Basics of Insulation and Vapor Barriers

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Dec. 2000

ATTIC ACCESS

Provide adequate insulation coverage and air sealing for the access between living space and the unconditioned attic

Buildings for the 21st Century

Buildings that are more energy-efficient, comfortable, and affordable...that's the goal of DOE's Office of Building Technology, State and Community Programs (BTS). To accelerate the development and wide application of energy efficiency measures, BTS:

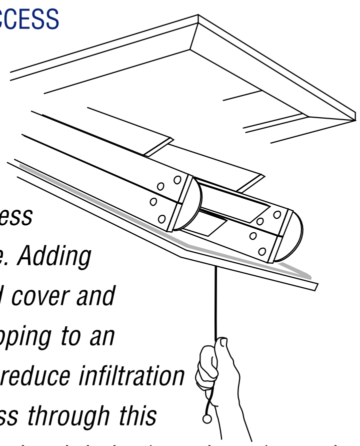
- Conducts R&D on technologies and concepts for energy efficiency, working closely with the building industry and with manufacturers of materials, equipment, and appliances
- Promotes energy/money saving opportunities to both builders and buyers of homes and commercial buildings
- Works with State and local regulatory groups to improve building codes, appliance standards, and guidelines for efficient energy use
- Provides support and grants to States and communities for deployment of energy-efficient technologies and practices

DON'T LEAVE A HOLE IN THE CEILING

A home's attic access, such as an attic hatch, pull-down stairs, or knee-wall door, often goes uninsulated, representing one of the biggest deficiencies in the thermal barrier between the attic and conditioned space. This gap in the attic insulation increases heat loss in winter and heat gain in summer, and makes indoor living areas uncomfortable.

Such accesses are often not sealed properly. A ¼-inch gap around the perimeter of an attic access can potentially leak the same amount of air supplied by a typical bedroom heating duct (~100 CFM). Unsealed, the attic access in a home leaks energy dollars and causes the house to be less comfortable.

ATTIC ACCESS

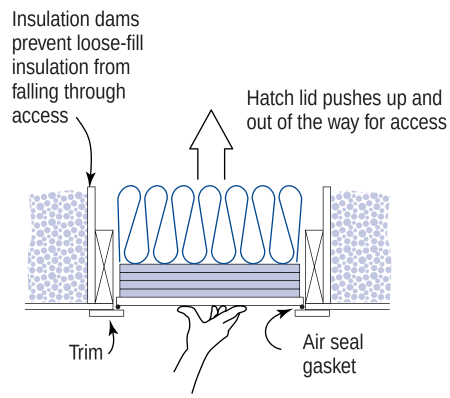


An attic access is a big hole. Adding an insulated cover and weatherstripping to an access can reduce infiltration and heat-loss through this passageway. Latch bolts (not shown) may be installed to help ensure an even tighter seal.

ATTIC HATCH

One inexpensive and common type of attic access is referred to as a *scuttle hole* or *attic hatch,* which is simply a removable portion of the ceiling that allows entry to the attic above. A scuttle hole is commonly located in a closet or main hallway.

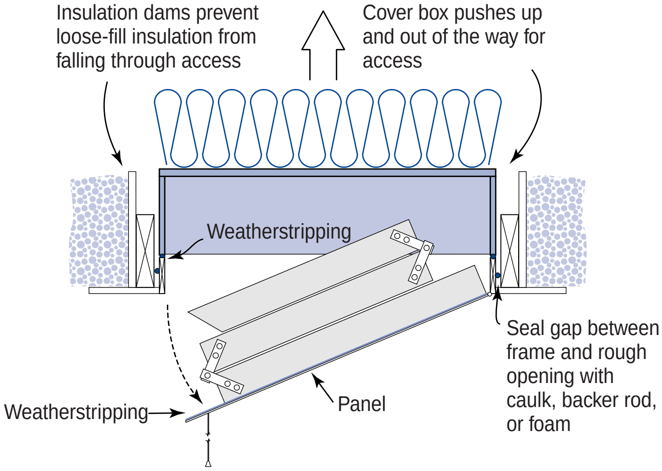
SCUTTLE HOLE COVER



To create the hatch, the installer should cut a plywood piece or save the ceiling drywall piece that is cut out for the hole. To ensure a tight fit, securely fasten the trim around the hole to the ceiling and make sure that it is flat and level. An uneven base can cause air leakage. Weatherstripping can be installed either on the hatch itself or on the inside of the trim or base where the hatch rests. Adding a latch bolt will help ensure a tighter seal.

After the trim or base is aligned to seal properly, insulation should be added to the attic side of the hatch. Rigid insulated sheathing is recommended. Cut the insulated sheathing ¼ inch smaller than the hatch size to allow for clearance when moving the access panel. Apply 3 or 4 inches of insulation to the hatch with construction adhesive and screws. As an added measure, glue the kraft-paper side of batt insulation to the top of the last layer of rigid insulation. Try to achieve the same total R-value as recommended by the 1995 Model Energy Code (MEC)(see page 4) or DOE Insulation Fact Sheet. Order the Insulation Fact Sheet (DOE/CE-0180) from the Energy Efficiency and Renewable Energy Clearinghouse or access it from the Internet at www.ornl.gov/roofs+walls.

PULL-DOWN ATTIC STAIRS



An attic stair cover box is made from rigid insulation. It drops down from the attic side to seal and insulate the pull-down stairs.

ATTIC STAIRS

Pull-down stairs are another common type of attic access. The frame for the stairs fits in a rough opening and leaves a gap, much like that for a door or window, which must be sealed. If the gap is small (less than ½ inch), caulk can be used as the sealant. If a larger opening exists, then non-expanding foam or a backing material (backer rod) is recommended in conjunction with caulk. Expanding foam can be used, but care must be taken because of its highly expansive nature; it could warp the frame and interfere with the ability of the stairs to open or close properly. To ensure a tight fit between the stairs' flat panel and the frame, weatherstripping or gasket material should be added either to the frame or the panel. Latch bolts may be installed to help ensure a tighter seal.

To insulate attic stairs access, a lightweight, moveable box can be constructed from rigid foam or fibrous ductboard to fit over the stairs from the attic side. Insulating kits are also available through weatherization suppliers or from local hardware stores.

As with all home projects, follow the attic stairs manufacturer's instructions for proper installation. Manufacturer's guidelines often provide unique techniques and safety considerations for each particular unit. For safety and the extended life of the stairs, be sure to cut the stairs to the proper length. This action will prevent strain on the hinges and reduce wear on the pivotal joints of the stairs.

ATTIC ACCESS LOCATION

Location of an attic access is important. If possible, locate the access in an unconditioned part of the house (e.g., garage, covered patio, or porch) that is also secure against potential break-ins. A garage location, where the vented attic is uninsulated, can eliminate the need for sealing and insulation.

For a pull-down attic staircase, make sure that opening the stairs will not interfere with the placement of furniture. The position of the staircase in relation to ceiling joists might also affect location—placing the staircase between joists instead of across joists can speed installation because structural cross-member framing is not as complicated.

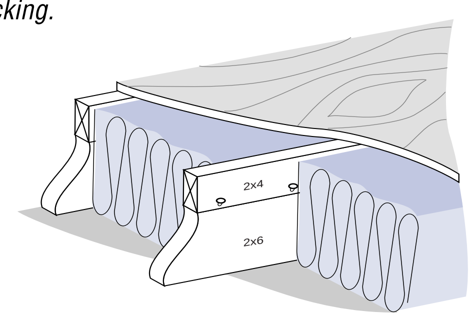
ATTIC DECKING

Attic decking is often used to provide additional storage space or a platform for an HVAC unit or hot water tank installed in the attic. The decking is often installed directly on top of the ceiling joists; this limits the amount of space available for insulation and lowers the attic's average R-value.

To ensure proper insulation depth, the attic decking must be raised above the ceiling joists. To accomplish this "edge-nail" 2x4's or 2x6's to the tops of the ceiling joists where the decking is to be located or, as an option for trusses, lag 2x4 members to the truss webbing at the desired height. Install the decking securely to the top of the raised lumber after the insulation has been installed.

INCREASE ATTIC INSULATION LEVELS UNDER DECKING

For many products, an insulation depth of 10 to 14 inches is needed to achieve an R-30 to R-38 insulation value. Thus, a 2x4 or 2x6 extension needs to be added to a 2x6 joist to provide sufficient depth before installing decking.



CONSTRUCT AN ATTIC STAIRS COVER BOX

Use the template shown here to cut pieces from a single 4x8 foot sheet of ½-inch rigid insulation for a box 53½ inches long (51½ inches inside), 24¾ inches wide (22¾ inches inside), and 9 inches high inside. This box will fit stairs with an outside framing dimension of 53½ inches by 24¾ inches. Adjust dimensions to fit the specific stairs being installed. Be sure to carefully measure both inside and outside dimensions to the appropriate length, width, and depth clearances for the cover box.

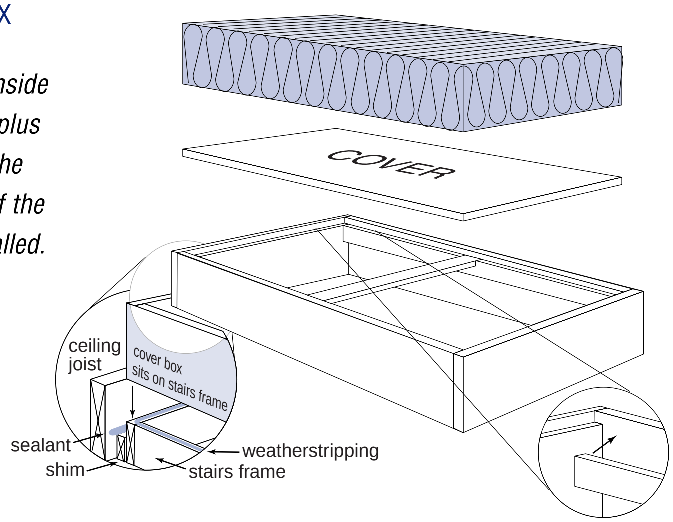
Create the box as shown: Apply adhesive/mastic and use roofing nails to construct the two end and two side pieces. Assemble the side and end pieces into a box using adhesive and longer nails. Add the center support brace and cover piece with glue and nails. A faced insulation batt may be glued to the cover piece with adhesive applied to the paper backing.

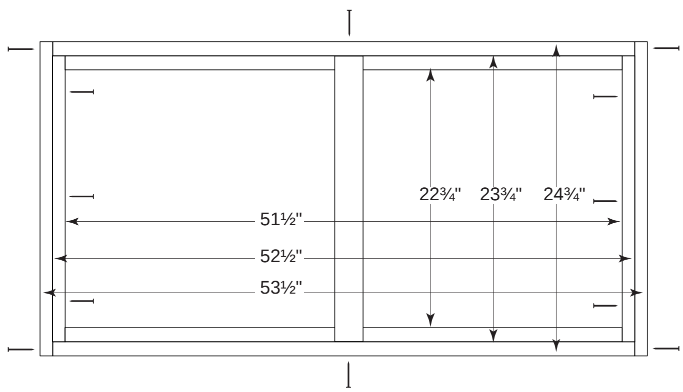
✓ **MATERIALS NEEDED:**

- ½-inch rigid insulation
- Insulation batt (optional)
- Duct sealing mastic or construction adhesive
- 1-inch roofing nails (8d or 16d)
- Tape measure, sharp utility knife and straight-edge, or table/circular saw
- Weatherstripping/gasket material with adhesive

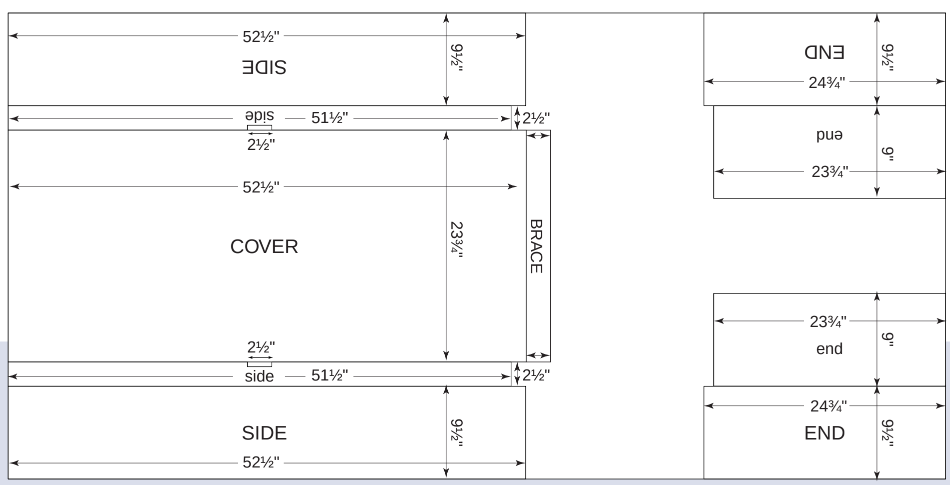
ATTIC STAIRS COVER BOX

Pay careful attention to inside and outside dimensions plus height requirements for the specific measurements of the attic staircase being installed. The cover box should rest squarely on top of the attic stairs frame. Shim and seal the gap between the frame and rough opening and install weatherstripping.





Assemble side pieces, end pieces, and brace as shown. The cover piece will drop in and be attached with adhesive and nails.



All pieces can be cut out of one 4'x8' sheet of rigid insulation. Use a table saw for smooth, accurate cuts.

ATTIC ACCESS

For more information, contact:

Energy Efficiency and Renewable Energy Clearinghouse (EREC)
1-800-DOE-3732
www.eren.doe.gov

Or visit the BTS Web site at
www.eren.doe.gov/buildings

Or refer to the Builder's Guide
Energy Efficient Building Association, Inc.
651-268-7585
www.eeba.org

Written and prepared for the U.S. Department of Energy by:

Southface Energy Institute
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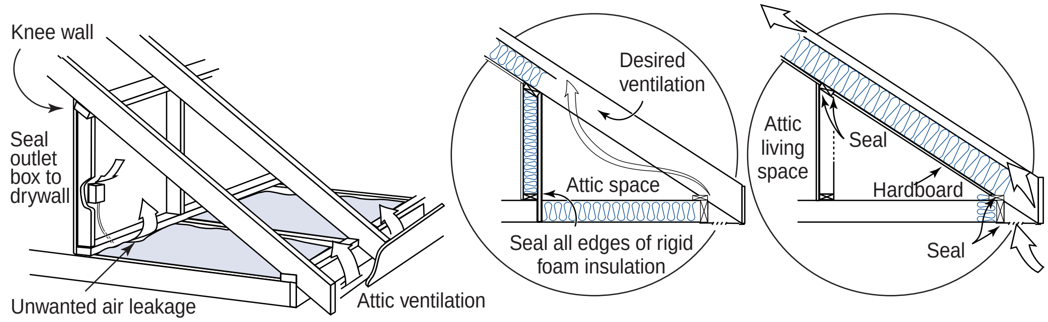
Oak Ridge National Laboratory
Buildings Technology Center
423-574-5178
www.ornl.gov/ornl/btc

The Model Energy Code can be obtained from the International Code Council by calling 703-931-4533

MECcheck, a companion compliance software package, can be ordered from DOE by calling 1-800-270-CODE or downloaded directly from the Web at www.energycodes.org/resid/resid.htm.

ATTIC KNEE WALL



The attic knee wall is often underinsulated and leaky. Install adequate insulation and air seal around the living space for continuity in the building envelope when addressing the knee-wall door.

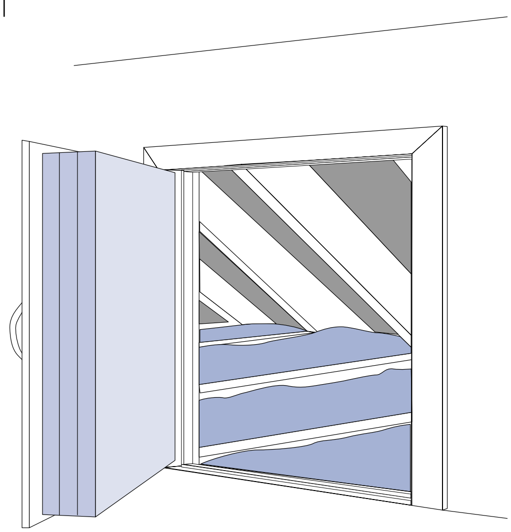
KNEE WALLS

Another type of attic access is a knee-wall door. A knee wall is typically a partial height wall that is usually found in the upstairs level of finished-attic homes. Knee walls are notoriously leaky and often poorly insulated. Make sure that the knee-wall door is weatherstripped and has a latch that pulls it tightly against the frame and weatherstripping to achieve a solid seal. Use construction adhesive and screws to attach rigid insulation to the attic side of the door. Some attic doors are full-height interior doors which should be insulated, weatherstripped, and equipped with a tight threshold.

Inspect the rest of the knee wall and adjust insulation levels to meet those recommended in the 1995 MEC or DOE Insulation Fact Sheet. If not enough insulation is installed, first air seal the knee wall before insulating. Consider covering the back of the vertical knee wall with rigid insulation. Insulated sheathing, with the seams caulked or sealed with housewrap tape, reduces heat flow and minimizes the comfort problems commonly associated with drafty attic knee walls.

In new construction, an improved approach is to insulate and air seal the rafter space along the sloped ceiling of the knee wall. The rafters should be covered with a sealed air barrier, such as drywall, rigid insulation, or foil-faced hardboard. One advantage of this approach is that the storage area as well as any ductwork is now inside a more tempered space.

KNEE-WALL DOOR



Add R-value to a knee-wall door by adhering rigid insulation boards (sandwiched together with construction adhesive and screws) to the back of the door. Pay special attention to the clearance between the insulation and the door frame and air sealing details.

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BASEMENT INSULATION

Create a comfortable basement environment that is free of moisture problems and easy to condition

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INTRODUCTION

The primary foundations in the United States are slab-on-grade, crawlspace, and basement. Basements can be a good choice for sites that slope steeply and in climates having cold winters with deep frost penetration. Although deeper excavation is required for structural reasons, the additional cost can result in a comfortable and habitable space.

Basements are notorious for problems with water intrusion, cold temperatures, humidity, mold, and uncomfortable, if not unhealthy, living conditions. A properly sealed, insulated, and moisture-protected basement will increase comfort, save on energy costs, improve durability, and reduce entry of moisture, soil gases, and other potential irritants or pollutants into the home.

However, basement walls are one of the most controversial areas of a home to insulate and seal. Many builders, even in far northern states, feel that insulating basement walls is too expensive and does not provide a reasonable payback. Also, builders of daylight or walkout basements often only insulate the framed section of the basement. Yet energy codes typically require a thermal boundary between the house and unconditioned basement or between a conditioned basement and the outside air and earth.

KEYS TO AN EFFECTIVE BASEMENT

Moisture control – using a water-managed foundation system to drain rainwater and groundwater away from foundations.

Airtight construction – sealing all air leaks between the conditioned space and the outside prior to insulation installation.

Complete insulation coverage – properly installing the correct insulation levels, making sure the insulation coverage is continuous and complete, and aligning the insulation barrier with the air barrier.

ANNUAL SAVINGS WITH BASEMENT WALL INSULATION

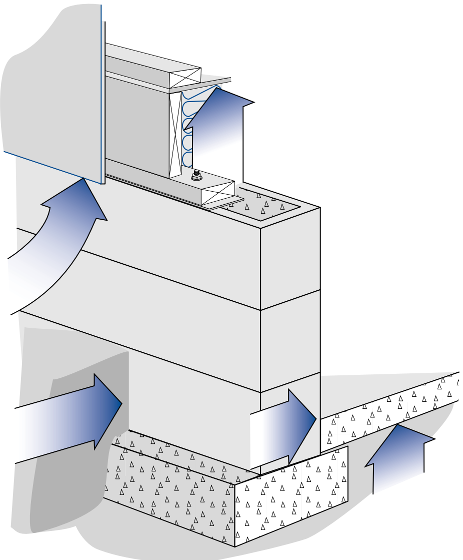
The energy savings of basement wall insulation vary depending on the local climate, type of heating system, cost of energy, and lifestyle of the occupant. Typical annual savings are provided in the table for a standard, 1,500 square-foot home with a conditioned basement that is heated by natural gas ($0.72/therm).

U.S. Cities	R-10*	R-20**
Buffalo, NY	$350	$390
Denver, CO	$310	$360
Minneapolis, MN	$400	$450
Seattle, WA	$280	$320
St. Louis, MO	$250	$290
Washington, DC	$250	$280

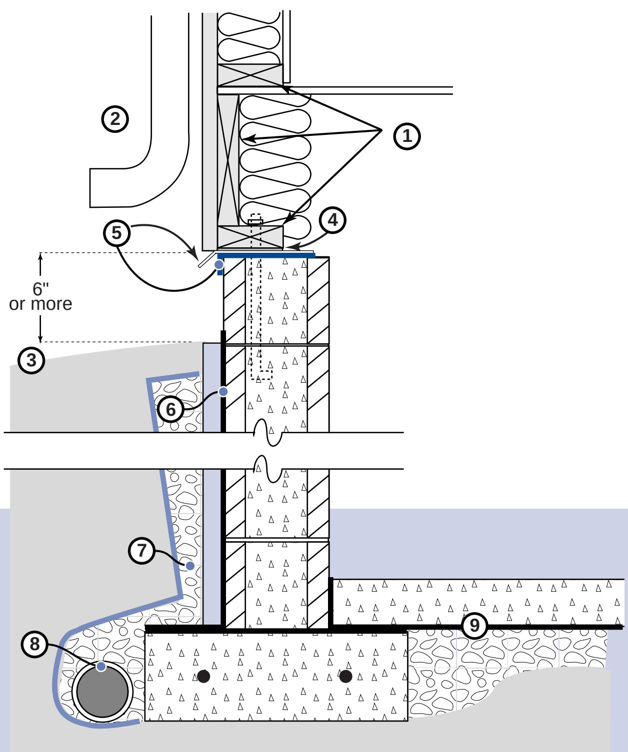
* Such as 2 to 3 inches of exterior foam insulation.
** Such as with most insulated concrete forms.

MOISTURE FLOW IN BASEMENTS

Water forces attack a basement foundation at several points. It is key to deter water at these entry points to preserve the integrity of the dwelling and enhance the living environment.



WATER-MANAGED BASEMENT WALL AND FOUNDATION



WATER-MANAGED FOUNDATION SYSTEM

Most basement water leakage is due to either bulk moisture leaks or capillary action. Bulk moisture is the flow of water through holes, cracks, and other discontinuities into the home's basement walls. Capillary action occurs when water wicks into the cracks and pores of porous building materials, such as masonry block, concrete, or wood. These tiny cracks and pores can absorb water in any direction–even upward.

The best approaches for preventing these problems will depend on the local climate and style of construction, but the following general rules apply to most basement designs.

1. Keep all untreated wood materials away from earth contact.
2. Provide drainage, such as gutters, to conduct rainwater away from the house.
3. Slope the earth away from all sides of the house for at least 5 feet at a minimum 5% grade (3 inches in 5 feet). Establish drainage swales to direct rainwater around the house.
4. Add a sill gasket to provide air sealing.
5. Install a protective membrane, such as caulked metal flashing or EPDM-type membrane, to serve as a capillary break that reduces wicking of water up from the masonry foundation wall. This membrane can also serve as a termite shield on top of the insulation board.
6. Dampproof all below-grade portions of the foundation wall and footing to prevent the wall from absorbing ground moisture by capillary action.
7. Place a continuous drainage plane over the dampproofing or exterior insulation to channel water to the foundation drain and relieve hydrostatic pressure. Drainage plane materials include special drainage matts, high-density fiberglass insulation products, and washed gravel. All drainage planes should be protected with a filter fabric to prevent dirt from clogging the intentional gaps in the drainage material.
8. Install a foundation drain directly below the drainage plane and beside the footing, not on top of the footing. This prevents water from flowing against the seam between the footing and the foundation wall. Surround a perforated 4-inch plastic drainpipe with gravel and wrap both with filter fabric.
9. Underneath the basement's slab floor, install a capillary break and vapor retarder, consisting of a layer of 6- to 10-mil polyethylene over at least 4 inches of gravel.

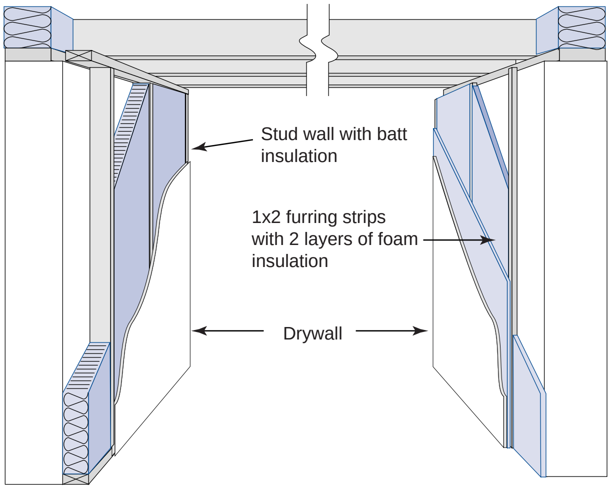
BASEMENT INSULATION PLACEMENT

In most cases, a basement should be considered a conditioned space with insulation installed in the exterior basement walls. Even in a house with an unconditioned basement, the basement is more connected to the other living spaces of the home than to the outside. This makes basement wall insulation preferable to insulating the basement ceiling.

Advantages of basement wall insulation include:

- Basement spaces, whether conditioned or not, are warmer and more comfortable.
- Compared to insulating the basement ceiling, insulating basement walls:
  - — requires less insulation (1,350 square feet of wall insulation for a 36- by 48-foot basement with 8-foot walls, compared with 1,725 square feet of basement ceiling insulation),
  - — more easily achieves continuous thermal and air leakage boundaries because basement ceilings are typically penetrated with electrical wiring, plumbing, and ductwork,
  - — requires little, if any increase in the size of heating and cooling equipment–the heat loss and air leakage through the basement ceiling is similar to that through the exterior walls of the basement.
- Piping and ductwork are located within the conditioned volume of the house so they do not require insulation for energy efficiency or protection against freezing.

INTERIOR BASEMENT WALL INSULATION STRATEGIES



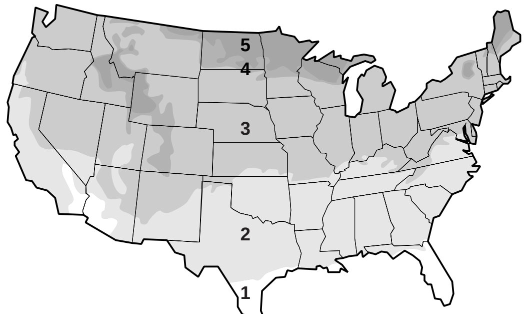
Disadvantages of basement wall insulation include:

- Costs may exceed those for insulating the basement ceiling, depending on the materials and approach selected.
- If the surrounding soil contains radon gas, the home will require a mitigation system underneath the basement floor.
- In termite-prone areas, exterior foam insulation in ground contact allows a path for termites to access the walls of the home undetected. Check with local code officials to determine acceptance of exterior foam application. Some installations will require non-invasive termite detection systems, such as termite baits. One of the nation's leading foam insulation manufacturers has released a rigid foam with borate insect repellent.

R-VALUES RECOMMENDED FOR BASEMENT INSULATION

The International Energy Conservation Code's basement wall insulation requirements, based on Heating Degree Days (HDD), are as follows:

HDD Zone	R-value Interior	R-value Exterior
1 (0-1,500)	none	none
2 (1,501-4,500)	R-5 to R-9	R-5 to R-10
3 (4,501-8,500)	R-9 to R-10	R-10
4 (8,501-9,000)	R-10 to R-19	R-10 to R-15
5 (> 9,000)	R-19	R-15



HDD=Heating Degree Days

Consult your local weather bureau for your city's actual Heating Degree Days, a measurement commonly used to determine fuel consumption and/or the cost of heating during a heating season.

BASEMENT INSULATION

For more information, contact:

Energy Efficiency and Renewable Energy Clearinghouse (EREC)
1-800-DOE-3732
www.eren.doe.gov

Or visit the BTS Web site at www.eren.doe.gov/buildings

Or refer to the Builder's Guide
Energy Efficient Building Association, Inc.
952-881-1098
www.eeba.org

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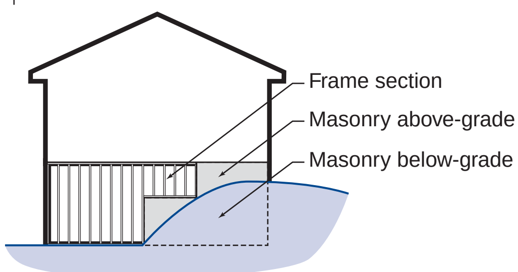
International Energy Conservation Code can be obtained from the International Code Council by calling 703-931-4533 www.intlcode.org

MECcheck, a companion compliance software package, can be ordered from DOE by calling 1-800-270-CODE or downloaded directly from the Web at www.eren.doe.gov/buildings/ codes_standards/buildings/.

BASEMENT INSULATION TECHNIQUES

Basement insulation levels should be selected in accordance with the International Energy Conservation Code or DOE Insulation Fact Sheet (DOE/CE-0180), which can be obtained from DOE or the web at www.ornl.gov/roofs+walls. Be sure to insulate both the masonry and stud walls of daylight basements.

DAYLIGHT BASEMENT



There are three primary ways to insulate the masonry portion of a basement wall:

1. **Exterior insulation**—1 to 3 inches are recommended for most climate zones. Extruded polystyrene (R-5 per inch) is durable and moisture resistant. Expanded polystyrene (R-4 per inch) is less expensive, but it has a lower insulating value. High-density, drainable, fiberglass insulation or fiberous drainboard does not insulate as well as foam but provides a drainage plane. Leave a 6-inch gap between the insulation and wood foundation elements to provide a termite inspection area. Insulate rim joists.
2. **Interior insulation**—usually installed behind interior framing or with furring strips placed against the foundation wall (see figure on page 3). Joints and penetrations through the drywall must be well sealed to prevent movement of moisture laden air into the insulation and possible condensation. Insulate rim joists.
3. **Insulated Concrete Forms**—comparatively new products that are relatively easy to install. Once the hollow foam blocks are stacked, the cores are filled with concrete. Most products provide continuous insulation on the interior and exterior. They also provide surfaces for attaching drywall, brick ties, and other finish materials. Many new insulated concrete forms are treated with termite-resistant chemicals. Insulate rim joists.

RADON CONTROL IN BASEMENTS

Radon is a radioactive gas that occurs in some soils. It can enter a home through the foundation and floor system. If it occurs in concentrations greater than 4 pico-curies per liter, it may pose a health risk to the home occupants.

To guard against radon problems:

- Install a 4-inch or greater gravel base with a continuous layer of 6-mil polyethylene on top of the gravel.
- Embed a "T" fitting attached to a 3-inch or larger diameter gas-tight pipe through the polyethylene barrier into the sub-slab aggregate before the slab is poured.
- Pour the slab and seal all slab joints and penetrations.
- Extend the gas-tight pipe vertically through an interior wall and terminate it at least 12 inches above the roof.
- Have an electrician stub-in a junction box in the attic.
- After construction is complete, test the basement for radon with an EPA-listed radon test kit, or hire a qualified technician. If the test shows concentrations above 4 pico-curies per liter, install a small blower to the pipe in the attic to depressurize the sub-slab space. If use of the blower does not reduce radon levels below 4 pico-curies per liter, consult with local radon experts.

For more detailed instructions, visit the EPA radon web site http://www.epa.gov/iaq/radon/.

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January 2002 DOE/GO-102002-0776

CEILINGS AND ATTICS

Install Insulation and Provide Ventilation

Buildings for the 21st Century

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BENEFITS OF CEILING INSULATION

Insulating ceilings is one of the most cost-effective energy efficiency measures. In addition to reducing heat loss in the winter and heat gains in the summer, ceiling insulation improves comfort by bringing ceiling temperatures closer to room temperatures and providing an even temperature distribution throughout the house.

When planning and managing ceiling insulation projects, make sure

- Ceiling is properly sealed
- Correct insulation levels are selected
- Insulation is properly installed
- Insulation coverage is continuous and complete
- Attic ventilation is maintained

Attic floors over flat ceilings are often the easiest part of an exterior building envelope to insulate. They are usually accessible and have ample room for insulation. However, many homes use cathedral ceilings or have attic knee walls that present unique insulation requirements.

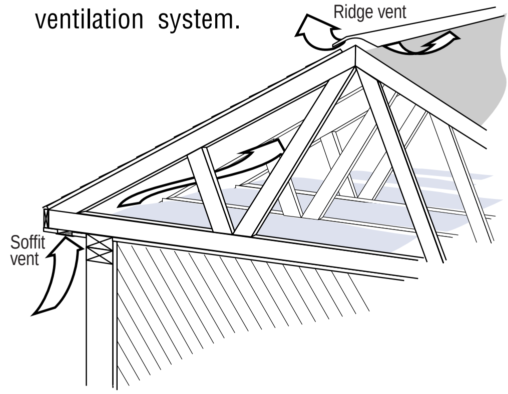
ATTIC VENTILATION

Most building codes require roof vents to expel moisture that could cause insulation or other building materials to deteriorate during winter. In summer, ventilation may reduce roof temperatures, thus lengthening a roof's life.

However, researchers are investigating whether attic ventilation is beneficial for all climates. For years, researchers have believed the cooling benefits of ventilating a well-insulated attic are negligible. Some experts also question whether ventilation effectively removes moisture. Until the research results are available and accepted, builders should follow local code requirements, which usually dictate attic ventilation.

ATTIC VENTILATION

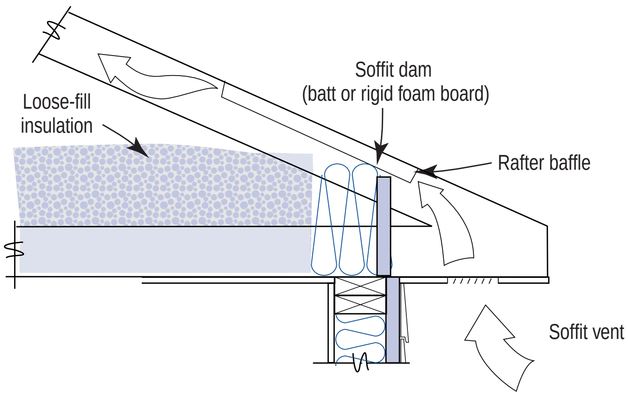
Continuous ridge and soffit vents form an effective attic ventilation system.



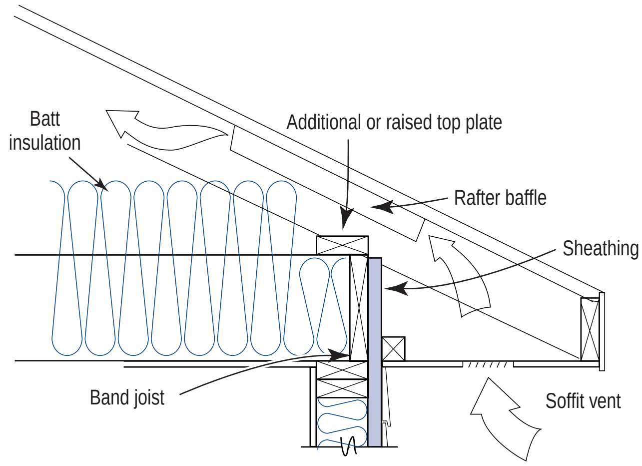
A combination of continuous ridge vent along the peak of the roof and continuous soffit vents at the eaves provides the most effective ventilation. A rule of thumb is to use 1 sq. ft. of net vent opening for every 150 sq. ft. of insulated ceiling or 1:300 if the insulation has a vapor barrier. Vent area should be divided equally between the ridge and soffits.

Cap vents and gable vents can supplement a roof design that has insufficient ridge vent area. Turbine vents can also be used, although they require annual maintenance. Electrically powered roof ventilators are not recommended because they consume more energy than they save. Powered vents can also remove conditioned air from a home through ceiling leaks and bypasses, pull pollutants from the crawlspace into a home, and cause exhaust gases from fireplaces and combustion appliances to enter a home.

ATTIC EAVES



This oversized truss shows loose-fill insulation that is blocked or dammed at the eave with a soffit dam (a piece of fiberglass batt or rigid insulation). A rafter baffle creates a channel for air flow.



A raised top plate increases the height for insulation and ventilation at the eaves.

INCREASING THE ROOF HEIGHT AT THE EAVE

One problem area in many roof designs occurs at the eave, where there is often insufficient space for full insulation without blocking air flow from the soffit vents. Often the insulation is compressed to fit the space, diminishing its R-value.

For a truss roof, consider *raised heel* or *oversized (cantilevered) trusses* that form elevated overhangs in combination with rafter baffles and soffit dams. These should provide clearance for both ventilation and full-height insulation. Use of 2- to 2½-foot overhangs also provides more room for insulation at the wall junction and additional window shading.

In stick-built roofs, where rafters and ceiling joists are cut and installed on the construction site, laying an additional top plate across the top of the ceiling joists at the eave will raise the roof height, prevent compression of the attic insulation, and permit ventilation. When installing a raised top plate, place a band joist at the open joist cavities of the roof framing. The band joist helps prevent windwashing of the attic insulation—where air entering the soffit vents flows through the attic insulation—which can reduce attic insulation R-values on extremely cold days or add moisture to the insulation. The band joist also serves as a soffit dam for the insulation.

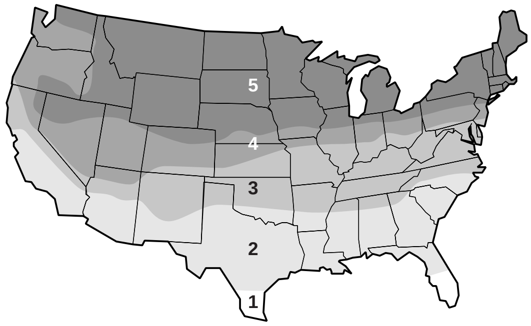
CEILING INSULATION R-VALUES

The 1995 Model Energy Code (MEC) and DOE Insulation Fact Sheet provide recommended R-values for geographical locations in the continental United States. The following table provides some general guidance.

HDD Zone		Ceiling R-value
1	(0-500)	R-19
2	(501-3,000)	R-30
3	(3,001-5,000)	R-38
4	(5,001-6,000)	R-38
5	(6,001-10,000)	R-49

HDD=Heating Degree Days

(Consult your local weather bureau for your city's actual annual heating degree days.)



ATTIC INSULATION TECHNIQUES

Loose-fill or batt insulation is typically installed in an attic. Although installation costs may vary, blowing loose-fill attic insulation—fiberglass, rock wool, or cellulose—is usually less expensive than installing batts and provides better coverage.

✓ Steps for installing loose-fill and batt insulation

1. Seal all attic-to-home air leaks, especially chases, dropped ceilings, wiring and plumbing penetrations, light fixtures, and bathroom fans. Most insulation does not stop air flow.
2. Install blocking (metal flashing) to maintain clearance requirements (usually 3 inches) for heat-producing equipment found in an attic, such as flues, chimneys, and exhaust fans.
3. Use only IC-rated recessed lights because they are airtight and can be covered with insulation.
4. Select insulation levels in accordance with the 1995 MEC or the DOE Insulation Fact Sheet. The Insulation Fact Sheet (DOE/CE-0180) can be ordered from the Energy Efficiency and Renewable Energy Clearinghouse or accessed from the Internet at www.ornl.gov/roofs+walls.
5. Locate the attic access in an unconditioned part of the house if possible. Otherwise, weatherstrip the attic access and insulate it by attaching insulation to the cover or by installing an insulated cover box.
6. If mechanical equipment or storage areas are located in the attic, elevate the attic decking to allow full-height insulation to be installed.

✓ Additional steps for installing loose-fill insulation

1. Prior to hanging ceiling drywall, install rafter baffles to preserve ventilation from soffit vents and use insulation dams at the soffit, porch, garage, and attic access to prevent the insulation from spilling.
2. Follow the manufacturer's specifications (number of bags per square feet) to obtain complete coverage of the blown insulation at consistent depths and to avoid fluffing the insulation.
3. As required by the 1995 MEC, make sure the installer:
   - Provides attic rulers to show proper blown depth (facing the attic entrance, one ruler for every 300 sq. ft.)
   - Provides an accurate attic "report card" showing that sufficient density was installed

✓ Additional steps for installing batt insulation

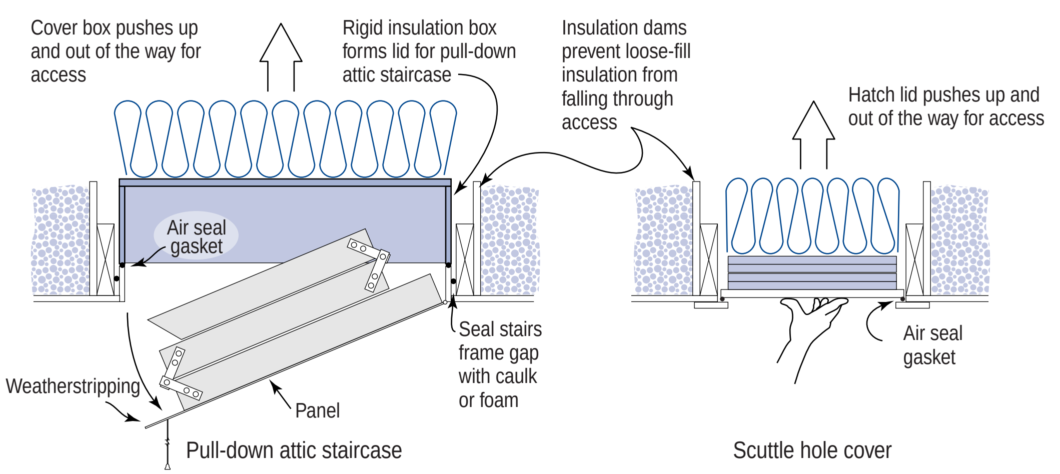
1. Cover the top of the ceiling joists or the bottom cord of the truss with insulation.
2. Obtain complete coverage of full-thickness, non-compressed insulation. Make certain batts completely fill the joist cavities. Shake batts to ensure proper loft. If joist spacing is uneven, patch gaps in the insulation with scrap pieces. Do not compress the insulation with wiring, plumbing or ductwork (cut slits in the insulation if necessary).

ENERGY-EFFICIENT CATHEDRAL CEILINGS

Cathedral ceilings must provide space between the roof deck and ceiling for adequate insulation and ventilation. For most areas of the U.S., the 1995 MEC recommends R-25 to R-38 insulation in a cathedral ceiling. This can be achieved through the use of truss joists, scissor truss framing, or sufficiently large rafters. For example, cathedral ceilings built with 2x12 rafters have space for standard 10-inch, R-30 batts and ventilation.

ATTIC ACCESS

When the attic access is located in the conditioned space of the house, build an insulated attic access cover to provide continuous ceiling insulation coverage and use blocking to prevent full-height, loose-fill insulation from falling through the access.



CEILINGS AND ATTICS

For more information, contact:

Energy Efficiency and Renewable Energy Clearinghouse (EREC)
1-800-DOE-3732
www.eren.doe.gov

Or visit the BTS Web site at
www.eren.doe.gov/buildings

Or refer to the Builder's Guide
Energy Efficient Building Association, Inc.
651-268-7585
www.eeba.org

Written and prepared for the U.S. Department of Energy by:

Southface Energy Institute
404-872-3549
www.southface.org

Oak Ridge National Laboratory
Buildings Technology Center
423-574-5178
www.ornl.gov/ORNL/BTC

The Model Energy Code can be obtained from the International Code Council by calling 703-931-4533

MECcheck, a companion compliance software package, can be ordered from DOE by calling 1-800-270-CODE or downloaded directly from the Web at www.energycodes.org/resid/resid.htm.

Foil-faced batt insulation is often used in cathedral ceilings because it has a 0.5 perm rating and provides the permeability often required for use in ceilings without attic spaces. A *vent baffle* should be installed between the insulation and roof decking to ensure that the ventilation channel is maintained.

If roof framing provides insufficient space for required insulation, higher insulation values can be obtained by either attaching furring strips to the underside of the rafters (that permit additional insulation to be installed), using high-density batts (high-density R-30 batts are about the same thickness as R-25 batts and fit into 2x10 framing), or adding rigid foam insulation under the rafters. Rigid foam insulation offers a resistance to thermal bridging through wood rafters. Rigid foam insulation must be covered with a fire-rated material when used on the interior of a building. Half-inch drywall usually complies, but check with local building codes for confirmation.

KNEE WALLS

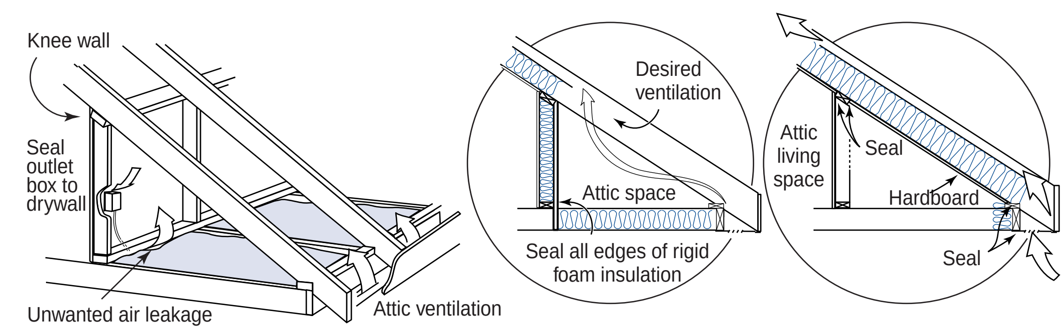
Knee walls are vertical walls with attic space directly behind them. They are often found in houses with finished attics and dormer windows, such as in story-and-a-half designs.

One approach to constructing an energy-efficient knee wall is to first air seal the knee wall using conventional techniques (i.e., seal the bottom plate, seal penetrations through the drywall, etc.). The open joist ends below the knee wall should be plugged with squares of cardboard, metal flashing, or rigid insulation; cellulose insulation blown at a high density; or batt insulation stuffed into plastic bags. The plugs should be sealed to the joists using caulk or spray foam.

The knee wall and attic floor in the attic space behind it should be insulated to recommended levels. The same techniques for achieving higher insulation levels in cathedral ceilings can be applied to knee walls. Twine is often used to hold the batt insulation in place. The technique of adding rigid foam insulation over the framing is particularly effective. Rigid insulation can be notched to fit over the floor joists. Sealing rigid insulation to floor joists effectively blocks open floor joists.

A better approach is to insulate and air seal the rafter space along the sloping ceiling of the knee wall attic space. The rafters should receive recommended insulation levels. They should be covered with a sealed air barrier, such as drywall or foil-faced hardboard. The barrier must be caulked to the top plate of the exterior wall below the attic space and to the top plate of the knee wall itself. All other cracks and holes must be sealed as well. One advantage of this technique is that any ductwork located in this space is now inside the conditioned space.

ATTIC KNEE WALL DESIGN



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February 2000 DOE/GO10099-771

CRAWLSPACE INSULATION

Improve comfort and increase durability in the home

Buildings for the 21st Century

Buildings that are more energy efficient, comfortable, and affordable… that's the goal of DOE's Office of Building Technology, State and Community Programs (BTS). To accelerate the development and wide application of energy efficiency measures, BTS:

- Conducts R&D on technologies and concepts for energy efficiency, working closely with the building industry and with manufacturers of materials, equipment, and appliances
- Promotes energy/money saving opportunities to both builders and buyers of homes and commercial buildings
- Works with state and local regulatory groups to improve building codes, appliance standards, and guidelines for efficient energy use
- Provides support and grants to states and communities for deployment of energy-efficient technologies and practices

EFFECTIVE CRAWLSPACE INSULATION

A properly sealed, moisture-protected, and insulated crawlspace will increase comfort, save on energy costs, improve the durability of the home, and reduce entry of moisture, radon, and other potential irritants or pollutants into the home. Whichever design is followed, the keys to an effective crawlspace are:

Moisture control –using a water-managed foundation system to drain rainwater and groundwater away from foundations.

Airtight construction –sealing all air leaks between the conditioned space and the outside prior to insulation installation.

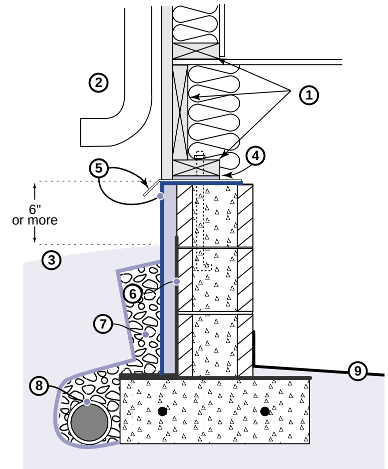
Complete insulation coverage –properly installing the correct insulation levels and making sure the insulation coverage is continuous and complete.

WATER-MANAGED FOUNDATION SYSTEM

A crawlspace is susceptible to moisture and deterioration problems because of contact with the earth. The best approaches for preventing these problems will depend on the local climate and style of construction, but the following general rules apply to most crawlspace designs.

1. Keep all untreated wood materials away from the earth.
2. Provide rain drainage, such as gutters, to conduct rainwater away from the house.
3. Slope the earth away from the house for at least 5 feet at a minimum 5% grade (3 inches in 5 feet). Establish drainage swales to direct rainwater around the house.
4. Add a sill gasket to provide air sealing.

WATER-MANAGED CRAWLSPACE FOUNDATION



5. Install a protective membrane, such as an EPDM-type membrane, to serve as a capillary break that reduces wicking of water from the masonry wall. This membrane, in addition to metal flashing, can serve as a termite shield.
6. Dampproof the below-grade portion of the foundation wall to prevent the wall from absorbing ground moisture by capillary action.
7. Install drainage plane material or gravel against the foundation wall to relieve hydrostatic pressure and channel water to the foundation drain.
8. Provide a foundation drainage system at the bottom of the footing, not on top, when the foundation floor (interior grade) is below the exterior grade. Surround a perforated 4-inch drain pipe with gravel and cover them with filter fabric.
9. Install 6-mil polyethylene across the crawlspace floor to prevent soil moisture from migrating into the crawlspace. Overlap and tape all seams by 12 inches, and seal the polyethylene 6 inches up the crawlspace walls.

CRAWLSPACE WALL INSULATION TECHNIQUES

For years, standard building practice was to insulate underneath the floor over a ventilated, unconditioned crawlspace. A better approach is to build a well sealed, unventilated crawlspace (i.e., build the crawlspace like a basement) by sealing and insulating the foundation walls rather than the subfloor.

Advantages to insulating the crawlspace walls are:

- Problems associated with ventilating the crawlspace are avoided.
- Less insulation is required (around 400 square feet for a 1,000-square-foot crawlspace with 3-foot walls).
- Piping and ductwork are within the conditioned volume of the house so they do not require insulation for energy efficiency or protection against freezing.
- Air sealing between the house and crawlspace is less critical.

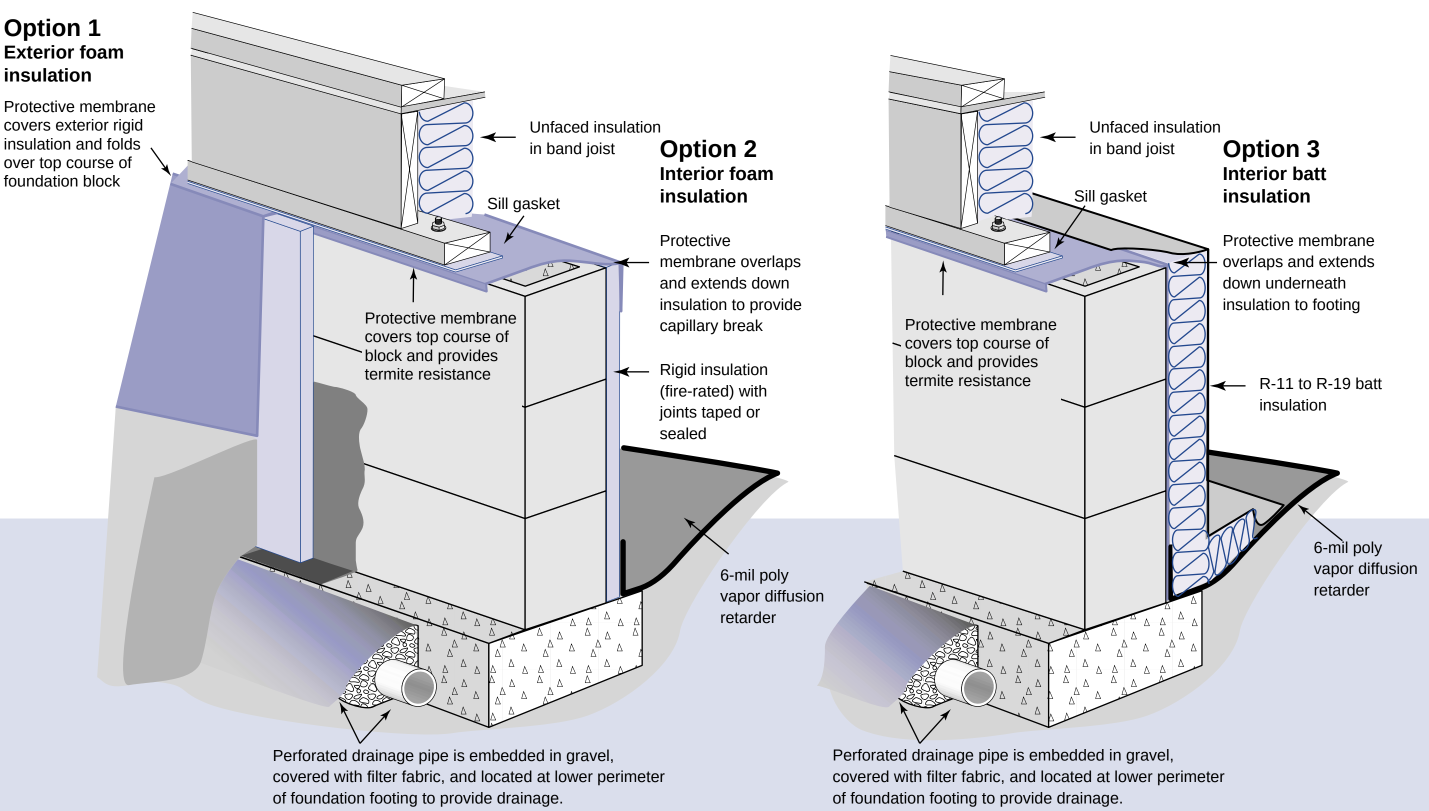
Disadvantages to insulating the crawlspace walls are:

- The insulation may be damaged by rodents, pests, or water.
- A radon mitigation system will require ventilation of the crawlspace to the exterior. Not planning for radon-resistant construction may necessitate air sealing the floor in order to mitigate the radon through ventilation.
- The crawlspace must be built airtight and the air barrier must be maintained.
- The access door to the crawlspace must be located inside the home through the subfloor unless an airtight, insulated access door in the perimeter wall is built and maintained.

STEPS FOR INSTALLING CRAWLSPACE WALL INSULATION

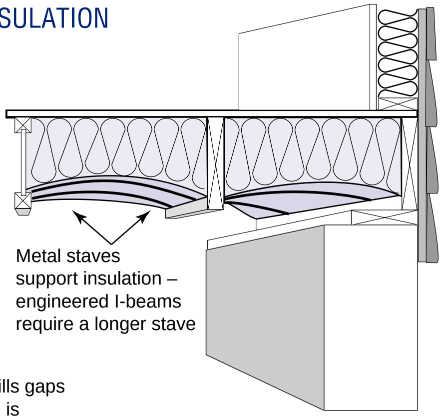
1. Review plans for this method of foundation insulation with pest control and local building officials to ensure code compliance.
2. Eliminate or seal the foundation vents.
3. Ensure that combustion furnaces and water heaters located in the crawlspace are sealed-combustion units equipped with a powered combustion system.
4. Seal all air leaks through the exterior wall during and after construction, including the band joist.

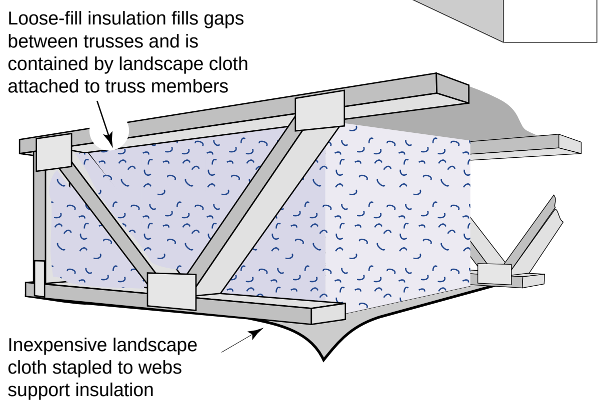
INSULATED CRAWL SPACE WALLS—3 OPTIONS



5. Locate the crawlspace access inside the home or install an access through the perimeter that will remain airtight after repeated use.
6. Select insulation levels in accordance with the International Energy Conservation Code or the DOE Insulation Fact Sheet. The Insulation Fact Sheet (DOE/CE-0180) can be ordered from the Energy Efficiency and Renewable Energy Clearinghouse or accessed from the Internet at www.ornl.gov/roofs+walls.
7. Install rigid or batt insulation using one of three options (exterior foam, interior foam, or interior batt) to achieve complete insulation coverage. Insulate the band joist with batt insulation, and the crawlspace access if it is located in the wall. Install a continuous termite shield between the band joist and masonry foundation wall that covers the wall insulation and extends completely outside, or leave a 2- to 4-inch insulation gap at the top for termite inspection.
8. Install a supply outlet in the crawlspace, relying on the leakiness of the floor to provide the return air path.

UNDERFLOOR INSULATION





INSULATING TRUSS FLOOR SYSTEMS

Instead of batt insulation, a better approach is to install netting or rigid insulation to the underside of the floor trusses and filling the space created between the netting or insulation and subfloor with a loose-fill insulation.

STEPS FOR INSTALLING UNDERFLOOR INSULATION

1. During the early phases of construction, meet with the mechanical subcontractors (plumbing, electrical, and heating/cooling) to inform them of the importance of keeping the space between floor joists as clear as possible. Run drain lines, electrical wiring, and ductwork below the bottom of the insulation so that a continuous layer of insulation can be installed. For protection against freezing, supply plumbing may be located within the insulation. The best approach is to run supply plumbing together in a few joist spaces. The insulation can be split and run around the piping.
2. Seal all air leaks between the conditioned area of the home and the crawlspace. High-priority leaks include holes around bathtub drains and other drain lines, plenums for ductwork, and penetrations for electrical wiring, plumbing, and ductwork (including duct boot connections at the floor).
3. Select insulation levels in accordance with the International Energy Conservation Code or the DOE Insulation Fact Sheet.
4. Insulation batts with an attached vapor barrier are usually used to insulate framed floors. Obtain insulation with the proper width for the joist spacing of the floor being insulated. Complete coverage is essential – leave no insulation voids. The batts should be installed flush against the subfloor to eliminate any gaps that may serve as passageways for cold air to flow between the insulation and the subfloor. The batts should be cut to the full length of the joist being insulated and slit to fit around wiring and plumbing. Insulate the band joist area between air ducts and the floor as space permits. Use insulation hangers (wire staves) spaced every 12-18 inches to hold the floor insulation in place without compressing the insulation more than 1 inch.
5. The orientation of the vapor barrier depends on the home's location. In most of the country, the vapor barrier should face upward. However, in certain regions of the Gulf states and other areas with mild winters and hot summers, it should face downward.
6. Insulate all ductwork in the crawlspace.
7. Insulate all hot and cold water lines in the crawlspace unless they are located within the insulation.
8. Close crawlspace vents after making sure the crawlspace is dry and all construction materials have dried out.

CRAWLSPACE INSULATION

For more information, contact:

Energy Efficiency and Renewable Energy Clearinghouse (EREC)
1-800-DOE-3732
www.eren.doe.gov

Or visit the BTS Web site at
www.eren.doe.gov/buildings

Or refer to the Builder's Guide
Energy Efficient Building Association, Inc.
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www.eeba.org

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MECcheck, a companion compliance software package, can be ordered from DOE by calling 1-800-270-CODE or downloaded directly from the Web at: www.energycodes.org/resid/resid.htm.

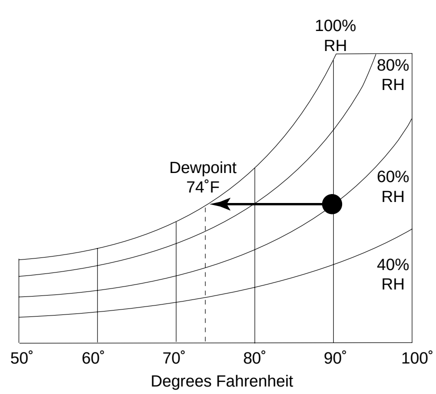
ARE CRAWLSPACE VENTS NECESSARY?

Most building codes require crawlspace vents to aid in removing moisture from the crawlspace. However, many building professionals are now recognizing that an unvented crawlspace (or closing crawlspace vents after the crawlspace has had time to dry out after construction) is the best option in homes using proper moisture control and exterior drainage techniques for two reasons.

First, ventilation in the winter is undesirable in order to keep crawlspaces warmer. Second, warm, moist outdoor air brought into the crawlspace through foundation vents in the summer is often unable to dehumidify a crawlspace and, in fact, can lead to increased moisture levels in the crawlspace.

For example, a crawlspace kept cool by the ground in the summer may have a temperature of 65°F and 90% relative humidity (RH)—the dew point temperature of the air is 62°F. The dew point of outdoor air at 90°F and 60% RH is about 74°F. Thus, outdoor air brought into the crawlspace will actually increase the moisture level until water condenses out on cool crawlspace surfaces such as floor joists, foundation walls, and air-conditioning ducts. As framing stays moist, mold grows and dry rot develops.

PSYCROMETRIC CHART



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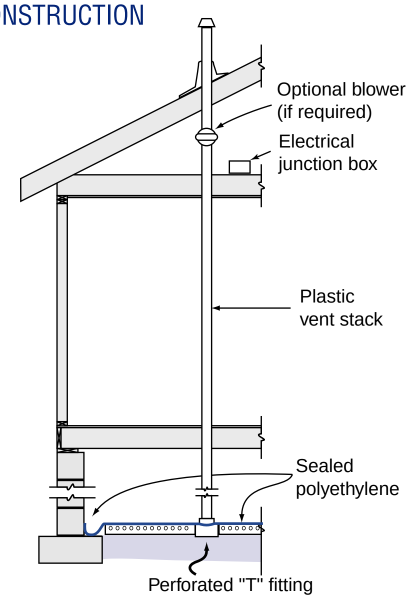
December 2000 DOE/GO2000-0774

BUILD IN RADON RESISTANCE

Radon is a radioactive gas that occurs in some soils. It can enter a home through the foundation and floor system. If it occurs in significant concentrations (greater that 4 pico-curies per liter), it may pose a severe health risk to the home occupants. To guard against radon problems:

- Install a sealed, continuous layer of 6-mil polyethylene over the crawlspace floor.
- Install a plastic tee below the polyethylene that protrudes through the polyethylene.
- Install a vertical 3-inch plastic pipe from the foundation to the roof through an interior wall.
- Connect the tee to the vertical 3-inch plastic pipe for passive mitigation.
- Have an electrician stub-in a junction box in the attic.
- Test the bottom conditioned room for radon with an EPA-listed radon test kit, or hire a qualified technician. If the house has a high radon concentration, install an active radon mitigation system by attaching a small blower to the plastic pipe in the attic to expel the gases to the outside.
- If radon levels are especially high (over 25 pico-curies per liter), consult with local radon experts.

RADON RESISTANT CONSTRUCTION



Technology Fact Sheet

SLAB INSULATION

Improve comfort and save energy in homes with slab-on-grade floors

Buildings for the 21st Century

Buildings that are more energy efficient, comfortable, and affordable…that's the goal of DOE's Office of Building Technology, State and Community Programs (BTS). To accelerate the development and wide application of energy efficiency measures, BTS:

- Conducts R&D on technologies and concepts for energy efficiency, working closely with the building industry and with manufacturers of materials, equipment, and appliances
- Promotes energy/money saving opportunities to both builders and buyers of homes and commercial buildings
- Works with state and local regulatory groups to improve building codes, appliance standards, and guidelines for efficient energy use
- Provides support and grants to states and communities for deployment of energy-efficient technologies and practices

SLAB-ON-GRADE FLOORS PROVIDE AN INEXPENSIVE AND VERSATILE FOUNDATION

Slab-on-grade floors are often the least expensive foundation system and can expedite the construction process. The foundation consists of a concrete slab poured over at least 4 inches of gravel and a layer of 10-mil polyethylene. Virtually any floor covering works well with a slab, although wood flooring systems may require installation of wooden furring strips prior to attaching the wood flooring material.

Homes use slab-on-grade floors in two ways: either as the bottom floor of a home or as the floor in a daylight basement—where the floor level is about even with outside earth. Areas with mild winters do not require a deep foundation. In these regions, slab-on-grade foundations may prove an ideal choice for flat lots.

Care must be taken in designing a home with a slab foundation to avoid a "squat" appearance. For example, porches are at grade level in houses with a slab foundation, rather than being elevated above the yard. The hard surface of the slab foundation may cause injuries, more frequent breakage of dropped objects, and tired feet unless it is covered with carpeting or other softer floor finishes. Use of slab foundations can also make it more difficult to install wiring, plumbing, and ductwork, so the design of these systems into the construction plans and process is essential.

BENEFITS OF INSULATING SLAB-ON-GRADE FLOORS

Slabs lose energy primarily as a result of heat conducted outward and through the perimeter of the slab. In most sections of the country, insulating the exterior edge of the slab can reduce winter heating bills by 10 to 20 percent.

SLAB INSULATION

Provides a thermal break to the perimeter of slab-on-grade foundations.

In climates with mild winters, slab insulation in a typical 1,800 square-foot home would save $50 to $60 annually. R-10 slab insulation for an 1,800 square-foot home would typically cost $300 to $600 to install. Thus, the insulation would pay for itself in 5 to 10 years.

The investment in slab insulation is also economical when it is part of the mortgage. An insulation cost of $450 would add about $38 to the annual mortgage. Since the insulation saves over $50 per year on energy bills, savings exceed the extra mortgage costs and the investment in slab insulation pays off from the beginning.

Slab insulation is important not only to save on energy bills, but also to improve comfort. Cold concrete slabs are one of the most notorious sources of discomfort in a home. Installing slab insulation around the perimeter of the slab will reduce heat loss and make the slab easier to heat. An insulated slab also provides thermal mass to store heat and moderates indoor temperatures.

OFFICE OF BUILDING TECHNOLOGY, STATE AND COMMUNITY PROGRAMS
ENERGY EFFICIENCY AND RENEWABLE ENERGY • U.S. DEPARTMENT OF ENERGY

SLAB INSULATION TECHNIQUES

Slab insulation can be installed following one of two basic techniques: installing rigid insulation directly against the exterior of the slab and footing or building a "contained" or "floating" slab with interior insulation. Whichever design is followed, the keys to an effective slab foundation are:

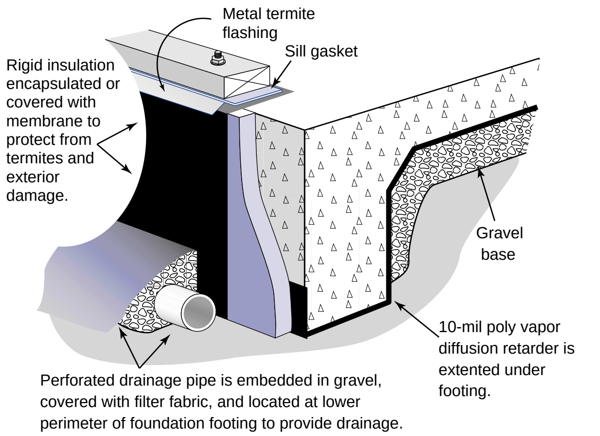
Moisture control—using a water-managed foundation system to drain rainwater and groundwater away from the foundation.

Airtight construction—sealing interfaces between the slab foundation and the exterior wall to reduce infiltration into the house.

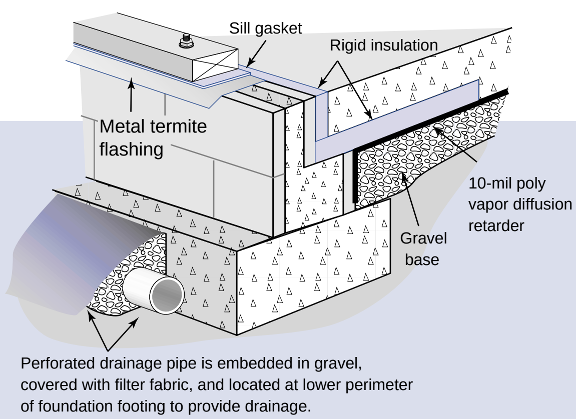
Complete insulation coverage—properly installing the correct insulation levels and making sure the insulation coverage is continuous and complete.

PERIMETER INSULATION— SLAB-ON-GRADE CONSTRUCTION

Provide good drainage away from the foundation and capillary breaks for a durable foundation. Perimeter insulation increases comfort in the living space.



FLOATING SLAB-ON-GRADE CONSTRUCTION



MOISTURE AND AIR LEAKAGE CONTROL

1. Keep all untreated wood materials away from the earth.
2. Install well-designed guttering and downspouts that are connected to a drainage system diverting rainwater completely away from the house.
3. Slope the earth away from the house for at least 5 feet at a minimum 5% grade (3 inches in 5 feet). Establish drainage swales as needed to direct rainwater around the house.
4. Add a sill gasket membrane between the slab and bottom plate to provide air sealing.
5. Install a protective membrane (such as rubberized roofing material or ice-dam protection membranes) to serve as a capillary break that reduces wicking of water up from the foundation. This membrane can also serve as a termite shield.
6. Install a foundation drain directly beside the bottom of the footing. The foundation drain assembly includes a filter fabric, gravel, and a perforated plastic drain pipe typically 4 inches in diameter. Locate the drain beside the footing, not on top, to avoid water flowing against the seam between the footing and the foundation wall and prevent wicking from a web footing through the stem wall.
7. Install a capillary break and moisture barrier under the slab floor, consisting of a layer of 10-mil polyethylene placed over at least 4 inches of gravel.

INSULATION

1. Review the plan for slab insulation with pest control and local building officials to ensure code compliance.
2. Select insulation levels in accordance with the International Energy Conservation Code (IECC) or DOE Insulation Fact Sheet. The Insulation Fact Sheet (DOE/CE-0180) can be ordered from the Energy Efficiency and Renewable Energy Clearinghouse or accessed from the Internet at www.ornl.gov/roofs+walls.
3. Install rigid insulation using one of the two general designs shown to achieve complete insulation coverage of the slab perimeter. Use only insulation approved for below-grade use.

R-VALUES AND RECOMMENDED DEPTH FOR SLAB INSULATION

The IECC specifies both the R-value of the slab insulation and the minimum distance for the insulation from the top of the slab downward based on a locality's Heating Degree Days (HDDs):

Heating Degree Days	Feet Installed Vertically	R-value of Slab Insulation
0 to 2,499	none required	
2,499 to 4,500	2 feet	R-4
4,500 to 6,000	2 feet	R-5
6,000 to 7,200	4 feet	R-6
7,200 to 8,700	4 feet	R-7
8,700 to 10,000	4 feet	R-8
10,000 to 12,400	4 feet	R-9
12,400 to 14,000	4 feet	R-10

HDD=Heating Degree Days

(Consult your local weather bureau for your city's actual annual Heating Degree Days.) Heating Degree Days is a term used to help indicate the heating needed for any certain day. This method is commonly used to determine fuel consumption and/or the cost of heating during a season by using historical weather trends to calculate average seasonal temperatures.

4. If insulation is installed on the exterior of the slab:
   - The insulation should be installed from the top of the slab to the bottom of the frost line unless a termite inspection gap is required.
   - Encapsulate or cover the exterior face of the insulation with a protective membrane to serve as a capillary break and to protect the insulation from termites.
   - Cover the above-grade portion of the insulation exposed to outside air using a stucco coating, pressure-treated wood, brick, or aluminum flashing. When covering insulation, be conscious of how to detect termites in areas prone to termite infestation. Some states in termite-prone areas have addressed this issue by requiring a termite inspection gap near the top of the slab insulation.

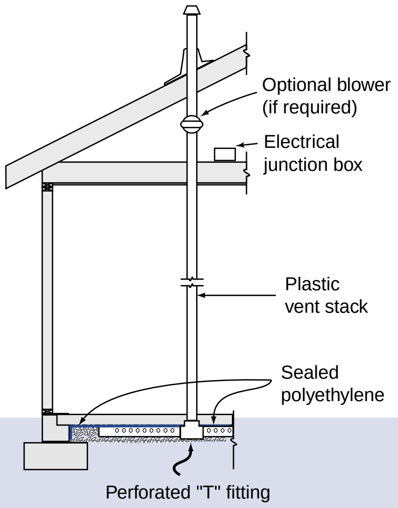
BUILD IN RADON RESISTANCE WHEN INSTALLING SLAB-ON-GRADE FOUNDATIONS

Radon is a radioactive gas that occurs in some soils. It can enter a home through the foundation and floor system. If it occurs in significant concentrations (greater than 4 pico-curies per liter), it may pose a severe health risk to the home occupants. To guard against radon problems in concrete slabs:

- Use a 4- to 6-inch gravel base and a continuous layer of 10-mil polyethylene on top of the gravel.
- Install a tee below the polyethylene that protrudes through the polyethylene and extends above the poured floor height.
- Connect the tee to a 3-inch vertical plastic pipe that extends to the roof through an interior wall.
- Pour the slab and seal all slab joints with caulk.
- Have an electrician stub-in a junction box in the attic.
- Test the bottom-most conditioned room for radon with an EPA-listed radon test kit, or hire a qualified technician. If the house has a high radon concentration, install an active radon mitigation system by attaching a small blower to the plastic pipe in the attic to expel the gasses to the outside.
- If radon levels are especially high (over 25 pico-curies per liter), consult with local radon experts.

RADON-RESISTANT CONSTRUCTION

Passive radon-resistant construction is an inexpensive first cost. It can easily be upgraded if active mitigation is later required to cure a radon problem.



SLAB INSULATION

For more information, contact:

Energy Efficiency and Renewable Energy Clearinghouse (EREC)
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Or refer to the Builder's Guide *Energy Efficient Building Association, Inc.*
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MECcheck, a companion compliance software package, can be ordered from DOE by calling 1-800-270-CODE or from the Web at www.energycodes.org/resid/resid.htm.

SPECIAL REQUIREMENTS OF SLAB INSULATION FOR TERMITE CONTROL

Over the past decade, reports of termite infestations in homes with exterior slab insulation have become more frequent. These pests tunnel undetected through the insulation to gain access to the wood framing in the walls. Some insurance companies no longer guarantee homes with slab insulation against termite damage. Recent rulings by national code organizations, such as the International Code Council, prohibit installing foam insulation in contact with the ground in several southern states (South Carolina, Florida, Georgia, Alabama, Mississippi, Louisiana, Arkansas, and Texas).

An alternative to slab edge insulation is to create a contained or floating slab with interior foam insulation. This non-monolithic approach provides termite resistance because the insulation is sealed within the slab. However, builders in the Southeast United States recently reported termite infestations through foam insulation on contained slabs.

Termite prevention is a key goal when installing slab insulation, especially where a visual inspection of the foundation is not possible. The key to controlling termites is proper treatment, a regular inspection policy, and a strong warranty from a termite company. Before construction, confer with a pest control company to ensure a favorable termite contract.

✓ FOLLOW THESE GUIDELINES TO OFFSET TERMITE PROBLEMS:

- Provide effective moisture control systems.
- Remove all wood from around the foundation before backfilling.
- Install termite shields continuously under the sill plate of the building. While not 100 percent effective, the termite shield may deter or delay widespread infestation and may also force termites into an exposed area where they can be detected. It should project beyond the sill plate and all other portions of the exterior wall. A continuous layer of a membrane such as rubberized roofing material used in commercial buildings may be used as an alternative to the termite shield.
- Use a foam insulation with a termiticide. Usually a derivative of boric acid, the termiticide should pose no more threat to home owners than traditional termite treatments. One of the nation's leading foam insulation manufacturers is planning to offer a termite-treated insulation board on the market in the year 2000 or 2001.

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December 2000 DOE/GO102000-0775

Buildings for the 21st Century

Buildings that are more energy efficient, comfortable, and affordable…that's the goal of DOE's Office of Building Technology, State and Community Programs (BTS). To accelerate the development and wide application of energy efficiency measures, BTS:

- Conducts R&D on technologies and concepts for energy efficiency, working closely with the building industry and with manufacturers of materials, equipment, and appliances
- Promotes energy/money saving opportunities to both builders and buyers of homes and commercial buildings
- Works with state and local regulatory groups to improve building codes, appliance standards, and guidelines for efficient energy use
- Provides support and grants to states and communities for deployment of energy-efficient technologies and practices

WALL INSULATION

Provide Moisture Control and Insulation in Wall Systems

EFFECTIVE WALL INSULATION

Properly sealed, moisture-protected, and insulated walls help increase comfort, reduce noise, and save on energy costs. However, walls are the most complex component of the building envelope to insulate, air seal, and control moisture.

The keys to an effective wall are:

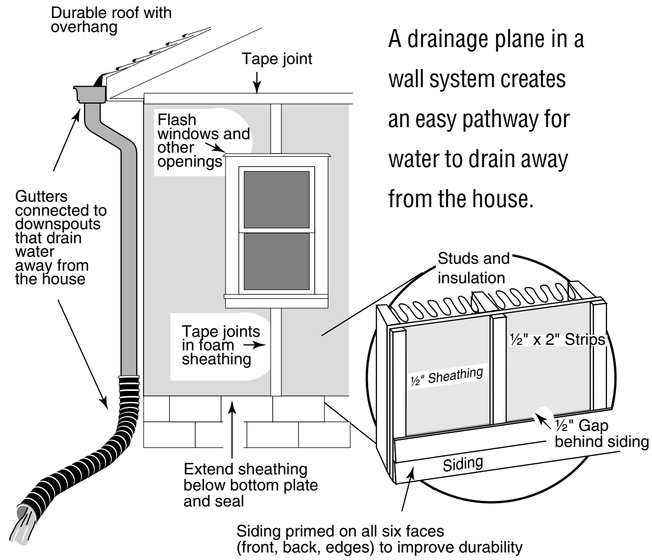
- Airtight construction—all air leaks sealed in the wall during construction and prior to insulation installation.
- Moisture control—exterior rain drainage system, continuous air barrier, and vapor barrier located on the appropriate side of the wall.
- Complete insulation coverage—advanced framing to maximize insulation coverage and reduce thermal bridging, no gaps or compressed insulation, and continuous insulated sheathing.

AIR SEALING

Air sealing reduces heat flow from air movement (convection) and prevents water vapor in the air from entering the wall. In a 100-square-foot wall, one cup of water can diffuse through drywall without a vapor barrier in a year, but 50 cups can enter through a ½-inch, round hole. In fact, sealing air leaks is 10 to 100 times as important as installing a vapor barrier.

MOISTURE CONTROL

Air sealing and moisture control make insulation more effective. It is a myth that installing vapor barriers is the most important step for controlling moisture in walls. Vapor barriers only retard moisture due to diffusion, while most moisture enters walls either through fluid capillary action or as water vapor through air leaks.



A drainage plane in a wall system creates an easy pathway for water to drain away from the house.

✓ Prevent rain penetration

Causes of rain leaks through exterior walls include improper installation of siding materials; poor-quality flashing, weatherstripping, or caulking around joints in the building exterior (such as windows, doors, and bottom plates); and wind-driven rain that penetrates the exterior finish. To enhance protection against rain penetration, create a drainage plane within the wall system of the home.

✓ Control moisture in walls

All climates require these steps:

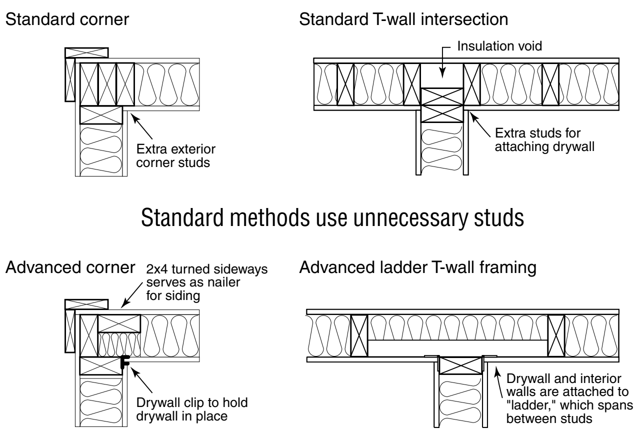
- Install a polyethylene ground cover on the earth floor of houses with crawl spaces and slope the ground away from the foundations of all houses.
- Install a continuous vapor barrier that has a Perm rating of less than one (see page 3).
- Place a termite shield, sill gaskets, or other vapor-impermeable membrane on the top of the foundation wall. This action will prevent moisture from wicking into the framed wall from the concrete foundation wall by capillary action.

WALL FRAMING WITH ADVANCED FRAMING TECHNIQUES

Building experts have performed considerable research on ways to reduce the amount of lumber in our homes while maintaining structural integrity. The U.S. Forestry Products Association and other organizations have devised an “optimum value engineering” (OVE) framing system that reduces unnecessary lumber use and improves the whole-wall R-value by reducing thermal bridging and maximizing the wall area that is insulated. Selected OVE practices include:

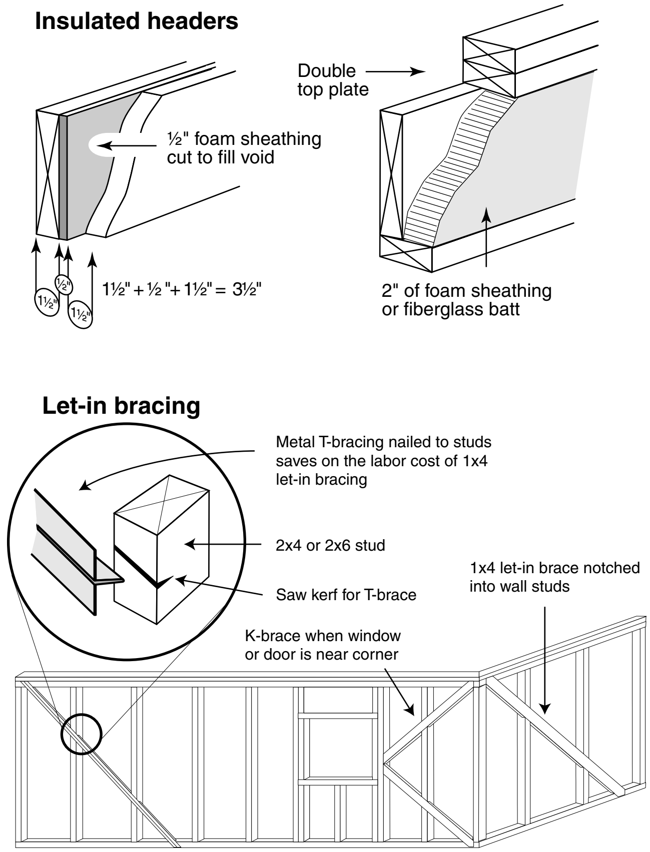
- Design the house to use materials efficiently by employing simpler shapes and volumes, compact designs, and designs based on a 2-foot module.
- Frame at 24-inch rather than 16-inch centers.
- Design headers for loading conditions and use insulated headers.
- Locate window and door openings in-line with established framing and size windows to fit within existing stud spacing.
- Eliminate unnecessary framing at intersections using two-stud rather than three-stud corners and ladder blocking where interior partitions intersect exterior walls.
- Use let-in bracing to allow the use of insulated sheathing in corners.
- Eliminate curtailed studs (cripples) under windows.
- Align roof, wall, and floor framing members (studs and joists) vertically throughout the structure so that a single top plate can be used.

STANDARD FRAMING VERSUS ADVANCED FRAMING CROSS-SECTION



Comparison	Standard	Advanced
Insulation Voids	3%	0%
Framing factor	15-25%	10-15%
Batt R-value	R-13	R-13
Sheathing R-value	R-0.5 to 2.0	R-2.5
Effective Average R-value	R-11.1	R-14.6 (30% higher)

INSULATED HEADERS AND LET-IN BRACING



2X6 WALL CONSTRUCTION

In most code jurisdictions, 2x6’s can be spaced on 24-inch centers, rather than 16-inch centers used for 2x4’s. The advantages of using 2x6 studs on 24-inch centers are:

- The thicker wall cavity provides room for R-19 or R-21 wall insulation.
- Overall, thermal bridging through studs is reduced due to the higher R-value of 2x6’s and less stud area in the wall.
- Less framing reduces labor costs.
- There is more space for insulating around piping, wiring, and ductwork.

The economics of 2x6 wall construction is favorable primarily in areas with significant winters and homes in which windows and doors occupy 10 percent or less of the total wall area. Walls with substantial window and door area may require almost as much framing as 2x4 walls because each opening can add extra studs. Additionally, the window and door jambs must be wider, requiring the purchase of a jamb extender that increases costs by $12 to $15 per opening.

Thicker insulated sheathing may be a less expensive way to increase overall R-value than 2x6 construction, especially in homes with more window and door area. Another factor to consider is that the interior finish or exterior siding may bow slightly between studs when using 24-inch centers.

WHAT TYPE OF INSULATION SHOULD I USE?

The home designer has an increasing array of insulation products from which to choose to insulate wood-framed walls. The wide variety of insulation materials often makes it difficult to determine the most cost-effective products and techniques. Refer to the Model Energy Code (MEC) or DOE Insulation Fact Sheet for R-value recommendations for your climate and building type. The DOE Insulation Fact Sheet (DOE/CE-0180) can be ordered from the Energy Efficiency and Renewable Energy Clearinghouse or accessed from the Internet at www.ornl.gov/roofs+walls.

- *Fiberglass and rock wool batts*—2x4 walls can hold R-13 or R-15 batts; 2x6 walls can have R-19 or R-21 products. Generally, batt insulation is the least expensive wall insulation material but requires careful installation for effective performance (see page 4).
- *Cellulose insulation*, made from recycled newsprint, comes primarily in loose-fill form. It can be installed in walls using a dry-pack process or a moist-spray technique. It generally costs more than batt insulation, but it offers reduced air leakage through the wall cavity plus improved sound deadening.
- *Fiberglass and rock wool loose-fill insulation* provide full coverage with a “Blow-in Blanket” System (BIBS) that involves blowing insulation into open stud cavities behind a net.
- *Rigid foam insulation* has a higher R-value per inch than fiberglass or cellulose and stops air leaks, but it is considerably more expensive. It is manufactured in sheet-good dimensions and is often used as the outer layer of insulation.
- *Foam-in-place insulation* can be blown into walls and reduces air leakage. Some types use carbon dioxide in the manufacturing process rather than more environmentally harmful gases such as pentane or hydrochlorofluorocarbons.

WALL SHEATHINGS

Some builders use ½-inch wood sheathing (R-0.6) or asphalt-impregnated sheathing, usually called blackboard (R-1.3), to cover the exterior framing before installing siding. Instead, consider using ½-inch foam insulated sheathing (R-2 to R-3.5). Sheathing thicker than ½ inch will yield even higher R-values.

Foam sheathing has these advantages:

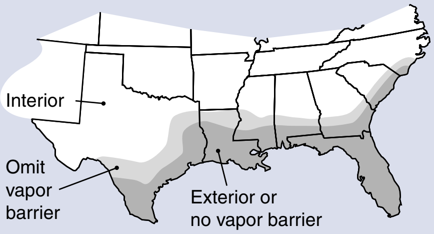
- The continuous layer of insulation reduces thermal bridging through wood studs, saving energy and improving comfort.
- It is easier to cut and install than heavier weight sheathing products.
- It protects against condensation on the inside wall by keeping the interior of the wall warmer.
- It usually costs less than plywood or oriented strand board (OSB).

Ensure that the sheathing completely covers, and is sealed to, the top plate and band joist at the floor. Most sheathing products come in 8-, 9-, or 10-foot lengths to allow complete coverage of the wall. Once it is installed, patch all holes, penetrations, and seams with caulk or housewrap tape.

Because of its insulation advantages over plywood and OSB, foam sheathing is best when used continuously in combination with let-in bracing, which provides structural support similar to that offered by plywood or OSB. Some builders use two layers of sheathing—plywood or OSB for structural support and a seam-staggered layer of rigid foam for insulation. When the total depth of the sheathing material exceeds ½ inch, make certain the window and door jambs are adjusted for the total wall thickness. Some flanged windows are readily adaptable to this approach.

VAPOR BARRIER PLACEMENT BY GEOGRAPHICAL LOCATION

In most cold climates, vapor barriers should be placed on the interior (warm-in-winter) side of walls. However, the map shows that in some southern climates, the vapor barrier should be omitted, while in hot and humid climates, such as along the Gulf coast and in Florida, the vapor barrier should be placed on the exterior of the wall.



Perm Ratings of Different Materials
(Rating of 1 or less qualifies as a vapor barrier)

Asphalt-coated paper backing on insulation	0.40
Polyethylene plastic (6 mil)	0.06
Plywood with exterior glue	0.70
Plastic-coated insulated foam sheathing	0.4 to 1.2
Aluminum foil (.35 mil)	0.05
Vapor barrier paint or primer	0.45
Drywall (unpainted)	50
Drywall (painted - latex paint)	2-3

WALL INSULATION

For more information, contact:

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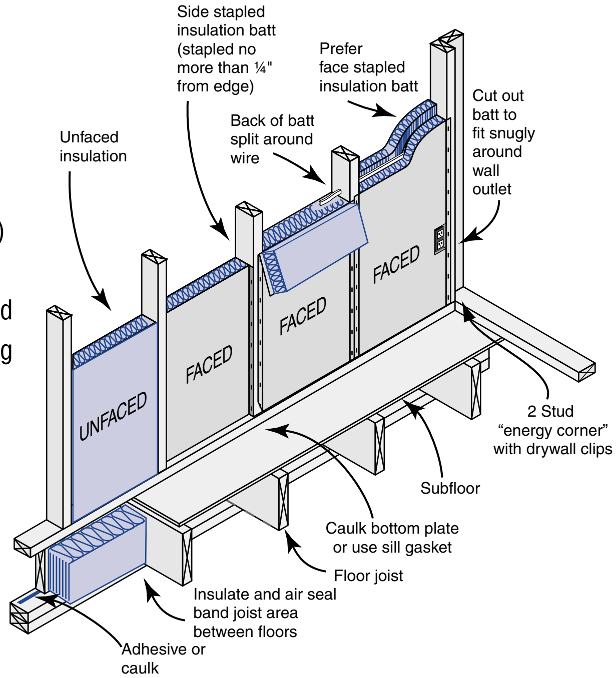
STEPS FOR EFFECTIVE WALL CONSTRUCTION AND INSULATION

1. Review the plans and specifications and identify all walls (including bandjoists) between conditioned (heated and cooled) spaces and unconditioned spaces (exterior, attics, crawl spaces, garages, and mechanical rooms). Use advanced framing techniques to increase insulation levels and reduce lumber use.
2. Use diagonal corner bracing (let-in bracing) on exterior walls to substitute for corner plywood sheathing and allow continuous insulated sheathing.
3. Use foam sheathing for insulating headers to reduce framing heat loss.
4. Seal all air leaks through walls before insulating, including under the bottom plate, band joist areas between floors, electrical boxes, and all electrical, plumbing, and HVAC penetrations.
5. Use caulk and backer rod or non-expanding spray foam, not insulation, to seal around window and door jambs.
6. If fixtures such as stairs or shower/tub enclosures cover exterior walls and do not allow easy installation of insulation after the sheathing is attached, insulate behind these components in advance using R-13 or R-19 batts and cover with a weatherproof barrier (½-inch drywall, plastic, or other sheet material).
7. Select insulation levels based on the MEC and the DOE Insulation Fact Sheet.
8. Face-staple batts because side stapling creates channels for air flow and compresses the insulation, thus reducing the R-value. If face stapling is not an option, use unfaced batts or carefully side staple within ¼ inch of the stud face.



9. Obtain full coverage of batt or blown wall insulation. Cut batt insulation to fit snugly into non-standard stud spaces and to completely fill cavity.
10. Slit batt insulation to fit around the back and front side of electrical wiring and plumbing without compressing or tearing the insulation.
11. Notch out batt insulation around electrical boxes and use scraps to insulate behind the box.
12. Once the interior drywall is in place, seal all penetrations with durable caulking.

Fiberglass Batt Insulation Characteristics

Thickness (inches)	R-value	Cost (¢/sq.ft.)
3½	11	12-16
3⅝	13	15-20
3½	15 (high density)	34-40
6 to 6¼	19	27-34
5¼	21 (high density)	33-39
8 to 8½	25	37-45
8	30 (high density)	45-49
9½	30 (standard)	39-43
12	38	55-60

This chart is for comparison only. Determine actual thickness, R-value, and cost from manufacturer or local building supply.

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October 2000 DOE/GO-102000-0772

5.C.2.1 Vapor Barrier Journal Paper

RE: TASK ORDER NO. **KAAX-3-32443-05**
UNDER
TASK ORDERING AGREEMENT NO. **KAAX-3-32443-00**

PREPARED FOR:

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Vapor Barriers

The function of a vapor barrier is to retard the migration of water vapor. Where it is located in an assembly and its permeability is a function of climate, the characteristics of the materials that comprise the assembly and the interior conditions. Vapor barriers are not typically intended to retard the migration of air. That is the function of air barriers.

Confusion on the issue of vapor barriers and air barriers is common. The confusion arises because air often holds a great deal of moisture in the vapor form. When this air moves from location to location due to an air pressure difference, the vapor moves with it. This is a type of migration of water vapor. In the strictest sense air barriers are also vapor barriers when they control the transport of moisture-laden air.

An excellent discussion about the differences between vapor barriers and air barriers can be found in Quirouette (1985)[1].

Vapor barriers are also a cold climate artifact that have diffused into other climates more from ignorance than need. The history of cold climate vapor barriers itself is a story based more on personalities than physics. Rose (1997)[2] regales readers of this history. It is frightening indeed that construction practices can be so dramatically influenced by so little research and reassuring indeed that the inherent robustness of most building assemblies has been able to tolerate such foolishness.

What Do We Really Want to Do?

Two seemingly simple requirements for building enclosures bedevil engineers and architects almost endlessly:

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

Water can come in several phases: liquid, solid, vapor and adsorbed. The liquid phase as rain and ground water has driven everyone crazy for hundreds of years but can be readily understood - drain everything and remember the humble flashing. The solid phase also drives everyone crazy when we have to shovel it or melt it, but at least most professionals understand the related building problems (ice damming, frost heave, freeze-thaw damage). But the vapor phase is in a class of craziness all by itself. We will conveniently ignore the adsorbed phase and leave it for someone else to deal with.

The fundamental principle of control of water in the liquid form is to drain it out if it gets in – and let us make it perfectly clear – it will get in if you build where it rains or if you put your building in the ground where there is water in the ground. This is easy to understand, logical, with a long historical basis.

The fundamental principle of control of water in the sold form is to not let it get solid and if it does – give it space or if it is solid not let it get liquid and if it does drain it away before it can get solid again. A little more difficult to understand, but logical and based on solid research. Examples of this principle is the use of air entrained concrete to control freeze-thaw damage and the use of attic venting to provide cold roof decks to control ice damming.

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[1] Quirouette, R.L.; The Difference Between a Vapor Barrier and an Air Barrier; Building Practice Note 54, Division of Building Research, National Research Council of Canada, ISSN 0701-5216, Ottawa, Ontario, Canada, July 1985.

[2] Rose, W.; Moisture Control in the Modern Building Envelope: The History of the Vapor Barrier in the US – 1923 to 1952, APT, Volume XXVIII, Number 4, 1997.

The fundamental principle of control of water in the vapor form is to keep it out and to let it out if it gets in. Simple right? No chance. 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.

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 is simple to understand, except we have trouble deciding what side of a wall is the cold or warm side. Logically, this means we need different strategies for different climates. We also have to take into account differences between summer and winter.

Finally, complications arise when materials can store water. This can be both good and bad. A cladding system such as a brick veneer can act as a reservoir after a rainstorm and significantly complicate wall design. Alternatively, wood framing or masonry can act as a hygric buffer absorbing water lessening moisture shocks.

What is required is to define vapor control measures on a more regional climatic basis and to define the vapor control measures more precisely.

Part of the problem is that we struggle with names and terms. We have vapor retarders, we have vapor barriers, we have vapor permeable we have vapor impermeable, etc. What do these terms mean? It depends on whom you ask and whether they are selling something or arguing with a building official. In an attempt to clear up some of the confusion the following definitions are proposed:

Vapor Retarder[3]: The element that is designed and installed in an assembly to retard the movement of water by vapor diffusion.

The unit of measurement typically used in characterizing the water vapor permeance of materials is the "perm". It is further proposed here that there should be several classes of vapor retarders (this is nothing new – it is an extension and modification of the Canadian General Standards Board approach that specifies Type I and Type II vapor retarders – the numbers here are a little different however):

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 perm or less and greater than 1.0 perm

Test Procedure for vapor retarders: ASTM E-96 Test Method A (the desiccant method 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 perm 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 proposed by the author.

[3] taken somewhat from ASHRAE Fundamentals 2001, Chapter 23

Continuing in the spirit of finally defining terms that are tossed around in the enclosure business. It is also proposed that materials be separated into four general classes based on their permeance (again nothing new, this is an extension of the discussion in ASHRAE Journal, February 02 – Moisture Control for Buildings)[4]:

Vapor impermeable:	0.1 perm or less
Vapor semi-impermeable:	1.0 perm 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

Recommendations for Building Enclosures
The following building assembly recommendations are climatically based (see **Appendix I**) and are sensitive to cladding type (brick or stone veneer, stucco) and structure (concrete block, steel or wood frame, precast concrete).

The recommendations apply to residential, office, commercial, school and retail occupancies. The recommendations do not apply to special use enclosures such as spas, pool buildings, museums, hospitals, data processing centers or other engineered enclosures.

The following things are discouraged:

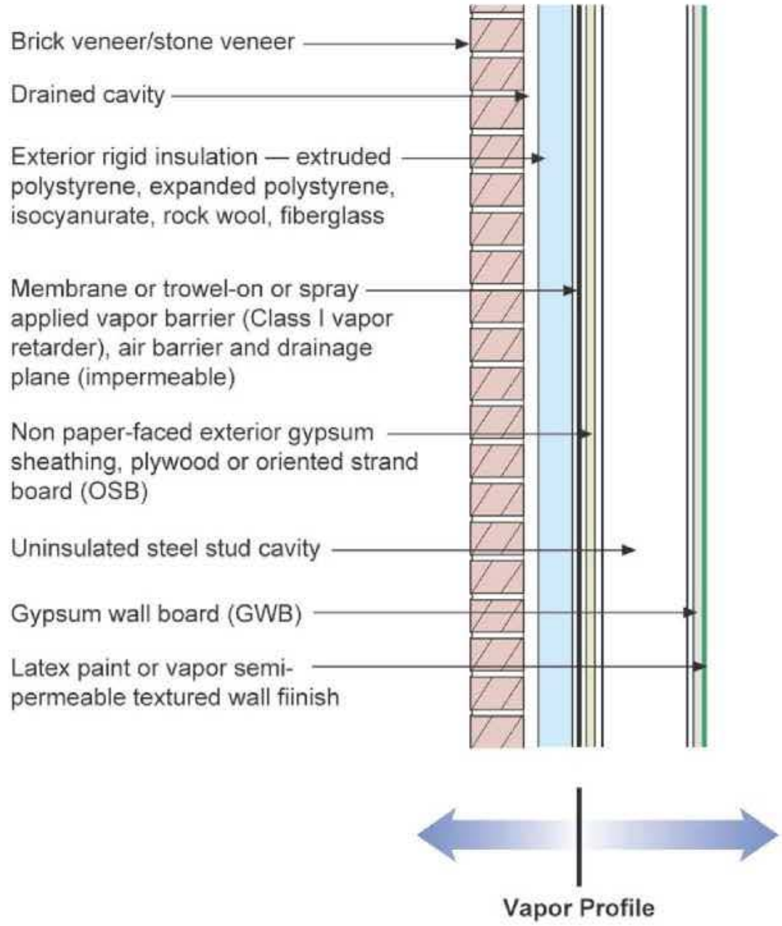
- The installation of vapor barriers on both sides of assemblies – i.e. "double vapor barriers".
- The installation of vapor barriers such as polyethylene vapor barriers, foil faced batt insulation and reflective radiant barrier foil insulation on the interior of air-conditioned assemblies.
- The installation of vinyl wall coverings on the inside of air-conditioned assemblies.
- The placement of a layer of sand between polyethylene vapor barriers and concrete slabs on grade.
- The installation of polyethylene vapor barriers on the interior of internally insulated basements.

The following things are encouraged:

- The construction of assemblies that are able to dry by diffusion to at least one side and in many cases to both sides.
- The ability to use insulating sheathings in cold climates without the creation of "double vapor barriers".
- The ability to use of damp spray insulations in cold climates with insulating sheathings without the creation of "double vapor barriers"

[4] Lstiburek, J.W.; Moisture Control For Buildings; ASHRAE Journal, February, 2002.

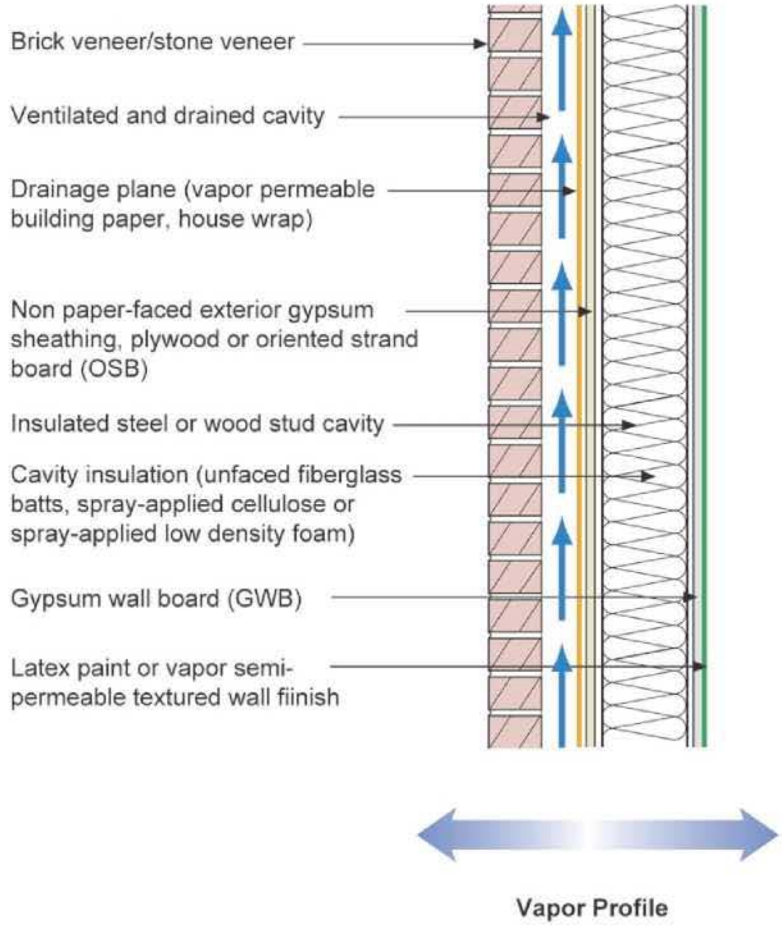
Figure 5
Frame Wall With Exterior Insulation and Brick or Stone Veneer



Applicability: All hygro-thermal regions

This wall is a variation of Figure 1 – but without the moisture storage (or hygric buffer) capacity. This wall is also a robust wall assembly. It is constructed from non-water sensitive materials and has a high drying potential inwards due to the frame wall cavity not being insulated. It can also be constructed virtually anywhere. In cold climates condensation is limited on the interior side of the vapor barrier as a result of installing all of the thermal insulation on the exterior side of the vapor barrier (which is also the drainage plane and air barrier in this assembly). In hot climates any moisture that condenses on the exterior side of the vapor barrier will be drained to the exterior since the vapor barrier is also a drainage plane. This wall assembly will dry from the vapor barrier inwards and will dry from the vapor barrier outwards.

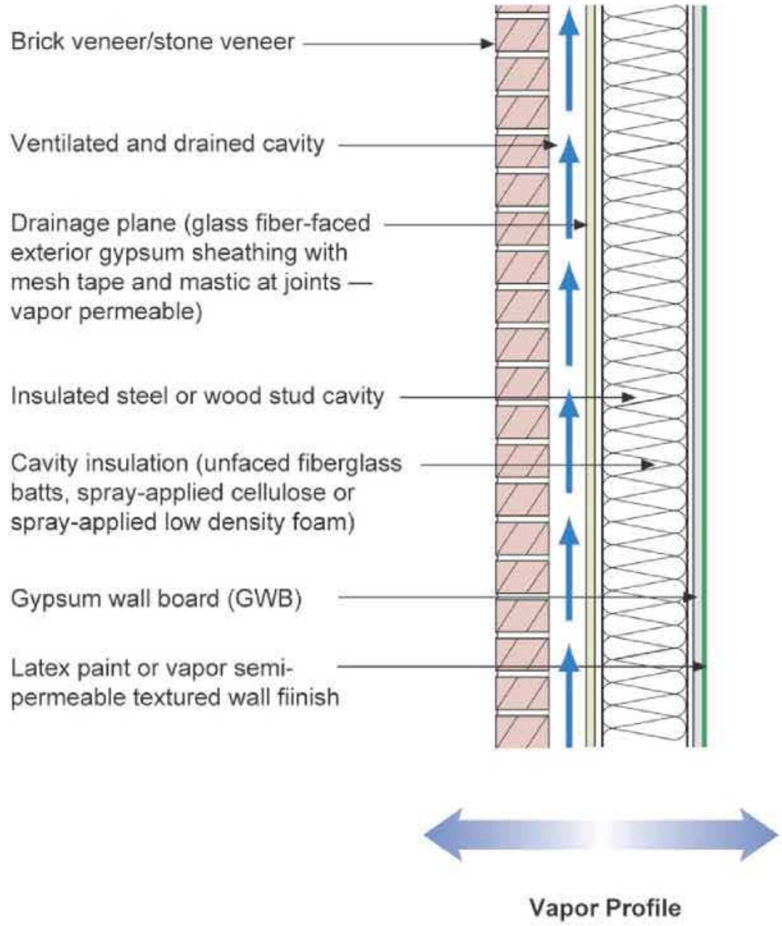
Figure 6
Frame Wall With Cavity Insulation and Brick or Stone Veneer



Applicability: Limited to mixed-humid, hot-humid, mixed-dry, hot-dry and marine regions – can be used with hygro-thermal analysis in some areas in cold regions (Zone 5, but not Zone 6; see **Appendix III**)- should not be used in very cold and subarctic/arctic regions

This wall is a flow through assembly – it can dry to both the exterior and the interior. It has a Class III vapor retarder on the interior of the assembly (the latex paint on the gypsum wallboard). It is critical in this wall assembly that the exterior brick veneer (a "reservoir" cladding) be uncoupled from the wall assembly with a ventilated and drained cavity. Experience has shown that this assembly works well when the cavity behind the brick veneer is at least 2 inches wide and is free from mortar droppings. It must also have air inlets at its base and air outlets at its top in order to provide back ventilation of the brick veneer. The drainage plane in this assembly is the building paper or building wrap. The air barrier can be any of the following: the interior gypsum wallboard, the exterior gypsum wallboard or the exterior building wrap.

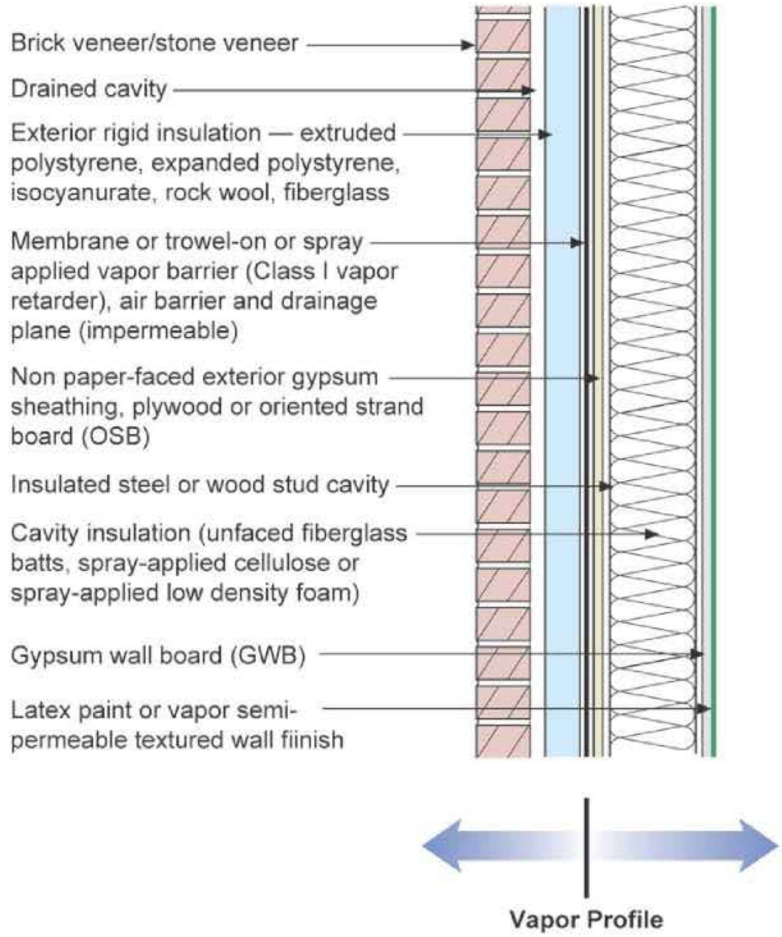
Figure 7
Frame Wall With Cavity Insulation and Brick or Stone Veneer



Applicability: Limited to mixed-humid, hot-humid, mixed-dry, hot-dry and marine regions – can be used with hygro-thermal analysis in some areas in cold regions (Zone 5, but not Zone 6; see **Appendix III**)- should not be used in very cold and subarctic/arctic regions

This wall is a variation of Figure 6. The exterior gypsum sheathing becomes the drainage plane. As in Figure 6 this wall is a flow through assembly – it can dry to both the exterior and the interior. It has a Class III vapor retarder on the interior of the assembly (the latex paint on the gypsum wallboard). It is also critical in this wall assembly that the exterior brick veneer (a "reservoir" cladding) be uncoupled from the wall assembly with a ventilated and drained cavity. Experience has shown that this assembly works well when the cavity behind the brick veneer is at least 2 inches wide and is free from mortar droppings. It must also have air inlets at its base and air outlets at its top in order to provide back ventilation of the brick veneer. The air barrier in this assembly can be either the interior gypsum wallboard or the exterior gypsum sheathing.

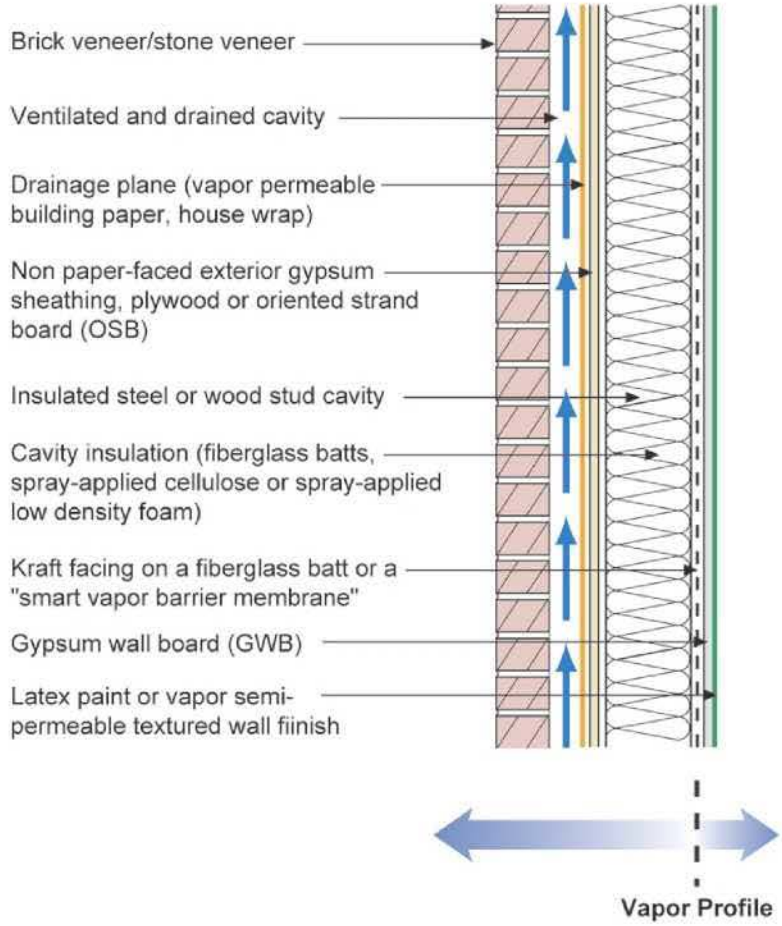
Figure 8
Frame Wall With Exterior Rigid Insulation With Cavity Insulation and Brick or Stone Veneer



Applicability: All hygro-thermal regions except subarctic/arctic – in cold and very cold regions the thickness of the foam sheathing should be determined by hygro-thermal analysis so that the interior surface of the foam sheathing remains above the dew point temperature of the interior air (see **Appendix III – section 4**)

This wall is a variation of Figure 5. In cold climates condensation is limited on the interior side of the vapor barrier as a result of installing some of the thermal insulation on the exterior side of the vapor barrier (which is also the drainage plane and air barrier in this assembly). In hot climates any moisture that condenses on the exterior side of the vapor barrier will be drained to the exterior since the vapor barrier is also a drainage plane. This wall assembly will dry from the vapor barrier inwards and will dry from the vapor barrier outwards. Since this wall assembly has a vapor barrier that is also a drainage plane it is not necessary to back vent the brick veneer reservoir cladding as in Figure 6 and Figure 7. Moisture driven inwards out of the brick veneer will condense on the vapor barrier/drainage plane and be drained outwards.

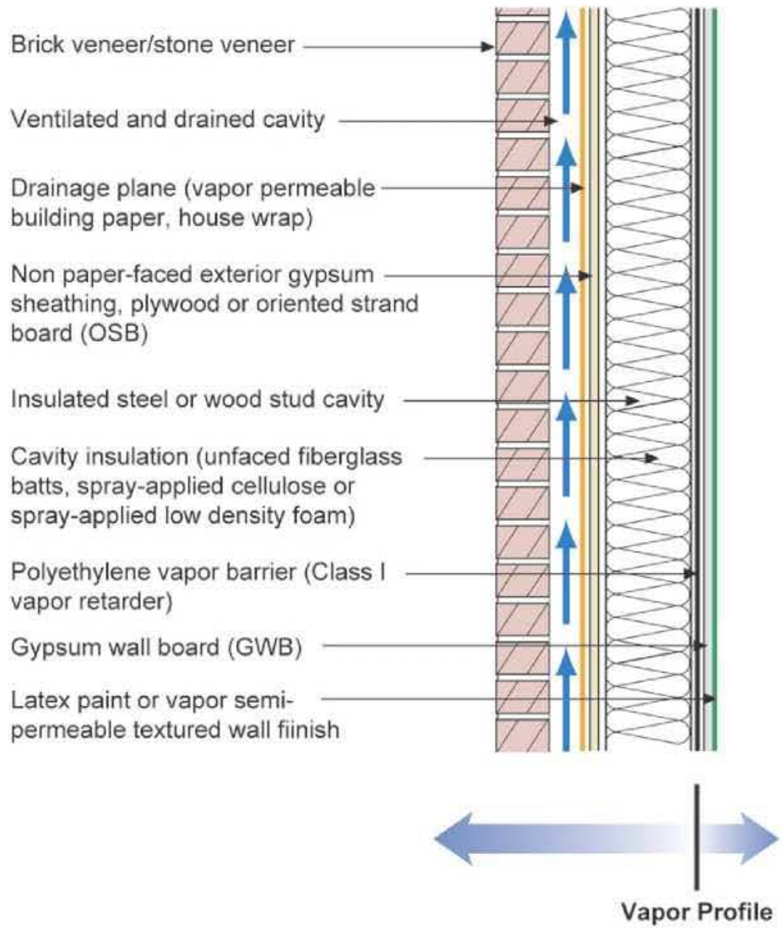
Figure 9
Frame Wall With Cavity Insulation and Brick or Stone Veneer With Interior Vapor Retarder



Applicability: Limited to cold and very cold regions

This wall is a variation of Figure 6 except it has a Class II vapor retarder on the interior limiting its inward drying potential – but not eliminating it. It still considered a flow through assembly – it can dry to both the exterior and the interior. It is critical in this wall assembly – as in Figure 6 and Figure 7 - that the exterior brick veneer (a "reservoir" cladding) be uncoupled from the wall assembly with a ventilated and drained cavity. Experience has shown that this assembly works well when the cavity behind the brick veneer is at least 2 inches wide and is free from mortar droppings. It must also have air inlets at its base and air outlets at its top in order to provide back ventilation of the brick veneer. The drainage plane in this assembly is the building paper or building wrap. The air barrier can be any of the following: the interior gypsum wallboard, the exterior gypsum wallboard or the exterior building wrap.

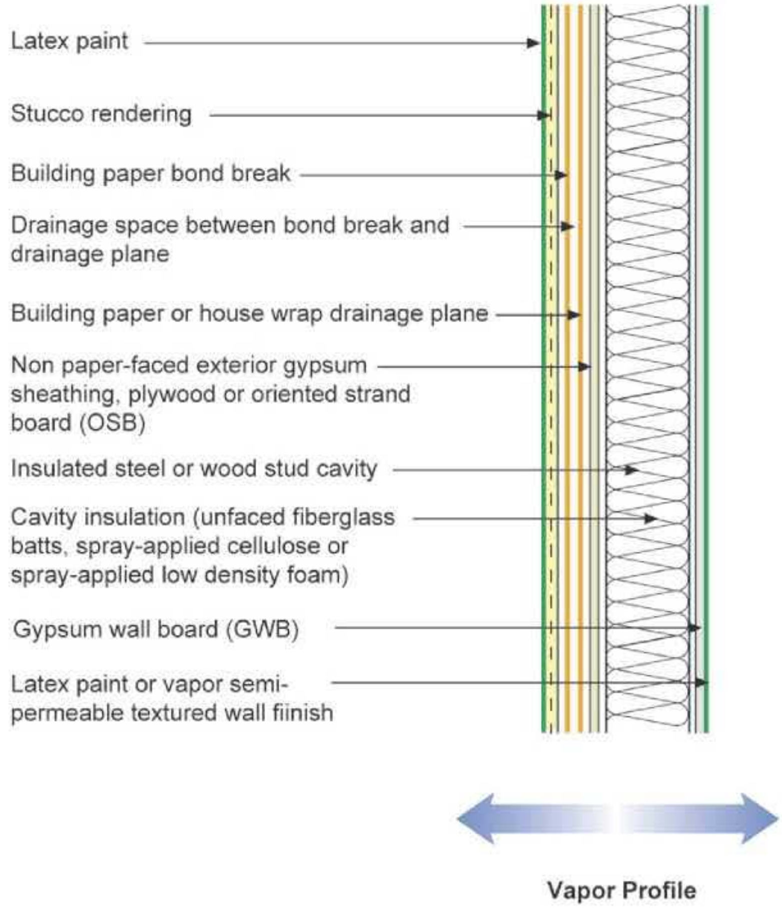
Figure 10
Frame Wall With Cavity Insulation and Brick or Stone Veneer With Interior Vapor Barrier



Applicability: Limited to very cold, subarctic and arctic regions

This wall is a further variation of Figure 6 but now it has a Class I vapor retarder on the interior (a "vapor barrier") completely eliminating any inward drying potential. It is considered the "classic" cold climate wall assembly. It is critical in this wall assembly – as in Figure 6, Figure 7 and Figure 9 - that the exterior brick veneer (a "reservoir" cladding) be uncoupled from the wall assembly with a ventilated and drained cavity. Experience has shown that this assembly works well when the cavity behind the brick veneer is at least 2 inches wide and is free from mortar droppings. It must also have air inlets at its base and air outlets at its top in order to provide back ventilation of the brick veneer. The drainage plane in this assembly is the building paper or building wrap. The air barrier can be any of the following: the interior polyethylene vapor barrier, the interior gypsum wallboard, the exterior gypsum wallboard or the exterior building wrap.

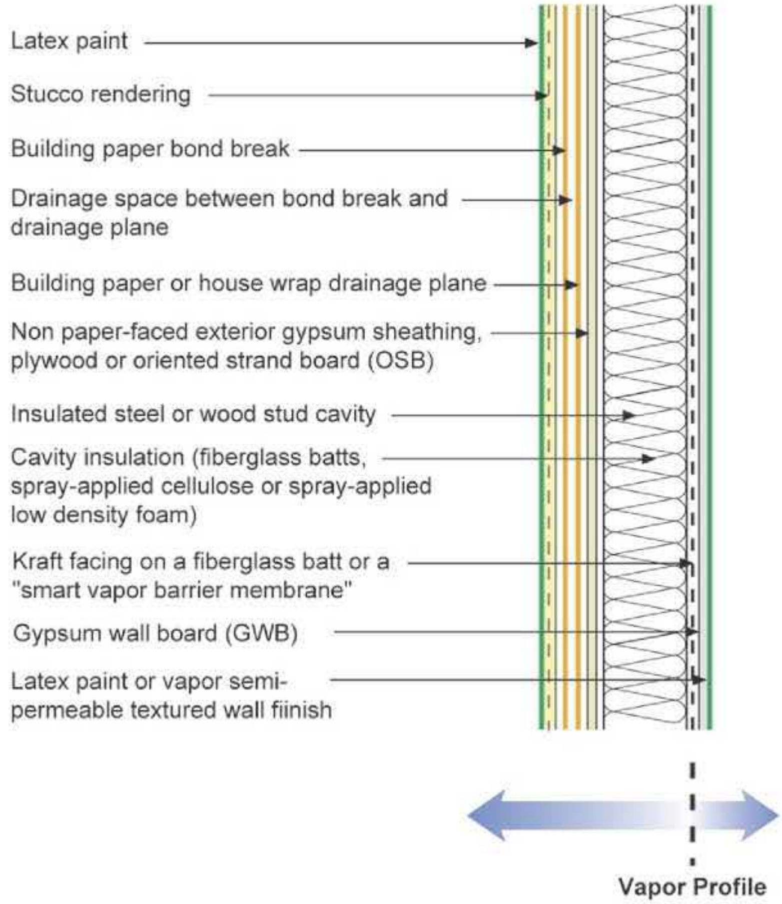
Figure 11
Frame Wall With Cavity Insulation and Stucco



Applicability: Limited to mixed-humid, hot-humid, mixed-dry, hot-dry and marine regions – can be used with hygro-thermal analysis in some areas in cold regions (Zone 5, but not Zone 6; see **Appendix III**) – should not be used in very cold, and subarctic/arctic regions

This wall is also a flow through assembly similar to Figure 6 – but without the brick veneer – it has a stucco cladding. It can dry to both the exterior and the interior. It has a Class III vapor retarder on the interior of the assembly (the latex paint on the gypsum wallboard). It is critical in this wall assembly that a drainage space be provided between the stucco rendering and the drainage plane. This can be accomplished by installing a bond break (a layer of tar paper) between the drainage plane and the stucco. A spacer mat can also be used to increase drainability. Alternatively, a textured or profiled drainge plane (building wrap) can be used. The drainage plane in this assembly is the building paper or building wrap. The air barrier can be any of the following: the interior gypsum wallboard, the exterior stucco rendering, the exterior sheathing or the exterior building wrap.

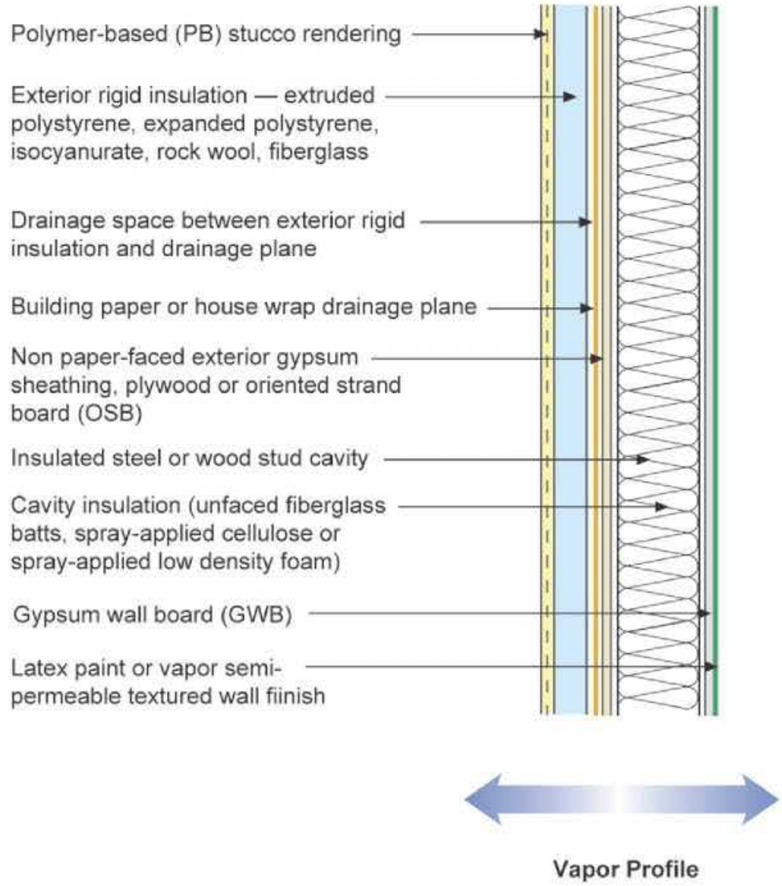
Figure 12
Frame Wall With Cavity Insulation and Stucco With Interior Vapor Retarder



Applicability: Limited to cold and very cold regions

This wall is a variation of Figure 6 and Figure 11 except it has a Class II vapor retarder on the interior limiting its inward drying potential – but not eliminating it. It still considered a flow through assembly – it can dry to both the exterior and the interior. It is critical in this wall assembly – as in Figure 11 – that a drainage space be provided between the stucco rendering and the drainage plane. This can be accomplished by installing a bond break (a layer of tar paper) between the drainage plane and the stucco. A spacer mat can also be used to increase drainability. Alternatively, a textured or profiled drainge plane (building wrap) can be used. The drainage plane in this assembly is the building paper or building wrap. The air barrier can be any of the following: the interior gypsum wallboard, the exterior stucco rendering, the exterior sheathing or the exterior building wrap.

Figure 13
Frame Wall With Exterior Rigid Insulation With Cavity Insulation and Stucco

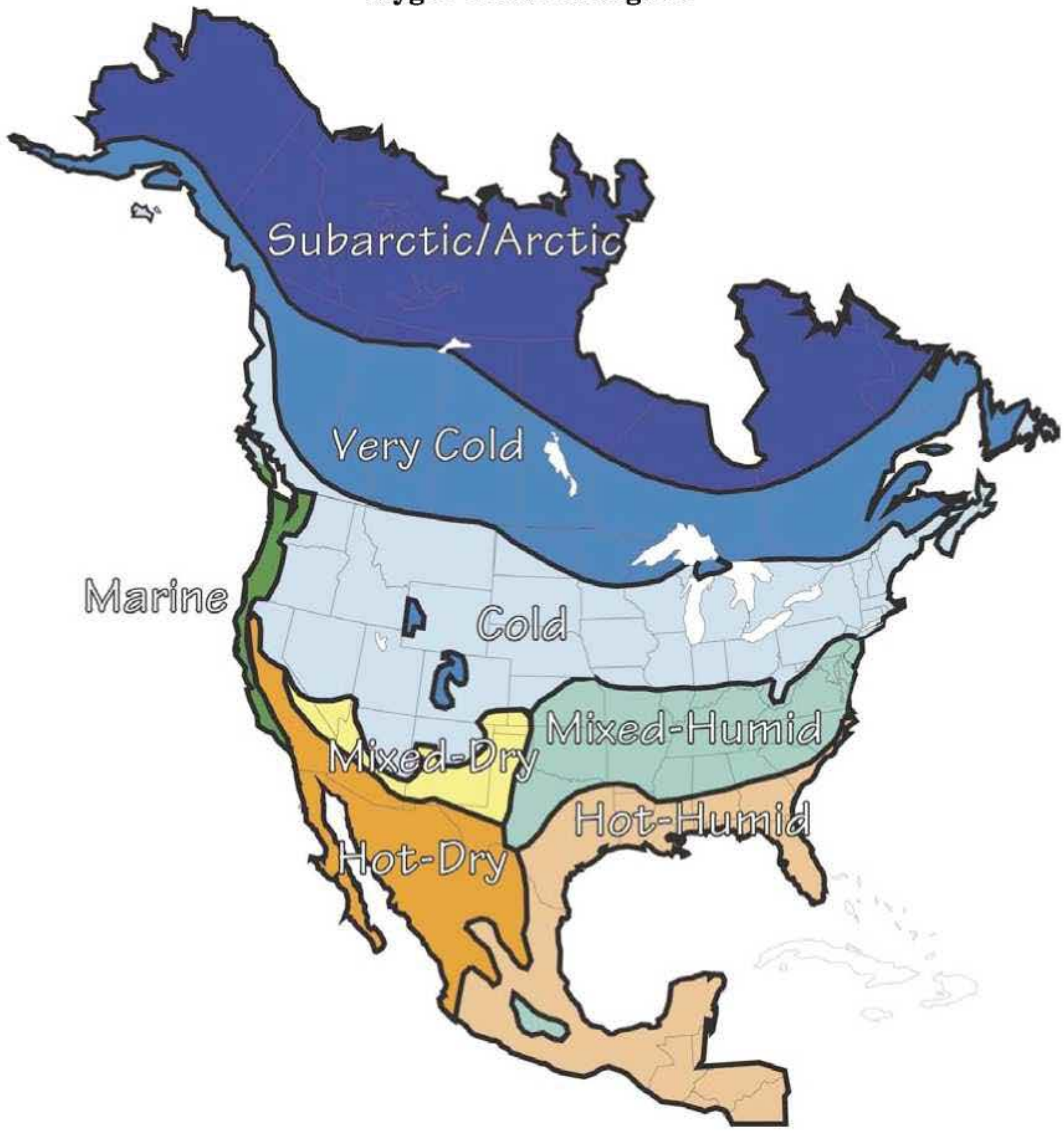


Applicability: All hygro-thermal regions except subarctic/arctic – in cold and very cold regions the thickness of the foam sheathing should be determined by hygro-thermal analysis so that the interior surface of the foam sheathing remains above the dew point temperature of the interior air (see **Appendix III – section 4**)

This is a water managed exterior insulation finish system (EIFS). Unlike "face-sealed" EIFS this wall has a drainage plane inboard of the exterior stucco skin that is drained to the exterior. It is also a flow through assembly similar to Figure 6. It can dry to both the exterior and the interior. It has a Class III vapor retarder on the interior of the assembly (the latex paint on the gypsum wallboard). It is critical in this wall assembly that a drainage space be provided between the exterior rigid insulation and the drainage plane. This can be accomplished by installing a spacer mat or by providing drainage channels in the back of the rigid insulation. Alternatively, a textured or profiled drainge plane (building wrap) can be used. The drainage plane in this assembly is the building paper or building wrap. The air barrier can be any of the following: the interior gypsum wallboard, the exterior stucco rendering, the exterior sheathing or the exterior building wrap.

Appendix I

Hygro-Thermal Regions



Subarctic and Arctic
A subarctic and arctic climate is defined as a region with approximately 12,600 heating degree days (65 degrees F basis) *[7,000 heating degree days (18 degrees C basis)]* or greater.

Very Cold
A very cold climate is defined as a region with approximately 9,000 heating degree days or greater (65 degrees F basis) *[5,000 heating degree days (18 degrees C basis)]* or greater and less than 12,600 heating degree days (65 degrees F basis) *[7,000 heating degree days (18 degrees C basis)].*

Cold
A cold climate is defined as a region with approximately 5,400 heating degree days (65 degrees F basis) *[3,000 heating degree days (18 degrees C basis)]* or greater and less than

approximately 9,000 heating degree days (65 degrees F basis) *[5,000 heating degree days (18 degrees C basis)]*

Mixed-Humid
A mixed-humid and warm-humid climate is defined as a region that receives more than 20 inches *(50 cm)* of annual precipitation with approximately 4,500 cooling degree days (50 degrees F basis) *[2,500 cooling degree days (10 degrees C basis)]* or greater and less than approximately 6,300 cooling degree days (50 degrees F basis) *[3,500 cooling degree days (10 degrees C basis)]* and less than approximately 5,400 heating degree days (65 degrees F basis) *[3,000 heating degree days (18 degrees C basis)]* and where the average monthly outdoor temperature drops below 45 degrees F *(7 degrees C)* during the winter months.

Marine
A marine climate meets is defined as a region where all of the following occur:

- a mean temperature of the coldest month between 27 degrees F *(-3 degrees C)* and 65 degrees F *(18 degrees C);*
- a mean temperature of the warmest month below 72 degrees F *(18 degrees C);*
- at least four months with mean temperatures over 50 degrees F *(10 degrees C);* and
- a dry season in the summer, the month with the heaviest precipitation in the cold season has at least three times as much precipitation as the month with the least precipitation

Hot-Humid
A hot-humid climate is defined as a region that receives more than 20 inches *(50 cm)* of annual precipitation with approximately 6,300 cooling degree days (50 degrees F basis) *[3,500 cooling degree days (10 degrees C basis)]* or greater and where the monthly average outdoor temperature remains above 45 degrees F *(7 degrees C)* throughout the year.

This definition characterizes a region that is similar to the ASHRAE definition of hot-humid climates where one or both of the following occur:

- a 67 degree F *(19.5 degrees C)* or higher wet bulb temperature for 3,000 or more hours during the warmest six consecutive months of the year; or
- a 73 degree F *(23 degrees C)* or higher wet bulb temperature for 1,500 or more hours during the warmest six consecutive months of the year.

Hot-Dry, Warm-Dry and Mixed-Dry
A hot-dry climate is defined as region that receives less than 20 inches *(50 cm)* of annual precipitation with approximately 6,300 cooling degree days (50 degrees F basis) *[3,500 cooling degree days (10 degrees C basis)]* or greater and where the monthly average outdoor temperature remains above 45 degrees F *(7 degrees C)* throughout the year.

A warm-dry and mixed-dry climate is defined as a region that receives less than 20 inches *(50 cm)* of annual precipitation with approximately 4,500 cooling degree days (50 degrees F basis) *[2,500 cooling degree day (10 degrees C basis)]* or greater and less than approximately 6,300 cooling degree days (50 degrees F basis) *[3,500 cooling degree days (10 degrees C basis)]* and less than approximately 5,400 heating degree days (65 degrees F basis) *[3,000 heating degree days (18 degrees C basis)]* and where the average monthly outdoor temperature drops below 45 degrees F *(7 degrees C)* during the winter months.

Appendix II

More Definitions – Taking On The Air Barrier

The following is an extension of the definitions proposed in ASHRAE Journal, February 02 – Moisture Control For Buildings[9].

Air barrier systems are systems of materials used to control airflow in building enclosures. They typically completely enclose the air within a building. The physical properties, which distinguish air barriers from other materials, are the ability to resist airflow and air pressure.

Air barrier systems are intended to resist the air pressure differences that act on them. Rigid materials such as gypsum wallboard, exterior sheathing materials like plywood or OSB, and supported flexible barriers (rigid materials on both sides of the barriers) are typically effective air barrier systems if joints and seams are sealed and if they are supported by rigid materials. Their rigidity aids in their ability to resist air pressures, which act on them.

Continuity of air barrier systems at holes, openings and penetrations of building enclosures is a key performance indicator of an effective air barrier.

Often, rubber or bitumen-based membranes are adhered to masonry or sheathing materials to create an air barrier system. These rubber or bitumen-based membranes are also impermeable and are therefore also vapor barriers.

Many, but not all, air barriers are vapor barriers and many, but not all, vapor barriers are air barriers.

Air barrier:	The element in an assembly designed and constructed to control air leakage between a conditioned space and an unconditioned space.
Conditioned Space[†]:	The part of the building that is designed to be thermally conditioned for the comfort of occupants or for other occupancies or for other reasons.
Indoor Air[†]:	Air in a conditioned space.
Outdoor Air[†]:	Air outside the building. It can enter the conditioned space via the ventilation system, or by infiltration through holes in the pressure boundary or designed ventilation openings.

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

Pressure Boundary[†]:	Primary air enclosure boundary separating conditioned air and unconditioned air. For example, a volume that has more leakage to the outside than to the conditioned space would be considered outside the pressure boundary such as vented unconditioned attics and vented unconditioned crawlspaces.

[9] Lstiburek, J.W.; Moisture Control For Buildings; ASHRAE Journal, February, 2002.
[†] Taken from ASHRAE Standard 62.2

Air Retarders[†]:	Materials or systems that reduce air flow or control airflow but do not resist 50 percent or more of the air pressure drop across an assembly.
Occupiable Space[†]:	Any enclosed space inside the pressure boundary and intended for human activities, including but not limited to, all habitable spaces, toilets, closets, halls, storage and utility areas, and laundry areas.
Habitable Space[†]:	Building space intended for continual human occupancy. Such space generally includes areas used for living, sleeping, dining, and cooking, but does not generally include bathrooms, toilets, hallways, storage areas, closets, or utility rooms.

And Finally – Defining the Drainage Plane

Drainage planes are water repellant materials (building paper, house wrap, foam insulation, etc), which are located behind the cladding and are designed and constructed to drain water that passes through the cladding. They are interconnected with flashings, window and door openings, and other penetrations of the building enclosure to provide drainage of water to the exterior of the building. The materials that form the drainage plane overlap each other shingle fashion or are sealed so that water flow is down and out of the wall.

[†] Taken from ASHRAE Standard 62.2

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Vapor Diffusion Retarders and Air Barriers

Vapor diffusion retarders, air retarders, and air/vapor retarders all relate to the interaction of temperature and moisture in and around the building envelope. A vapor barrier or vapor diffusion retarder (VDR) is a material that reduces the rate at which water vapor can move through a material. The older term "vapor barrier" may still be used, however, this is incorrect since it implies that the material stops all of the moisture transfer. Since everything allows some water vapor to diffuse through it to some degree, the term "vapor diffusion retarder" is more accurate. No matter what you call them, they have become an important building issue for most regions. The following information describes what they are, how they work, and when to use them.

The Thermal-Moisture Dynamic

Water vapor moves in and out of a building basically in three ways: with air currents, by diffusion through materials, and by heat transfer. Of these three, air movement is the dominant force because, like most fluids, air naturally moves from a high pressure area to a lower one by the easiest path possible. This is generally through any available hole in the building envelope. Moisture transfer by air currents is very fast (in the range of several hundred cubic feet of air per minute) and accounts for more than 98% of all water vapor movement in building cavities. Thus it's very important that unintended paths that it may follow be carefully and permanently sealed. The other two driving forces are much slower processes and most common building materials slow moisture diffusion to a large degree, although never stop it completely.

In decades past, buildings did not need to restrict the flow of airborne moisture, since when the building cavities got wet they also generally dried quickly due to the "leaky" construction methods that allowed air to move freely through the building envelope. So the water vapor movement really didn't matter much until the introduction of thermal insulation. When insulation is added, the temperature of the water vapor can drop very quickly since it is being isolated from the heat of the building (in the winter) or from the outdoors in the summer if the building is being air-conditioned.

Whether from the indoors or outdoors, airborne water vapor entering the envelope of the building through holes around plumbing pipes, ductwork, wiring, and electrical outlets are some of the less obvious, yet important, points where air can move in and out of the thermal envelope. During the winter in Northern climates, any warm air entering the walls from the house cools and condenses it's water vapor inside building cavities. In the South, humid air does much the same except it comes from the outdoors and condenses inside the wall cavities during the cooling season.

The laws of physics govern how moist air reacts within various temperature conditions. This behavior is technically referred to as "psychrometrics." A psychrometric chart is used by professionals to determine at what temperature and moisture concentration water vapor begins to condense. This is called the "dew point." By understanding how to find the dew point, you will better understand how to avoid moisture problems in your house.

Relative humidity (RH) refers to the amount of moisture contained in a quantity of air compared to the maximum amount of moisture the air could hold at the same temperature. As air warms, its ability to hold water vapor increases. As air cools this capacity decreases. For example according to the psychometric chart: air at 68?F (20?C) with 0.216 ounces of water (H_2O) per pound of air (14.8g H_2O/kg air) has a 100% RH. The same air at 59?F (15?C) reaches 100% RH with only 0.156 ounces of water per pound of air (10.7g H_2O/kg air). The colder air holds about 28% of the moisture that the warmer air does. The moisture that the air can no longer hold condenses on the first cold surface it encounters (the dew point.) If this surface is within an exterior wall cavity wet insulation and framing will be the result.

In this example, we can control two things?temperature and moisture content. The R-value of the wall cavity insulation moderates the effect of temperature across the building envelope cavity. An airtight, vapor diffusion retarder, properly installed towards the warm side of this cavity, reduces the amount of moisture entering it. Except in deliberately ventilated spaces, such as attics, these two factors work together to reduce the opportunity for condensation in a house's ceilings, walls, and floors.

Types of Vapor Diffusion Retarders

Vapor diffusion retarders (VDRs) are typically available as membranes or coatings. Membranes are generally thin, flexible materials, but also include thicker sheet materials sometimes termed "structural" vapor diffusion retarders. Materials such as rigid insulation, reinforced plastics, aluminum, and stainless steel are relatively resistant to water vapor diffusion. These types of vapor diffusion retarders are usually mechanically fastened and the sealed at the joints.

Thinner membrane types of VDRs come in rolls or as integral parts of building materials. A common example of this is aluminum- or paper-faced fiberglass roll insulation. Foil-backed wallboard is another type commonly used. Polyethylene, a plastic sheet material, can be used as a VDR for above grade walls and ceilings (only) in very cold climates (in locations with 8000 Heating Degree Days or higher).

Most paint-like coatings also retard vapor diffusion. While it was once believed that only coatings with low perm ratings (see below) constituted the only effective VDR, it is now believed that any paint or coating is effective at restricting most water vapor diffusion in milder climates.

Perm Ratings

The ability of a material to retard the diffusion of water vapor is measured by units known as "perms" or permeability. A perm at 73.4?F (23?C) is a measure of the number of grains of water vapor passing through a square foot of material per hour at a differential vapor pressure equal to one inch of mercury (1" W.C.) Any material with a Perm rating of less than 1.0 is considered a vapor retarder. Knowledgeable professionals typically use VDRs with ratings of 0.1 or less. However, if you carefully seal the warm-side VDR and interior finish, you can also safely install a low permeable material, such as rigid insulation board (a perm rating as high as 1.4) on the cold side of walls.

A good rule to remember is: To prevent trapping any moisture in a cavity the cold-side material's Perm rating should be at least five times greater than the value of the warm-side.

Installing Vapor Diffusion Retarders

It is important for VDRs to minimize condensation or moisture problems in the following areas of a building: walls, ceilings, and floors; under concrete slabs; and in crawl spaces. A continuous VDR with reliable air sealing is very important if you have a house constructed on a concrete slab. Use a VDR with a perm value of less than 0.50 if you also have a high water table.

In moderate heating dominated climates (less than 4,000 Heating Degree Days), materials like painted gypsum wallboard and plaster wall coatings impede moisture diffusion to acceptable levels and no further VDR is needed. In more extreme climates, a VDR is advisable for new construction. VDRs perform best when installed closest to the warm side of a structural assembly. In cold climates this is towards the interior of the building. In hot/wet climates, this is towards the exterior of the building. Reasonable rules-of-thumb to follow when placing vapor retarders are:

- For climates having 2200 or more heating degree days (HDD; a HDD is a unit that measures how often outdoor daily dry-bulb temperatures fall below an assumed base, normally 65ºF (18ºC) locate the VDR on the warm side of the exterior structural assembly. If possible, locate it on the inside of the assembly using the "one third, two thirds rule": the VDR has one third of the cavity insulation to its warm side, two thirds to the cold side. This protects the retarder from physical damage through errant construction or remodeling activities.

- For climates with fewer than 2200 HDD (cooling-dominated climates) where the building is near, but not quite in, the 2200HDD zone (a.k.a. fringe zone) place the VDR in the same location as climates farther north. Farther south (about 1900 HDD) it is unimportant where it goes. For climates even farther south than this, and one generally hotter and more humid, some professionals recommend omitting the VDR completely. This is due to the winter heating loads and summer cooling loads being roughly equal. Any choice of location ends up having the VDR on the wrong side of the structure half of the year. However, other building science research indicates that it should be applied directly under the exterior finish and is sometimes itself the exterior finish. An air/vapor retarder, described below, may be a better choice for this situation.

When installing a VDR it should be continuous and as close to perfect as possible. This is especially important in very cold climates and in hot and humid climates. Be sure to completely seal any tears, openings, or punctures that may occur during construction. Cover all appropriate surfaces. Otherwise you risk moist air condensing within the cavity, which would lead to dampened insulation. The thermal resistance of wet insulation is dramatically decreased, and prolonged wet conditions will induce mold and wood rot.

For crawl spaces under the house, carefully cover the crawlspace floor. This is to slow ground moisture from evaporating into the crawlspace and condensing there. In addition, it's now considered a good practice to completely seal crawl spaces and carefully insulate the inside face of the foundation walls. Seal all foundation vents too. Be aware that this may be contrary to your community's building code. Discrepancies between current building science and building codes can be difficult to resolve satisfactorily. Many people have resolved this issue by renaming the crawlspace a "short basement" on their construction plans.

To avoid building code conflicts concerning crawl spaces use the following guidelines: Make sure the height of the space exceeds local regulatory requirements (usually 4 feet or 1.22 m)

- Install plenty of perimeter drainage and some central floor drains in the crawl space
- Slope the floor of the space towards the floor drains
- Lay down at least two layers of six-mil (0.015 cm) thick polyethylene plastic sheets as the VDR. Overlap the seams at least 2 feet (0.61 m). Extend the plastic up the foundation walls (avoid covering the vents in the event that you may need to open them again in the future).

These measures allow for emergency drainage and ventilation. As an option you can also pour two inches (51mm) of concrete over this to protect the polyethylene VDR from damage.

Vapor Retarders in Existing Buildings

Except for extensive remodeling projects, it's difficult to add materials like sheet plastic as a VDR to an existing home. However, many existing homes don't really need a more effective VDR than the more than likely numerous layers of paint on their walls and ceilings. These multiple layers are quite effective as a VDR in all but the most extreme northern climates.

"Vapor barrier" paints are also an effective option for colder climates. If the Perm rating of the paint is not indicated on the label, an alternative is to read the paint formula. The paint label usually indicates the percent of pigment. To be a good VDR it should have a relatively high percent of solids and thick in application. Glossy paints are generally more effective VDRs than flat paints and acrylic paints are generally better than latex paints. When in doubt apply more coats of paint. However, it's best to use paint labeled as a VDR and follow the directions for applying it.

In any case, the key to controlling unwanted water vapor movement is the careful air-sealing of gaps in the structure and not the VDR alone.

Air Barriers

Air barriers are intended to block random air movement through building cavities. Air barriers can be made of almost anything. A continuous air barrier is an important feature in energy-efficient design not only for the energy it can save but also because the water vapor carried by the air is the primary way moisture related damage gets started in structural cavities. As the water vapor cools it condenses and so promotes structural damage, rotting wood, other mold growth. Air barriers reduce this problem by stopping much of the air movement but still allowing what water vapor that does get in to diffuse back out again.

Some common materials used for this purpose are: "house wrap," plywood, drywall (gypsum) board and foam board. Many of these materials are also used for insulation, structural purposes, and finished surfaces. What to choose and how to use it depends mainly on where you are building and the climate. A discussion of all the choices is beyond the scope of this article. Please see the reference section at the end for books dealing with this issue.

The most common air barrier material is use today is "house wrap." Some wraps have better weathering or water repelling abilities than others. All come in a variety of sizes for different purposes and are made of fibrous spun polyolefin plastic, matted into sheets and rolled up for shipping. Sometimes, they also have other materials woven or bonded to them to make it more resistant to tearing.

House wraps are usually wrapped around the exterior of a house during construction. Sealing all of the joints with "house wrap tape" is a good practice that improves the wrap's performance about 20%. All house wrap manufacturers have a special tape for this purpose.

In wet climates house wrap sometimes reacts poorly with certain kinds of wood siding. Lignin (a natural occurring substance in many species of wood) is water-soluble and acts as a detergent. Like all detergents, it decreases surface tension and so destroys the house wrap's ability to repel water. Field research has shown that wood lignin makes it easier for liquid water to pass into the wall. Certain types of wood siding like redwood, cedar, and manufactured hardboard siding seem to accelerate the problem. To avoid this problem, carefully attach heavy building paper (30 pound asphalt impregnated) to the walls as a substitute for house warp or install felt-paper over the house wrap as a water repellent surface that is unaffected by wood lignin.

It's also a good practice to use the "airtight drywall approach" on the interior wall finishes too. Both methods together effectively build an airtight wall that will have no moisture problems.

Air/Vapor Retarders

An air/vapor retarder attempts to combine water vapor and the air movement control with one material. This method is most appropriate for wet Southern climates where keeping humid outdoor air from entering the building cavities is critical during the cooling season.

It's generally placed around the perimeter of the building just under the exterior finish, or it may actually be the exterior finish. In many cases it's constructed of one, or a combination of, the following: polyethylene plastic sheets, builder's foil, foam board insulation, and other exterior sheathings. The key to making this method work effectively is to permanently and carefully seal all of the seams and penetrations, including around windows, doors, electrical outlets, plumbing stacks, and vent fans.

Missed gaps of any size not only increase energy use, but also increase the risk of moisture damage to the house especially during the cooling season. An air/vapor retarder should also be carefully inspected after installation before other work covers it. If small holes are found, you can repair them with caulk or polyethylene or foil tape. Areas with larger holes or tears should be removed and replaced. Patches should always be large enough to cover the damage and overlap any adjacent wood framing.

Metrics

The following unit conversion information is pertinent to the subject of VDRs:

BASIC METRIC CONVERSIONS	***TO GET***	***MULTIPLY***	***BY***
Permeance at 73.4$^{?}$F [23$^{?}$C]	ng/m^2.s.Pa	grain/ft^2.h.1in.Hg	57.2148
Thermal Resistance (R) [RSI]	RSI	R	0.1761
Thermal Conductance (U) [k]	W/m^2.$^{?}$C	Btu.ft^2.h.$^{?}$F	5.6783
Vapor Transmission Rate (WVTR) at 73.4$^{?}$F [23$^{?}$C] and 50% RH	G/m^2.d (WVT=permeance x vapor pressure differential at specific temperature and RH)	grain/ft^2.d	0.6975

For more information on air barriers, contact the:

Air Barrier Association of America
Email: abaa@airbarrier.org

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For more information, including a detailed discussion of design variations, operating principles, and the possible advantages and disadvantages of specific types of VDRs, air barriers, and air/vapor retarder systems, consult the following publications and articles.

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