal envelope.

During testing:

1. *Exterior windows and doors, fireplace and stove doors shall be closed, but not sealed, beyond the intended weatherstripping or other infiltration control measures;*
2. *Dampers including exhaust, intake, makeup air, backdraft and flue dampers shall be closed, but not sealed beyond intended infiltration control measures;*
3. *Interior doors, if installed at the time of the test, shall be open;*
4. *Exterior doors for continuous ventilation systems and heat recovery ventilators shall be closed and sealed;*
5. *Heating and cooling systems, if installed at the time of the test, shall be turned off; and*
6. *Supply and return registers, if installed at the time of the test, shall be fully open.*

5 TESTING: Presenting Results

A permanently affixed certificate posted on or near the electrical panel is not a new requirement in the IECC. However, the information required on the certificate ***NOW*** includes results of duct and whole-house pressure tests in addition to the predominant R-values of insulation installed in or on ceiling/roof, walls, foundations, and ducts outside conditioned spaces; fenestration U-factors and solar heat gain coefficients (SHGCs); and efficiencies of heating, cooling, and service water heating equipment.

As a recommendation for verification of testing, whomever performs the testing should also submit the test results to the building official and/or general contractor, confirming the air leakage levels have been met.

R401.2 Certificate (Mandatory)

A permanent certificate shall be completed and posted on or in the electrical distribution panel by the builder or registered design professional. The certificate shall list the results from any required duct system and building envelope air leakage testing done on the building.

2012 IECC Energy Efficiency Certificate

Insulation Rating	R-Value	
Ceiling / Roof	_______	
Wall	_______	
Floor / Foundation	_______	
Ductwork (unconditioned spaces):	_______	
Glass & Door Rating	**U-Factor**	**SHGC**
Window	_______	_______
Door	_______	_______
Heating & Cooling Equipment	**Efficiency**	
Heating System:________________	_______	
Cooling System:________________	_______	
Water Heater:________________	_______	
Testing Results		
Ducts (unconditioned spaces):	____CFM/100 ft² of conditioned floor area	
Whole House	____ACH @ 50 Pascals	

Name:______________________________ Date:_______

Comments:

The illustration is an Energy Efficiency Certificate that can be created and printed using DOE's Building Energy Codes Program software called RES*check*™.

www.energycodes.gov

6 VENTILATION: Requirements

Many building scientists believed mechanical ventilation should have been part of the building design even prior to the 2012 IECC. However, there are disagreements as to the level of envelope tightness at which mechanical ventilation is necessary due to health and safety concerns. This is no longer a question given the new air leakage requirements of the 2012 IECC and other provisions in the International Residential Code (IRC) and International Mechanical Code (IMC). The 2012 IECC does not specifically address the requirements for whole-house mechanical ventilation, but it references the ventilation requirements of the IRC or IMC as a mandatory provision.

IECC, R403.5 Mechanical Ventilation (Mandatory)
*The building shall be provided with ventilation that meets the requirements of the **International Residential Code** or **International Mechanical Code**, as applicable, or with other approved means of ventilation. Outdoor air intakes and exhausts shall have automatic or gravity dampers that close when the ventilation system is not operating.*

Both the 2012 IRC and IMC require mechanical ventilation when the air infiltration rate of the dwelling unit is < 5 ACH when tested with a blower door in accordance with the 2012 IECC provisions.

IRC, Section R303.4 Mechanical Ventilation
Where the air infiltration rate of a dwelling unit is less than 5 air changes per hour when tested with a blower door at a pressure of 0.2 inch w.c. (50 Pa) in accordance with Section N1102.4.1.2, the dwelling unit shall be provided with whole-house ventilation in accordance with Section M1507.3.

Section N1102.4.1.2 is the extraction of the air leakage requirements in the IECC, Section R402.4. ICC duplicated the language from the IECC residential provisions in the IRC, Chapter 11, Energy Efficiency.

IMC, Section 401.2 Ventilation Required

Where the air infiltration rate in a dwelling unit is less than 5 air changes per hour when tested with blower door at a pressure of 0.2-inch water column (to Pa) in accordance with Section 402.4.1.2 of the International Energy Conservation Code, the dwelling unit shall be ventilated by mechanical means in according with Section 403.

IECC, Section R403.5.1 Whole-House Mechanical Ventilation System Fan Efficacy

Mechanical ventilation system fans shall meet the efficacy requirements of Table 403.5.1.

Exception: *Where mechanical ventilation system fans are integral to tested and listed HVAC equipment, they shall be powered by an electronically commutated motor.*

Table 4. 2012 IECC Table R403.5.1, Mechanical Ventilation System Fan Efficacy

Fan Location	Air Flow Rate Minimum (CFM)	Minimum Efficacy (CFM/watt)	Air Flow Rate Maximum (CFM)
Range Hoods	Any	2.8	Any
In-line Fan	Any	2.8	Any
Bathroom, Utility Room	10	1.4	< 90
Bathroom, Utility Room	90	2.8	Any

In addition, ASHRAE Standard 62.2 provides guidance on the appropriate ventilation for acceptable indoor air quality in low-rise residential buildings. The standard specifies that forced ventilation is required in houses with a natural infiltration rate less than 0.35 ACH. This is typically accomplished with heat recovery ventilation or exhaust fans running constantly or periodically. The standard offers guidance for incorporating whole-house systems into a home. This standard is not referenced in the IECC, though some jurisdictions and states adopt this standard as part of their requirements.

For more information on whole-house mechanical ventilation, refer to **Appendix B**.

Ventilation Systems

There are several options for mechanical ventilation systems. Spot ventilation, using exhaust-only fans in the kitchen and bathroom, removes water vapor and pollutants from specific locations in the home, but does not distribute fresh air. Balanced ventilation systems, such as air-to-air exchangers, heat-recovery ventilators, and energy recovery ventilators, both supply and exhaust air.

Table 5: Pros and Cons of Various Mechanical Ventilation Systems

Ventilation Type	Pros	Cons
Exhaust Only Air is exhausted from the house with a fan	• Easy to install • Simple method for spot ventilation • Inexpensive	• Negative pressure may cause backdrafting • Makeup air is from random sources • Removes heated or cooled air
Supply Only Air is supplied into the house with a fan	• Does not interfere with combustion appliances • Positive pressures inhibit pollutants from entering • Delivers to important locations	• Does not remove indoor air pollutants at their source • Brings in hot or cold air or moisture from the outside • Air circulation can feel drafty • Furnace fan runs more often unless fan has an ECM (variable-speed motor)
Balanced Air Exchange System Heat and energy recovery ventilators supply and exhaust air	• No combustion impact • No induced infiltration/exfiltration • Can be regulated to optimize performance • Provides equal supply and exhaust air • Recovers up to 80% of the energy in air exchanged	• More complicated design considerations • Over ventilation unless the building is tight • Cost

Heat and Energy Recovery Ventilation Systems

Heat recovery ventilators (HRVs) and energy recovery (or enthalpy recovery) ventilators (ERVs) both provide a controlled way of ventilating a home while minimizing energy loss by using conditioned exhaust air to warm or cool fresh incoming air. There are some small wall or window-mounted models, but the majority are central, whole-house ventilation systems that share the furnace duct system or have their own duct system. The main difference between an HRV and an ERV is the way the heat exchanger works. With an ERV, the heat exchanger transfers water vapor along with heat energy, while an HRV only transfers heat. The ERV helps keep indoor humidity more constant. However, in very humid conditions, the ERV should be turned off when the air conditioner is not running. Air-to-air heat exchangers or HRVs are recommended for cold climates and dry climates. ERVs are recommended for humid climates. Most ERV systems can recover about 70%–80% of the energy in the exiting air. They are most cost effective in climates with extreme winters or summers, and where fuel costs are high. ERV systems in cold climates must have devices to help prevent freezing and frost formation.

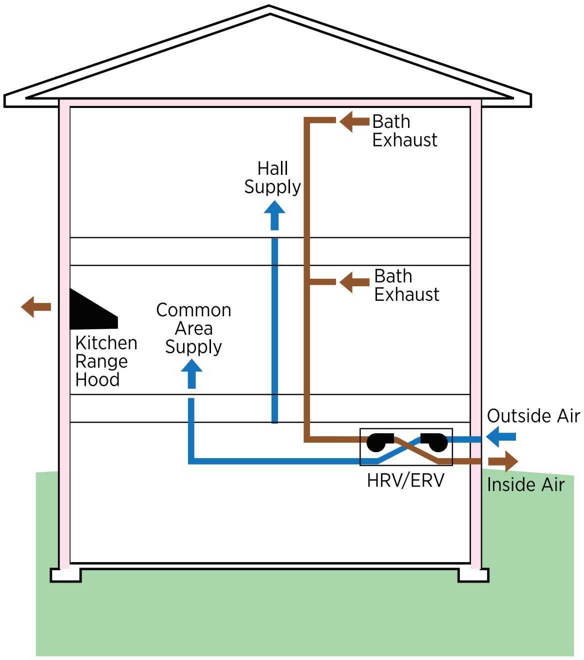


Figure 13. Heat and energy recovery ventilators bring in fresh air, exhaust stale air, and save energy by transferring heat into incoming air through a heat exchanger (Ruud 2011).

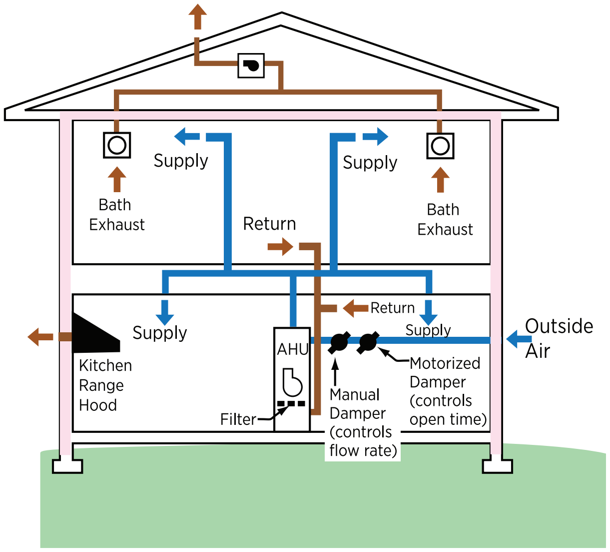


Figure 14. Semi-balanced ventilation systems provide fresh air and exhaust stale air but flow rates may not be balanced (Ruud 2011).

7 HVAC SIZING: Requirements

Reducing infiltration can reduce the loads on the building, which in turn can reduce the required sizes of the heating and cooling equipment. The 2012 IECC contains a mandatory requirement that equipment be sized according to Air Conditioning Contractors of America (ACCA) Manual S, based on loads calculated in accordance with ACCA Manual J (or other approved means of calculating the loads and equipment sizing). Many jurisdictions allow the use of other heating system sizing calculators. Builders/contractors should check with the governing jurisdiction to see what they accept. The builder or contractor will also need to make an assumption when calculating the loads based upon the tested air leakage rate (changes per hour at 50 pascals) of the home. Since the IECC requires $\leq$ 3 ACH for climate zones 3-8 or $\leq$ 5 ACH for climate zones 1-2, at a 50 pascals pressure test, the infiltration rate assumption will need to be at the applicable ACH when running the load calculations.

R403.6 Equipment Sizing (Mandatory)

Heating and cooling equipment shall be sized in accordance with ACCA Manual J or other approved heating and cooling calculation methodologies.

C.b

8 CASE STUDIES: Alternative Methods of Construction

Some builders are currently building energy efficient homes in the cold and very cold climates that achieve the low air leakage rates specified in the 2012 IECC ($\leq$ 3 ACH in climate zones 3-8). The following case studies showcase five cold climate builders who worked with Building America research teams. The builders used a variety of energy efficiency measures, including such things as insulated concrete forms (ICFs) and wood-framed walls with studs on 24-inch centers. The energy efficiency measures and testing results are summarized in Table 6 and the tested air leakage rates are highlighted in yellow.

Table 6. Summary of Energy Efficiency Measures Incorporated in Case Study Homes in the Cold Climate

	Devoted Builders Kennewick, WA	Nelson Construction Farmington, CT
Project	Mediterranean Villas Pasco, WA 230 duplex and triplex units 1,140 - 2,100 ft^2 Market rate	Hamilton Way Farmington, CT 10 single family homes 2,960 - 3,540 ft^2 Market rate
Tested Air Leakage and Sealing	**Tested at 0.8 to 2.0 ACH at 50 Pa; Spray foam ceiling deck**	**Tested at < 3.0 ACH at 50 Pa; Foam critical seal of rim and floor joists**
Walls	R-25 ICF	2x6 24-in. o.c.
Wall Insulation	R-25 ICF	2-inch foil-faced polyisocyanurate R-13 sheathing, plus R-19 cellulose in stud cavities
Attic Insulation	R-49 blown-in cellulose on ceiling	R-50 blown-in fiberglass on ceiling
Foundation Insulation	R-25 ICF perimeter foundation insulation with floating slab	2-inch/R-10 XPS below slab; 2-inch/R-10 XPS in thermomass basement walls
Ducts	In conditioned space or in attic covered with spray foam and blown cellulose	In conditioned space in dropped ceiling or between joists
Air Handler	In conditioned space	In conditioned basement
HERS	54 - 68	53 - 54
HVAC	8.5 HSPF/14 SEER heat pumps	94% AFUE gas furnace; SEER 14 air conditioner
Windows	U-0.29	U-0.32, SHGC-0.27, double-pane, low-e, vinyl framed
Water Heating	84% EF tankless gas water heater	82% EF tankless gas water heater
Ventilation	Energy recovery ventilator	Temperature- and timer-controlled fresh air intake; exhaust fan ducted to draw from main living space; transfer grilles
Green	3-star BuiltGreen certified homes	2008 “Best Energy Efficient Green Community” by CT Home Builders Association; 2010 NAHB Energy Value Housing gold award
Lighting and Appliances	70% hardwired CFL lighting; ENERGY STAR refrigerators, dishwashers, and clothes washers	100% CFLs; optional appliances
Solar	No	Optional 7-kW PV systems
Verification	100% are third party tested and inspected, all homes met federal tax credit criteria since 2007	All Builders Challenge certified

AC = air conditioner; ACH = air changes per hour; AFUE = annual fuel utilization efficiency; CFL = compact fluorescent lights; Ef = energy factor; HERS = Home Energy Rating System; HSPF = Heating Seasonal Performance Factor; ICF = insulated concrete form;

Table 6. Summary of Energy Efficiency Measures Incorporated in Case Study Homes in the Cold Climate (continued)

Rural Development, Inc. **Turner Falls, MA**	**S&A Homes** **Pittsburgh, PA**	**Shaw Construction** **Grand Junction, CO**
Wisdom Way Solar Village Greenfield, MA 20 duplex units 1,140 - 1,770 ft² Affordable housing	East Liberty Development, Inc. 6 single-family urban infill 3,100 ft² Above market rate	Burlingame Ranch Phase 1 Aspen, CO 84 units in 15 multi-family buildings 1,325 ft² Affordable
Tested at 1.1 to 1.5 ACH at 50 pa	**Tested at 3.0 ACH at 50 Pa; all penetrations and studs sealed**	**Tested at 2.5 in² leakage per 100 ft² of envelope**
Double walled (two 2x4 16-in. o.c. walls, 5 inches apart)	2x6 24-in. o.c.	2x6 24-in. o.c.
R-42 dense-pack, dry blown cellulose	R-24 blown fiberglass	R-24 of 3.5" high-density spray foam
R-50 blown-in cellulose on ceiling	R-49 blown-in fiberglass on ceiling	R-50 high-density foam at sloped roof, R-38 at flat roofs
Full uninsulated basement with R-40 blown cellulose under first floor	Precast concrete basement walls with steel-reinforced concrete studs at 2.5 in. XPS R-12.5	Slab with R-13 XPS edge; some basements with R-13 interior polyisocyanurate; R-28 of spray-foam insulation on ground under slab
No ducts	In conditioned space in open-web floor trusses	No ducts
None	In conditioned basement	None
8 - 18	51 - 55	54 - 62
Small sealed-combustion 83% AFUE gas-fired space heater on main floor; no AC	Two-stage 96%-AFUE gas furnace with multi-speed blower; SEER-14 AC	0.9 AFUE condensing gas boiler with baseboard hot water radiators
Triple-pane U-0.18 on north/east/west sides; double-pane U-0.26 on south side	U-0.33, SHGC-0.30, double-pane	U-0.37, SHGC-0.33 fiberglass-framed, double-pane
Solar thermal with tankless gas backup	82% EF tankless gas water heater	Solar thermal with gas boiler back-up
Continuous bathroom exhaust	Passive fresh air duct to return plenum; fan-cycler on 50% of time for fresh air circulation, bath exhausts	Heat-recovery ventilator
LEED Platinum	Meets LEED (not certified)	LEED Certified
100% CFLs; refrigerator, dishwasher	100% CFLs and ENERGY STAR refrigerator, dishwashers, and clothes washer	90% CFL; ENERGY STAR refrigerator, dishwashers, clothes washers, ceiling fans
2.8 to 3.4-kW PV; flat-plate collector solar thermal water heating	No	10-kW PV on one building; solar hot water heating on all buildings
All HERS rated	All Builders Challenge certified	All federal tax credit qualified

o.c. = on center wood framed walls; Pa = pascals; PV = photovoltaic; SEER = Seasonal Energy Efficiency Ratio; SHGC = solar heat gain coefficient; XPS = extruded polystyrene

CASE STUDIES/SUMMARY

Devoted Builders, LLC

http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/ba_bp_devoted_cold.pdf

Nelson Construction

http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/ba_bp_nelson_cold.pdf

Rural Development, Inc.

http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/ba_bp_ruraldevelopment_cold.pdf

S&A Home

http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/ba_bp_sahomes_cold.pdf

Shaw Construction

http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/ba_bp_shaw_cold.pdf

APPENDIX A:
References and More Information on Air Sealing

2012 IECC. 2012 International Energy Conservation Code, Section 402.4 "Air Leakage," Section 403.5 "Mechanical Ventilation," International Code Council (ICC), Washington, DC. www.iccsafe.org/Store/Pages

2012 IRC. 2012 International Residential Code, Section M 1507.3, R303.4, R403.5

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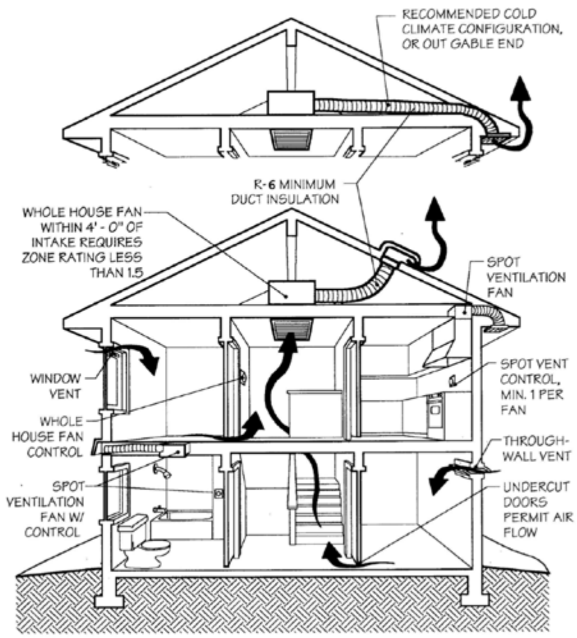
APPENDIX B: Code Note

Whole-House Mechanical Ventilation

[ASHRAE 62.2-2010, 2012 IECC, 2012 IRC]
PNNL-SA-83104



ASHRAE Standard 62.2, Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings, defines the roles of and minimum requirements for mechanical and natural ventilation systems to achieve acceptable indoor air quality. This material supplements requirements contained in the national model energy codes with respect to mechanical ventilation systems. At this time, the residential provisions of the IECC do not reference ASHRAE 62.2.

Ventilation
The process of supplying outdoor air to or removing indoor air from a dwelling by natural or mechanical means. Such air may or may not have been conditioned.

Mechanical Ventilation
The active process of supplying air to or removing air from an indoor space by powered equipment.

Natural Ventilation
Ventilation occurring as a result of only natural forces.

CFM
Cubic feet per minute, a standard measurement of airflow.

In the past, no specific requirements for ventilation were imposed for residential buildings because leakage in envelope components and natural ventilation were considered adequate to maintain indoor air quality. As envelope construction practices have improved, the need to provide fresh air to homes via mechanical means has increased.

ASHRAE Standard 62.2 provides guidelines for ventilation requirements. In addition to addressing whole-house ventilation, the standard also addresses local exhaust (kitchens and bathrooms) and criteria for mechanical air-moving equipment. Ventilation requirements for safety (including combustion appliances, adjacent space concerns, and location of outdoor air inlets) are also addressed.

To comply with the ASHRAE standard, residential buildings (including manufactured homes) are required to install a mechanical ventilation system. An override control for the occupants is also required.

Plan Review

1. Confirm that a mechanical ventilation system that provides the appropriate ventilation rate (CFM) is called out. See ASHRAE 62.2-2010, Table 4.1a, for details.
2. Check that the planned ventilation rate does not exceed 7.5 CFM per 100 ft^2 if located in a very cold climate or a hot, humid climate. See Tables 8.1 and 8.2 for details.
3. Check that local exhaust systems for kitchens and bathrooms have been planned for appropriately.

Field Inspection

1. Confirm that a mechanical ventilation system that provides the appropriate ventilation rate (CFM) is installed.
2. Confirm that occupant override control has been installed as required by ASHRAE 62.2-2010 section 4.4, and 2012 IRC, section M1507.3.

Code Citations*

ASHRAE 62.2-2010, Table 4.1a (I-P) Ventilation Air Requirements, CFM
[2012 IRC Table M1507.3.3(1) Continuous Whole-House Ventilation System Airflow Rate Requirements]

Floor Area (ft^2)	0-1 Bedrooms	2-3 Bedrooms	4-5 Bedrooms	6-7 Bedrooms	7+ Bedrooms
< 1,500	30	45	60	75	90
1,500 - 3,000	45	60	75	90	105
3,001 - 4,500	60	75	90	105	120
4,501 - 6,000	75	90	105	120	135
6,001 - 7,500	90	105	120	135	150
> 7,500	105	120	135	150	165

ASHRAE 62.2-2010, Table 8.1 Hot, Humid U.S. Climates

Mobile, AL	Savannah, GA	Wilmington, NC
Selma, AL	Valdosta, GA	Charleston, SC
Montgomery, AL	Hilo, HI	Myrtle Beach, SC
Texarkana, AR	Honolulu, HI	Austin, TX
Apalachicola, FL	Lihue, HI	Beaumont, TX
Daytona, FL	Kahului, HI	Brownsville, TX
Jacksonville, FL	Baton Rouge, LA	Corpus Christi, TX
Miami, FL	Lake Charles, LA	Dallas, TX
Orlando, FL	New Orleans, LA	Houston, TX
Pensacola, FL	Shreveport, LA	Galveston, TX
Tallahassee, FL	Biloxi, MS	San Antonio, TX
Tampa, FL	Gulfport, MS	Waco, TX
	Jackson, MS	

ASHRAE 62.2-2010, Table 8.2 Very Cold U.S. Climates

Anchorage, AK	Marquette, MI	Fargo, ND
Fairbanks, AK	Sault Ste. Marie, MI	Grand Forks, ND
Caribou, ME	Duluth, MN	Williston, ND
	International Falls, MN	

2012 IECC, Section R403.5 Mechanical ventilation (Mandatory)
The building shall be provided with ventilation that meets the requirements of the International Residential Code or International Mechanical Code, as applicable, or with other approved means of ventilation. Outdoor air intakes and exhausts shall have automatic or gravity dampers that close when the ventilation system is not operating.

2012 IRC, Section R303.4 Mechanical ventilation
Where the air infiltration rate of a dwelling unit is less than 5 air changes per hour when tested with a blower door at a pressure of 0.2 inch w.c. (50 Pa) in accordance with Section N1102.4.1.2, the dwelling unit shall be provided with whole-house ventilation in accordance with Section M1507.3.

2012 IRC, Section M1507.3 Whole-house mechanical ventilation system
Whole-house mechanical ventilation systems shall be designed in accordance with Sections M1507.3.1 through M1507.3.3.

M1507.3.1 System design
The whole-house ventilation system shall consist of one or more supply or exhaust fans, or a combination of such, and associated ducts and controls. Local exhaust or supply fans are permitted to serve as such a system. Outdoor air ducts connected to the return side of an air handler shall be considered to provide supply ventilation.

M1507.3.2 System controls
The whole-house mechanical ventilation system shall be provided with controls that enable manual override.

M1507.3.3 Mechanical ventilation rate
The whole-house mechanical ventilation system shall provide outdoor air at a continuous exchange rate of not less than that determined in accordance with Table M1507.3.3(1).

Exception: The whole-house mechanical ventilation system is permitted to operate intermittently where the system has controls that enable operation for not less than 25-percent of each 4-hour segment and the ventilation rate prescribed in Table M1507.3.3(1) is multiplied by the factor determined in accordance with Table M1507.3.3(2).2012.

Table 7.4. 2012 IRC Table M1507.3.3(2) Intermittent Whole-House Mechanical Ventilation Rate Factors

Run-Time Percentage in Each 4-Hour Segment	25%	33%	50%	66%	75%	100%
Factor	4.0	3.0	2.0	1.5	1.3	1.0

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Building Energy Codes

Insulating Raised Floors in Hot, Humid Climates

Raised floor home in Baton Rouge

Research Findings on Moisture Management

LSU AgCenter Research & Extension

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Forest Products Laboratory

Raised Floor Living
RaisedFloorLiving.com

Raised floor homes in New Orleans

Table of Contents

Introduction

This document summarizes key information based on a cooperative research project conducted by the U.S. Department of Agriculture's Forest Products Laboratory and the Louisiana State University Agricultural Center. The study was supported by the Forest Products Laboratory, APA–The Engineered Wood Association and the Southern Pine Council. This summary is intended for homeowners, builders, architects, insulation contractors, home inspectors, building officials and consultants. The study itself (Glass and others, 2010) and additional references for further reading are given at the end of this summary.

Why does moisture management matter?

We generally want our homes to be safe, durable and comfortable – all while requiring reasonable amounts of energy for heating or cooling. The last thing homeowners want is to find mold or decay in their homes. The key to preventing growth of mold and decay fungi is proper moisture management. It also is essential for preventing corrosion of nails and screws that hold the structure together and avoiding expansion/contraction damage such as cupping or buckling of wood flooring.

How much moisture is too much?

Wood has a strong affinity for water vapor. At a relative humidity of 50 percent at room temperature, wood holds about 10 percent of its dry weight as absorbed moisture. This percentage commonly is called moisture content. At 80 percent relative humidity, wood moisture content is about 16 percent. When moisture content increases, wood expands. When wood dries, it shrinks. Expansion/contraction damage depends on how much the moisture content changes and how sensitive the particular construction or wood product is to such changes.

The traditional guideline for protecting wood and wood products from rot or decay is to keep the moisture content below 20 percent. Studies have shown, however, that mold growth can occur on wood at moisture content levels above 15 to 18 percent, and corrosion of metal fasteners in treated wood can occur when moisture content exceeds 18 to 20 percent. Reaching these moisture content levels does not mean mold growth or corrosion will necessarily occur. For each of these moisture-related problems, a key factor is the amount of time the wood spends at an elevated moisture level.

How does insulation affect moisture levels?

The rates of wetting and drying of building assemblies, whether they are floors, walls or ceilings, can be affected by thermal insulation. The job of thermal insulation is to slow down heat flow – to help keep the inside of the house warm when it's cold outside and cool when it's hot outside. In addition to its thermal resistance, insulation provides some resistance to moisture migration, and this resistance can vary widely between different types of insulation. Insulation's effect on limiting heat flow will coincidentally make certain parts of the floor assembly warmer (or cooler) than other parts of the assembly. This is important because wood tends to dry when it is warm relative to its surroundings and is prone to moisture accumulation when it is cooler than its surroundings.

Figure 1. Example of an open crawl space.

Figure 2. Example of a wall-vented crawl space.

Three different crawl space types

For the purpose of discussing moisture management, **crawl spaces** can be classified into three different types.

1. We refer to open pier-and-beam foundations as **open crawl spaces**. (See Figure 1, page 3.) Open crawl spaces may have a continuous wall on just the front side and be open on the other sides.
2. We refer to crawl spaces with continuous perimeter walls that include vents to the outside as **wall-vented crawl spaces**. (See Figure 2.)
3. Finally, we refer to crawl spaces with continuous perimeter walls with no vents as **closed crawl spaces**. (See Figure 3.)

A closed crawl space, with regard to air and water vapor movement, is effectively part of the interior space and is intended to be isolated from the ground and the exterior. The ground and perimeter walls typically are covered with a vapor barrier, and the crawl space may be provided with conditioned air. A number of studies in various climates have shown this type of crawl space can remain safely dry, but this method of construction is not typical and is risky in flood hazard areas.

Building codes require that raised floor foundations in flood hazard areas permit floodwaters to move through the space underneath the building. That can be achieved in closed crawl spaces with breakaway panels or vents that normally stay closed but open when floodwaters exert pressure. The long-term ability of these devices to remain sufficiently airtight to provide an essentially closed crawl space has not been demonstrated. Furthermore, in the event of a flood, the crawl space will flood, and the perimeter walls will inhibit drainage and drying after the flood. In addition, potential floodwater contaminants and mold growth, which may occur subsequent to flooding in a closed crawl space, will be coupled with indoor air. Because of these hazards, the closed crawl space is not advisable in flood-prone areas.

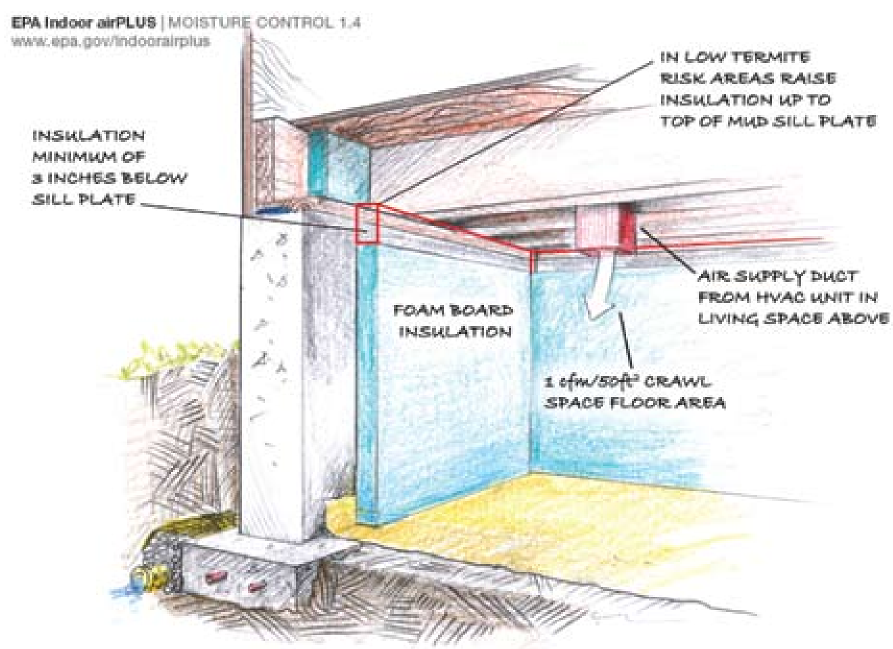

Figure 3. Sketch of a closed crawl space with conditioned air supply.
[Illustration: Dennis Livingston, Community Resources.
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Managing rainwater and soil moisture

Site grading and management of roof runoff can largely determine how wet the soil becomes under a house. In general, the soil around the foundation should be graded so water drains away from the building. Wet soil under a raised house can supply a large amount of humidity to crawl spaces, especially in wall-vented crawl spaces.

An established method of limiting evaporation of moisture from wet soil into wall-vented crawl spaces is to cover the soil with a vapor retarder such as polyethylene, typically 0.15 millimeters (6 mil) or thicker. The use of soil covers in wall-vented crawl spaces is based on a large body of research. If site conditions allow rainwater to wind up on top of the soil cover, however, the soil cover may be counterproductive.

Results from this study showed humidity levels (on an absolute scale) in open crawl spaces were essentially the same as outdoors. This means evaporation from the soil under an open crawl space is overpowered by a high rate of air exchange between the crawl space and the outdoors. This finding suggests if a house is to be built on a site with poor grading and drainage, an open crawl space would be preferable to a wall-vented crawl space.

Water vapor movement

Water vapor generally diffuses from an area of higher concentration to one with lower concentration. This often corresponds with migration from higher temperature to lower temperature. For example, when a building is air-conditioned and the outdoor climate is hot and humid, water vapor migrates through the building shell from outdoors to indoors. This is referred to as inward vapor drive.

Inward vapor drive means water vapor will be absorbed by the subfloor from the outside. This absorbed moisture will migrate through the subfloor and will dry to the inside. When the rate of wetting is higher than the rate of drying, moisture will accumulate in the subfloor. If the moisture content gets too high for too long, problems like mold and rot can occur.

To protect the subfloor from moisture accumulation, the insulation under the subfloor should be selected to provide enough resistance to the inward vapor drive.

Experimental study

Conditions were monitored in a dozen Louisiana homes – eight in New Orleans and four in Baton Rouge. Eleven of the 12 homes were located in flood hazard areas and were constructed with open pier foundations. The sole home in the sample with a wall-vented crawl space incorporated a vapor-retarding soil cover, in accordance with conventional recommendations. The 11 other homes (with open crawl spaces) did not incorporate soil covers.

Air temperature and humidity were measured with data loggers placed indoors, outdoors and in crawl spaces. Moisture content and temperature of the wood or plywood subfloor was measured, typically twice each month. Monitoring started in October 2008 and concluded in October 2009.

Figure 4a. Example of rigid, foil-faced polyisocyanurate foam.

Figure 4b. Example of closed cell spray foam.

The sample of 12 houses included six different insulation systems:

A. 2-inch-thick, rigid, foil-faced polyisocyanurate foam insulation installed below the floor joists. All seams were sealed with foil tape, penetrations were sealed with spray foam and rim joist areas were insulated with spray foam type D below (Figure 4a, page 5).

B. 2 inch average thickness of approximately 2 pounds per cubic foot closed cell sprayed polyurethane foam below the subfloor (Figure 4b).

C. 2.6 inch average thickness of medium-density (1 pound per cubic foot) open cell sprayed polyurethane foam below the subfloor.

D. 3.4 inch average thickness of low-density (0.5 pounds per cubic foot) open cell sprayed polyurethane foam below the subfloor (Figure 4c).

E. Same as D, except with the addition of one coat of a spray-applied vapor retardant paint coating (nominal perm rating less than 0.5).

F. 6.25-inch, kraft-faced fiberglass batts installed between floor joists with the kraft facing up against the subfloor, supported by metal rods (Figure 4d, page 7).

All insulation systems were nominally R-13, except the batt insulation, which was nominally R-19.

Houses in New Orleans originally were insulated with fiberglass batt insulation. Contractors removed batt insulation from half of the floor and replaced it with rigid foam or spray foam insulation. Floors in the Baton Rouge houses were insulated entirely with rigid foam and/or spray foam.

Results

The main results are summarized here, followed by a discussion of the main factors affecting subfloor moisture levels and the implications.

- For all 12 houses the predominant vapor drive was inward from May through October (when air conditioning was running). During the other months, the difference between indoor and outdoor water vapor pressure (a way of expressing humidity on an absolute scale) was small.

Figure 4c. Example of open cell spray foam.

Figure 4d. Example of typical fiberglass batt insulation.

- Air temperature in open crawl spaces was very close to outdoor air temperature. These crawl spaces were slightly warmer than outdoors in cold weather and slightly cooler than outdoors in warm weather.
- In contrast, the wall-vented crawl space was considerably warmer than outdoors in cold weather and considerably cooler than outdoors in warm weather.
- In all crawl spaces, water vapor pressure essentially was the same as outdoor vapor pressure.
- Moisture conditions within plywood or solid wood subfloors were found to depend on several variables:
  - Season of the year.
  - Indoor temperature during summer.
  - Type of interior floor finish.
  - Type of under-floor insulation.

Seasonal effect

In most cases, a seasonal trend was observed of higher subfloor moisture content during summer and lower subfloor moisture content during winter. This is a result of the subfloor being cooler than the crawl space during the months when air conditioning is running and warmer than the crawl space during the winter. The seasonally varying temperature differences between the subfloor and the crawl space are amplified by the thermal insulation, which is located between the subfloor and the crawl space.

Air conditioning and indoor temperature

For a given type of insulation and interior floor finish, subfloor moisture content generally increased with decreasing indoor temperature during summer. That is, the cooler the air conditioning was keeping the temperature indoors, the wetter the subfloor. The potential for low air conditioning set-point temperatures to cause problematic moisture accumulation in floors over crawl spaces in the southeastern United States has been recognized for decades (Verrall 1962).

A cautious designer should select floor insulation that can accommodate lower-than-average temperatures during the air conditioning season without resulting in moisture accumulation in the subfloor. On the other hand, homeowners in hot, humid climates can reduce the risk of seasonal moisture accumulation if they set the thermostats controlling their air conditioners as high as they feel is practical. Houses in the study with summertime indoor temperatures of 78 degrees F or higher did not show elevated subfloor moisture levels, regardless of the type of floor insulation. Higher air conditioner thermostat settings will, along with reducing the risk of moisture problems in subfloors, result in less energy consumption. Use of ceiling fans and stand-alone dehumidifiers can improve summertime comfort levels in homes with higher air conditioning set-point temperatures.

Interior floor finish

For a given indoor temperature and type of insulation, summertime subfloor moisture content generally was higher under an impermeable floor finish such as vinyl than under carpet. Vinyl is very impermeable and prevents inward drying of the subfloor. Carpet, on the other hand, is much more permeable to water vapor. Hardwood flooring with polyurethane finish and ceramic tile are less permeable than carpet but considerably more permeable than vinyl. Impermeable floor finishes, by inhibiting inward drying of the subfloor, raise summertime subfloor moisture content.

Types of insulation and resistance to water vapor flow

For a given indoor temperature and type of interior floor finish, higher subfloor moisture content during summer was found with more permeable insulation. Greater permeability allows for water vapor to migrate through insulation and into subfloor materials.

Foam board faced with aluminum foil is essentially impermeable to water vapor. Closed cell spray foam insulation is somewhat impermeable. These types of insulation showed good performance, preventing summertime moisture accumulation in subfloors.

In contrast, open cell spray foam and batt insulation are much more permeable. Open cell foam gave subfloor moisture contents above 20 percent in some cases when vinyl flooring was present and the air-conditioned indoor temperature was relatively low during the summer. This type of insulation was not reliable for preventing summertime moisture accumulation in subfloors.

Batt insulation, although giving lower subfloor moisture contents on average than open cell foam, also gave some elevated moisture levels (above 20 percent moisture content). The glass fibers do not provide much resistance to water vapor diffusion, but the kraft paper facing, right below the subfloor, does provide some resistance. The kraft facing becomes more permeable as relative humidity increases, however, and in the southeastern United States, the outdoor relative humidity commonly is above 80 percent.

In a few instances, open cell foam was finished with a coat of vapor retardant paint. One reason for choosing this combination is that open cell foam plus paint is less expensive than closed cell foam. If the floor finish was carpet, the application of vapor retardant paint over open cell foam had no discernable effect on subfloor moisture content. It should be noted, however, that subfloor moisture contents under carpeted floors never became elevated, due to the moderately high vapor permeability of the carpet.

In contrast, if the floor finish was vinyl, the vapor retardant paint applied over open cell foam appeared to result in lower subfloor moisture contents on average (relative to an otherwise identical floor system with the vapor retardant paint omitted), but some individual moisture readings still exceeded 16 percent moisture content. The data regarding the effect of vapor retardant paint were not conclusive, and further research is needed to determine whether the combination of open cell foam and vapor retardant paint can be a reliable strategy for preventing summertime moisture accumulation in subfloors in this climate.

Raised floor home in Baton Rouge

Summary

Twelve houses in New Orleans and Baton Rouge, La., were monitored over a one-year period. In all 12 houses the predominant vapor drive was inward from May through October (when air conditioning was running). During the other months, the difference between indoor and outdoor water vapor pressure was small.

The air temperature in open crawl spaces was very close to outdoor air temperature. These crawl spaces were slightly warmer than outdoors in cold weather and slightly cooler than outdoors in warm weather. In contrast, the wall-vented crawl space was considerably warmer than outdoors in cold weather and considerably cooler than outdoors in warm weather. In all crawl spaces, water vapor pressure was essentially the same as outdoor vapor pressure.

Moisture conditions within plywood or solid wood subfloors generally showed a seasonal trend of higher moisture content during the summer and lower moisture content during the winter. Subfloor moisture content during summer generally increased with decreasing indoor temperature (the lower the air conditioning kept the temperature, the wetter the subfloor), increased with decreasing permeability of the interior floor finish (wetter subfloor under vinyl than under carpet) and increased with increasing permeability of the under-floor insulation (wetter subfloor with open cell sprayed polyurethane foam than with closed cell sprayed polyurethane foam). **Foil-faced rigid foam and closed cell sprayed polyurethane foam exhibited good performance, keeping subfloor moisture content within acceptable levels.** In contrast, open cell sprayed polyurethane foam and fiberglass batt insulation were not reliable for preventing summertime moisture accumulation in subfloors.

Questions and answers

1. The study results indicate that open cell sprayed polyurethane foam and fiberglass batt insulation are not always reliable for raised floor systems in this climate. Is there a suitable retrofit for a raised floor system in which either open cell foam or fiberglass insulation is already installed?

Answer: The study did not address this issue directly. The study did find, however, that properly sealed foil-faced rigid foam insulation installed below the floor joists (without any insulation in the joist spaces) prevented summertime subfloor moisture accumulation. This performance is attributed to the vapor-impermeable aluminum foil facing and the air-sealing details at all edges and penetrations. We therefore expect this type of insulation to be a suitable retrofit for a raised floor system already equipped with fiberglass insulation. As long as the existing insulation and subfloor have not been exposed to elevated moisture levels, it would not be necessary to remove the insulation.

If it is not feasible to add foil-faced rigid foam (due to obstructions, affordability, etc.), the risk of subfloor wetting may be reduced in batt insulated floors by keeping the air conditioning thermostat setting at 78 degrees F or higher and replacing vinyl and other impermeable floorings with more permeable floorings. Although the study did not investigate the effect of drooping batt insulation, we would expect that drooping batts pose an additional risk due to humid air bypassing the kraft vapor retarder, leading to increased moisture accumulation in the cool subfloor of an air-conditioned home. We advise making sure all batts are held in full contact with the subflooring.

Likewise, risk of moisture problems in homes with open cell foam subfloor insulation may be reduced by the same strategies (higher thermostat settings and more permeable flooring). Although the study did not investigate the effect of multiple coats of vapor retardant paint over open cell foam, it is possible this strategy would result in lower summertime subfloor moisture levels.

2. The study results indicate closed cell spray foam is a suitable insulation for raised floor systems in southern Louisiana. Should the floor joists, as well as the subflooring, be covered with closed cell spray foam?

Answer: The study did not address this issue, and we therefore cannot make explicit recommendations. It could be argued from building science principles, however, that covering the joists in wall-vented crawl spaces with closed cell foam is likely to keep them drier *during summer months. As the study indicated, in a wall-vented crawl space, crawl space temperature can be noticeably cooler than outside temperature during summer months while water vapor pressure in the crawl space is very close to that of the outdoor environment. This results in high relative humidity levels in the crawl space. Under these conditions, the joists are likely to reach higher than desirable moisture levels. Therefore, isolating the joists from crawl space conditions by covering them with closed cell foam could reasonably be expected to limit the peak moisture content they reach during summer months. In contrast, in open crawl spaces, both temperature and vapor pressure are very similar to outdoor conditions, and thus seasonal peak moisture content of the floor joists is expected to remain in a safe range. For this reason, covering the joists in open crawl spaces with closed cell foam is not expected to provide substantial benefits.*

3. Will covering floor joists with spray foam increase the risk of termite infestation?

Answer: Covering the joists with spray foam can interfere with performing periodic inspections for termites. The degree of risk concerning termite infestation depends on location of the joists and whether they are preservative treated. Joists that are in contact with piers – or near perimeter walls in the case of wall-vented crawl spaces – have the potential to serve as infestation routes. If joists are not pressure treated, spraying them with borate preservative coating will substantially lower infestation risk. Homeowners who have contracts with pest control operators for termite inspection should follow the contract terms.

4. What is a suitable time of year to install closed cell spray foam insulation?

Answer: In a new home that is not yet occupied, the season for installation would not appear to matter, although it is important to ensure that the floor system is adequately dry before installing the insulation. A floor deck that was constructed with wet lumber or that was exposed to rain before the building was enclosed should be allowed to dry. In an existing occupied home that is air-conditioned during the summer, installation would be best done during late fall, winter or early spring. The floor system moisture content at time of installation will be less important if the interior floor covering is vapor-permeable.

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DIVISION 5. PROVISIONS FOR FLOOD HAZARD REDUCTION

Sec. 9-70.17. General standards.

In all areas of special flood hazards, the following provisions are required for all new construction and substantial improvements:

(1) All new construction or substantial improvements shall be designed (or modified) and adequately anchored to prevent flotation, collapse or lateral movement of the structure resulting from hydrodynamic and hydrostatic loads, including the effects of buoyancy;

(2) All new construction or substantial improvements shall be constructed by methods and practices that minimize flood damage;

(3) All new construction or substantial improvements shall be constructed with materials resistant to flood damage;

(4) All new construction or substantial improvements shall be constructed with electrical, heating, ventilation, plumbing and air conditioning equipment and other service facilities that are designed and/or located so as to prevent water from entering or accumulating within the components during conditions of flooding;

(5)

All new and replacement water supply systems shall be designed to minimize or eliminate infiltration of floodwaters into the system;

(6)

New and replacement sanitary sewage systems shall be designed to minimize or eliminate infiltration of floodwaters into the system and discharge from the system into floodwaters; and

(7)

On-site waste disposal systems shall be located to avoid impairment to them or contamination from them during flooding.

(Ord. No. 87-012, § 7, 3-30-1987)

Sec. 9-70.18. Specific standards.

In all areas of special flood hazards where base flood elevation data has been provided as set forth in division 3, section 9-70.7, division 4, section 9-70.14, subsection (8), or division 5, section 9-70.19, subsection (d), the following provisions are required:

(1)

Residential construction. New construction and substantial improvement of any residential structure shall have the lowest floor (including basement) elevated as a minimum, to one foot above the highest of the base flood elevation shown on the effective FIRM and the Flood Hazard Recovery Data Map. A registered professional engineer, architect or land surveyor shall submit a certification to the floodplain administrator that the standard of this subsection, as proposed in division 4,section 9-70.15, subsection (a)(1), is satisfied.

(Ord. No. 04-032, § 3, 6-7-2004)

(2)

Nonresidential construction. New construction and substantial improvement of any commercial, industrial or other nonresidential structure shall either have the lowest floor (including basement) elevated to one foot above the highest of the base flood elevation shown on the effective FIRM and the Flood Hazard Recovery Data Map or, together with attendant utility and sanitary facilities, be designed so that below the base flood level the structure is watertight with walls substantially impermeable to the passage of water and with structural components having the capability of resisting hydrostatic and hydrodynamic loads and effects of buoyancy. A registered professional engineer or architect shall develop and/or review structural design, specifications and plans for the construction, and shall certify that the design and methods of construction are in accordance with accepted standards of practice as outlined in this subsection. A record of such certification which includes the specific elevation (in relation to mean sea level) to which such structures are floodproofed shall be maintained by the floodplain administrator.

(Ord. No. 04-032, § 3, 6-7-2004)

(3)

Enclosures. New construction and substantial improvements, with fully enclosed areas below the lowest floor that are usable solely for parking of vehicles, building access or storage in an area other than a basement and hydrostatic flood forces on exterior walls by allowing for the entry and exit by a registered professional engineer or architect or meet or exceed the following minimum criteria:

a.

A minimum of two openings having a total net area of not less than one square inch for every square foot of enclosed area subject to flooding shall be provided;

b.

The bottom of all openings shall be no higher than four inches above grade;

(Ord. No. 05-045, § 2, 7-11-2005)

c.

Openings may be equipped with screens, louvers, valves or other coverings or devices provided that they permit the automatic entry and exit of floodwaters.

(Ord. No. 00-028, 4-17-2000)

(4)

Manufactured homes.

a.

Require that all manufactured homes to be placed within Zone A on a community's FHBM or FIRM shall be installed using methods and practices which minimize flood damage. For the purpose of this requirement, manufactured homes must be elevated and anchored to resist flotation, collapse or lateral movement. Methods of anchoring may include, but are not limited to, use of over-the-top or frame ties to ground anchors. This requirement is in addition to applicable State and local anchoring requirements for resisting wind forces.

b.

Require that manufactured homes that are placed or substantially improved within Zones A1-30, AH, and AE on the community's FIRM on sites: (i) outside of a manufactured home park or subdivision, (ii) in a new manufactured home park or subdivision, (iii) in an expansion to an existing manufactured home park or subdivision, or (iv) in an existing manufactured home park or subdivision on which a manufactured home has incurred "substantial damage" as a result of a flood, be elevated on a permanent foundation such that the lowest floor of the manufactured home is elevated to or above the base flood elevation and be securely anchored to an adequately anchored foundation system to resist flotation, collapse, and lateral movement.

c.

Require that all manufactured homes be placed or substantially improved on sites in an existing manufactured home park or subdivision with Zones A1-30, AH and AE on the community's FIRM that are not subject to the provision of subpart (4) of this section be elevated so that either:

(i)

The manufactured home shall have the lowest floor elevated as a minimum, to one foot above the highest of the base flood elevation shown on the effective FIRM and the Flood Hazard Recovery Data Maps flood elevation, or

(ii)

The manufactured home chassis is supported by reinforced piers or other foundation elements of at least equivalent strength that are no less than 36 inches in height above grade and be securely anchored to an adequately anchored foundation system to resist flotation, collapse, and lateral movement.

(5)

Recreational vehicles. Require that recreational vehicles placed on sites within Zones A1-30, AH, and AE on the community's FIRM either: (i) be on the site for fewer than 180 consecutive days, (ii) be fully licensed and ready for highway use, or (iii) meet the permit requirements of article 4, section C(1), and the elevation and anchoring requirements for "manufactured homes" in subsection (4) of this section. A recreational vehicle is ready for highway use if it is on its wheels or jacking system, is attached to the site only by quick disconnect type utilities and security devices, and has no permanently attached additions.

(Ord. No. 87-012, § 8, 3-30-1987; Ord. No. 96-063, 11-4-1996; Ord. No. 00-028, 4-17-2000; Ord. No. 07-063, § 1(App. A), 11-5-2007)

Sec. 9-70.19. Standards for subdivision proposals.

(a)

All subdivision proposals including manufactured home parks and subdivisions shall be consistent with division 1, sections 9-70.2, 9-70.3 and 9-70.4 of this article.

(b)

All proposals for the development of subdivisions including manufactured home parks and subdivisions shall meet development permit requirements of division 3, section 9-70.8, division 4, section 9-70.15 and the provisions of division 5 of this article.

(c)

Base flood elevation data shall be generated for subdivision proposals and other proposed development including manufactured home parks and subdivisions which is greater than 50 lots or five acres, whichever is lesser, if not otherwise provided pursuant to division 3, section 9-70.7 or division 4, section 9-70.14, subsection (8) of this article.

(d)

All subdivision proposals including manufactured home parks and subdivisions shall have adequate drainage provided to reduce exposure to flood hazards.

(e)

All subdivision proposals including manufactured home parks and subdivisions shall have public utilities and facilities such as sewer, gas, electrical and water systems located and constructed to minimize or eliminate flood damage.

(Ord. No. 87-012, § 9, 3-30-1987)

Sec. 9-70.20. Standards for areas of shallow flooding (AO/AH Zones).

Located within the areas of special flood hazard established in division 3, section 9-70.7, the areas designated as shallow flooding. These areas have special flood hazards associated with base flood depths of one to three feet where a clearly defined channel does not exist and where the path of flooding is unpredictable and where velocity flow may be evident. Such flooding is characterized by ponding or sheet flow; therefore, the following provisions apply:

(1)

All new construction and substantial improvements of residential structures have the lowest floor (including basement) elevated above the highest adjacent grade at least as high as the depth number specified in feet on the community's FIRM (at least two feet if no depth number is specified):

(2)

All new construction and substantial improvements of nonresidential structures:

a)

Have the lowest floor (including basement) elevated above the highest adjacent grade at least as high as the depth number specified in feet on the community's FIRM (at least two feet if no depth number is specified); or

b)

Together with attendant utility and sanitary facilities be designed so that below the base flood level the structure is watertight with walls substantially impermeable to the passage of water and with structural components having the capability of resisting hydrostatic and hydrodynamic loads of effects of buoyancy;

(3)

A registered professional engineer or architect shall submit a certification to the floodplain administrator that the standards of this section, as proposed in division 4, section 9-70.15, subsection (a)(1), are satisfied;

(4)

Require within Zones AH or AO adequate drainage paths around structures on slopes, to guide floodwaters around and away from proposed structures.

Sec. 9-18. Drainage requirements for residential construction.

(a)

Requirement for a drainage plan. Before a construction permit will be issued, a drainage plan must be approved for all residential sites requiring a permit for the construction of improvements or additions if 25 percent or 1,500 square feet, whichever is smaller, of the lot will be disturbed or regraded.

(b)

Objectives of drainage plan.

(1)

Prevent stormwater from flowing onto adjacent property unless appropriate drainage easement agreement is obtained; and

(2)

Control fill that may increase flood damage.

(c)

Definitions. Unless specifically defined below, words or phrases used in this section shall be interpreted to give them the meaning they have in common usage and to give this section its most reasonable application.

(1)

Special flood hazard area means the land in the floodplain subject to a one percent or greater chance of flooding in any given year.

(2)

Base flood means the flood having a one percent chance of being equaled or exceeded in any given year.

(3)

Structure means any area of a walled or roofed building.

(4)

Elevated structure means any area of a walled or roofed building having the bottom of the lowest horizontal structure member of the floor elevated above the ground.

(5)

Two-year frequency means a rainfall intensity having a 50 percent probability of occurrence in any given year that occurs on the average of every two years over a long period of time.

(6)

No net increase means that the volume of material placed on a lot at any time must not be greater than the amount of material removed from the lot during demolition and subsequent grading operations.

(7)

Fill credit means the volume of material removed from the lot during demolition of an existing structure that may be imported onto the lot for construction, grading and drainage purposes. The fill credit may be determined using the chart maintained by the building official or by calculating the volume of material removed from the lot during demolition and subsequent grading operations. Any fill above the base flood elevation (BFE) will not count against the fill credit for the lot.

(Ord. No. 05-024, § 2, 4-18-2005; Ord. No. 05-044, § 2, 7-11-2005; Ord. No. 05-085, § 2, 12-7-2005)

(8)

Pier and beam foundation construction means the floor of the structure is elevated above the ground, supported by a number of piers and beams, such that floodwaters may rise and recede under the floor of the structure. The area under the structure should be graded such that water will not pond.

(9)

The height to which any point on the lot, other than the foundation, may be filled is limited to an elevation calculated by multiplying the distance from the curb by one percent per foot and adding the top of curb elevation. Existing elevations which are higher than the calculated elevations are not required to be cut to meet the requirements of this section. The calculation only applies to fill above the existing elevation. The one percent does not apply to proposed interior grades or cross-slopes of swales. In no case shall any point on the lot be filled more than eight inches above the existing (pre-construction) elevations.

(Ord. No. 05-044, § 2, 7-11-2005)

(10)

A lot on which more than four inches of fill is placed shall be required to install pressure-treated rot boards or retaining walls on either side of the area in which the fill increases the elevation of the lot above that of its neighbors. Rot board or retaining wall height in front of the building line is limited to one inch above finished grade.

(Ord. No. 05-044, § 2, 7-11-2005)

(11)

Yard Amenities are defined as pools, spas, fountains, waterfalls, outdoor kitchens, barbeque pits, fireplaces and other similar outdoor raised features.

The one percent and eight inch maximum fill limit does not apply to yard amenities.

(Ord. No. 05-085, § 2, 12-7-2005)

(d)

Contents of drainage plan.

(1)

Survey and elevation data. The drainage plan shall include data obtained by a topographical survey performed under the supervision of and signed, sealed and dated by a professional land surveyor registered in the State of Texas. The topographical survey shall include as a minimum, the location and elevation of existing sidewalks, curb/gutters, ditches, storm sewers, sanitary sewers and the existing elevations of the lot. The survey should be completed prior to demolition of any structures on the property to provide baseline conditions to establish the fill credit for the property. The elevations shall be based on the current datum and vertical benchmark system being used by the city and should be at a maximum spacing of 20 feet throughout the property. The city will furnish, upon request, location and elevation of benchmarks available within the city. The drainage plan shall show the proposed finished floor elevation and the finished grade elevations of all proposed paving and grading on the site and shall include existing and planned spot elevations at a maximum of 20 feet spacing covering the lot:

a.

Along the perimeter of the lot;

b.

Grid across the lot; and

c.

Finished floor and adjacent finished grade along the perimeter of all slabs, including but not limited to buildings, sidewalks, patios, driveways, and decks.

(2)

Requirement to drain. Drainage of the lot may be obtained by surface or subsurface means, or a combination of the two, as is appropriate and necessary so that the stormwater falling on the residential lot upon which construction is planned will drain into the street, ditch or storm sewer system of the city and not onto adjacent property. However, as a minimum requirement, each lot will be required to provide drainage on each side, or in the case of a corner lot, on the sides adjoining the adjacent lots, designated to carry the two year design storm, sloping to the street, ditch, or storm sewer. Cross sectional elevation of the swale shall be shown on the drainage plan at three points: at the house, at the swale flow line, and at the side property line. A minimum of three elevations are required to adequately define a swale cross section. The engineer preparing the drainage plan shall provide supporting calculations to demonstrate that the drainage system meets the design criteria. Cross section elevations of a swale shall be provided at the front property line, the front of the house, the midpoint of the house, the back of the house and at the beginning of the swale.

(3)

Limitation on lot fill for property located in the special flood hazard area.

a.

Option 1 - Elevated structure without fill. The proposed improvements to a property shall result in no net increase in volume of material on the lot with the exception of the small amount of concrete used for pier and beam foundation construction that may be permitted by the building official. The fill credit volume may be used to increase the elevation of the lot no more than the amount needed to create a maximum elevation equal to a one percent slope from the existing street, top of curb, edge of road (if no curb exists) or existing ditch high bank, but in no case shall more than eight inches of fill be allowed. The engineer preparing the drainage plan must provide calculations and supporting data demonstrating that no net increase in volume of material is proposed.

b.

Option 2 - Elevated structure with fill. If the existing ground elevation at the proposed structure is equal to or above the base flood elevation (BFE) and the finished floor of the proposed structure will be elevated to one foot above the BFE by means of fill, then no additional fill on the lot will be allowed. Any volume of material used to raise the existing lot elevation to the one percent or eight inch maximum fill limit for grading and drainage purposes must be mitigated by lowering the finished grade below the existing (pre-construction) elevation elsewhere on the lot. The engineer preparing the drainage plan must provide calculations and supporting data demonstrating that no net increase in volume of material is proposed with the exception of raising the finished floor to one foot above the BFE.

(Ord. No. 05-024, § 2, 4-18-2005; Ord. No. 05-044, § 3, 7-11-2005)

(4)

Limitations on lot fill for property not located in the special flood hazard area. Lot fill shall be limited to no more than the amount necessary to achieve adequate drainage based on generally accepted engineering design practices but no more than the amount needed to create a maximum elevation equal to a one percent slope from the existing street, top of curb, edge of road (if no curb exists) or existing ditch high bank. In no case shall more than eight inches of fill be allowed on any lot.

(Ord. No. 05-024, § 2, 4-18-2005; Ord. No. 05-044, § 3, 7-11-2005)

(5)

Engineer's seal. The drainage plan shall be prepared, certified, sealed and signed by a civil engineer licensed as a professional engineer in the State of Texas.

(e)

Certificate of occupancy. As a condition precedent to the issuance of any certificate of occupancy, a second topographical survey shall be made under the supervision of a registered professional land surveyor registered in the State of Texas which shall show the "as-built" elevation of the residence and the finished grade elevations of the lot, patios, drives, sidewalks, landscaped areas, etc. A civil engineer licensed as a Professional Engineer in the State of Texas shall review the "as-built" survey for conformance with the approved drainage plan. The Engineer or an Engineer-in-Training in his employ shall conduct a site visit of the location shown on the survey at a date equal to or after the date of the "as-built" survey. The Engineer shall draft a letter with the following statement to be attached to and submitted with the "as-built" survey:

I, ____________, a Professional Engineer licensed in the State of Texas, have reviewed the "as-built" survey of this property and, on the basis of that review and a visit to the site, state that it conforms to the design and intent of the approved drainage plan submitted for permit and is in compliance with Chapter 9, Buildings, Section 9-18, Drainage requirements for residential construction, of the Code of Ordinances of the City of Bellaire, Texas.

_____ (Date)	_____ (Seal & Signature)

The Building Official shall deny a Certificate of Occupancy until the "as-built" survey and the Engineer's statement have been properly submitted and approved.

(Ord. No. 10-037, § 1(App. A), 6-7-2010)

(f)

Duty to maintain drainage. All drainage improvements detailed in the drainage plan must be maintained to prevent stormwater runoff from flowing onto adjacent property.

Interim measures to prevent stormwater from flowing onto adjacent properties shall be provided and maintained during construction. It is the responsibility of the owner and all subsequent owners to maintain the drainage on their property and to assure that no additional fill is added over the amount in the approved drainage plan. No alterations to the approved drainage plan shall be performed without first having submitted a revised drainage plan and obtaining the proper approval. The city building official shall maintain a copy of all drainage plans approved by the city.

(g)

Penalties. Any owner or agent of a residential building site or lot for which a drainage plan is required that fails to comply with, or is in violation of, any of the requirements or provisions of this section, or fails to maintain the approved drainage, shall be subject to a fine in an amount not to exceed $500.00. Each day during which any such violation is committed or continues shall be considered a separate offense.

(h)

Variance.

(1)

Where a baseline fill credit does not exist, as in the case of remodeling or yard amenity addition, the building official may allow excess fill credit for yard amenities, based upon the facts and circumstances of each application, as long as the objectives of the drainage plan continue to be met.

(2)

The building and standards commission of the city, upon application and hearing, shall have the power and authority to allow a variance from the requirements of this section upon a finding that the strict application of the requirements of this section will affect a hardship of the property and that the proposed design complies with the spirit and intent of this section and provides protection to the neighboring properties at least equivalent to that provided by this section. The building and standards commission shall require that sufficient evidence or proof be submitted to substantiate any claims that may be made regarding such applications.

(Ord. No. 05-024, § 2, 4-18-2005; Ord. No. 05-085, § 3, 12-7-2005)

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Insulations, Sheathings and Vapor Retarders

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Joseph Lstiburek

Abstract:

Two seemingly innocuous requirements for building enclosure assemblies bedevil builders and designers almost endlessly: keep water vapor out, let the water vapor out if it gets in. It gets complicated because, sometimes, the best strategies to keep water vapor out also trap water vapor in.

Insulations, Sheathings and Vapor Retarders

Two seemingly innocuous requirements for building enclosure assemblies bedevil builders and designers almost endlessly:

- keep water vapor out
- let the water vapor out if it gets in

It gets complicated because, sometimes, the best strategies to keep water vapor out also trap water vapor in. This can be a real problem if the assemblies start out wet because of rain or the use of wet materials (wet framing, concrete, masonry or damp spray cellulose, fiberglass or rock wool cavity insulation).

It gets even more complicated because of climate. In general, water vapor moves from the warm side of building assemblies to the cold side of building assemblies. This means we need different strategies for different climates. We also have to take into account differences between summer and winter.

The good news is that water vapor moves only two ways - vapor diffusion and air transport. If we understand the two ways, and know where we are (climate zone) we can solve the problem.

The bad news is that techniques that are effective at controlling vapor diffusion can be ineffective at controlling air transported moisture, and vice versa.

Building assemblies, regardless of climate zone, need to control the migration of moisture as a result of both vapor diffusion and air transport. Techniques that are effective in controlling vapor diffusion can be very different from those that control air transported moisture.

Vapor Diffusion and Air Transport of Vapor

Vapor diffusion is the movement of moisture in the vapor state through a material as a result of a vapor pressure difference (concentration gradient) or a temperature difference (thermal gradient). It is often confused with the movement of moisture in the vapor state into building assemblies as a result of air movement. Vapor diffusion moves moisture from an area of higher vapor pressure to an area of lower vapor pressure as well as from the warm side of an assembly to the cold side. Air transport of moisture will move moisture from an area of higher air pressure to an area of lower air pressure if moisture is contained in the moving air (Figure 1).

Vapor pressure is directly related to the concentration of moisture at a specific location. It also refers to the density of water molecules in air. For example, a cubic foot of air containing 2 trillion molecules of water in the vapor state has a higher vapor pressure (or higher water vapor density) than a cubic foot of air containing 1 trillion molecules of water in the vapor state. Moisture will migrate by diffusion from where there is more moisture to where there is less. Hence, moisture in the vapor state migrates by diffusion from areas of higher vapor pressure to areas of lower vapor pressure.

Moisture in the vapor state also moves from the warm side of an assembly to the cold side of an assembly. This type of moisture transport is called thermally driven diffusion.

The second law of thermodynamics governs the exchange of energy and can be used to explain the concept of both vapor pressure driven diffusion and thermally driven diffusion. The movement of moisture from an area of higher vapor pressure to an area of lower vapor pressure as well as from the warm side of an assembly to the cold side of an assembly is a minimization of available "system" energy (or an increase in entropy).

When temperature differences become large, water vapor can condense on cold surfaces. When condensation occurs, water vapor is removed from the air and converted to liquid moisture on the surface resulting in a reduction in water vapor density in the air near the cold surface (i.e. a lower vapor pressure). These cold surfaces now act as "dehumidifiers" pulling more moisture towards them.

Vapor diffusion and air transport of water vapor act independently of one another. Vapor diffusion will transport moisture through materials and assemblies in the absence of an air pressure difference if a vapor pressure or temperature difference exists. Furthermore, vapor diffusion will transport moisture in the opposite direction of small air pressure differences, if an opposing vapor pressure or temperature difference exists. For example, in a hot-humid climate, the exterior is typically at a high vapor pressure and high temperature during the summer. In addition, it is common for an interior air conditioned space to be maintained at a cool temperature and at a low vapor pressure through the dehumidification characteristics of the air conditioning system. This causes vapor diffusion to move water vapor from the exterior towards the interior. This will occur even if the interior conditioned space is maintained at a higher air pressure (a pressurized enclosure) relative to the exterior (Figure 2).

Vapor Retarders

The function of a vapor retarder is to control the entry of water vapor into building assemblies by the mechanism of vapor diffusion. The vapor retarder may be required to control the diffusion entry of water vapor into building assemblies from the interior of a building, from the exterior of a building or from both the interior and exterior.

Vapor retarders should not be confused with air barriers whose function is to control the movement of air through building assemblies. In some instances, air barrier systems may also have specific material properties which also allow them to perform as vapor retarders. For example, a rubber membrane on the exterior of a masonry wall installed in a continuous manner is a very effective air barrier. The physical properties of rubber also give it the characteristics of a vapor retarder; in fact, it can be considered a vapor "barrier." Similarly, a continuous, sealed polyethylene ground cover installed in an unvented, conditioned crawlspace acts as both an air barrier and a vapor retarder; and, in this case, it is also a vapor "barrier." The opposite situation is also common. For example, a building paper or a housewrap installed in a continuous manner can be a very effective air barrier. However, the physical properties of most building papers and housewraps (they are vapor permeable - they "breathe") do not allow them to act as effective vapor retarders.

Water Vapor Permeability

The key physical property which distinguishes vapor retarders from other materials, is permeability to water vapor. Materials which retard water vapor flow are said to be impermeable. Materials which allow water vapor to pass through them are said to be permeable. However, there are degrees of impermeability and permeability and the classification of materials typically is quite arbitrary. Furthermore, under changing conditions, some materials that initially are "impermeable," can become "permeable." Hygroscopic materials change their permeability characteristics as relative humidity increases. For example, plywood sheathing under typical conditions is relatively impermeable. However, once plywood becomes wet, it can become relatively permeable. As a result we tend to refer to plywood as a vapor semi-permeable material.

Non-hygroscopic materials such as polyethylene or plastic housewraps do not change their permeability as a function of relative humidity.

The unit of measurement typically used in characterizing permeability is a "perm." Many building codes define a vapor retarder as a material that has a permeability of one perm or less as tested under dry cup test method.

Materials are typically tested in two ways to determine permeability: dry cup testing and wet cup testing. Some confusion occurs when considering the difference between wet cup perm ratings and dry cup perm ratings. A wet cup test is conducted with 50 percent relative humidity maintained on one side of the test sample and 100 percent relative humidity maintained on the other side of the test sample. A dry cup test is conducted with 0 percent relative humidity maintained on one side of the test sample and 50 percent relative humidity maintained on the other side of the test sample.

Different values are typical between the two tests for materials that absorb and adsorb water — materials that are hygroscopic. As the quantity of adsorbed water on the surface of hygroscopic materials increases, the vapor permeability of the materials also increases. In other words, for hygroscopic materials, the vapor permeability goes up as the relative humidity goes up.

In general, for hygroscopic materials, the wet cup test provides perm ratings many times the dry cup test values. For non-hygroscopic materials, materials that are hydrophobic, there is typically no difference between wet cup and dry cup test results. For plywood, a hygroscopic material, a dry cup permeability of 0.5 perms is common. However, as the plywood gets wet, it "breathes" and wet cup permeabilities of 3 perms or higher are common.

Materials can be separated into four general classes based on their permeance:

• vapor impermeable	0.1 perm or less
• vapor semi-impermeable	1.0 perms or less and greater than 0.1 perm
• vapor semi-permeable	10 perms or less and greater than 1.0 perm
• vapor permeable	greater than 10 perms

Materials that are generally classed as impermeable to water vapor are:

- rubber membranes,
- polyethylene film,
- glass,
- aluminum foil,
- sheet metal,
- foil-faced insulating sheathings, and
- foil-faced non-insulating sheathings.

Materials that are generally classed as vapor semi-impermeable to water vapor are:

- oil-based paints,
- most vinyl wall coverings,
- unfaced extruded polystyrene greater than 1-inch thick, and
- traditional hard-coat stucco applied over building paper and OSB sheathing.

Materials that are generally classed as vapor semi-permeable to water vapor are:

- plywood,
- bitumen impregnated kraft paper,
- OSB,
- unfaced expanded polystyrene (EPS),
- unfaced extruded polystyrene (XPS)— 1-inch thick or less,
- fiber-faced isocyanurate,
- heavy asphalt impregnated building papers (#30 building paper), and
- most latex-based paints.

Depending on the specific assembly design, construction and climate, all of these materials may or may not be considered to act as vapor retarders. Typically, these materials are considered to be more vapor permeable than vapor impermeable. Again, however, the classifications tend to be quite arbitrary.

Materials that are generally classed as permeable to water vapor are:

- unpainted gypsum board and plaster,
- unfaced fiberglass insulation,
- cellulose insulation,
- synthetic stucco,
- some latex-based paints,
- lightweight asphalt impregnated building papers (#15 building paper),
- asphalt impregnated fiberboard sheathings, and
- "housewraps."

Part of the problem is that we struggle with names and terms. We use the terms vapor retarder and vapor barrier interchangeably. This can get us into serious trouble. Defining these terms is important.

A vapor retarder is the element that is designed and installed in an assembly to retard the movement of water by vapor diffusion. There are several classes of vapor retarders:

Class I vapor retarder	0.1 perm or less
Class II vapor retarder	1.0 perm or less and greater than 0.1 perm
Class III vapor retarder	10 perms or less and greater than 1.0 perm

(Test procedure for vapor retarders: ASTM E-96 Test Method A — the desiccant or dry cup method.)

Finally, a vapor barrier is defined as:

Vapor barrier	A Class I vapor retarder

The current International Building Code (and its derivative codes) defines a vapor retarder as 1.0 perms or less using the same test procedure. In other words, the current code definition of a vapor retarder is equivalent to the definition of a Class II vapor retarder used here.

Air Barriers

The key physical properties which distinguish air barriers from other materials are continuity and the ability to resist air pressure differences. Continuity refers to holes, openings and penetrations. Large quantities of moisture can be transported through relatively small openings by air transport if the moving air contains moisture and if an air pressure difference also exists. For this reason, air barriers must be installed in such a manner that even small holes, openings and penetrations are eliminated.

Air barriers must also resist the air pressure differences that act across them. These air pressure differences occur as a combination of wind, stack and mechanical system effects. Rigid materials such as interior gypsum board, exterior sheathing and rigid draftstopping materials are effective air barriers due to their ability to resist air pressure differences.

Magnitude of Vapor Diffusion and Air Transport of Vapor

The differences in the significance and magnitude vapor diffusion and air transported moisture are typically misunderstood. Air movement as a moisture transport mechanism is typically far more important than vapor diffusion in many (but not all) conditions. The movement of water vapor through a 1-inch square hole as a result of a 10 Pascal air pressure differential is 100 times greater than the movement of water vapor as a result of vapor diffusion through a 32-square-foot sheet of gypsum board under normal heating or cooling conditions (see Figure 4).

In most climates, if the movement of moisture-laden air into a wall or building assembly is eliminated, movement of moisture by vapor diffusion is not likely to be significant. The notable exceptions are hot-humid climates or rain wetted walls experiencing solar heating.

Furthermore, the amount of vapor which diffuses through a building component is a direct function of area. That is, if 90 percent of the building enclosure surface area is covered with a vapor retarder, then that vapor retarder is 90 percent effective. In other words, continuity of the vapor retarder is not as significant as the continuity of the air barrier. For instance, polyethylene film which may have tears and numerous punctures present will act as an effective vapor barrier, whereas at the same time it is a poor air barrier. Similarly, the kraft-facing on fiberglass batts installed in exterior walls acts as an effective vapor retarder, in spite of the numerous gaps and joints in the kraft-facing.

It is possible and often practical to use one material as the air barrier and a different material as the vapor retarder. However, the air barrier must be continuous and free from holes, whereas the vapor retarder need not be.

In practice, it is not possible to eliminate all holes and install a "perfect" air barrier. Most strategies to control air transported moisture depend on the combination of an air barrier, air pressure differential control and interior/exterior moisture condition control in order to be effective. Air barriers are often utilized to eliminate the major openings in building enclosures in order to allow the practical control of air pressure differentials. It is easier to pressurize or depressurize a building enclosure made tight through the installation of an air barrier than a leaky building enclosure. The interior moisture levels in a tight building enclosure are also much easier to control by ventilation and dehumidification than those in a leaky building enclosure.

Combining Approaches

In most building assemblies, various combinations of materials and approaches are often incorporated to provide for both vapor diffusion control and air transported moisture control. For example, controlling air transported moisture can be accomplished by controlling the air pressure acting across a building assembly. The air pressure control is facilitated by installing an air barrier such as glued (or gasketed) interior gypsum board in conjunction with draftstopping. For example, in cold climates during heating periods, maintaining a slight negative air pressure within the conditioned space will control the exfiltration of interior moisture-laden air. However, this control of air transported moisture will not control the migration of water vapor as a result of vapor diffusion. Accordingly, installing a vapor retarder towards the interior of the building assembly, such as the kraft paper backing on fiberglass batts is also typically necessary. Alternatives to the kraft paper backing are low permeability paint on the interior gypsum board surfaces.

In the above example, control of both vapor diffusion and air transported moisture in cold climates during heating periods can be enhanced by maintaining the interior conditioned space at relatively low moisture levels through the use of controlled ventilation and source control. Also, in the above example, control of air transported moisture during cooling periods (when moisture flow is typically from the exterior towards the interior) can be facilitated by maintaining a slight positive air pressure across the building enclosure thereby preventing the infiltration of exterior, hot, humid air.

Overall Strategy

Building assemblies need to be protected from wetting by air transport and vapor diffusion. The typical strategies used involve vapor retarders, air barriers, air pressure control, and control of interior moisture levels through ventilation and dehumidification via air conditioning. The location of air barriers and vapor retarders, pressurization versus depressurization, and ventilation versus dehumidification depend on climate location and season.

The overall strategy is to keep building assemblies from getting wet from the interior, from getting wet from the exterior, and allowing them to dry to either the interior, exterior or both should they get wet or start out wet as a result of the construction process or through the use of wet materials.

In general moisture moves from warm to cold. In cold climates, moisture from the interior conditioned spaces attempts to get to the exterior by passing through the building enclosure. In hot climates, moisture from the exterior attempts to get to the cooled interior by passing through the building enclosure.

Cold Climates

In cold climates and during heating periods, building assemblies need to be protected from getting wet from the interior. As such, vapor retarders and air 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 control of moisture entry from the interior by installing interior vapor retarders, interior air barriers along with 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 should they get wet. In cold climates and during heating periods, building assemblies dry towards the exterior. Therefore, permeable ("breathable") materials are often specified as exterior sheathings.

In general, in cold climates, air barriers and vapor retarders are installed on the interior of building assemblies, and building assemblies are allowed to dry to the exterior by installing permeable sheathings and building papers/housewraps towards the exterior. A "classic" cold climate wall assembly is presented in Figure 5.

Hot Climates

In hot climates and during cooling periods the opposite is true. Building assemblies need to be protected from getting wet from the exterior, and allowed to dry towards the interior. Accordingly, air barriers and vapor retarders are installed on the exterior of building assemblies, and building assemblies are allowed to dry towards the interior by using permeable interior wall finishes, installing cavity insulations without vapor retarders (unfaced fiberglass batts) and avoiding interior "non-breathable" wall coverings such as vinyl wallpaper. Furthermore, conditioned spaces are maintained at a slight positive air pressure with conditioned (dehumidified) air in order to limit the infiltration of exterior, warm, potentially humid air (in hot, humid climates rather than hot, dry climates). A "classic" hot climate wall assembly is presented in Figure 6.

Mixed Climates

In mixed climates, the situation becomes more complicated. Building assemblies need to be protected from getting wet from both the interior and exterior, and be allowed to dry to either the exterior, interior or both. Three general strategies are typically employed:

- Selecting either a classic cold climate assembly or classic hot climate assembly, using air pressure control (typically only pressurization during cooling), using interior moisture control (ventilation/air change during heating, dehumidification/air conditioning during cooling) and relying on the forgiveness of the classic approaches to dry the accumulated moisture (from opposite season exposure) to either the interior or exterior. In other words the moisture accumulated in a cold climate wall assembly exposed to hot climate conditions is anticipated to dry towards the exterior when the cold climate assembly finally sees heating conditions, and vice versa for hot climate building assemblies;
- 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 would be from the interior to exterior during heating periods, and from the exterior towards the interior during cooling periods. In this approach air pressure control and using interior moisture control would also occur. The location of the air barrier can be towards the interior (sealed interior gypsum board), or towards the exterior (sealed exterior sheathing). A "classic" flow-through wall assembly is presented in Figure 7; or
- Installing the vapor retarder roughly in the middle of the assembly from a thermal perspective. This is typically accomplished by installing impermeable or semi-impermeable insulating sheathing on the exterior of a frame cavity wall (see Figure 8). For example, installing 1.5 inches of foil-faced insulating sheathing (approximately R-10) on the exterior of a 2x6 frame cavity wall insulated with unfaced fiberglass batt insulation (approximately R-19). The vapor retarder is the interior face of the exterior impermeable insulating sheathing (Figure 8). If the wall assembly total thermal resistance is R-29 (R-19 plus R-10), the location of the vapor retarder is 66 percent of the way (thermally) towards the exterior (19/29 = .66). In this approach air pressure control and utilizing interior moisture control would also occur. The location of the air barrier can be towards the interior or exterior.

The advantage of the wall assembly described in Figure 8 is that an interior vapor retarder is not necessary. In fact, locating an interior vapor retarder at this location would be detrimental, as it would not allow the wall assembly to dry towards the interior during cooling periods. The wall assembly is more forgiving without the interior vapor retarder than if one were installed. If an interior vapor retarder were installed, this would result in a vapor retarder on both sides of the assembly significantly impairing durability.

Note that this discussion relates to a wall located in a mixed climate with an exterior impermeable or semi-impermeable insulating sheathing. Could a similar argument be made for a heating climate wall assembly? Could we construct a wall in a heating climate without an interior vapor retarder? How about a wall in a heating climate with an exterior vapor retarder and no interior vapor retarder? The answer is yes to both questions, but with caveats.

Control of Condensing Surface Temperatures

The performance of a wall assembly in a cold climate without an interior vapor retarder (such as the wall described in Figure 8) can be more easily understood in terms of condensation potentials and the control of condensing surface temperatures.

Figure 9 illustrates the performance of a 2x6 wall with semi-permeable OSB sheathing (perm rating of about 1.0 perms, dry cup; 2.0 perms, wet cup) covered with building paper and vinyl siding located in Chicago, IL. The interior conditioned space is maintained at a relative humidity of 35 percent at 70 degrees Fahrenheit. For the purposes of this example, it is assumed that no interior vapor retarder is installed (unpainted drywall as an interior finish over unfaced fiberglass, yech!). This illustrates a case we would never want to construct in a cold climate, a wall with a vapor retarder on the exterior (semi-permeable OSB sheathing and no vapor retarder on the interior.

The mean daily ambient temperature over a one-year period is plotted (Figure 9). The temperature of the insulation/OSB sheathing interface (back side of the OSB sheathing) is approximately equivalent to the mean daily ambient temperature, since the thermal resistance values of the siding, building paper and the OSB sheathing are small compared to the thermal resistance of the insulation in the wall cavity. The dew point temperature of the interior air/water vapor mix is approximately 40 degrees Fahrenheit (this can be found from examining a psychrometric chart). In other words, whenever the back side of the OSB sheathing drops below 40 degrees Fahrenheit, the potential for condensation exists at that interface should moisture migrate from the interior conditioned space via vapor diffusion or air movement.

From the plot it is clear that the mean daily temperature of the back side of the OSB sheathing drops below the dew point temperature of the interior air at the beginning of November and does not go above the dew point temperature until early March. The shaded area under the dew point line is the potential for condensation, or wetting potential for this assembly should moisture from the interior reach the back side of the OSB sheathing. With no interior vapor retarder, moisture from the interior will reach the back side of the plywood sheathing.

Figure 10 illustrates the performance of the wall assembly described in Figure 8, a 2x6 wall insulated on the exterior with 1.5 inches of rigid foil-faced impermeable insulating sheathing (approximately R-10, perm rating of about 0.1 perms, wet cup and dry cup), located in Chicago, IL. The wall cavity is insulated with unfaced fiberglass batt insulation (approximately R-19). Unpainted drywall is again the interior finish (no interior vapor retarder). Now this wall assembly also has a vapor retarder — in fact, it has a vapor barrier — on the exterior, but with a huge difference. This exterior vapor retarder (vapor barrier) has a significant insulating value since it is a rigid insulation. The temperature of the first condensing surface within the wall assembly, namely the cavity insulation/rigid insulation interface (the back side of the rigid insulation), is raised above the interior dew point temperature because of the insulating value of the rigid insulation. This illustrates a case we could construct in a cold climate, a wall with a "warm" vapor retarder (vapor barrier) on the exterior and no vapor retarder on the interior.

The temperature of the condensing surface (back side of the rigid insulation) is calculated in the following manner. Divide the thermal resistance to the exterior of the condensing surface by the total thermal resistance of the wall. Then multiply this ratio by the temperature difference between the interior and exterior. Finally, add this to the outside base temperature.

$$T_{(interface)} = R_{(exterior)} / R_{(total)} \times (T_{in} - T_{out}) + T_{out}$$

where:

- $T_{(interface)}$ = the temperature at the sheathing/insulation interface or the temperature of the first condensing surface
- $R_{(exterior)}$ = the R-value of the exterior sheathing
- $R_{(total)}$ = the total R-value of the entire wall assembly
- T_{in} = the interior temperature
- T_{out} = the exterior temperature

The R-10 insulating sheathing raises the dew point temperature at the first condensing surface so that no condensation will occur with interior conditions of 35 percent relative humidity at 70 degrees Fahrenheit. In other words, no interior vapor retarder of any kind is necessary with this wall assembly if the interior relative humidity is kept below 35 percent. This is a "caveat" for this wall assembly. Now remember, this wall is located in Chicago, IL. This is another "caveat" for this wall assembly.

What happens if we move this wall to Minneapolis? Big change. Minneapolis is a miserable place in the winter. The interior relative humidity would have to be kept below 25 percent to prevent condensation at the first condensing surface. What happens if we move the wall back to Chicago and install a modest interior vapor retarder, such as one coat of a standard interior latex paint (perm rating of about 5 perms) over the previously unpainted drywall (perm rating of 20)? If we control air leakage, interior relative humidities can be raised above 50 percent before condensation occurs.

What happens if we move this wall to Tupelo, MS, and reduce the thickness of the rigid insulation? Another big change. Tupelo has a moderate winter. Figure 11 illustrates the performance of a 2x6 wall insulated on the exterior with 1 inch of rigid extruded polystyrene insulating sheathing (approximately R-5, perm rating of about 1.0 perms, wet cup and dry cup), located in Tupelo.

In Tupelo, with no interior vapor retarder of any kind, condensation will not occur in this wall assembly until interior moisture levels are raised above 45 percent, 70 degrees Fahrenheit during the coldest part of the heating season. Since these interior conditions are not likely (or desirable), the potential for condensation in this wall assembly is small.

What happens if we move the wall assembly described in Figure 9 that experienced condensation in Chicago to Las Vegas, NV? No condensation results (see Figure 12) until interior moisture levels exceed 40 percent relative humidity at 70 degrees F. In Las Vegas, an interior vapor retarder is not necessary to control winter condensation where interior moisture levels are maintained below 40 percent relative humidity.

Sheathings and Cavity Insulations

Exterior sheathings can be permeable, semi-permeable, semi-impermeable, impermeable, insulating and non-insulating. Mixing and matching sheathings, building papers and cavity insulations should be based on climate location and therefore can be challenging. The following guidelines are offered:

- Impermeable and semi-impermeable non-insulating sheathings are not recommended in cold climates (inward drying reduced due to requirement for interior vapor retarder, condensing surface temperature not controlled due to use of non-insulating sheathing).
- Impermeable and semi-impermeable non-insulating sheathings are not recommended for use with damp spray cellulose cavity insulations in cold climates.
- Impermeable insulating sheathings should be of sufficient thermal resistance to control condensation at cavity insulation/sheathing interfaces.
- Permeable sheathings are not recommended for use with brick veneers and stuccos due to moisture flow reversal from solar radiation (sun heats wet brick driving moisture into wall assembly through permeable sheathing).

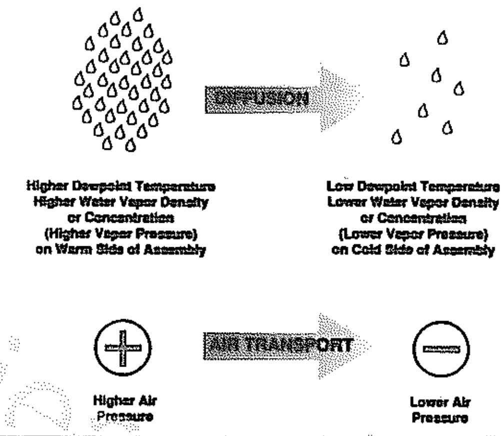

Figure 1
Water Vapor Movement
- Vapor diffusion is the movement of moisture in the vapor state as a result of a vapor pressure difference (concentration gradient) or a temperature difference (thermal gradient)
- Air transport is the movement of moisture in the vapor state as a result of an air pressure difference

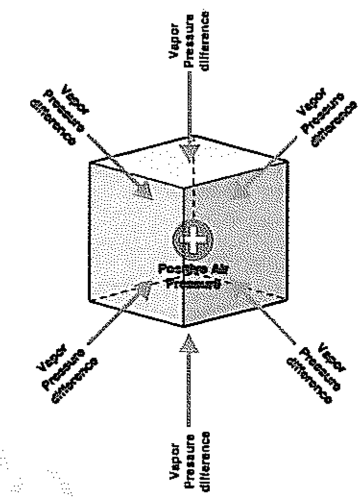

Figure 2
Opposing Air and Vapor Pressure Differences
- The atmosphere within the cube is under higher air pressure but lower vapor pressure relative to surroundings
- Vapor pressure acts inward in this example
- Air pressure acts outward in this example

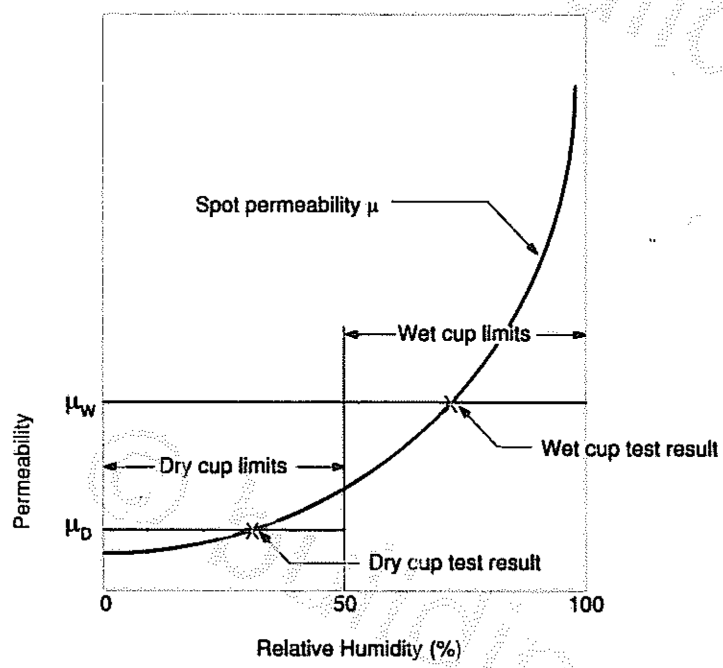

Figure 3
Permeability vs. Relative Humidity

- Typical relationship between dry- and wet-cup methods and spot permeability for many hygroscopic building materials such as asphalt impregnated felt building papers, plywood, OSB and kraft facings on insulation batts
- $\mu_W \approx$ 2 to 5 times greater than μ_D
- Wet cup testing occurs with 50% RH on one side of test specimen and 100% RH on other side
- Dry cup testing occurs with 0% RH on one side of test specimen and 50% RH on other side

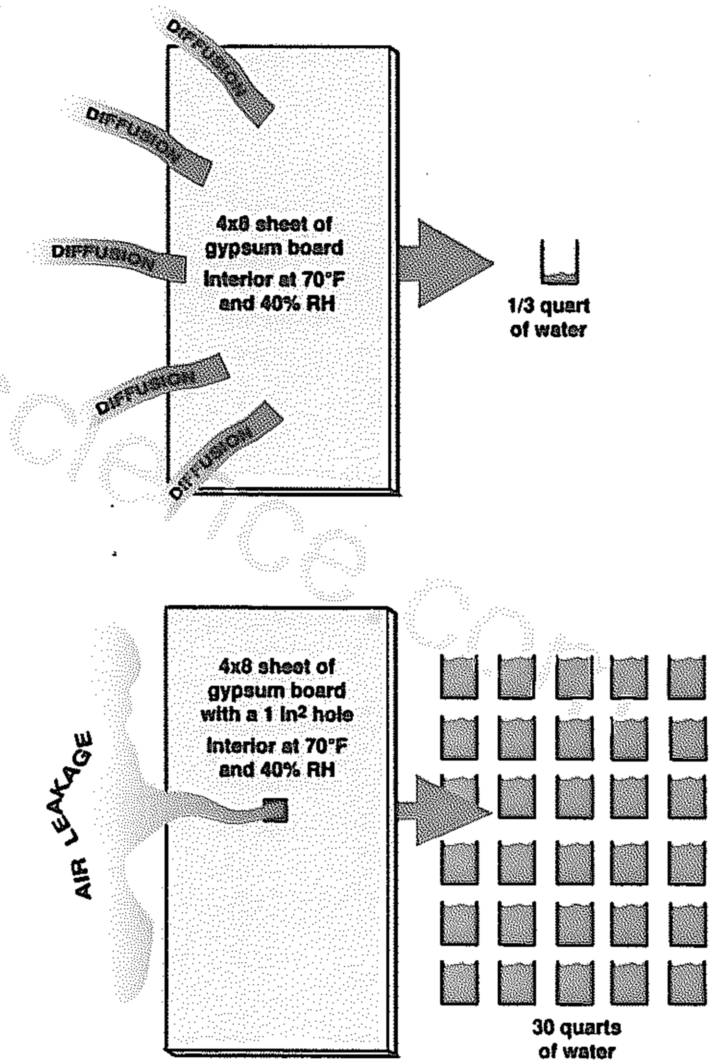

Figure 4
Diffusion vs. Air Leakage

- In most cold climates over an entire heating season, 1/3 of a quart of water can be collected by diffusion through gypsum board without a vapor retarder; 30 quarts of water can be collected through air leakage

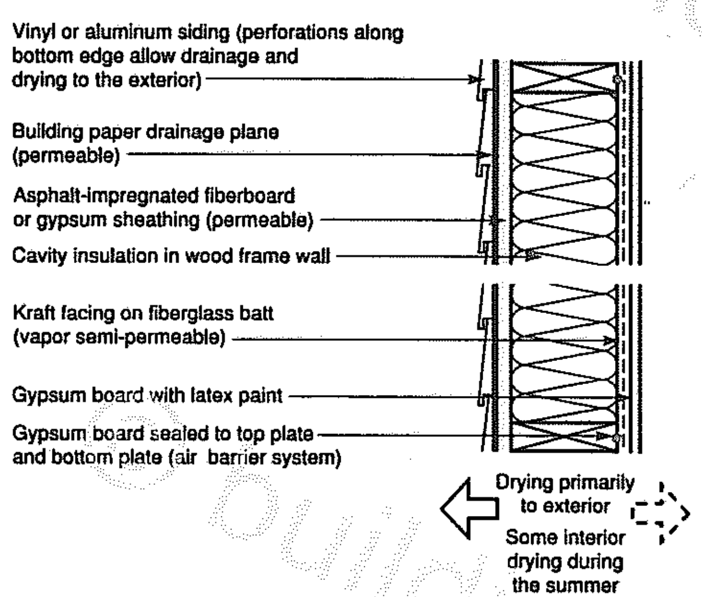

Figure 5
Classic Cold Climate Wall Assembly

- Vapor retarder to the interior (the kraft facing on the fiberglass batt)
- Air barrier to the interior
- Permeable exterior sheathing and permeable building paper drainage plane
- Ventilation provides air change (dilution) and also limits the interior moisture levels

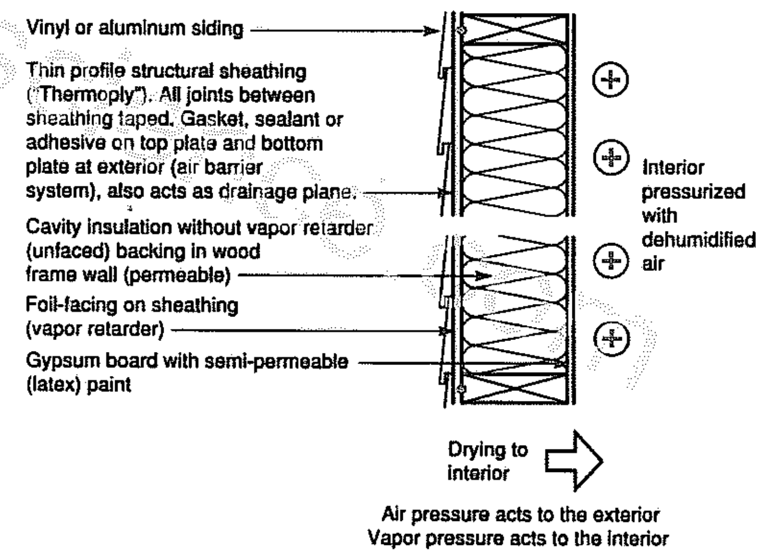

Figure 6
Classic Hot-Humid Climate Wall Assembly

- Vapor retarder to the exterior
- Air barrier 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 the infiltration of exterior, hot, humid air
- Air conditioning also provides dehumidification (moisture removal) from interior

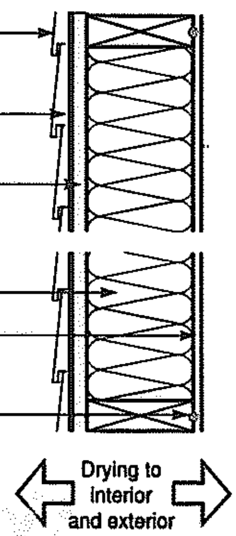

Figure 7
Classic Flow-Through Wall Assembly

- 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

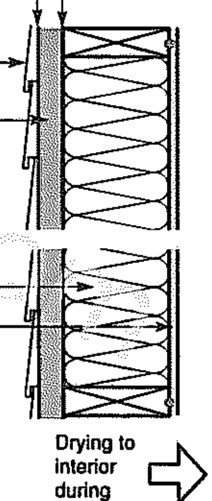

Figure 8
Vapor Retarder in the Middle of the Wall

- Air barrier 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

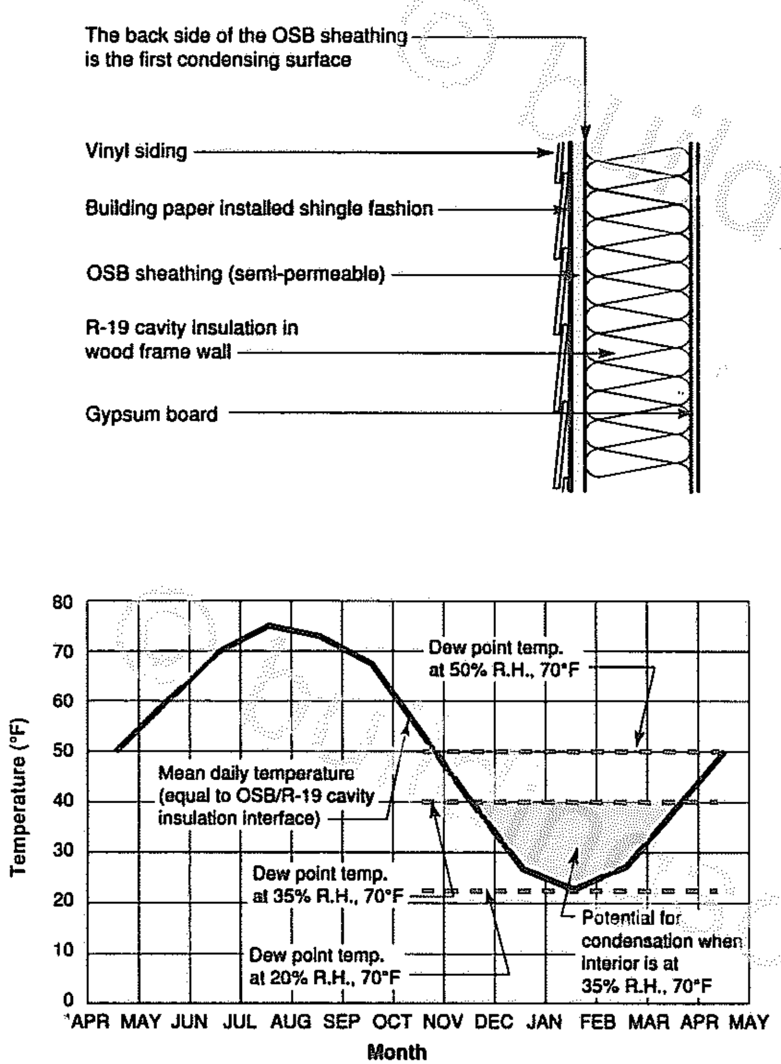

Figure 9

Potential for Condensation in a Wood Frame Wall Cavity in Chicago, Illinois

- By reducing interior moisture levels, the potential condensation is reduced or eliminated
- No condensation occurs if interior moisture levels are maintained below 20% RH at 70°F

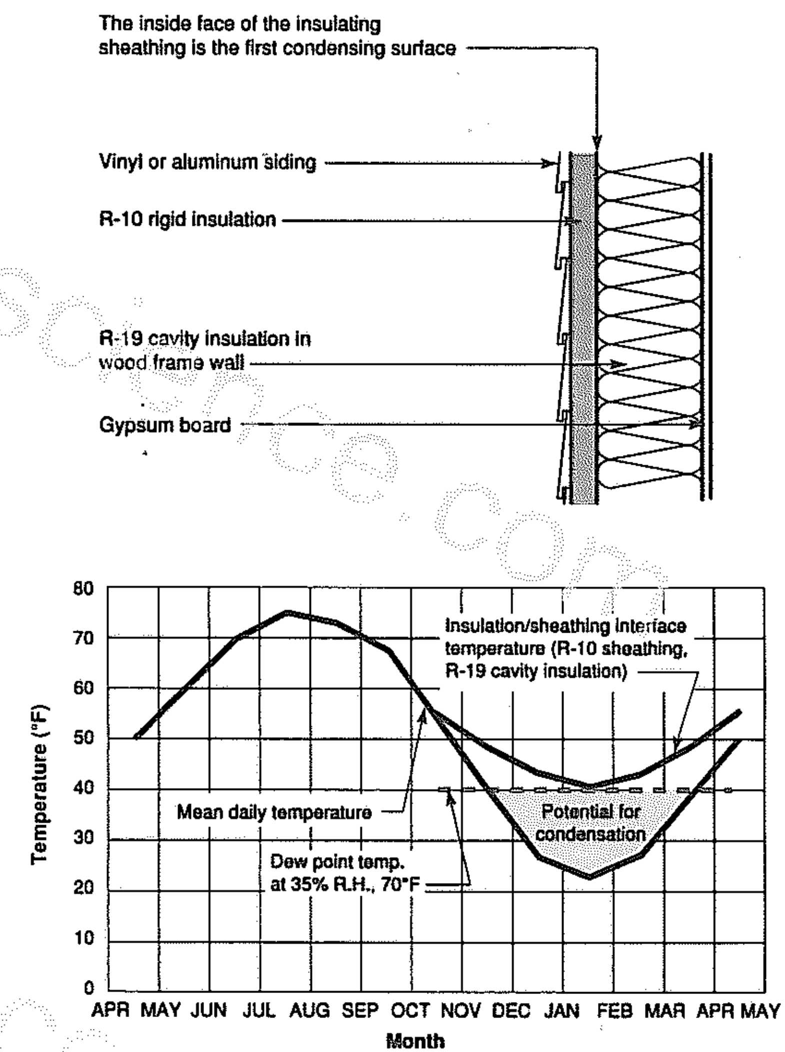

Figure 10

Potential for Condensation in a Wood Frame Wall Cavity Without an Interior Vapor Retarder in Chicago, Illinois

- The R-10 insulating sheathing raises the dew point temperature at the first condensing surface (cavity side of the foam sheathing) so that no condensation will occur when interior moisture levels are less than 35% relative humidity at 70°F

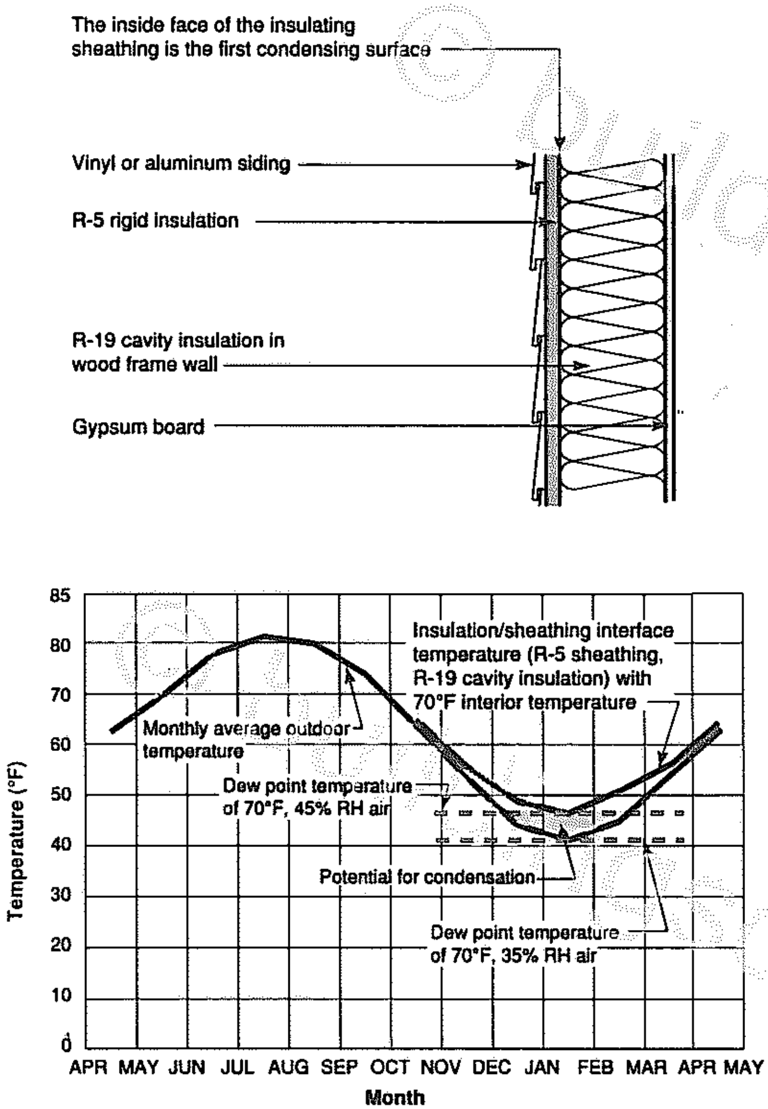

Figure 11
Potential for Condensation in Tupelo, Mississippi
- 3,150 heating degree days
- Winter design temperature 19°F
- Summer design temperature 94°F dry bulb; 78°F wet bulb

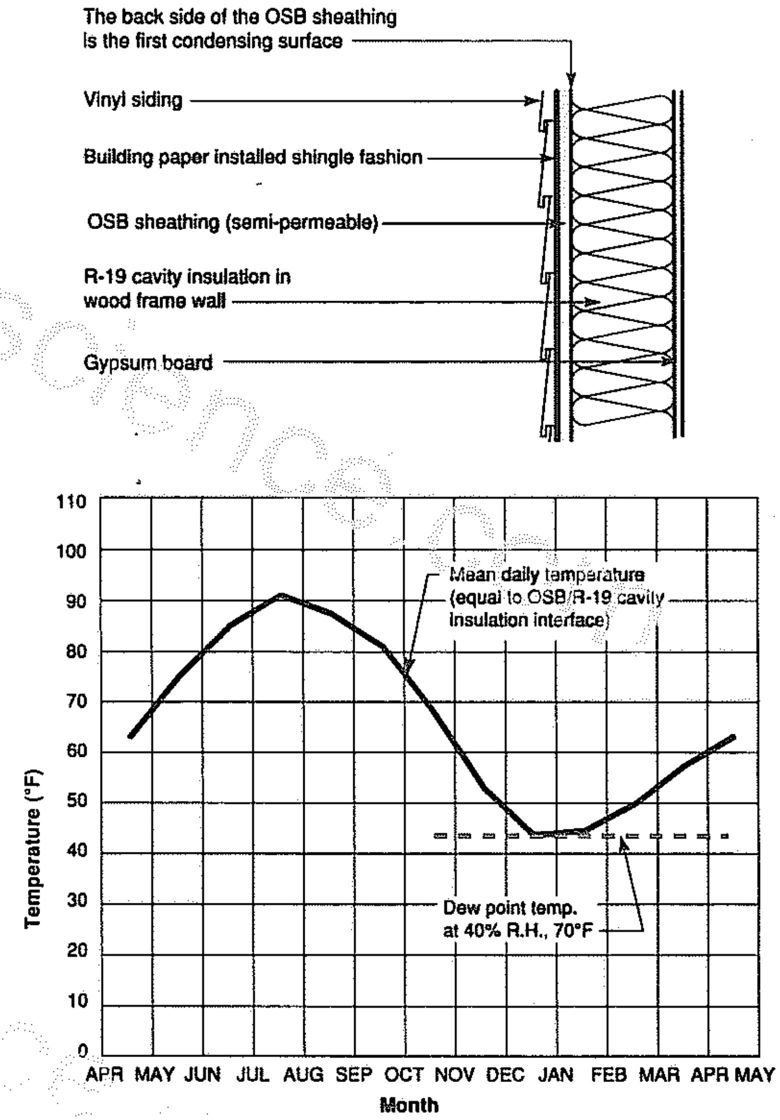

Figure 12
Potential for Condensation in Las Vegas, Nevada
- There is no potential for condensation until interior moisture levels exceed 40% RH at 70°F during the coldest months of the year
- An interior vapor retarder is not necessary in building assemblies in Las Vegas where interior moisture levels are maintained below 40% RH at 70°F during the heating period

About this Report

This report was first published in the Builder's Guide for Cold Climates, 2004 edition.

About the Author

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High-Performance Wall Assemblies

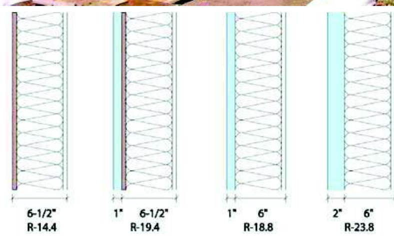
Tuesday May 14, 2013

1:00 p.m.

Presented by:

Ali Memari, Ph.D., P.E.

Pennsylvania Housing Research Center



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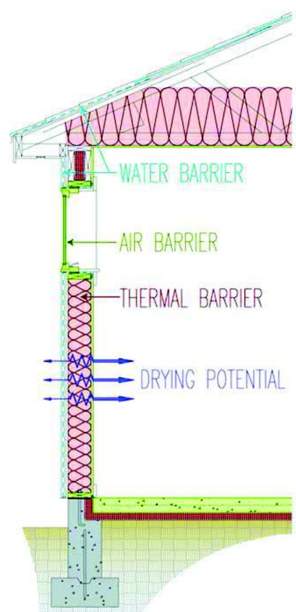
Presentation Objectives

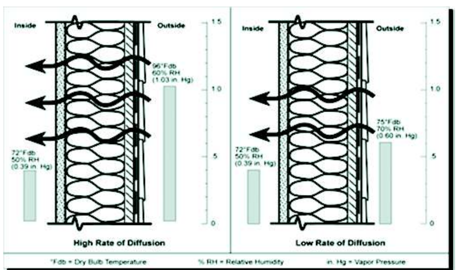
- Review the basic concept of heat transfer and definition of terms/parameters
- Illustrate calculation of U-factor and R-value for typical wall assemblies
- Discuss the basic concepts related to condensation in walls and ways to avoid or minimize moisture problems
- Introduce and present comparison of envelope walls with high R-values



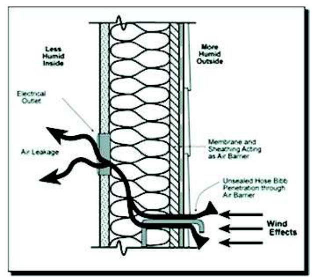
http://www.buildinggreen.com; Steve Baczek Architect

Understanding Condensation, Vapor Retarder, and Enclosure Configurations

- Mechanisms of Moisture Movement:
  - Water vapor moves from warmer side or higher air/vapor pressure side to colder side or lower air/vapor pressure side
  - Water vapor moves across the envelope either by air flow (e.g., air leakage) or by vapor diffusion through the material



Vapor diffusion through a wall



Air leakage through the wall

http://www.wbdg.org/resources/moisturemanagement.php

Vapor Retarder and Air Barrier

- The function of vapor retarder is to control vapor diffusion – retard vapor transport through the material
- The function of air barrier is to control vapor movement via air flow
- In some cases, an barrier may have material properties that can also function as vapor retarder – example: building paper

http://www.nachi.org/vapor-barriers.htm

http://imi-illinois.blogspot.com/2012/04/ air-barrier-training-at-abaa-conference

http://www.energyvanguard.com/blog-building-science

Attachment: High-Performance Wall Assemblies Handouts (1293 : City Council/BSC Workshop - Vapor Barrier)

Permeability, Perm

- The effectiveness of vapor retarders to retard vapor flow is expressed as permeability with unit referred to as “perm”.
- Ranges and example vapor barriers:
  - Perm≤0.1: vapor impermeable (rubber, glass, metal..)
  - Perm>0.1, ≤1.0: Vapor semi-impermeable (oil-based paint, vinyl, XPS≥1”…)
  - Perm>1.0, ≤10: Vapor semi-permeable (OSB, EPS, XPS<1”, latex-based paint…)
  - Perm>10: Vapor permeable (gypsum board, plaster, stucco, house wrap…)

http://www.jmhomeowner.com/insulation/install/vaporretarders.asp

http://www.buildinggreen.com/auth/article.cfm/2003/11/1/CertainTeed-MemBrain-First-Smart-Vapor-Retarder/

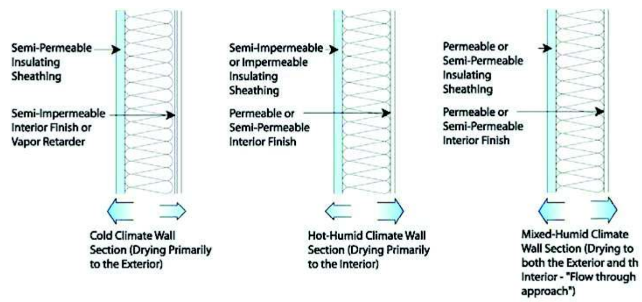
http://www.hpbmagazine.org/products/envelope/air-barriers

Classification of Vapor Retarders

- Class I Vapor Retarder: 0.1 perm or less
- Class II Vapor Retarder: >0.1 perm, ≤1.0 perm
- Class III Vapor Retarder: >1.0 perm, ≤10 perm
- Vapor Barrier = Class I Vapor Retarder
- Vapor Retarder vs. Air Barrier:
  - Air flow through a small hole can transport an order of magnitude more vapor compared to vapor diffusion through a drywall panel
  - Therefore, air barrier has a more important function compared to vapor retarder

Strategies to Control Vapor Transport

- The following strategies can be used:
  - Vapor retarders, Air barriers, Air pressure control
  - Control of interior moisture level (ventilation, dehumidifier)
- Overall strategy:
  - Reduce the chance of envelope to get wet (form condensation)
  - Build mechanisms for enclosure to dry to the interior or exterior if moisture accumulates

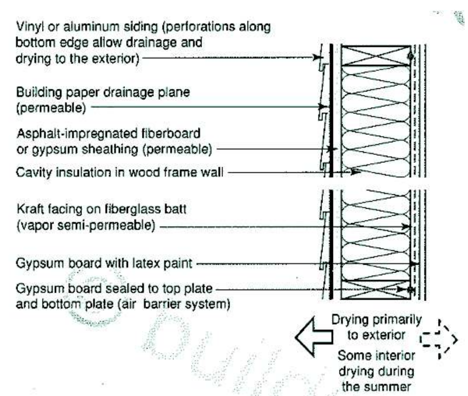


PHRC

http://www.buildingscience.com/documents/guides-and-manuals/gm-guide-insulating-sheathing

Wall Configuration for Cold Climates

- In cold climates moisture moves from warm interior to cold exterior so vapor retarder and air barrier is installed toward the interior warm surfaces
- Drying is toward the exterior, so permeable material is used as exterior sheathing



http://www.buildingscience.com/documents/reports/rr-0412-insulations-sheathings-and-vapor-retarders

Classic Cold Climate Wall Assembly

- Vapor retarder to the interior (the kraft facing on the fiberglass batt)
- Air barrier to the interior
- Permeable exterior sheathing and permeable building paper drainage plane
- Ventilation provides air change (dilution) and also limits the interior moisture levels

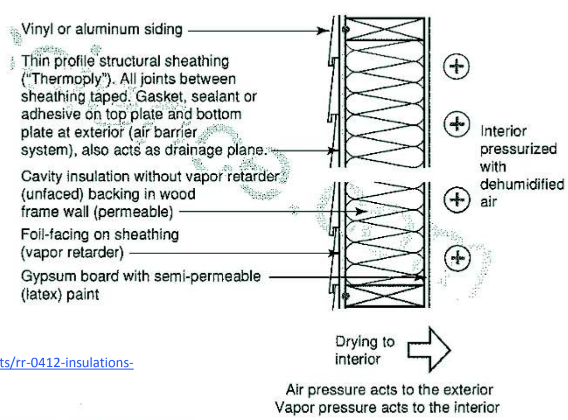
PHRC

Attachment: High-Performance Wall Assemblies Handouts (1293 : City Council/BSC Workshop - Vapor Barrier)

Wall Configuration for Hot Climates

- In hot climates or cooling season, the vapor drive is from exterior to the interior; therefore for such dominant climates the air barrier and vapor retarder should be placed on the exterior side
- The envelope should be allowed to dry toward the interior, so permeable interior wall finishes should be used.
- One may use un-faced fiberglass batt insulation in the cavity
- Should not use oil-based paint on the drywall or vinyl wallpaper
- The interior should have positive air pressure with dehumidified air to control infiltration of exterior warm air

Wall Configuration for Hot Climates



http://www.buildingscience.com/documents/reports/rr-0412-insulations-sheathings-and-vapor-retarders

Classic Hot-Humid Climate Wall Assembly

- Vapor retarder to the exterior
- Air barrier 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 the infiltration of exterior, hot, humid air
- Air conditioning also provides dehumidification (moisture removal) from interior

Insight
New Light in Crawlspaces

An edited version of this Insight first appeared in the ASHRAE Journal.

By Joseph W. Lstiburek, Ph.D., P.Eng., Fellow ASHRAE

Photograph 1: Icky Crawlspace—Note the condensation on the underside of the fiberglass insulation and the rot at the exposed portions of the crawlspace floor joists.

Photograph 2: Nice House Over Icky Crawlspace—This house with the crawlspace problem is in Washington, DC

Photograph 3: Ventilation Opening—Crawlspace has plenty of cross ventilation and good drainage.

Crawlspaces stink, they rot, and are just plain icky. **Photograph 1** shows the modern crawlspace, which is a forest of water droplets on the underside of fiberglass batt insulation. The exposed wood floor joists are rotting. The house over this crawlspace is not shabby (**Photograph 2**). Did I mention that this is a vented crawlspace (**Photograph 3**)? Oh, by the way, there is a continuous plastic sheet ground cover and excellent drainage. Everything in this crawlspace was done "right." It has code specified ventilation, a continuous impermeable ground cover, excellent drainage and still we have a mess. What caused this mess? The floor insulation. No way. Yup.

Think of the good old days – the Civil War, WWI, the Great Depression, WWII—crawlspaces were uninsulated. They were ventilated and they didn't have ground covers—and they didn't have problems. Why? The floor framing was pretty much always warmer than the ground (**Figure 1**). Everywhere, even in air-conditioned buildings. This was a pretty big deal as the temperature of the floor framing was above the dew point temperature of the exterior air that was used for "ventilation." And the old floor finishes tended to breathe—they were relatively vapor open. No one had heard of vinyl flooring yet.

The ground in crawlspaces is cold,[1] much colder than the outside air during the summer months. In an irony not appreciated except by building science geeks ventilation

[1] A reasonable rule-of-thumb to estimate crawlspace ground surface temperatures is to use the average annual ambient air temperature for that location.

air in the summer months in most parts of North America brings moisture into crawlspaces and deposits this moisture on surfaces that are below the ventilation air dew point. In the good old days this was the ground—or the ground cover which of course is at the same temperature as the ground. It was not typically the floor framing. And who cared if the ground or the ground cover was wet as long as the wood framing was not.

We don't get much ventilation air change in crawlspaces—the typical ventilation air change rate in a crawlspace is approximately 1 air change per hour (ach).[2] In determining crawlspace surface temperatures we can pretty much ignore the ventilation air change.[3] We can't ignore the ventilation air in the moisture balance but we can in the energy balance. Crawlspace surface temperatures are dominated by radiation and conduction, not by convection (**Figure 2**). And, as pointed out, old crawlspace floor framing was not only warmer than the ground but also warmer than the ventilation air dew point.

That all changes when we install insulation in crawlspace floor framing. The most common insulation installed in this location are fiberglass batts. When fiberglass batts are installed between floor joists the exposed bottom edges of the floor joists become much colder (**Figure 3**). The surface temperature of the underside of the fiberglass batt insulation is also much colder than the floor sheathing—within one or two degrees of the ground temperature. The energy picture within the crawlspace is radiation dominated– the floor assembly surfaces are in essence radiation coupled to the ground. The exposed surface of the fiberglass batt insulation is below the dewpoint temperature of the air in the crawlspace as is the exposed portion of the wood floor joists and condensation forms on both the surface of the insulation and the surface of the exposed wood (go to **Photograph 1** again).

Now let's look at the wood floor joist moisture content. Wood is hygroscopic—it "sees" relative humidity not vapor pressure. So we are going to need a psychrometric

2 This comes from using radon gas as a "tracer gas" – thank you EPA – your radon studies provided useful information at least in this regard.

3 This is another one of those engineering approximations that drives energy weenies crazy.

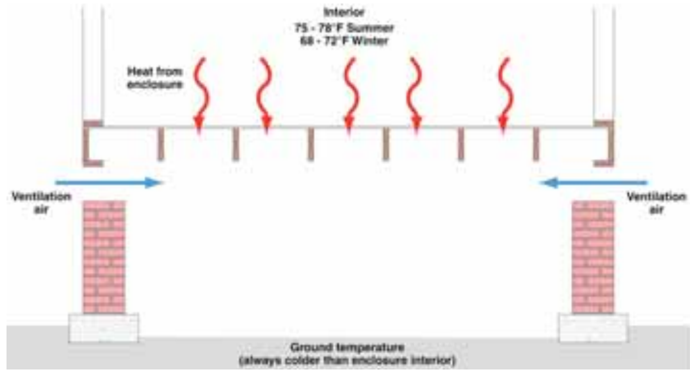


Figure 1: Old Crawlspaces—Old uninsulated and ventilated crawlspaces had warm floor assembly surfaces due to heat flow downward from occupied space above.

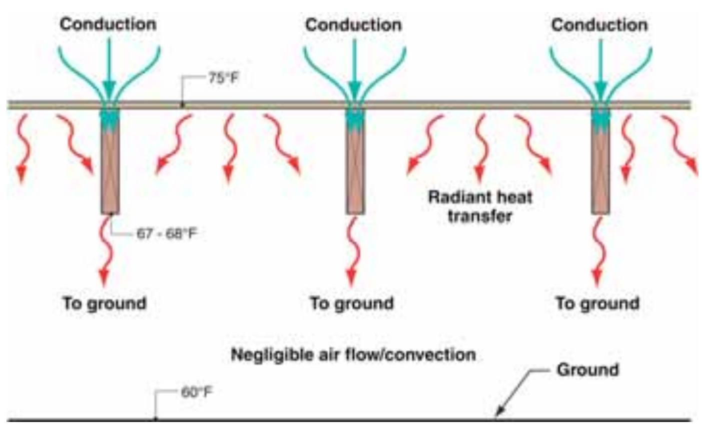


Figure 2: Old Crawlspace Temperatures—Surface temperatures are dominated by radiation and conduction, not by convection. Old crawlspace floor framing was not only warmer than the ground but also warmer than the ventilation air dew point.

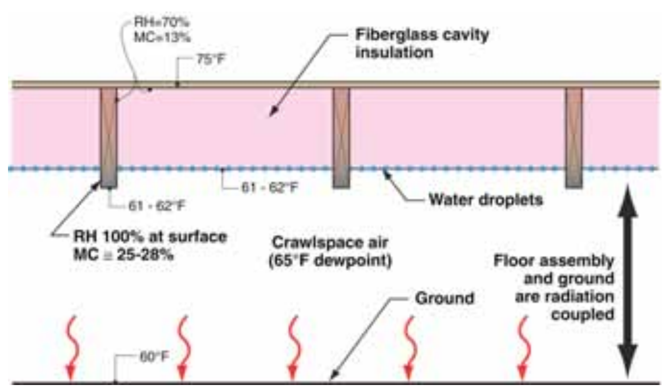


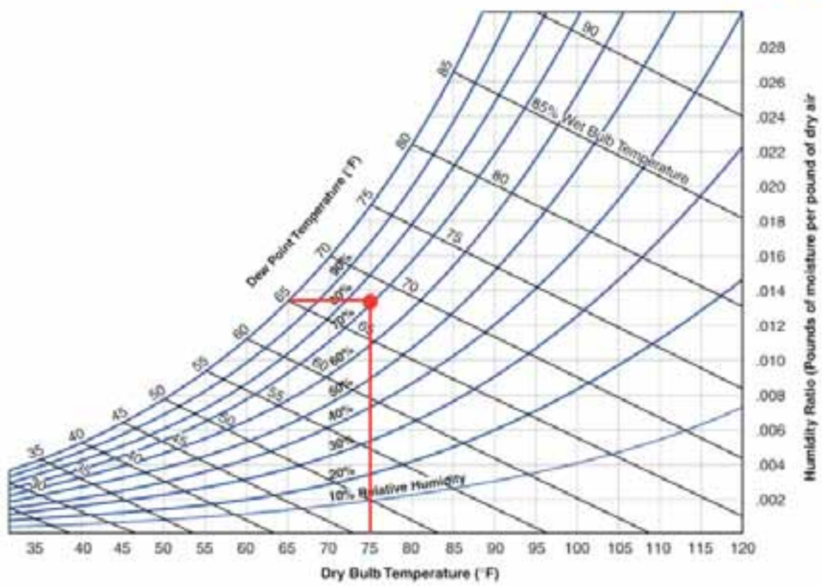
Figure 3: Insulated Crawlspace Temperatures—The surface temperature of the underside of the fiberglass batt insulation is colder than the floor sheathing—within one or two degrees of the ground temperature. The exposed surface of the fiberglass batt insulation is below the dewpoint temperature of the air in the crawlspace as is the exposed portion of the wood floor joists and condensation forms on both the surface of the insulation and the surface of the exposed wood.

Psychrometric Chart and Wood Sorption Curve

We know the dewpoint temperature of the air in the crawlspace—65 degrees F. We also know the temperature at the top of the floor joist–75 degrees F. We need to get the relative humidity at the surface of the wood at this location in order to go to the wood sorption curve and determine moisture content. The psychrometric chart's magic will give us the relative humidity. First, we make the simple engineering assumption that we can ignore the vapor permeance (or vapor resistance) of the fiberglass batt insulation. That leads to the second assumption that the vapor pressure in the crawlspace is uniform. Both are pretty reasonable assumptions within the range of accuracy we are dealing with (within 10 to 20 percent—and obtained very quickly—within seconds rather than hours using mind numbing numerical simulations based on questionable boundary conditions that are not much more accurate than 10 to 20 percent).

With the constant vapor pressure assumption we can trace a horizontal line from the 65 degree F. dewpoint state point on the saturation curve to where it crosses the vertical 75 degree dry bulb temperature line—and presto we get the relative humidity at the surface of the wood-70 percent (Figure A).

Figure A



We take this wonderful piece of information to the wood sorption curve and get a moisture content of 13 percent (Figure B). But look at the "error bar" – the shading on the curve. Neat eh! Wood is somewhat unpredictable—a characteristic I identify with—so although I say in the neighboring column that the wood moisture content is 13 percent—it could be anywhere between 10 and 16 percent. Or 13 percent plus or minus 3 percent. Keep those computer simulations and give me a psych chart and a sorption curve and a beer and I will beat you to the answer every time. Of course the 30 years of being beat up by the old masters also helps (thank you Dr. Onysko, Dr. Timusk, Mr. Gatley and Mr. Handegord).

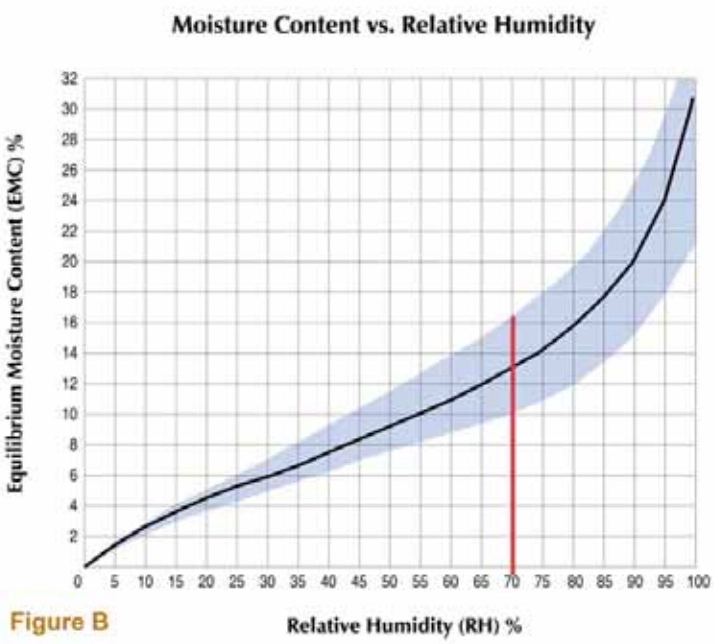


Figure B

chart and a sorption curve for wood. The temperature of the wood floor joist is 75 degrees F at the top (i.e. interior temperature). We have to figure out the crawlspace conditions. The air in the crawlspace comes from the outside—who knew? Let's pretend that this particular crawlspace is in Washington, DC. The average dew point of the exterior air during the summer months in Washington, DC is 65 degrees. Let's bring this air into the crawlspace—so therefore the dew point of the air in the crawlspace is 65 degrees. Recall that the top of the floor joist is 75 degrees. The floor joist sees the dew point of the air in the crawlspace (we can ignore the vapor permeance characteristics of the fiberglass batt insulation since it is so vapor open—just pretend that we have air rather than insulation here– but not just any air—air with a huge temperature drop— "insulating air"), but because the floor joist is 75 degrees at this location, the relative humidity at this location is 70 percent yielding a wood equilibrium moisture content of 13 percent. The floor joist is "dry" at the top and "wet" at the bottom. Why wet at the bottom? The surface of the wood is cold, below the dew point of the air in the crawlspace and therefore condensation forms on the wood. At fiber saturation the moisture content of wood is 28 percent (go to **Figure 3** again).

The wood floor joist moisture content increases in the downward direction as the wood becomes progressively colder (**Figure 4**). Another way of saying this—the warmer the wood, the drier the wood. Duh. If we were to wrap the floor joists completely with insulation we would warm up the wood thereby lowering the relative humidity the wood "sees" thereby lowering the moisture content. This is a pretty neat strategy that I will refer to later. So how low do we need to lower the moisture content of the wood? Below 19 percent to never see rot. Below 16 percent to never see mold. We could do this a couple of ways. One way is with spray foam insulation (**Figure 5**).

But before we go there, we need to check out something else. Although the wood moisture content increases as we go downward the vapor drive is upward. Huh? This wood stuff is pretty weird. The wood moisture content thing we just explained. Time to look at vapor diffusion.

The interior is dry (dew point of 55 degrees F) and the crawlspace is wet (dew point of 65 degrees F). The moisture flow by vapor diffusion is from the crawlspace up through the floor into the building—at least during the summer. So the vapor drive is

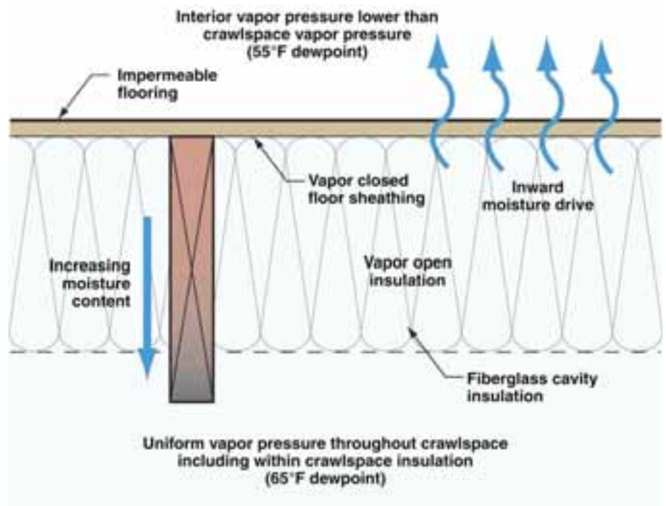


Figure 4: Moisture Dynamics—The wood moisture content increases as we move down the floor joist. At the same time the vapor drive is upward. The entire shaded area "sees" the same vapor pressure (dewpoint) due to the vapor openness of the fiberglass insulation. The entire vapor resistance is at the floor sheathing and flooring. If only the floor could breathe…it used to in the old days when we had wood floors and not vinyl…

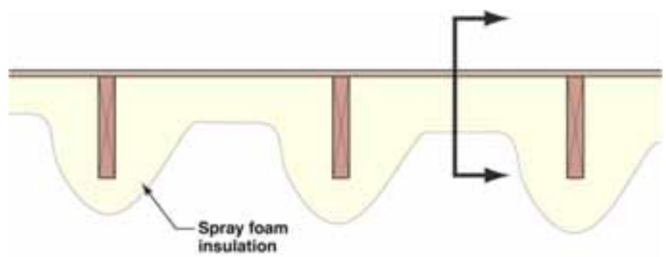


Figure 5: Warming the Wood—Wrapping the floor framing in foam insulation lowers the equilibrium moisture content of the wood. Warm wood is dry wood. Warm wood is happy wood. One not so minor issue, changing the temperature only gets you so far—the vapor drive upwards still needs to be addressed. The section line is the location of the cross-sections in Figure 8 which address the not so minor vapor drive issue.

upward even though the wood in the floor joist gets wetter as we go downward. The inward drive is "felt" completely at the floor sheathing and floor finish. We can pretty much ignore the vapor open fiberglass batt cavity insulation—no vapor resistance here. We can't ignore the vapor resistance of the floor sheathing and the floor finish.

If we were do something foolish like install vinyl flooring (0.1 to 0.5 perms) over OSB floor sheathing (1.0 perms) in an assembly like that described in **Figure 4** we would get a result that looks like **Photograph 4**. Notice the pink spots on the vinyl flooring. Reminds you of the pink spots on vinyl wall-covering.[4] Come to think of it, haven't we just constructed a wall with vinyl wall-covering and laid it down? Same principle, same problem. The floor does not "breathe." We have a vapor barrier on the wrong side of the assembly. So we can fix this problem by having a vapor permeable floor assembly—plywood sheathing (it is way more permeable than OSB) and carpet do the trick. Works, but it is kind of limiting. Oh, yeah, you also can't put furniture on the floor if the furniture is impermeable, so you have to hold it up to ventilate under it—same for cabinetry—you have to ventilate it as well. But what if I don't want plywood, carpet and ventilated furniture and cabinetry?

Photograph 4: Vinyl Flooring—Pink spots due to moisture problems arising from the impermeability of the vinyl flooring and ventilated and insulated crawlspace underneath.

Photograph 5: Conditioned Crawlspace—The way all crawlspaces should look. Dry, warm, part of the house, not part of the outside or part of the ground. Insulated on the perimeter not in the floor. Beautiful.

4 The pink color comes from digestive enzymes exuded from mold that react with the plasticizers in the vinyl. The mold comes from the substrate being wet because of the impermeability of the vinyl. No vinyl no problem.

The easy answer is to construct a conditioned crawlspace (**Photograph 5**). Construct it like a "mini-basement." Then you can have any floor finish you want and save a bunch of energy and money. But I know you folks. You are stubborn and insist on doing the vented crawlspace thing. Hey, maybe you need to because you are in a flood zone—it could happen that you actually have a legitimate reason to construct a vented crawlspace. So how should the floor assembly look?

Check out **Figure 6** and **Figure 7**. Both show foil faced rigid insulation under the floor framing. The wood is warm and therefore dry. The foil facing on the rigid insulation handles the vapor drive. The foil facing is an exceptional vapor barrier (< 0.1 perm). Beautiful. It gets better, the foil facing, if you expose the shiny side (face it down into the crawlspace) almost eliminates radiative coupling and means that the surface of the insulation approaches the temperature of the ventilation air reducing condensation. So why don't we see lots of this? Well, I forgot to mention that the rigid insulation needs to be airtight so that requires tiny people with good workmanship to seal the seams with foil tape that sticks in miserable environmental conditions forever. Having said that, a poor job using the approaches described in **Figure 6** and **Figure 7** are way better than what we typically get with **Photograph 1** and **Figure 3**.

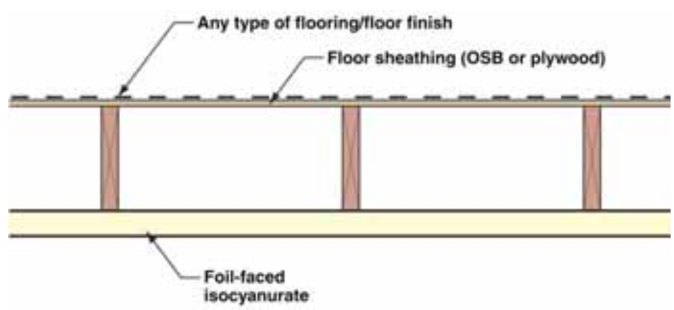


Figure 6: Vapor Barrier—Installing impermeable rigid insulation keeps the wood framing warm and provides a low perm layer that addresses the upward vapor drive. How impermeable? Less than 0.1 perms. Foil faced rigid insulations are the ticket here. This approach allows any type of flooring to be used above. Even better—exposing the shiny side of the foil facing (face it down into the crawlspace) almost eliminates radiative coupling and means that the surface of the insulation approaches the temperature of the ventilation air reducing condensation.

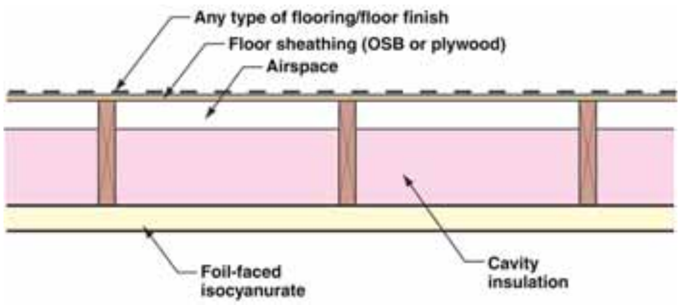


Figure 7: Cavity Insulation with Vapor Barrier—Adding impermeable foil faced insulating sheathing over fiberglass cavity insulation is a hybrid approach that uses the best qualities of both materials. Note that the optimum location for the airspace is above the cavity insulation. Are you folks paying attention at the EPA Energy Star Program? Makes for warmer floors—this is the same detail that should be used under bedrooms over garages.

All this leads us back to **Figure 5** and spray foam. Lots of folks are looking at this option due to the lack of tiny people with good workmanship.[5] The spray foam clearly handles the warming the wood thing. Any foam will work for the wood warming—low density, high density, whatever. Recall, just by warming the wood you lower it's equilibrium moisture content. Where things get difficult are with the vapor drive across the floor sheathing and the floor finish. Unless you stick to carpet, and ventilated furniture and ventilated cabinetry you are going to have to use high-density foam—at least 2 lb/ft^3 –due to its lower perm value. And at least 3 inches thick or thicker (gives you less than 1 perm at this thickness). **Figure 8** shows a few configurations that pretty much work everywhere. Even **Figure 8d**, with vinyl flooring, works in mixed-humid and hot-humid climates. Having said that, I think you should just say no to vinyl—that makes things a whole lot easier. If you really like vinyl, go with **Figure 6** or **Figure 7** or even better **Photograph 5** (the conditioned crawlspace or mini-basement).

What if I don't want to completely encase the floor framing? What if I want to go with **Figure 9** and **Photograph 6**? That works if the crawlspace does not get too cold—in the summer—if it is coupled more to the outside air than to the crawlspace ground temperature. Elevated crawlspaces with open piers work fine in this regard (**Photograph 7**).

Figure 8a – 8d: Spray Foam Configurations—Stick to closed cell 2 1b/ft3 density spray foam. Avoid vinyl flooring—except in dry and cold climates.

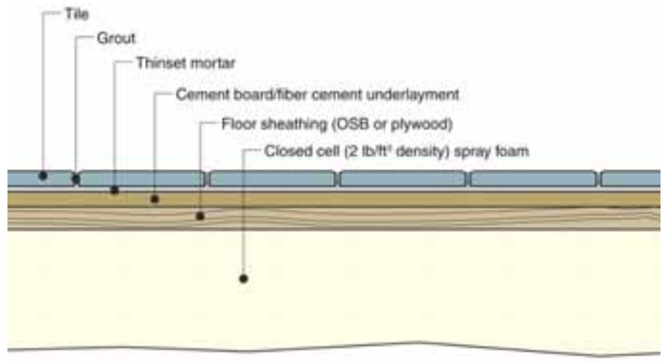


Figure 8a

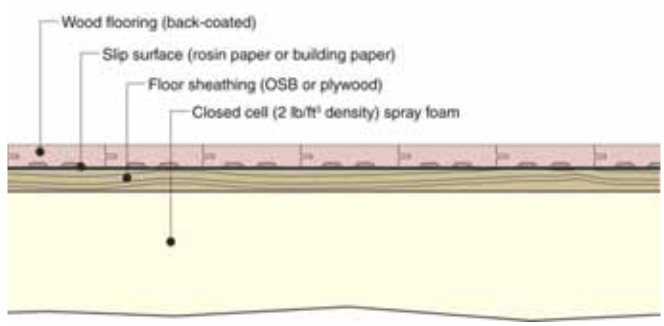


Figure 8b

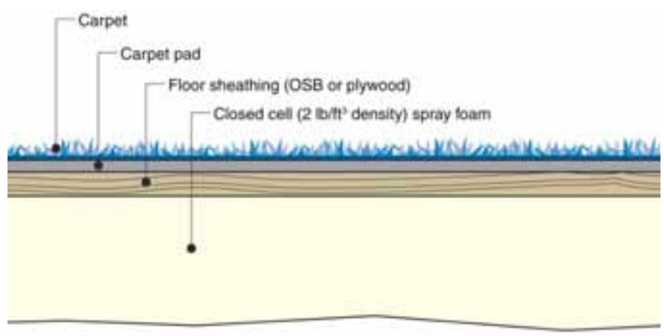


Figure 8c

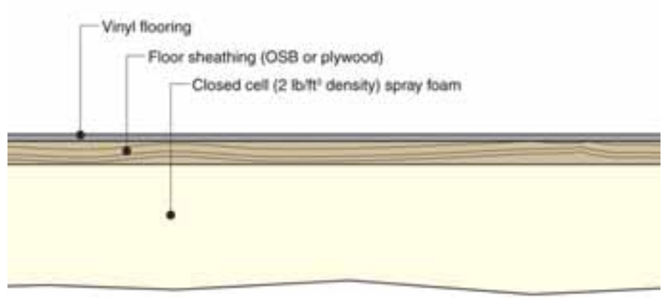


Figure 8d

[5] They all have gone on to fame and fortune in reality TV cable shows.

At the end of the day, recall that the best crawlspace of all is filled with concrete and called a slab—or dug out and called a basement.

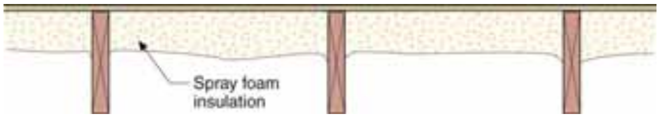


Figure 9: Not Encased Floor Framing—Use high-density foam, at least 2 lb/ft^3, due to its lower perm rate and couple the crawlspace to the outside. Elevate the crawlspace and use open pier construction.

Photograph 6: Spray Foam Between Joists—Floor framing is not completely encased with spray foam in this application. Works only where the crawlspace is open to the outside.

Photograph 7: Elevated and Open Crawlspace—Open pier construction and a trellis couple the crawlspace to the exterior.

BSC Information Sheet 310

Vapor Control Layer Recommendations

for all climates

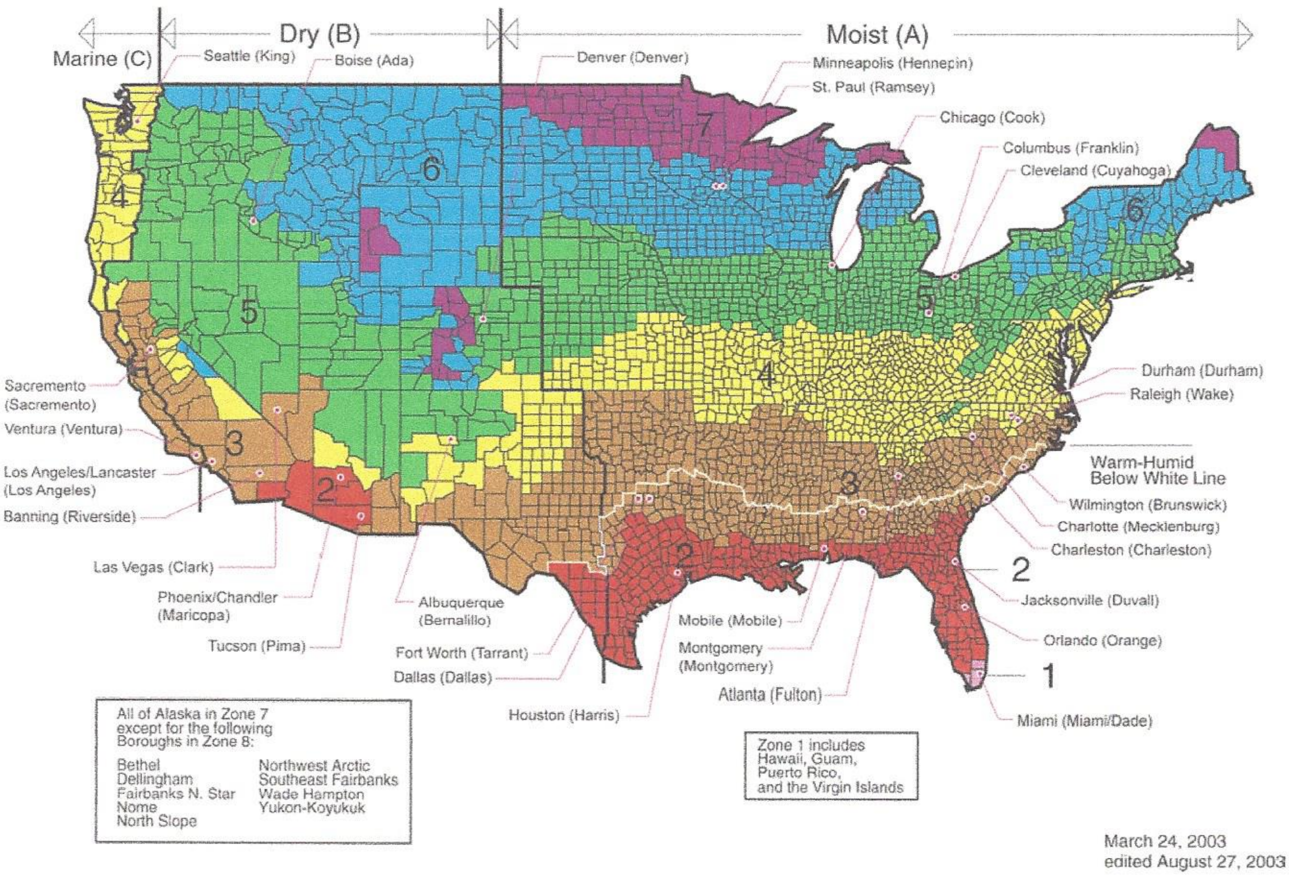
The current International Residential Code (IRC 2009) provides excellent guidance for the installation of vapor control layers. The requirements in the code can be used for wood framed structures with temperature and humidity conditions typical of residential occupancy.

Three classes of vapor control are defined depending on the vapor permeance of the vapor control layer.

- Class I . <0.1 perms e.g. polyethylene sheet, sheet metal, or aluminum facing.
- Class II. 0.1 - 1.0 perms e.g., kraft faced fibreglass batts, and some vapor control paints.
- Class III. 1.0 - 10 perms e.g. latex or enamel paints.

The level of vapor control required on the interior side of framed walls with typical fibrous cavity insulation (fibreglass, rockwool, or cellulose) is determined based on DOE climate zone of construction (see *climate map*).

No interior vapor control required on the interior side of framed walls in climate zones 1, 2, 3, 4a, or 4b.



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In hot, humid climates, a Class I or II vapor control layer on the interior of the framing can, and often does, cause premature building enclosure failure due to inward moisture drive condensation (see *RR-9302: Humidity Control in the Humid South*). BSC recommends avoiding Class I or II vapor control layer on the interior in these zones, or any material that acts inadvertently like a Class I or II vapor control layer such as reflective foil insulations, vinyl wall coverings, glass mirrors and epoxy paints.

A Class I or Class II vapor control layer is required by the IRC 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 block wall). However, BSC recommends avoiding Class I vapor control layers in general in wall assemblies, except in special use occupancies in cold climates such as indoor pools and spas.

Below grade spaces such as basements are of particular concern with respect to Class I vapor control layers. Because the moisture drive in below grade walls is always to the interior, installing a high level of vapor control on the interior of the wall will cause moisture related durability issues by trapping moisture in the enclosure (see *BSD-103: Understanding Basements*). However, a Class I vapor control layer could be used in a below grade assembly under the following conditions: (a) no moisture-sensitive material is trapped between the concrete and the Class I vapor control layer, (b) this space is completely isolated from air communication with the interior, and (c) the Class I vapor control layer is protected from interior-sourced condensation. An example of this assembly would be foil-faced polyisocyanurate applied to the basement wall, with the gap between insulation and concrete isolated and air sealed from the interior.

A Class III vapor retarder can be used instead of a Class I or Class II in zones 4c, 5, 6, 7, or 8 where one of the criteria for the specific zone from the list below is met. These criteria may depend on whether the cladding is vented or whether insulating sheathing is used.

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

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

- Vented cladding over OSB, plywood, fiberboard or exterior gypsum sheathing
- 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. Boston)

- Vented cladding over OSB, plywood, fiberboard or exterior gypsum
- Insulated sheathing with an R value ≥ 5 (e.g. 1" XPS) on a 2x4 framed wall
- Insulated sheathing with an R-value ≥ 7.5 (e.g. 1.5" XPS) on a 2x6 framed wall.

Zone 6 (e.g. Minneapolis)

- Vented cladding over high permeance (>10 perm) sheathings of fiberboard and exterior gypsum
- 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. International Falls or Alaska)

- 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.

In hot-humid climates, wetting from the exterior during the cooling season by air movement is a major concern. In hot-humid climates, building enclosures are constructed in an airtight manner to control air leakage openings, to expedite air pressure control (pressurization of the building enclosure during the cooling season), and to facilitate the dehumidification of indoor air, thereby limiting interior moisture levels. Controlled ventilation is also necessary to provide for the dilution of interior pollutants by controlled air change.

Vapor diffusion from the exterior is also a concern in hot-humid climates. Accordingly, vapor diffusion retarders in hot-humid climates can be located towards the exterior and walls, and other building assemblies can be designed and built to dry to the interior.

Vapor retarder on exterior Not interior

The absence of ground frost penetration concerns in this climate zone has led to a preponderance of crawlspace and ground slab construction. Basement foundations are rare, if not completely nonexistent. Both frame walls and masonry walls are common.

Moisture Within Building Assemblies

Cladding systems which can absorb significant amounts of moisture when exposed to rain—such as brick, masonry, wood and stucco—should only be incorporated in certain wall assemblies. Such assemblies are designed and built to deal with the inward migration of moisture driven by temperature gradients from the exterior to the interior. Solar radiation warming exterior wall surfaces creates these gradients, along with the air conditioning of interior surfaces. Problems often arise where this is not taken into account, such as the installation of vinyl wallpaper.

Vinyl interior wall coverings are not exclusive to masonry or concrete wall systems and are also used with wood frame construction. Vinyl interior wall coverings should never be used in this climate zone.

Where wet masonry, wet lumber (greater than 19% moisture content by weight), or wet-applied insulations (wet spray cellulose or wet-blown fiberglass) are installed in building assemblies, those assemblies must be designed and built in such a manner that they can dry to either the interior or exterior or the materials should be allowed to dry prior to enclosure.

High Interior Humidity Resulting in Mold and Surface Condensation

The practice of mechanical cooling coupled with some dehumidification for comfort reasons is widespread. This gives rise to continuous moisture flow by air leakage and vapor diffusion from the exterior to the interior-cooled area as a result of a higher outdoor vapor pressure than indoor vapor pressure. The outdoor-to-indoor vapor pressure differences in hot-humid climates are typically much greater than the vapor pressure differences in cold climates.

Reason for vapor retarder on outdoor (warm) side of crawl space insulation

The impacts of this high inward flow of moisture are manifested as elevated energy costs due to high cooling loads, building fabric deterioration from decay and corrosion, and health and safety concerns from mold and mildew growth.

Moisture movement by air leakage (the infiltration of exterior moisture laden air) is controlled by limiting air leakage openings, maintaining a positive air pressure within conditioned spaces relative to the exterior (pressurization – approximately 2 to 3 Pa), and by locating forced-air ductwork within conditioned spaces where possible coupled with duct air sealing, transfer grilles, and multiple returns to limit the effects of duct leakage and depressurization. Pressurization of building enclosures is expedited by airtight construction (2.00 l/(s-m^2)@75 Pa).

Moisture movement by vapor diffusion from the exterior can be controlled by the use of exterior vapor retarders in walls, roofs, and crawlspaces. Moisture movement by vapor diffusion from the interior is not a concern in hot-humid or hot climates – interior vapor retarders are unnecessary and should avoided.

High air change due to infiltration/exfiltration, duct leakage, and excessive ventilation can lead to elevated interior levels of moisture. This is contrary to cold climates, where the same mechanisms lead to low levels of interior moisture. This is due to the high exterior humidity conditions which occur for most of the year in hot-humid climates. The greater the amount of exterior air brought into an enclosure, the greater the amount of moisture brought in with it. As such, in hot-humid climates it is desirable to build tight enclosures and to ventilate these enclosures with outside air at a minimum, controlled rate. Minimum ventilation rates typically are established by indoor air quality issues and are stipulated by ASHRAE Standard 62.2, the strength of pollutant sources within enclosures or authorities having jurisdiction.

Relative humidity should be maintained at 60% or lower at 75°F (23.8°C) within the conditioned spaces during cooling periods (the key is to prevent 70% relative humidities from occurring adjacent to surfaces in order to control mold, mildew, and other biological growth). Humidity control within conditioned spaces is accomplished by the dehumidification capabilities of air-conditioning systems and source control. Latent cooling loads on air-conditioning systems can be higher than sensible cooling loads in these climates. As such, proper sizing of air-conditioning systems with consideration of dehumidification capabilities is important. Oversizing of air-conditioning equipment can lead to high interior humidity problems due to a lack of dehumidification capability (oversized air-conditioning equipment will not operate as often and therefore will dehumidify less than properly sized equipment). Source control typically involves direct venting of clothes dryers, bath, and kitchen exhaust systems as well as the use of crawlspace ground covers and sub-slab vapor barriers.

Mechanical System Concerns

Ductwork for forced-air heating and cooling systems should be installed within conditioned spaces where possible. Ductwork located in attics or vented crawlspaces must be air sealed with mastic (tapes are ineffective). The ductwork system and air handler should be tested for leakage (less than 5 percent leakage at 25 Pa). Leaky return ducts located in attics draw significant amounts of warm, moisture-laden air into the conditioned space from the attic, often creating moisture problems and increasing cooling loads. Leaky return ducts located in vented crawlspaces draw significant amounts of soil gas, moisture, possibly pesticides, radon, and other pollutants into the conditioned spaces, often creating moisture problems, increasing cooling loads, and risking occupant health and safety. Leaky supply ducts located in attics or vented crawlspaces lead to the depressurization of the conditioned space, which leads to the infiltration of exterior warm, moisture-laden air that often creates moisture problems and increases cooling loads.