Resource Appendix

This appendix contains Building Science Information Sheets that provide more information for specific inspection points on the BSC Building America Quality Control Checklist. Each Information Sheet is a one or two page document that can easily be printed for use on site or attached to a trade scope of work or contract. The most current version of these document, and other building science information, can be found at www.buildingscience.com/QA

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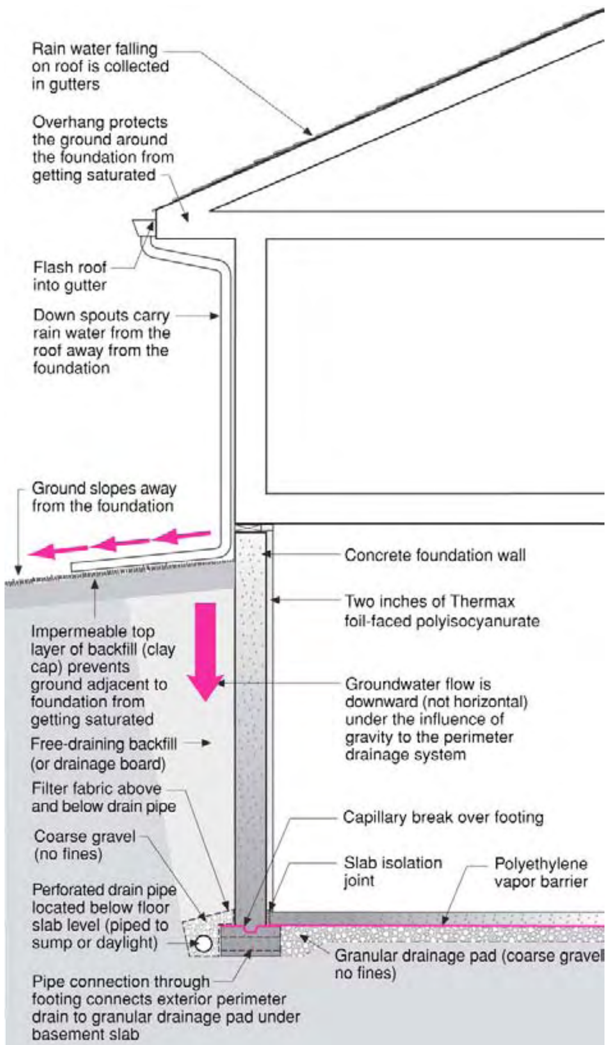
BSC Information Sheet 101

Groundwater Control

for All Climates



Groundwater Control with Basements

- Keep rain water away from the foundation perimeter
- Drain groundwater away in sub-grade perimeter footing drains before it gets to the foundation wall

Groundwater Control

Water managed foundation systems rely on two fundamental principles:

- keep rain water away from the foundation wall perimeter
- drain groundwater with sub-grade perimeter footing drains before it gets to the foundation wall

Water managed foundation systems are different from waterproofing systems. Waterproofing relies on creating a watertight barrier without holes. It can't be done. Even boats need pumps. Water managed foundation systems prevent the build-up of water against foundation walls, thereby eliminating hydrostatic pressure. No pressure, no force to push water through a hole. Remember, we know the foundation wall will have holes.

Mixing control joints with water management is a fundamental requirement for functional foundation systems that provide an extended useful service life. Dampproofing should not be confused with waterproofing. Dampproofing protects foundation materials from absorbing ground moisture by capillarity. Dampproofing is not intended to resist groundwater forces (hydrostatic pressure). If water management is used, waterproofing is not necessary. However, control of capillary water is still required (dampproofing). Dampproofing is typically provided by coating the exterior of a concrete foundation wall with a tar or bituminous paint or coating.

Draining groundwater away from foundation wall perimeters is typically done with free-draining backfill such as sand, gravel or other water-permeable material, or drainage boards or exterior foundation insulations with drainage properties.

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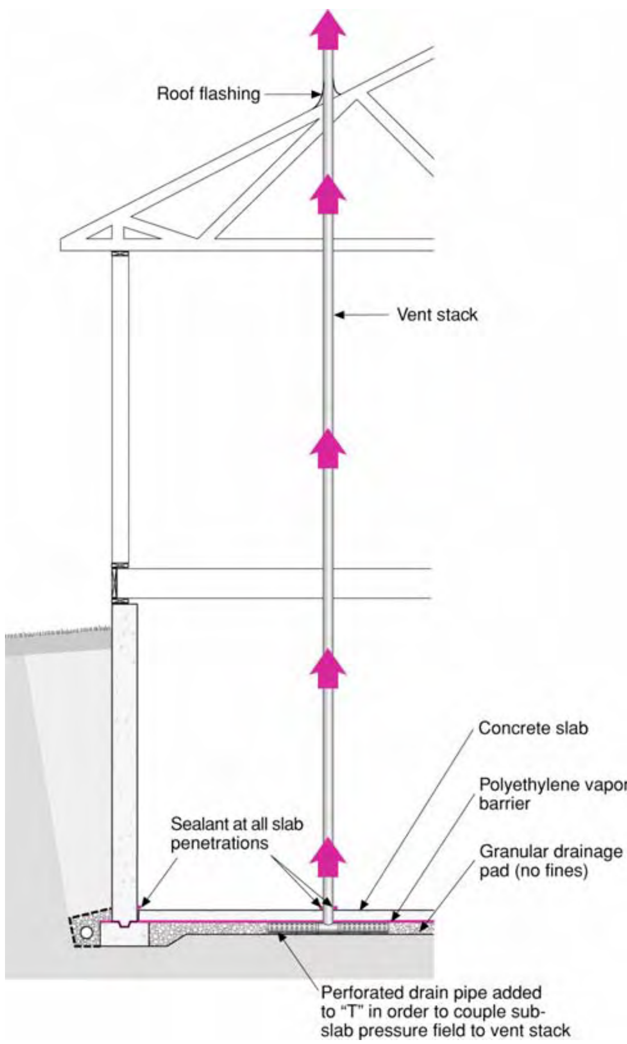
BSC Information Sheet 110

Soil Gas Control

for All Climates



Soil Gas Ventilation System—Basement Construction

- Granular drainage pad depressurized by active fan located in attic or by passive stack action of warm vent stack located inside heated space
- Avoid offsets or elbows in vent stack to maximize air flow

Soil Gas Control

Keeping soil gas (radon, water vapor, herbicides, termiticides, methane, etc.) out of foundations cannot be done by building hole-free foundations because hole-free foundations cannot be built. Soil gas moves through holes due to a pressure difference. Since we cannot eliminate the holes, the only thing we can do is control the pressure.

The granular drainage pad located under concrete slabs can be integrated into a sub-slab ventilation system to control soil gas migration by creating a zone of negative pressure under the slab. A vent pipe connects the sub-slab gravel layer to the exterior through the roof. This "passive" radon mitigation system is illustrated in the figure *Soil Gas Ventilation System—Basement Construction.*

An exhaust fan can be added later, if necessary, to make this an "active" mitigation system.

More information about radon and radon resistance construction can be found on the Environmental Protection Agency's website at: www.epa.gov/iaq/radon/

See also the following EPA documents:

- "Building Radon Out: A Step-by-Step Guide on How to Build Radon-Resistant Homes"
- "Radon Resistant Construction Architectural Drawings"
- "Model Standards and Techniques for Control of Radon in New Residential Buildings"

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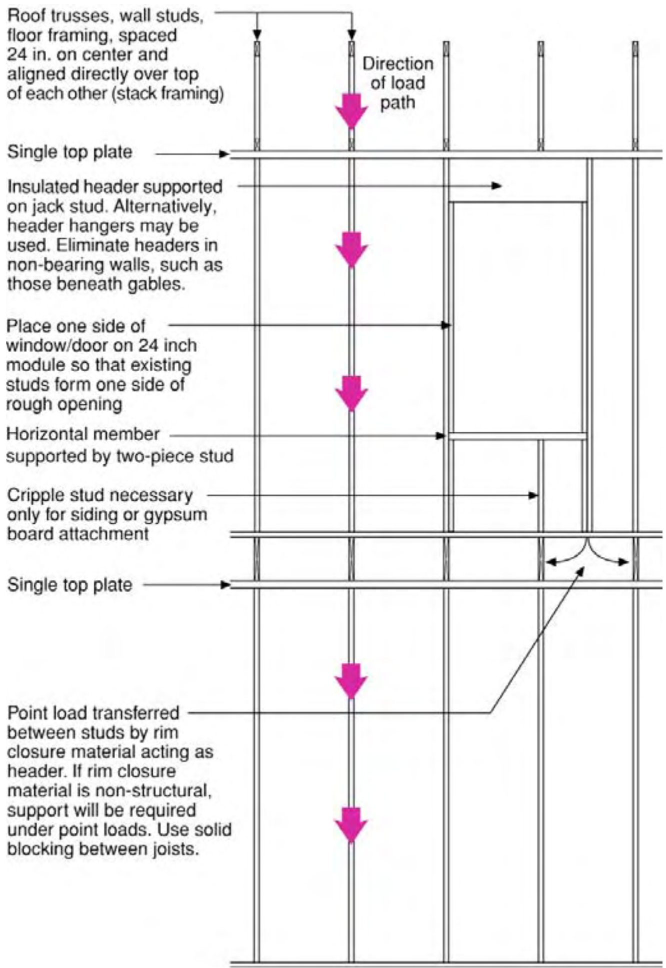
Common Advanced Framing Details

for All Climates



Stack Framing Elevation View

Common Advanced Framing Details

The NAHB Research Center developed optimum-value engineering (OVE) framing techniques to cut the cost of houses by omitting unnecessary lumber. Advanced Framing includes OVE framing techniques such as increasing joist, stud, and rafter spacing to 24 in.; placing doors and windows on stud layout; and using stacked framing for direct load transfer. Application of advanced framing not only saves on lumber and labor costs, but also supports better insulation detailing and reduces the occurrence of drywall cracking. This information sheet will explain the essential basis for advanced framing and some of the more common advanced framing details.

General Conditions:
Advanced framing, as the name implies, means using the lumber intelligently in wood framing. The foundations of advanced framing are 1.use common material dimensions (24-inch grid) as a basis for design to maximize material use and minimize waste and 2. efficient load transfer to reduce unnecessary framing members from the home. Some of the techniques used include stack framing allowing for the use of single top plates, elimination of wood beams/headers in non-load bearing walls, and two-stud corners. Framing around openings in exterior walls limited to those framing members needed for vertical load transfer (e.g. jack studs) or horizontal load resistance (e.g. king studs where needed around larger openings in larger buildings or high-wind areas).

Exterior Wall Openings:
Structural headers are reserved for bearing wall conditions – they are not needed in non-bearing walls and non-bearing partitions. Headers should be sized appropriately for the load. When possible a single header should be used, however for lager openings a double header may be required. At exterior walls the header should be pushed to the exterior to allow for insulation to be installed on the interior. A framing member on the flat should be used below the header to allow for attaching of the interior

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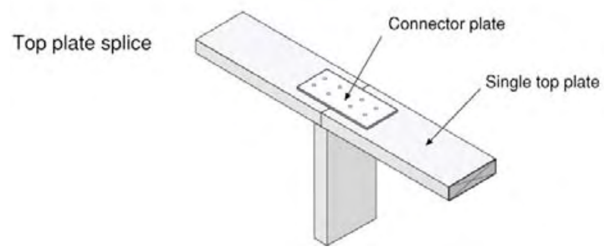
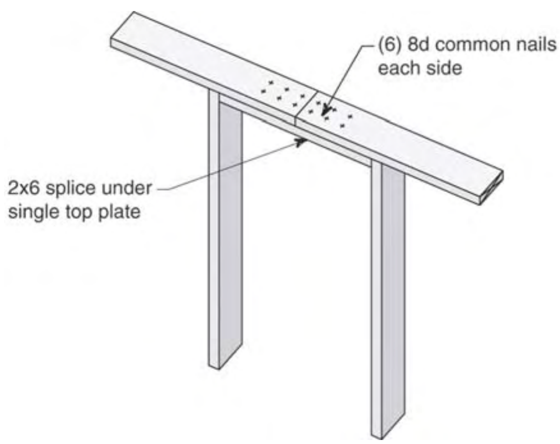
Top Plate Splice over Stud



- Top plate joint aligned over stud
- Connector plate provides structural continuity to top plate

Top Plate Splice between Studs



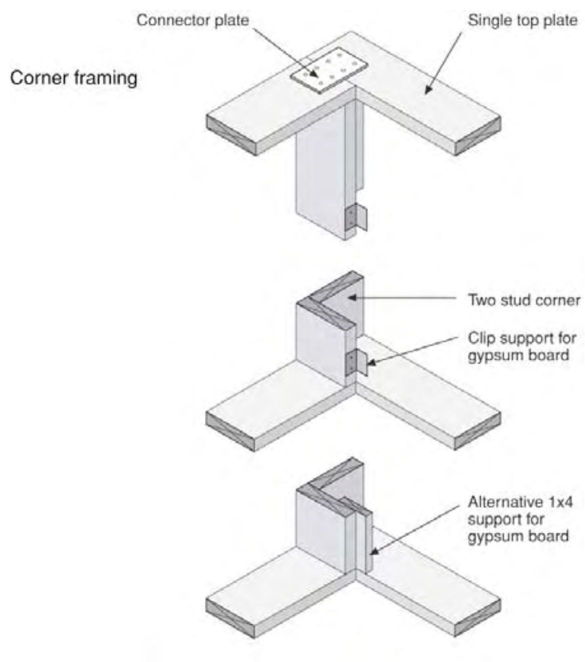
drywall. Openings should be aligned with stud spacing (at least one side, preferably two) where possible. Cripple studs are not needed to support sill studs where windows are "hung". Cripple studs are included at the wall stud spacing intervals for siding or interior finish attachment.

Exterior Wall Corners:
Advanced framing uses a two-stud corner as depicted on the following page. A two-stud corner provides the number of framing members necessary for structural support for most residential. Structural continuity between the two intersecting walls is provided by nailing the two studs together, a connector plate at the top of the wall, and nailing into the floor sheathing at the bottom of the wall. Where structural wall sheathing is needed for shear resistance, this can further connect the intersecting wall assemblies.

Single Top Plate:
With stack framing and structural rim board material transferring loads, a double top plate is not needed for load transfer. The framing members must be centered over the studs with a tolerance of no more than 1".

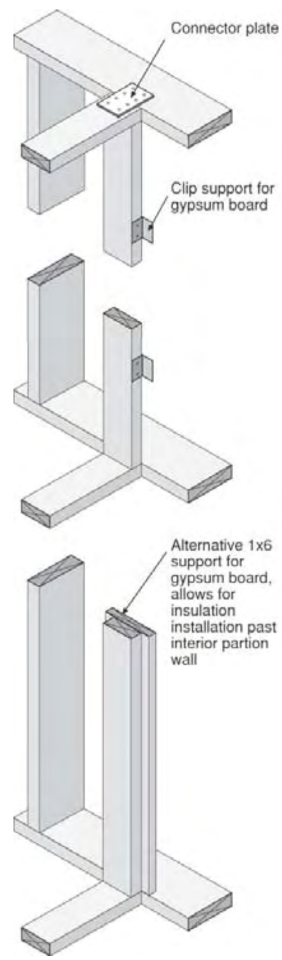
Partition Wall Connection:
Similar to exterior corners, adding additional stud framing for drywall support where partition walls intersect exterior walls creates unnecessary material use and unnecessary thermal bridges. The diagram to the right shows how dry wall support at this intersection can be provided by drywall clips or a 1x6 (alternately, a strip of plywood could be used) attached to the back of the partition's terminal stud. These measures allow insulation of full, or nearly full-, cavity depth to continue past the intersection. Structural connection between the partition wall and the exterior wall can be achieved by a connector plate at the top of the wall and nailing into the floor sheathing at the bottom of the wall.

Corner Framing of Exterior Wall



- Thermal bridging by framing is minimized
- Framing cavity space available to insulation is maximized
- Drywall attachment is to one wall only to reduce cracking resulting from differential wood shrinkage. Alternately, use floating corner for the exterior wall.

Partition Wall to Exterior Wall Intersection



- Thermal bridging by framing at intersection is avoided
- Insulation continues behind intersection
- Drywall attachment is to partition wall only to reduce cracking resulting from differential wood shrinkage. Alternately, use floating corner for one wall.

Suggestions for Further Research:

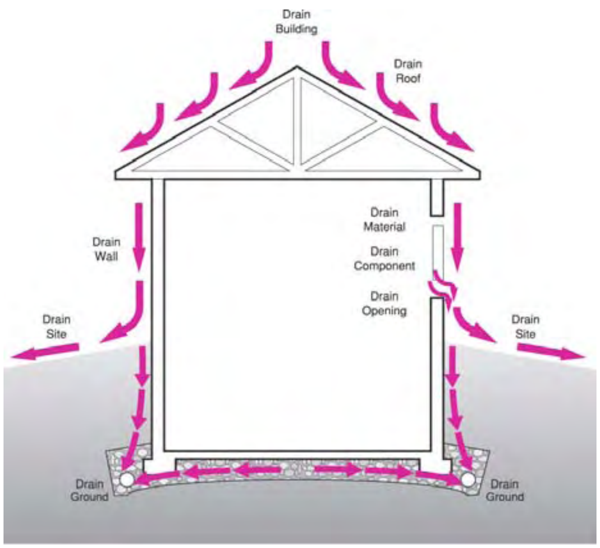
Lstiburek, Joseph W.; "The Future of Framing is Here," Fine Homebuilding Magazine, October/November 2005.

Lstiburek, Joseph W.; *Builder's Guide Series*, Building Science Press, 2006.

BSC Information Sheet 301

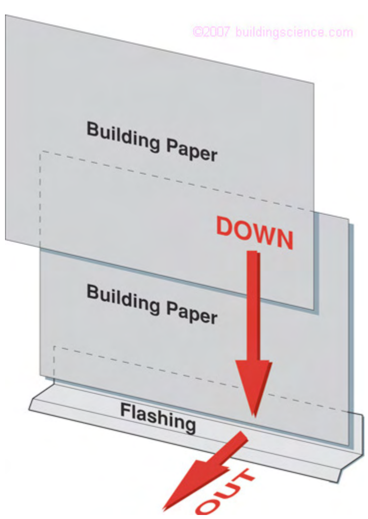
Drainage Plane/Water Resistive Barrier

for All Climates



Fundamental Rain Water Control

- Drain the site – slope grade away from building
- Drain the ground – foundation perimeter drain
- Drain the building – roof system
- Drain the assembly – drainage plane and water management system
- Drain the opening – pan flashings
- Drain the component
- Drain the material



Shingle Lapped Assembly

Drainage Plane / Water Resistive Barrier

"Rain is the single most important factor to control in order to construct a durable structure."

- Dr. Joseph Lstiburek

All exterior claddings pass some rainwater. Siding leaks, shingles leak, brick leaks, stucco leaks, stone leaks, etc. As such, some control of this penetrating rainwater is required.

Drainage planes (also referred to as "water resistive barrier" or WRB) are water repellent materials (building paper, house wrap, sheet or trowel applied membranes, foam insulation, coated structural sheathing , etc) that are located behind the cladding and interconnected with flashings, window and door openings, or other penetrations of the building enclosure in such a way as to drain water that passes through the cladding back out to the exterior.

Drainage Plane

Gravity is the driving force in drainage plane function. Gravity is very reliable. Water management techniques that ignore or try to counteract gravity – reverse lapped flashings for example – are bound to fail.

In order for a drainage plane to be effective it must be continuous in the field of the water repellent material and integrated with flashings and to the water management strategies of other enclosure assemblies (such as roofs, foundations, and windows).

The continuity of the drainage plane is maintained in two ways: 1) through shingle lapping of the materials 2) taping or sealing of material joints in a barrier approach.

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Drainage Space

In order for drainage to occur, a drainage space must be provided between the cladding and the drainage plane. The width of this space varies depending on cladding type and function.

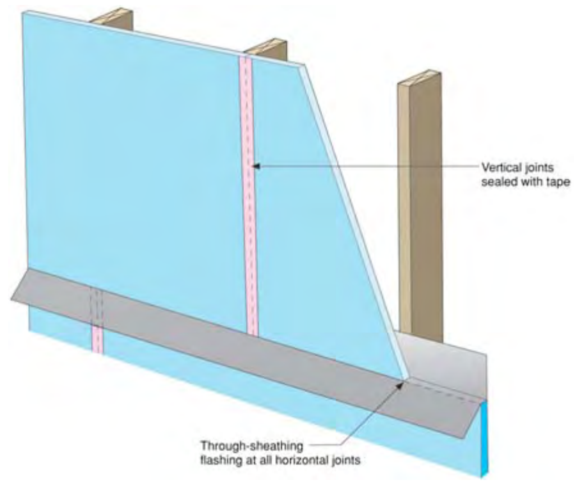
Effective drainage of rainwater can occur in drainage spaces as small as 1/16 to 1/8 inch (2 or 3 mm) (e.g. between two layers of building paper in a stucco cladding). Sometimes the drainage space is also called upon to act as a "ventilation space". Effective ventilation may require spaces as large as 3/4 to 1 inch (20 to 25 mm) depending on the moisture load.

For some cladding systems, e.g. aluminum or vinyl siding, this drainage space is inherent to the cladding system. Similarly brick and masonry veneers have an inherent space, however care must be taken during construction to keep the space clear or mortar so that drainage is not impeded. Products are also available (such as three dimensional plastic mesh products) that help to maintain a clear drainage space.

Wood lap siding has traditionally been installed tight to building paper drainage plane. This creates an intermittent drainage space and is largely dependant on the profile of the siding. This type of installation works well for most instances, however it often reduces the service life of the siding material and has been attributed to some building failures. Ideally wood siding and cementitious lap siding should be installed over vertical wood furring or a plastic spacer mesh to create a vented and drained space behind the cladding.

In stucco cladding, two layers of building paper can provide adequate drainage space. The outer layer of builder paper acts as a bond break between the stucco rendering and the inner layer of building paper . With building paper, the moisture in the stucco causes the paper to swell slightly and wrinkle during application of the stucco. Over time the paper dries leaving small drainage channels between the two layers of building paper. Improved performance can be achieved through the use of a plastic drainage

Barrier Assembly



Water Resistant Sheathing as Drainage Plane

- All joints and seams in sheathing sealed with compatible and durable tape

Wood Furring Strip Drainage Space

- Furring strips fastened to framing through insulating sheathing.
- All openings top and bottom provided with screen to prevent insect entry

Plastic Mesh Drainage Space

- All openings top and bottom provided with screen to prevent insect entry

mesh with a filter fabric (usually adhered to one side of the mesh) installed between the stucco renderings and the drainage mesh. This creates a larger and more effective drainage space for the system.

The principle of drainage applies to the design and construction of window and door components in the same way that it applies to walls and openings. Window and door openings should be drained to the exterior using the same principles used in the design and construction of wall assemblies in general. Consult the references listed below or BSC Information Sheet 14, Window Flashing for more on this topic.

Suggestions for Further Research:

"Understanding Drainage Planes," Building Science Digest-105, www.buildingscience.com.

"Rain Control in Buildings," Building Science Digest-013, www.buildingscience.com.

"Increasing the Durability of Buildings," Building Science Digest-144, www.buildingscience.com.

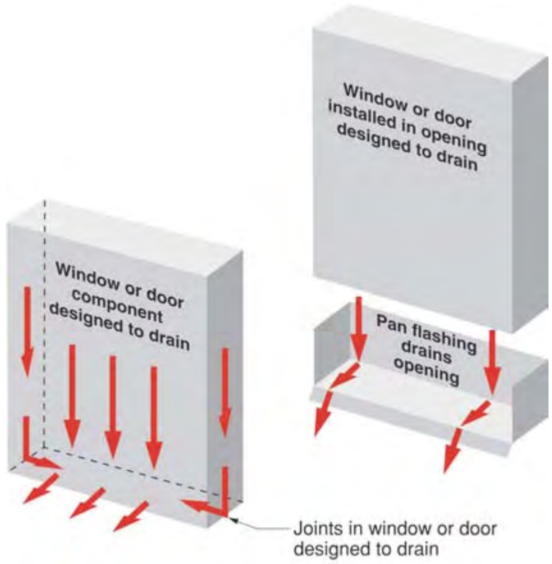
Lstiburek, Joseph W.; *Water Management Guide,*. Building Science Press, 2006.

Lstiburek, Joseph W.; *Builder's Guide Series*, Building Science Press, 2006

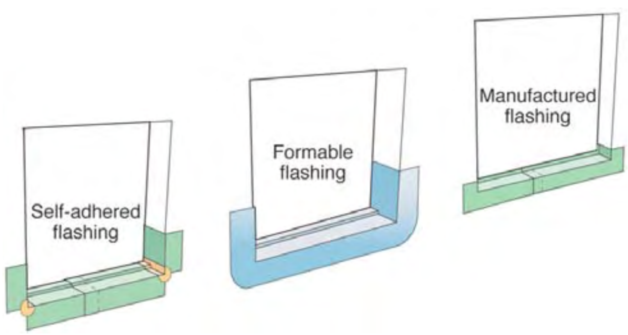
BSC Information Sheet 302

Pan Flashing for Exterior Wall Openings

for All Climates



Water Management Fundamentals: Drained Component, Drained Opening



Pan Flashing Materials

- Non-formable self-adhered membrane requires corner patches
- Formable flashing must be pressed into corners to prevent window corners from tearing membrane
- Two-piece manufactured flashing requires seal at joint

  Back dam of manufactured pan flashing must be protected from breakage during window installation

Pan Flashing for Exterior Wall Openings

Window and doors are typically installed using one of two approaches: 1) barrier system installation or 2) a drained system installation. Barrier installations do not provide for forgiveness to water infiltration through or around the window or door opening and should be limited to areas of low rainfall potential or areas where the area is protected (such as under overhangs or porches). Drained installations are designed to manage small amounts of water infiltration through or around the window or door opening, by collect and draining the water back out to the exterior. Central to the performance of a drained opening is a pan flashing.

A pan flashing is an element installed below every window and door designed to collect and direct any water that may leak through or around the opening back out to the exterior. As such the sealing of the window or door assemblies into the rough opening (through the use of membrane flashing and/or sealants) should be made at the jamb and head of the window, however the sill should be left free to drain to the exterior.

There are four essential characteristics of pan flashing:

1. the pan flashing surface is a durable waterproof material that provides a continuous water barrier without holes, tears or wrinkles that could retain water in the opening
2. the pan flashing has a back dam or positive slope to direct water to the outside of the wall
3. the pan flashing has end dams at the sides to prevent water from moving laterally into the wall
4. the pan flashing laps over the drainage plane beneath the opening

Material

In wood framed openings the pan flashings may be fashioned in the field from self-adhered

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flashing membrane, self-adhered formable flashing, non-water-sensitive sheet metal and certain liquid-applied waterproof membranes.

Manufactured pan flashing may also be used to drain the opening. Note that two-piece pan flashing will need to be sealed at the joint between the pieces and that pre-cast panned sills for masonry openings will need sealant at the joints with the side of the opening.

At concrete slab edges a seat may be cast into concrete to act as pan flashing for openings in the exterior wall.

Back Dam and Sloping

A block of wood nailed at the back of the rough opening sill can be used with membranes to create a back dam. Similarly, beveled siding can be nailed at the bottom of the rough opening to create a positive slope under the membrane. The back dams of manufactured pan flashing and sheet metal pan flashing must be protected against bending and breakage during window installation.

End Dam

Just as a back dam prevents water from being directed to the interior side of the opening, end dams are needed to prevent water from running laterally off the pan and into the wall. As with most critical details, it is the corners that present the real challenges.

When a membrane is turned up the jamb from the sill, it is important that the membrane make a tight corner and not span across or "chamfer" the corner. If the membrane is not tight to the corner it is vulnerable to being torn by the corners of the window unit – this would create a hole exactly where it is most dangerous.

When sheet metal is used to create flashing at inside corners, it is common practice to make a cut to allow the inside corner and then apply sealant over the seam. A much more durable technique is to create a flat folded "dog ear" to allow the inside corner between the end dam and back dam.

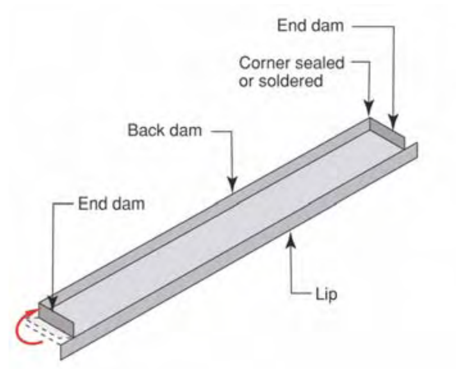
Drainage over Drainage Plane

The function of the pan flashing can be entirely subverted if the water collected in the pan flashing is not allowed to drain to the exterior (e.g. if the bottom flange of the window is sealed to the drainage plane) or if the pan flashing is somehow drained behind the drainage plane. To prevent reverse-lapping at the bottom of the pan flashing, it is important that the drainage plane material is installed at the bottom of the window *before* the pan flashing is installed. An alternative that can be employed with self-adhered flashing materials is to leave the release paper on the bottom flap of the pan flashing until after the housewrap or building paper is installed.

The bottom edge of the opening must remain open to allow for drainage. At the same time, integrity of the air barrier at the opening must be maintained. All windows and doors should be air sealed around their entire perimeters on the interior with sealant or non-expanding foam. The foam is installed from the interior prior to the installation of the interior trim.

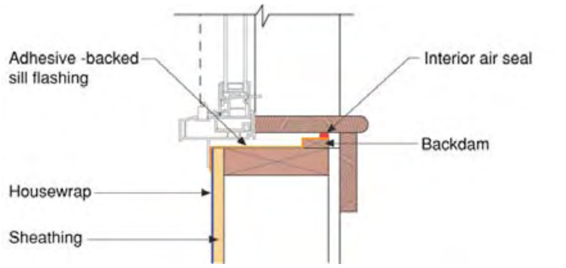
It may be helpful to use shims at the sill to ensure adequate drainage space. Where pest entry is a particular concern, copper mesh or similar screening may be used in this drainage opening.

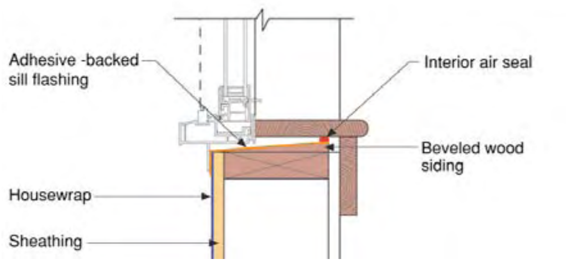
Sheet Metal Pan Flashing



- Corner between end dam and back dam should be folded not cut
- Back dam must be protected during window installation

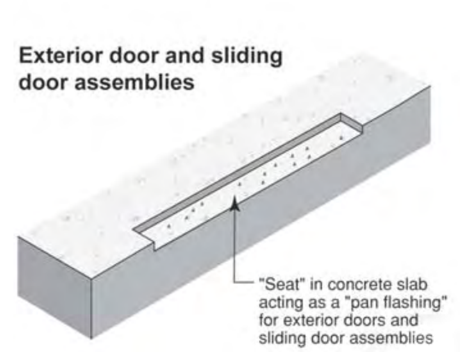
Back Dam Options for Membrane Pan Flashing





- A strip of wood nailed across the back of the rough opening sill forms a dam to prevent water from draining into the interior
- Beveled siding nailed over the sill creates positive drainage toward the exterior. Note that tapered shims in the opposite direction of the slope may be required to support interior trim.

Seat in Concrete as Pan Flashing



- A seat cast in concrete has inherent back dam and end dam.
- It is important that framing not extend into the seat below the top of the slab.

Suggestions for Further Research:

"Rain Control in Buildings," Building Science Digest-013, www.buildingscience.com.

"Understanding Drainage Planes," Building Science Digest-105, www.buildingscience.com.

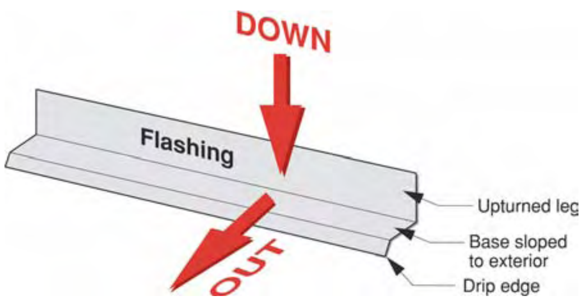
"Increasing the Durability of Buildings," Building Science Digest-144, www.buildingscience.com.

Lstiburek, Joseph W.; *Water Management Guide,*. Building Science Press, 2006.

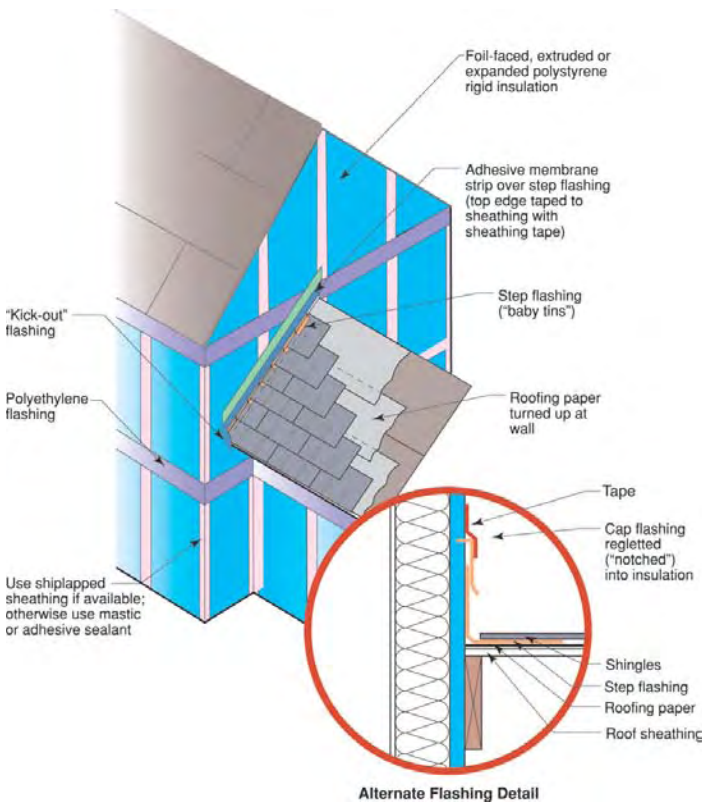
Lstiburek, Joseph W.; *Builder's Guide Series*, Building Science Press, 2006

Common Flashing Details

for All Climates



Flashing Fundamentals



Roof to Wall Flashing with Foam Sheathing

- Upturned leg of step flashing sealed to wall drainage plane with adhesive membrane. Top edge of adhesive membrane is taped to drainage plane with sheathing tape. Alternatively, a cap flashing can be regletted into the foam sheathing with tape forming a transition to the cap flashing.

Common Flashing Details

The fundamental principle of rainwater control is to shed water by layering materials in such a way that water is directed downwards and outwards out of the building.

Gravity is the driving force behind drainage. The "down" direction harnesses the force of gravity and the "out" direction gets the water away from the building enclosure assemblies, openings, components and materials. In general, the sooner water is directed out the better. Sooner, may not always be practical – such as at window openings where draining a window into a drainage space behind a cladding is often more practical than draining them to the exterior face of the cladding.

The most elegant expression of this concept is a flashing (see diagram to right). Flashings are the most under-rated building enclosure component and arguably the most important. Flashings are integrated with drainage planes creating, for all practical purposes, a flashing for the entire assembly.

Metal flashings on buildings serve a multiple of similar yet slightly different functions.

1. to direct water that has penetrated behind the cladding back out to the exterior (such as wall base flashing), or
2. to protect an interface between two different enclosure elements (such as roof to wall step flashing), or
3. to shed water over protruding building elements (such as window/door/trim flashing), or
4. all three.

- Flashings are needed wherever a drainage plane is terminated as at a roof edge or bottom of wall, or interrupted as at openings, intersection of assemblies, control joints, or penetrations of the drainage plane. Flashings must not direct water onto another building element in a way that concentrates moisture loading. Flashings

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are about reducing moisture loading on the building enclosure.

Step Flashing

Stepped flashing is used where a sloped shingled roof intersects a vertical wall. Step flashings are interwoven with the shingles and act essentially as shingles with an upturned leg to allow a transition of the vertical drainage plane of the wall to the drainage plane of the roof. The upturned leg of the step flashing is behind the vertical drainage plane or sealed to it with adhesive membrane and sheathing tape. The bottom leg of the step flashing is placed over the roof drainage plane.

A critical component of step flashings along the run of the roof slope is a kick-out flashing. The kick-out flashing directs water away from the adjoining wall and ensures that the step flashing is not concentrating water on the surface of that wall.

Head Flashings

Head flashings are used to direct water away from openings such as windows and doors. Head flashings should be installed with a positive slope to the exterior. The cladding above the head flashing should never rest on the flashing as this leads to problems with the flashing being bent in the wrong direction and sloped back towards the building. Head flashings should extent laterally past the opening on either side.

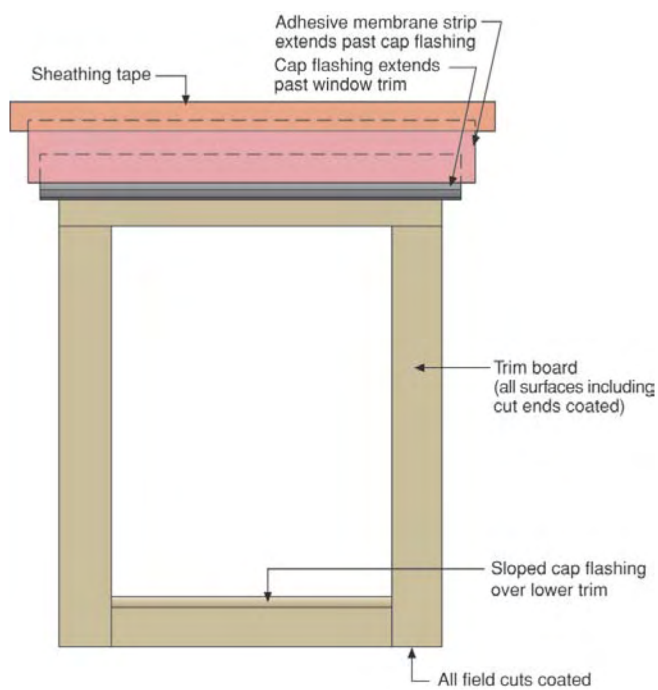
Improper Head Flashing Slope

Improper sloped head flashing directing water back towards the building

Kick-Out Flashing with Stucco Cladding

- The kick-out flashing directs water away from the adjoining wall surface
- Step flashing piece above is lapped over kick-out

Head Flashing over Drainage Plane Sheathing



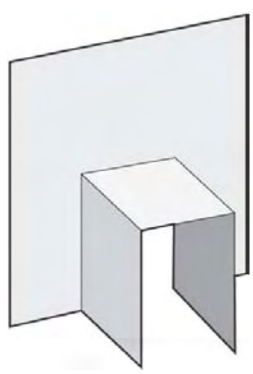
- Layers of the head flashing extend past subsequent layers
- Where the drainage plane is applied over the sheathing, (i.e sheathing itself is not the drainage plane) it should lap over the head or cap flashing

Flashing Penetrations

Flanged penetration covers can be readily integrated into a drainage plane. With lapped drainage planes such as building paper, the drainage plane material is place beneath the flanged cover, then the subsequent sheet is lapped over the flanged cover. In the case of drainage plane sheathings or housewraps, the flanged cover is sealed to the drainage plane using appropriate tape as illustrated below.

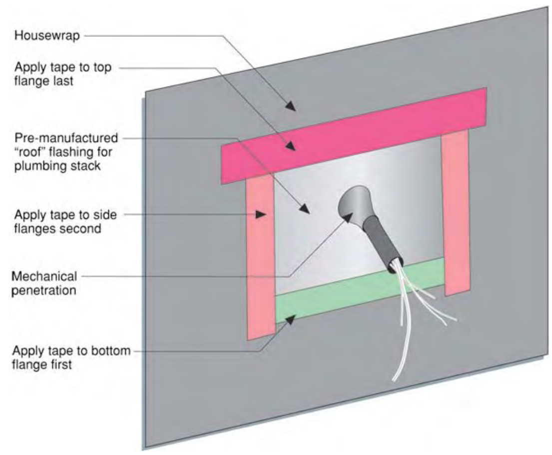
Cap flashing or other pre-manufactured flashings can provide elegant solutions to drainage plane penetrations. Where flashings need to be site-built from sheet metal, or flashing membranes, the finished installation must follow the fundamental flashing rules of *down* and *out*. Flashings must always direct water out over the cladding or drainage plane without openings that would allow water to be directed back into the wall.

Saddle Flashing



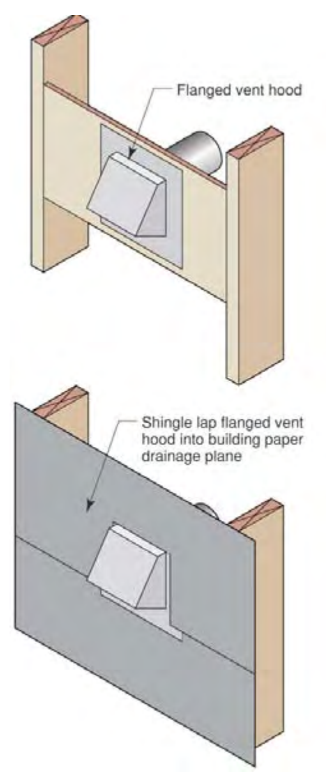
- A saddle flashing should be used for railing attachment and for cantilevered joists and beams penetrating exterior walls.

Flanged Penetration



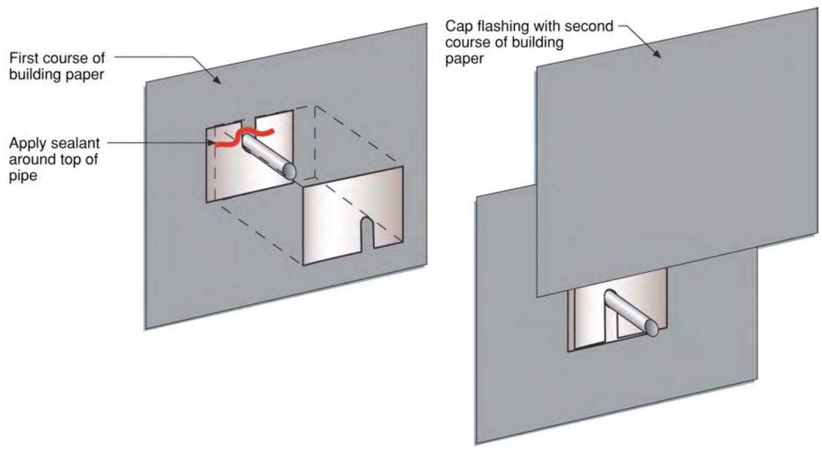
- Tape is applied in order from lower edge to sides to top edge so that it will lap correctly, i.e. shingle fashion

Flanged Penetration with Building Paper



- Lower piece of building paper tucked under flanged vent
- Upper piece of building paper lapped over flanged vent.

Flashed Pipe Penetration with Building Paper Drainage Plane



- Pipe flashing is shingle lapped into drainage plane.
- With non-lapped drainage planes, the top edge of the pipe flashing is sealed to the drainage plane with sheathing tape.

Suggestions for Further Research:

"Rain Control in Buildings," Building Science Digest-013, www.buildingscience.com.

"Understanding Drainage Planes," Building Science Digest-105, www.buildingscience.com.

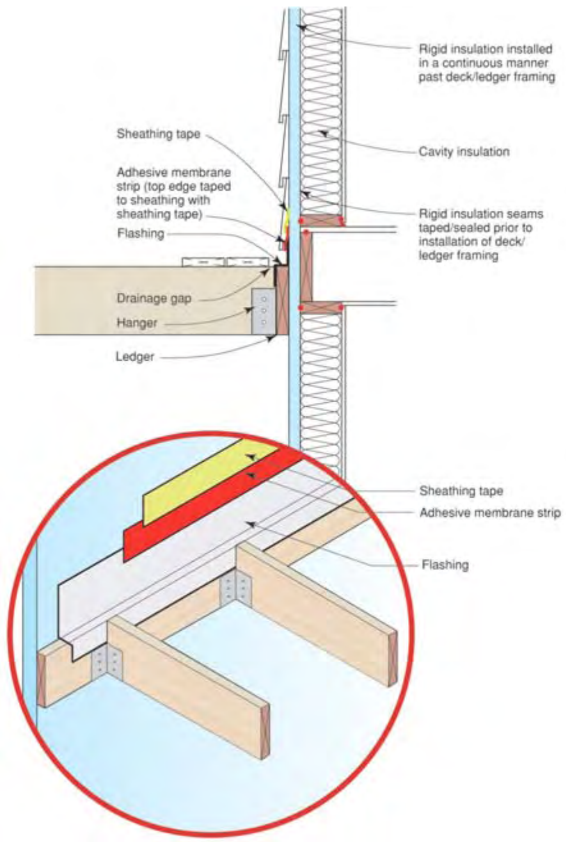
"Increasing the Durability of Buildings," Building Science Digest-144, www.buildingscience.com.

Lstiburek, Joseph W.; *Water Management Guide,*. Building Science Press, 2006.

Lstiburek, Joseph W.; *Builder's Guide Series*, Building Science Press, 2006

BSC Information Sheet 304

Integrating Deck Ledger Board with Drainage Plane *for All Climates*



Flashing Over Deck Ledger

- Ledger flashing directs water out over deck ledger
- Membrane flashing integrates metal flashing into the wall drainage plane
- Sheathing tape seals membrane flashing to drainage plane/sheathing
- Deck joist ends treated to reduce absorption of water

Integrating Deck Ledger Board with Drainage Plane

Maintaining drainage plane continuity at deck ledger locations provides a particular challenge. It is common practice to install a complete WRB on a wall assembly before attaching a deck ledger. Then, when the deck ledger is attached, structural connections at this location breech this water control layer or WRB. Pressed against the water control layer, the ledger acts as horizontal dam interrupting drainage and potentially directing water to fastener penetrations and into the wall. Even where the wall system protection remains in tact, the ledger board itself would be vulnerable to moisture degradation if not protected. Other building elements, such as mounting blocks used for the attachment of lighting fixtures, may present similar conditions as those described above. The techniques presented in this Information Sheet may be applied to deck ledgers as well as related elements.

Careful detailing and flashing of this connection is necessary for both the integrity of the building's drainage system and for the durability of the deck structure.

The diagram to the right shows flashing over a deck ledger board. The top of the flashing is integrated into the wall drainage plane (In this case, insulating sheathing installed in a continuous manner with seams taped also functions as the drainage plane). The ends of the joist should be treated with a sealant to reduce the absorption of water at the end of the joist.

Where the drainage plane is applied over the sheathing material as a separate component – as would be the case for housewrap or building paper applied over structural sheathing – a water proof membrane should be installed between the ledger board and the sheathing. The diagram on the following page illustrates the application of ledger board flashing in this situation.

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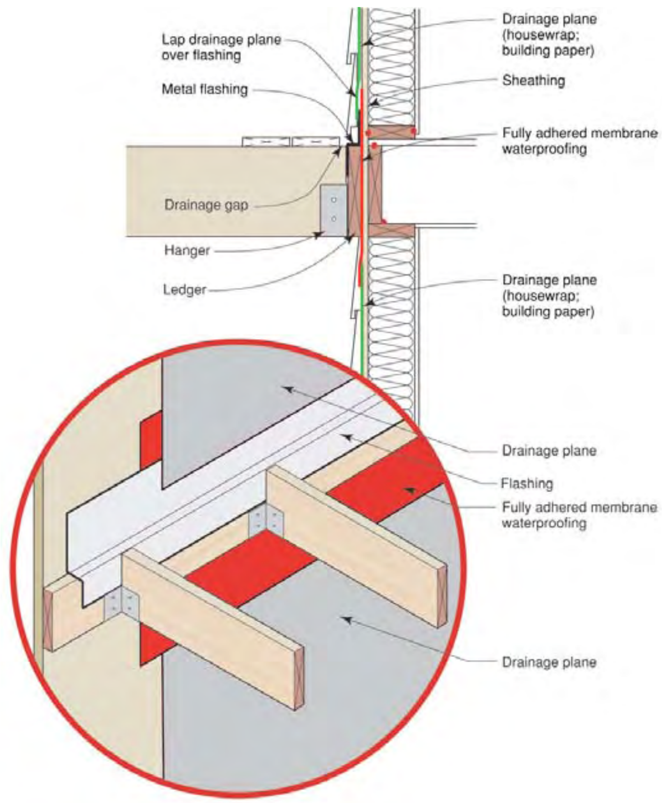
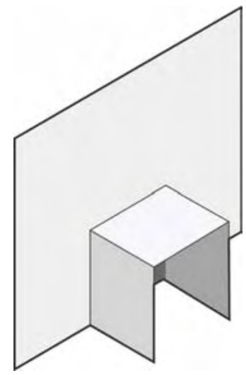
WRB Behind Deck Ledger



- Drainage plane above ledger to lap over flashing which is placed over waterproof membrane
- Drainage plane to be tucked under waterproof membrane below ledger
- Deck joist ends should be treated to reduce absorption of water

Saddle Flashing



- Deck ledger flashing to lap over saddle flashing.
- Saddle flashing may also be used for railing connections

Suggestions for Further Research:

"Rain Control in Buildings," Building Science Digest-013, www.buildingscience.com.

"Understanding Drainage Planes," Building Science Digest-105, www.buildingscience.com.

"Increasing the Durability of Buildings," Building Science Digest-144, www.buildingscience.com.

Lstiburek, Joseph W.; *Builder's Guide Series*, Building Science Press, 2006.

Lstiburek, Joseph W.; *Water Management Guide,*. Building Science Press, 2006.

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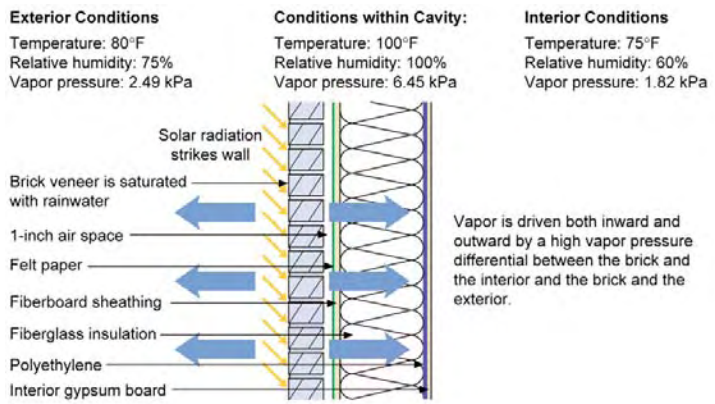
BSC Information Sheet 305

Reservoir Claddings

for All Climates



Inward Moisture Movement Due to Solar Radiation

- Absorptive claddings such as brick veneers, when used over a vapor permeable combination of exterior sheathing and weather-resistive barrier should have a ventilated cavity and high inward drying potential (i.e. no polyethylene vapor barriers).
- A ventilated cavity will both reduce inward driven moisture and increase drying to the exterior.
- An outer layer with moderate or low vapor permeance is recommended to control inward vapor drive.
- Vapor barriers such as polyethylene film, vinyl wall coverings, or foil-backed cavity insulation should not be installed on the interior side of air conditioned assemblies.

Reservoir Claddings

Reservoir claddings are materials that absorb and store a portion of water that falls on their surface. Claddings made of wood, fiber cement, stucco, concrete, and masonry all absorb water to varying degrees. Once the reservoirs get wet, the stored water can migrate elsewhere and cause problems. Therefore, reservoir claddings must be decoupled from water sensitive materials of the wall assembly.

As with any cladding in a water-managed assembly, drainage must be provided behind reservoir claddings. Drainage requires two things: 1) a drainage plane and 2) a drainage space (see Information Sheet 301 – Drainage Planes).

Absorbed water migrates by capillary transport or changes to a vapor and migrates by air flow or diffusion. Therefore, in addition to drainage, reservoir claddings also require control layers for capillary water, airflow, and water vapor. A proper drainage plane will also provide capillary control (in addition to dealing with bulk liquid water). Air flow control is provided by an air barrier to the interior of the drainage space. This air barrier could also be the drainage plane if the drainage plane is an air barrier material installed in a continuous manner with all joints sealed. Examples of drainage planes that also function as air barriers include liquid-applied exterior vapor retarder/air barriers, fully adhered impermeable sheet membrane, and air impermeable insulating sheathing with all joints taped.

Water vapor control is particularly important for reservoir claddings that may be exposed to sunshine – even in predominantly heating climates. When absorbent cladding materials or retained water in the drainage space is heated by solar exposure, very large inward water vapor drives can result. These inward drives can cause dangerous summertime condensation within wall cavities, especially if a low-permeance vapor barrier (e.g., polyethylene) or finish (e.g. vinyl wall paper, mirrors, and cabinets) are used on the interior. There are two methods of controlling this vapor drive: 1) ventilate the

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cladding, and 2) provide a vapor control layer behind the cladding. These may also be used in combination for situations of elevated moisture loading.

Cladding Ventilation

For claddings with significant reservoir capacity, including masonry and fiber-cement, ventilation is recommended to enhance moisture control. Ventilation, or exterior airflow behind the cladding driven by wind pressure differences on the face of the building or solar heated air rising, is useful since it accelerates drying by removing moisture from the drainage space. Ventilation bypasses the high vapor resistance of claddings such as vinyl siding, metal panels, and cement board, thereby allowing outward drying of the wall assembly.

A clear space is required behind cladding to encourage ventilation. While effective drainage of rainwater can occur in drainage spaces as small as 1/16 to 1/8 inch (e.g. between two layers of building paper in a stucco cladding), effective ventilation may require spaces as large as 3/4 to 1 inch depending on the moisture load (e.g. between a brick veneer and a building wrap). The greater the reservoir, the greater the moisture load, and the greater the ventilation required. Keeping the ventilation space clear may be challenging with masonry claddings such as brick veneers. It may be worthwhile to specify a wider ventilation cavity if quality control measures are not sufficient to keep mortar droppings from closing or constricting the ventilation space.

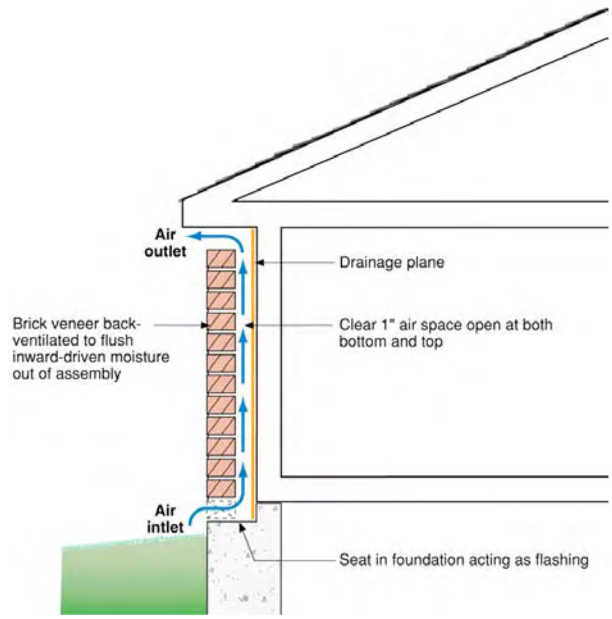
Effective ventilation also requires placement of clear vents at both the top and bottom of the wall. This will maximize the stack potential and hence the motive force to promote ventilation. Vent holes are also needed at horizontal interruptions of the wall such as window sills and heads.

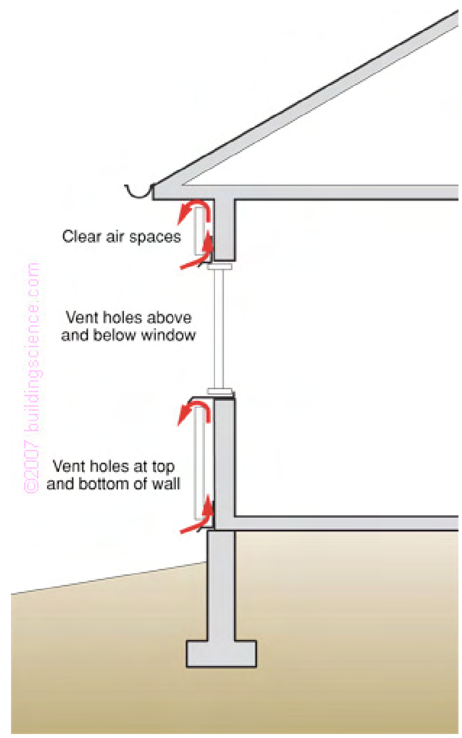
Vapor Control Layer

Another method of controlling inward vapor drive is to use a vapor control layer, or vapor retarder in conjunction with- or as the weather resistive barrier or sheathing layer. Even with ventilated cavities, additional control is often required to control inward vapor drives, and an outer layer with moderate or low vapor permeance (such as foam sheathings or thin-profile structural sheathing) is recommended. An example is shown in a diagram on the following page.

The degree of vapor control required is determined by the moisture loading, water sensitivity of materials, and inward drying potential. Care must be exercised to avoid using an exterior-side vapor retarder that interferes with outward drying where such is needed.

Ventilated Cladding

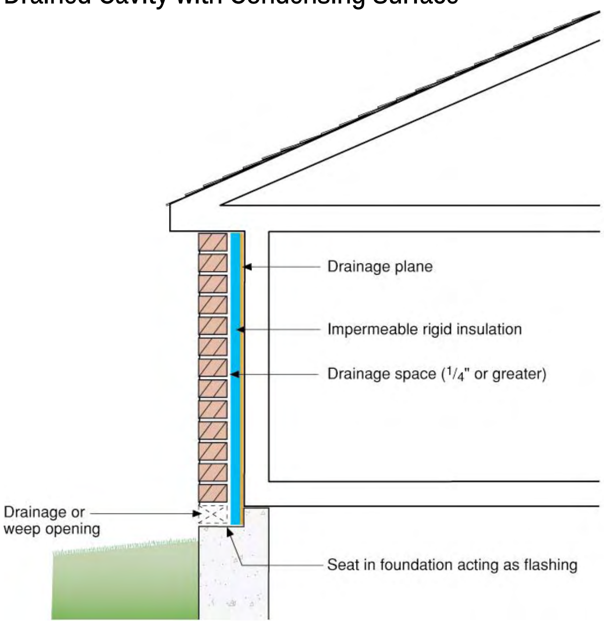




- To effectively uncouple a reservoir cladding from a wall system by using back ventilation, a clear cavity must be provided along with both air inlets at the top and bottom of each wall section.

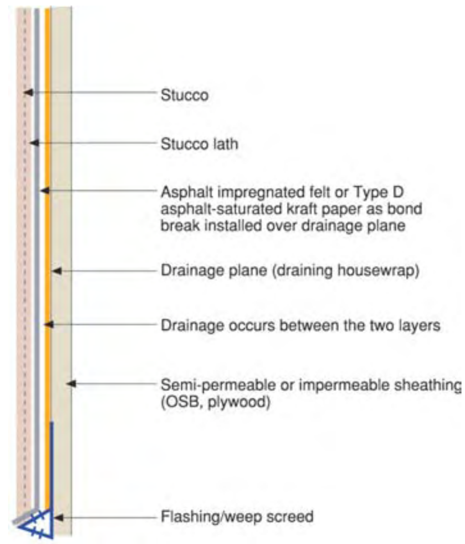
In cases of limited inward drying potential and water sensitivity of the assembly, robust control of inward vapor drive may be required. A reservoir cladding can also be uncoupled by providing a condensing surface such as an impermeable insulating sheathing or by using a fully adhered sheet membrane that is also impermeable (i.e. also a vapor barrier). This is a particularly attractive approach where it is not possible or practical to provide a cavity ("ventilation space") free from mortar droppings.

Drained Cavity with Condensing Surface



- To effectively uncouple a brick veneer from a wall system by using a condensing surface, the drainage plane must also be a vapor barrier. Alternatively, a vapor impermeable layer can be installed between the drainage plane and the brick veneer.
- Note the impermeable or foil-faced rigid insulation can be configured to perform as both the drainage plane and the vapor impermeable layer
- When a condensing surface is used to uncouple a brick veneer from a wall system, a ventilated air space is no longer necessary.

Stucco with Drainage Plan and Drainage Space



- Stucco applied over water sensitive materials must be uncoupled from the water sensitive materials. This can be accomplished via drainage and a capillary break.
- For drainage to occur, both a drainage plane and a drainage space are required. Therefore, the stucco must not bond continuously to the drainage plane, a bond break is necessary.
- The capillary break can be an airspace, foam sheathing or the drainage plane material itself
- Semi-permeable or impermeable sheathing provides control of inward vapor drive

Suggestions for Further Research:

"Understanding Drainage Planes," Building Science Digest-105, www.buildingscience.com.

"Understanding Vapor Barriers," Building Science Digest-106, www.buildingscience.com.

"Rain Control in Buildings," Building Science Digest-013, www.buildingscience.com.

"Increasing the Durability of Building Constructions," Building Science Digest-144, www.buildingscience.com.

Lstiburek, Joseph W.; *Water Management Guide,*. Building Science Press, 2006.

Lstiburek, Joseph W.; *Builder's Guide Series*, Building Science Press, 2006

BSC Information Sheet 306

Interior Water Management

for All Climates

Managing exterior sources of liquid water, i.e. rainwater and groundwater, are one of the principal functions of the building enclosure system, and site work (refer to Information Sheets 101, and 301-305). But sources of liquid water are not limited to the outside of the building. Plumbing and occupant behavior also represent potential sources of damaging liquid water entry and accumulation in buildings. These interior water sources should be anticipated in design and construction. This information sheet will present examples of strategies to manage risks of liquid water sources occurring on the interior of the building.

Water accumulation inside the building presents risks to occupant health as it can lead to growth of mold, support pest populations, and cause other IAQ problems. Accumulation of water inside the building can also be detrimental to building durability by causing rot and deterioration of building materials and by enabling damaging pest populations.

While it is true that new plumbing systems should not leak, it is reasonable to expect that even the best plumbing systems will develop problems over time. When plumbing equipment, water-using devices, or washing appliances fail they can result it catastrophic water leakage. Also accidents (e.g. over-watering house plants) and improper use of equipment (e.g. plugging overflow drains on a sink) happen. Finally, some interior water entry (e.g. water splashing out of tub, water dripping off boots and umbrella's near an entry) is a completely normal part of using the building. The risks represented by all of these factors can be managed with interior water management techniques.

Interior Water Management Measures

General Recommendations	
• Anticipate leaks and other sources of liquid water • Avoid water-sensitive materials in areas likely to get wet • Make leaks easy to notice	
Specific Recommendations	
Interior Liquid Water Source	**Risk Mitigation**
Plumbing - Leaks	**Required:** **-**pressure test system before acceptance -avoid locating pipes in exterior walls or unconditioned spaces **Recommended:** -access panels for inspection and where future service likely needed
Plumbing - Condensation	**Required:** -for plumbing in concealed spaces and cavities: continuous insulation, sealed joints and seams **Recommended:** -continuos insulation, sealed joints and seams for exposed pipes
Toilet Tanks	**Required:** Water-resistant floor finish in toilet rooms **Recommended:** Water-resistant wall finishes in toilet rooms

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Washing Machines	**Required:** -use only reinforced connector hoses -single throw valve to hot and cold water shut-off -floor drain or drain pan connected to drain -non-water sensitive flooring **Recommended:** construct laundry room as "wet room"
Bathrooms	**Required:** -water-resistant, moppable flooring -non paper-faced board in wet areas -drywall held off 1/2" above finished floor **Recommended:** **-**construct bath room as "wet room" -water-resistant wall finishes
Hot Water Tanks	**Required:** -locate only in rooms with floor drain and moppable, water-resistant floor surface -do not install in attics -shut-off valves to isolate water tank **Recommended:** **-**drain pan with plumbed connection to plumbing drain or sump
Dishwashers, Refrigerators and other Water-Using Appliances	**Required:** -water-resistant flooring beneath appliance -isolate area beneath appliance from water sensitive materials -shut-off valve for appliance water line at take-off **Recommended:** **-**contruct floor and enclosure beneath appliance such that leaks are readily noticed
Air Conditioners and Dehumidifiers	**Required:** -drain pan positively slopes to drain with no puddles -drainage plumbing maintains min 1/8"/ft slope (exclusive of trap) **Recommended:** do not install in attics
Building Entries	**Required:** -moppable, water-resistant flooring -avoid water-sensitive wall finishes **Recommended:** -moppable, water-resistant flooring in nearest closet -space for wet clothing and gear -avoid paper-faced gypsum board
Indoor Pools, Saunas, Green Houses, Hot Tub Rooms, etc.	**Required:** -manage liquid water risk -magage water vapor loads **Recommended:** obtain professional guidance

Plumbing Pipes

Plumbing pipes represent a potential liquid water source in two ways: 1) they may develop leaks, and 2) water may condense on cold water lines (i.e. "pipe sweat"). Both of these phenomena are likely. The water accumulation problems associated are compounded by the fact that plumbing is usually concealed and inaccessible within building cavities. Because of this water accumulation make occur for a long period of time without being noticed (e.g. condensation from cold water lines in confined cavities could support rodent or insect populations indefinitely). Also, the fact of plumbing pipes being enclosed within a wall may serve as a disincentive to repairs because of the disruption such repairs would entail.

Do not put plumbing in insulated exterior walls and ceilings. Insulated wall cavities experience greater temperature swings which put more expansion and contraction stress on pipes and, in cold climates, may result in frozen pipe leaks.

The aesthetic concerns and the desire to protect plumbing pipes may not allow pipes to be left entirely exposed. However, access panels should be provided where future service is anticipated (e.g. behind tub and shower valves, access to ice-maker line).

To prevent condensation on plumbing pipes, they should be insulated with air-impermeable insulation or airtight-jacketed insulation. The insulation should be continuous – covering all elbows and transitions – with seams and joints taped or sealed. It may be acceptable to leave cold water plumbing uninsulated where it is not enclosed in building cavities and where condensation dripping off pipes will not affect water sensitive materials.

Sweating Tanks

Condensation and water accumulation is also common on toilet bowl tanks. This does not typically occur on the outside of tanks on pressure-assisted flush models but water may accumulate within the enclosure around the pressurized inner tank. Flooring installed under and around toilets must be non-water-sensitive. Ideally, finishes of walls adjacent to toilets will also be non-water-sensitive.

Washing Machines and Laundry Rooms

Clothes washers can leak, especially the rubber hose connections. Reinforced hose connectors should be used. Washing machine hook-ups should be equipped with a single throw valve for the hot and cold water lines in order to facilitate shutting off the water supply to the appliance when not in use. These shut-off valves should be easily accessible and visible. Water leakage should be anticipated and managed by installing a floor drain and otherwise building the laundry room as a "wet room" (see below). A drain pan placed under the washer and plumbed to a drain line can manage water leaking from the appliance itself. With either a floor drain or drained pan, gas tight dry traps must be installed or the trap should be periodically filled and flushed.

Bathrooms and other Wet Areas

Since plumbing leaks and there's lots of plumbing in bathrooms, there will probably be leaks in bathrooms. Bathrooms are also likely to see a lot of water for other reasons (e.g. mis-directed shower nozzles, squirting and splashing tub toys, dripping towels, etc.). This water loading should be anticipated by constructing the bathroom as a "wet room".

Wet rooms should be equipped with floor drains, floor finishes that can be wet mopped and a raised sill in the doorway. Don't use paper-faced gypsum board or "green board" products (it is just paper with a green color) in wet areas such as tub and shower enclosures. It's best to use cement board, fiber cement board or paperless gypsum board, or cement plaster.

If gypsum board is used, keep the gypsum board up off floors _" everywhere at baseboard locations. When the inevitable leak or spill occurs, this space reduces the chance that the paper-faced wallboard will come into contact with water from a leak and suck it up into the wall.

Wet Room Construction

- moppable, water-resistant floor surface
- water-resistant floor extends wall-to-wall, continuous under fixtures and cabinets with only those penetrations needed for plumping pipes
- water-resistant baseboard material sealed to floor or floor material turned up wall and sealed at corners
- floor drain
- raised sill at doorway(s)
- no paper-faced gypsum board
- drywall held off $^1/_2$" above finished floor

Hot Water Tanks

Especially when they are old, water heaters can leak, pressure relief valves and drain pans for water heaters leak. Water heaters should be installed in rooms with drains and with floor systems that have floor coverings that are not water sensitive. In warm climates, it is best to install them in garages so when they leak they don't cause much damage. Never, ever install water heaters in attics.

Shut-off valves that can be used to isolate hot water tanks should be provided. These shut-off valves should be easily accessible and visible.

Other Water-Using Devices or Appliances

Any device or appliance that is connected to the plumbing system should be treated as a liquid water risk. Managing this risk requires that occupants are able to notice water leaks when they occur. It also important to ensure that small water leaks do not immediately affect water-sensitive materials. In kitchens, resilient flooring or other water-resistant flooring should be extended under refrigerators, dishwashers and sinks. Shut-off valves that can be used to isolate water using devices should be provided.

Air Conditioners and Dehumidifier

Air Conditioners and Dehumidifiers remove moisture in the air by condensing it on a cold coil

Single-Throw Shut-Off Valve

- Shut-off valves should be visible and accessible
- A single-throw valve should be used for appliances with both hot and cold water connections

and draining the condensate to a drain or to the outside. This involves plumbing and drain pans and therefore leakage.

Wherever air conditioners are located, their drain pans must be constructed and installed so that they actually drain condensed water way – mere overflow protection is not sufficient! Air conditioning and dehumidifying equipment that is intended to be a permanent part of the building must also have a permanent drain connection either to the plumbing system or to an outside drain away from the building.

Note that, from a water damage perspective, installing air conditioners in attics is as risky as installing water heaters in attics.

Building Entries

In locations where it rains or snows outdoors, or where occupants of the building might otherwise be exposed to liquid water, it is important to anticipate some liquid water near building entries. It is also advisable to accommodate cleaning activities near entries. Flooring at and near entries and in closest near entries should be non-water sensitive. It is also advisable to avoid using paper-faced gypsum board or paper-based finishes in these areas. Do not install carpeting as a floor finish near entries.

At least one of the anticipated frequent use entries of the building should provide space for the removal and storage of wet clothing and gear.

Indoor Pools, Saunas, Green Houses and Hot Tub Rooms, etc.

In some situations, owners or builders will insist that a home incorporating special spaces that entail hygro-thermal conditions that are starkly different from those of the rest of the building. Examples include indoor pools, saunas, green houses, hot tub rooms, steam baths, fish ponds, etc. Not only do these spaces introduce specific liquid water risks, they also introduce water vapor conditions that can be challenging to manage.

Extreme care must be exercised to effectively manage both the liquid water and the water vapor loads. Professional guidance should be sought. The resources listed below may provide some of the initial outline guidance.

Suggestions for Further Research:

"Increasing the Durability of Buildings," Building Science Digest-144, www.buildingscience.com.

"READ THIS: Before You Design, Build or Rennovate," Building Science Primer-040, www.buildingscience.com.

Lstiburek, Joseph W.; *Water Management Guide,.* Building Science Press, 2006.

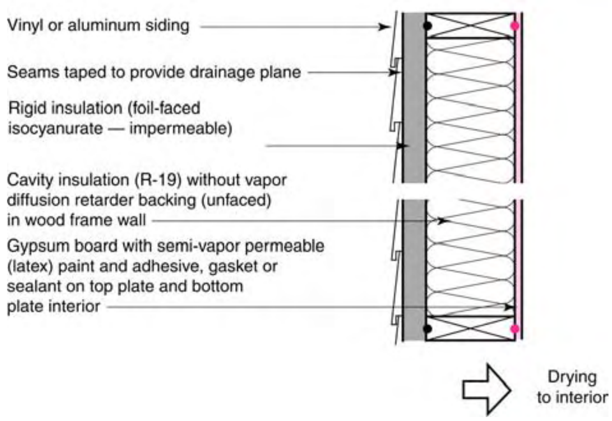
Lstiburek, Joseph W.; *Builder's Guide Series*, Building Science Press, 2006

BSC Information Sheet 311

Vapor Open Assemblies

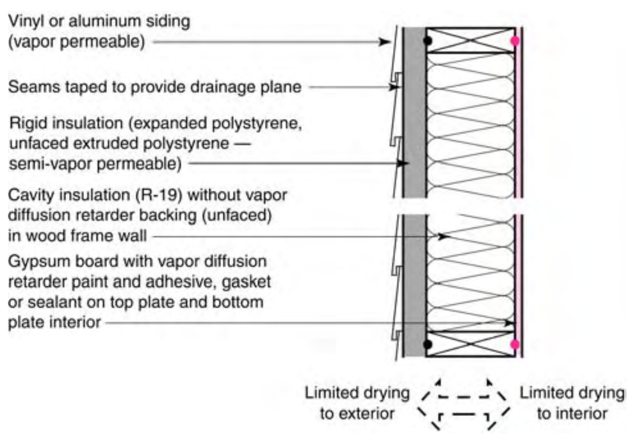
for All Climates

Example Wall Assemblies and Drying Direction



- Impermeable insulating sheathing prevents drying to the exterior . Gypsum board with latex paint allows drying to the interior.

Example Wall Assemblies and Drying Direction



- Semi-vapor permeable (unfaced) insulating sheathing allows limited drying to the exterior. Vapor diffusion retarder paint on the interior gypsum board limits but does not eliminate drying to the interior.

Vapor Open Assemblies

As they are typically used in buildings today, vapor barriers are a cold climate artifact that has migrated into other climates more from ignorance than need. Incorrect use of vapor barriers is leading to an increase in moisture-related problems. Vapor barriers were originally intended to prevent assemblies from getting wet. However, they often prevent assemblies from drying. Vapor barriers installed on the interior of assemblies prevent assemblies from drying inward. This can be a problem in any air-conditioned enclosure. This can be a problem in any below grade space. This can be a problem where brick is installed over building paper and vapor permeable sheathing. This can be a problem when there is also a vapor barrier on the exterior.

Also common is unintentional use of vapor barriers through the application of semi-impermeable finishes such as vinyl wall covering. Even cabinets, fixtures, mirrors, or picture frames can act as unwanted vapor barriers when placed against exterior walls.

Proper vapor control in assemblies is primarily a design responsibility. The viable strategies are informed by climate, exposure, cladding type, structure material, and also by an understanding of the intended occupancy and operation of the building. Consult the resources listed below for further discussion of vapor control in building assemblies.

What is fundamental to robust assemblies is that they have the ability to dry if they become wet. It is often said the buildings or walls need to "breathe." Actually, it is more correct to say that assemblies need to be able to *dry*.

Perhaps it goes without saying that moisture problems can be caused during the construction phase if water sensitive materials are allowed to become wet. Problems can also be caused if wet materials are enclosed by vapor retarder or vapor barrier materials before being allowed to dry (e.g. finishes applied over damp-spray

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insulation before it is dry, finishes applied over concrete that has not released sufficient construction moisture.

Using substitute materials having lower vapor permeance than those originally specified in an assembly may also lead to moisture problems in the near- or long-term, as these less permeable materials will inhibit drying of the assembly. Extreme care must be exercised not to substitute enclosure assembly materials with materials that are less vapor permeable. It is also critical not to install specified vapor retarders or vapor barriers over assemblies before these have had an opportunity to dry. Finally it is important to avoid the application of materials that will act as vapor retarders in locations where a vapor retarder is not specified.

The following table offers a general classification system for permeability of materials as well as the IRC vapor retarder classification. It is always recommended to consult manufacturer product data in order to permit a more precise comparison of material properties.

Vapor impermeable: Class I vapor retarder	0.1 perm or less
Vapor semi-impermeable: Class II vapor retarder	1.0 perm or less and greater than 0.1 perm
Vapor semi-permeable: Class III vapor retarder	10 perms or less and greater than 1.0 perm
Vapor permeable:	greater than 10 perms

Some sources will provide vapor permeability in terms of “wet cup” and “dry cup” conditions. Some materials (such as paints or wood products) become more permeable at higher relative humidity conditions; plastic materials (such as housewraps and foams) typically do not see this effect. “Wet cup” tests give material behavior at high humidity, while “dry cup” provide it for low humidity.

Suggestions for Further Research:

“Understanding Vapor Barriers,” Building Science Digest-106, www.buildingscience.com.

“Increasing the Durability of Buildings,” Building Science Digest-144, www.buildingscience.com.

Camrody, John and Joseph Lstiburek, *Moisture Control Handbook,* John Wiley & Sons, Inc. 1994

Lstiburek, J.W.; "Moisture Control For Buildings;" *ASHRAE Journal*, February 2002.

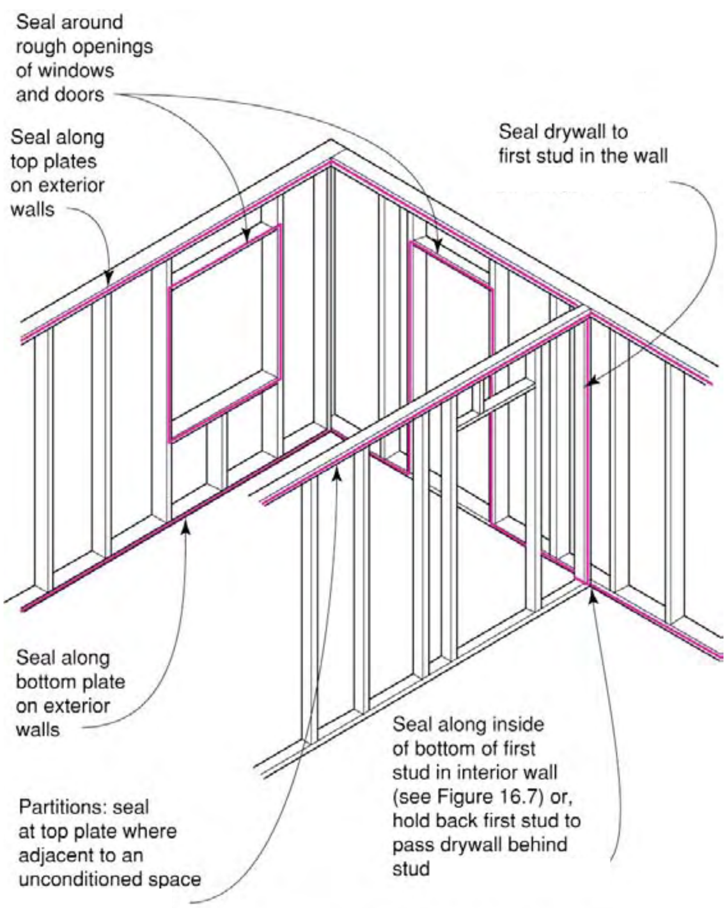
Lstiburek, Joseph W.; *Water Management Guide*,. Building Science Press, 2006.

Lstiburek, Joseph W.; *Builder’s Guide Series*, Building Science Press, 2006

Air Barriers–Airtight Drywall Approach

for All Climates

Sealing Perimeter of Drywall Assemblies



Air Barriers—Airtight Drywall Approach

Gypsum board drywall is, itself, a suitable air barrier material. The taping of drywall seams results in a plane of airtightness at the field of the wall. However, several steps must be taken to use this material property to create a continuous and complete air barrier system. To do this, it is important to create air barrier continuity at the perimeter of drywall assemblies, at all penetrations through the drywall, and, finally, in areas of the enclosure without interior drywall.

Drywall Assembly Perimeter

Air barrier continuity at the perimeter of drywall assemblies is achieved by sealing the edges of the drywall to solid framing materials. This requires a continuous bead of sealant along:

- all exterior wall bottom and top plates,
- all top plates at insulated ceilings,
- rough opening perimeters, and
- both sides of the first interior stud of partition walls.

The air seal at the partition wall intersection is shown in greater detail below.

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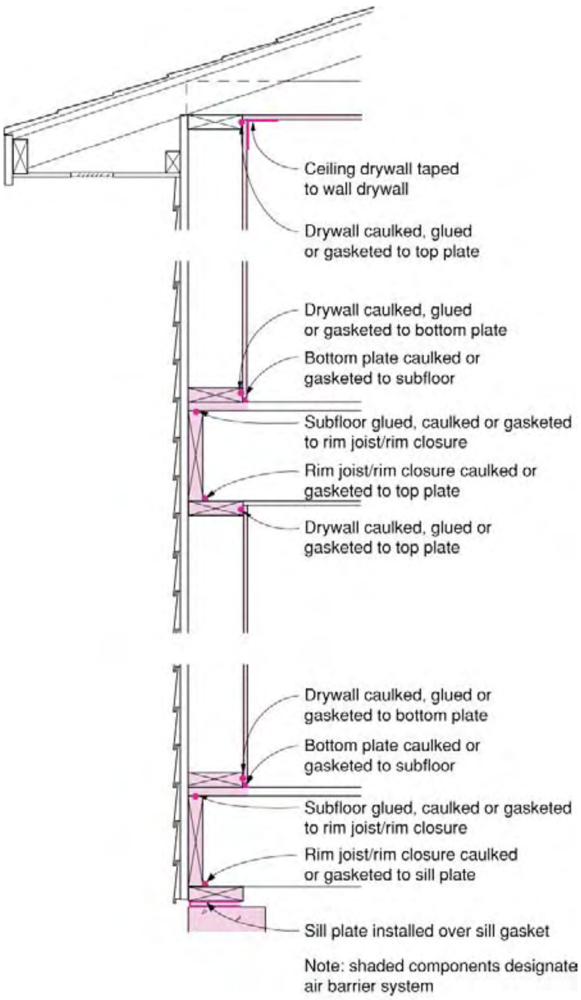
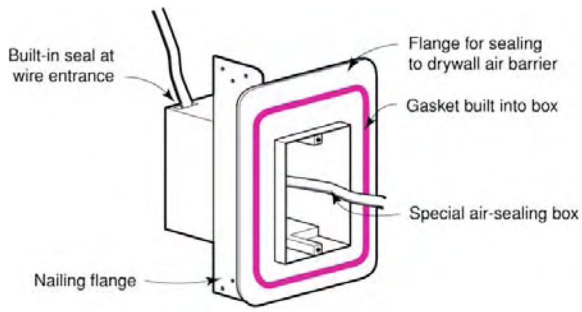
Airtight Drywall Approach – Interior Air Barrier Using Drywall and Framing

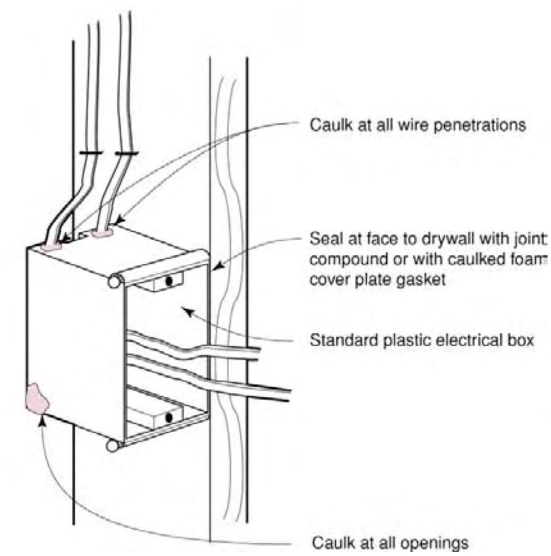


Penetrations of Drywall Assemblies

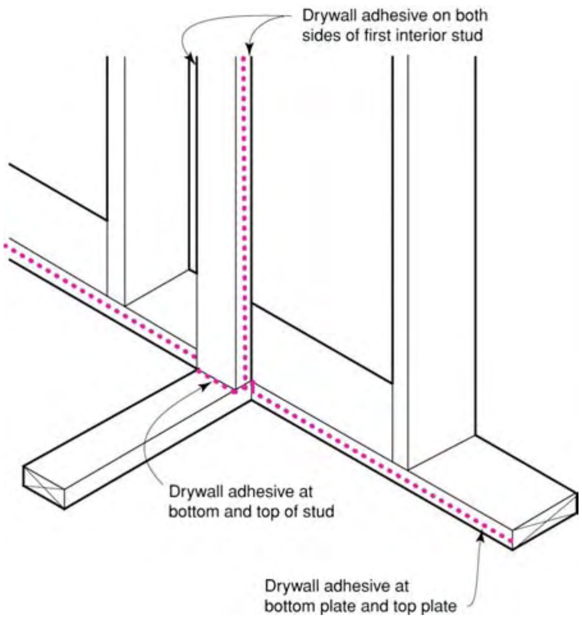
Typical penetrations in exterior wall and ceiling drywall assemblies include electric penetrations – electric boxes and recessed fixtures. Electric boxes can be made air tight by caulking or sealing all openings in the box (including around wire penetrations) and by sealing the face of the box to the drywall. Specially designed airtight electric boxes with flexible boot seals at wire penetrations and a gasketed flange at the face can also provide air barrier continuity.

Electric Box Penetrations



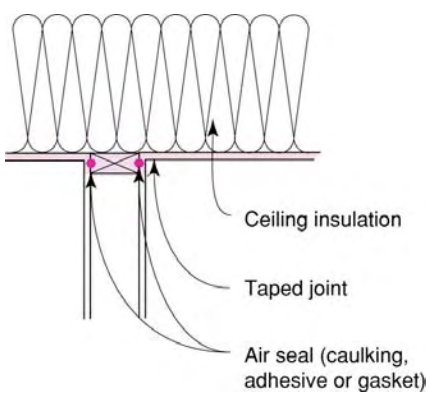


Air Sealing at Partition



- Adhesive at bottom and top of partition stud allows air barrier to transition uninterrupted to other side of partition
- Penetrations through first partition stud must also be sealed

Top Plate with Unconditioned Space Above

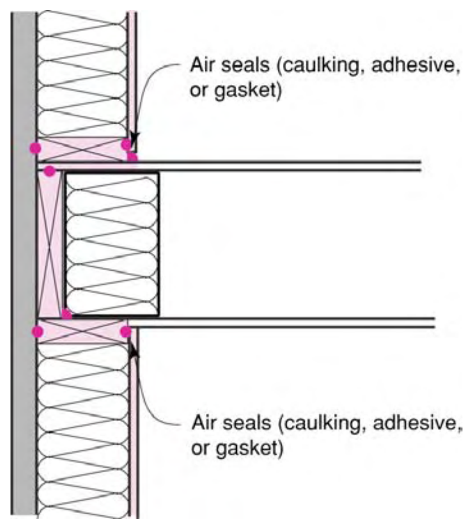


- Penetrations through top plate must also be sealed

Recessed ceiling fixtures in insulated ceiling should be both insulation contact ("IC")- and air tight rated. The housing of the recessed fixture should also be sealed (with caulk or an effective gasket) to the ceiling gypsum board.

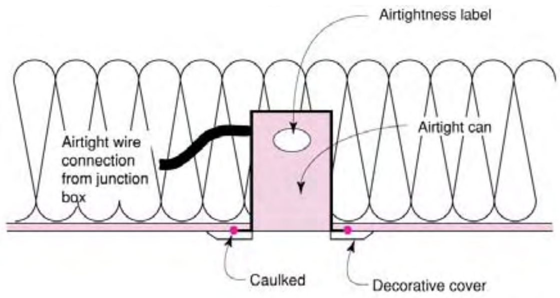
Structural Framing Air Barrier Transitions
Obviously, drywall cannot provide an air barrier where it is absent. The diagrams below and to the right show how the air barrier continuity is maintained through the framing at rim joist/band joist areas. These measures form a necessary complement to drywall sealing in the airtight drywall approach. Refer to other Information Sheets for air sealing details at other common conditions. The resources listed below also illustrate air sealing details and provide further discussion.

Intersection of Floor Joists and Exterior Wall



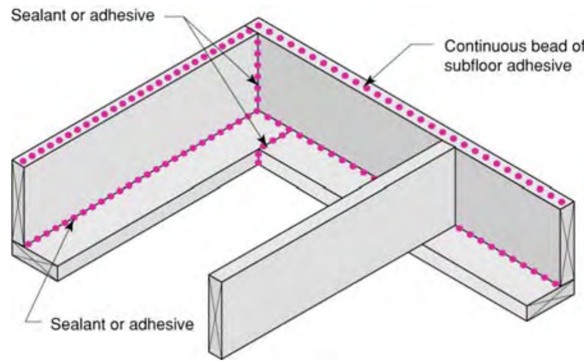
- Drywall sealed to top and bottom plates
- Bottom plate sealed to subfloor
- Subfloor sealed to rim closure board
- Rim closure board sealed to top plate

Recessed Fixture in Insulated Ceiling



- Fixture labeled IC-rated and airtight as determined by ASTM E-283 air leakage test
- Housing (not decorative trim piece) sealed to ceiling with caulk or gasket

Air Barrier Continuity at Rim Joist/Band Joist



- Continuous fillet bead applied at bottom of rim closure board
- Continuous bead of adhesive applied to top of rim closure board
- Sealant applied at all butt joints in rim closure board and sill plate/top plate
- Spray foam may also be used to seal between the sill/top plate, rim/band joist, and floor deck. Note that joints in the sill/top plate may not be sealed by the foam application.

Suggestions for Further Research:

"Understanding Air Barriers", Building Science Digest-104, www.buildingscience.com.

"READ THIS: Before You Design, Build, or Renovate," Building Science Primer-040, www.buildingscience.com.

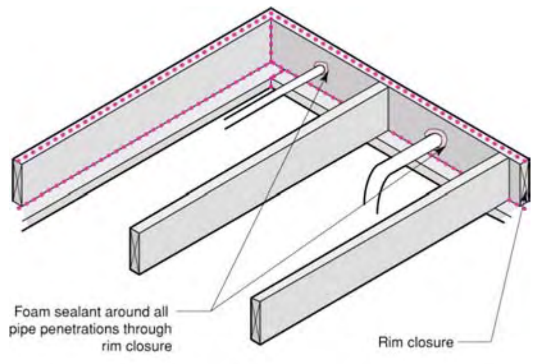
Lstiburek, Joseph W.; *Builder's Guide Series*, Building Science Press, 2006.

BSC Information Sheet 405

Sealing Air Barrier Penetrations

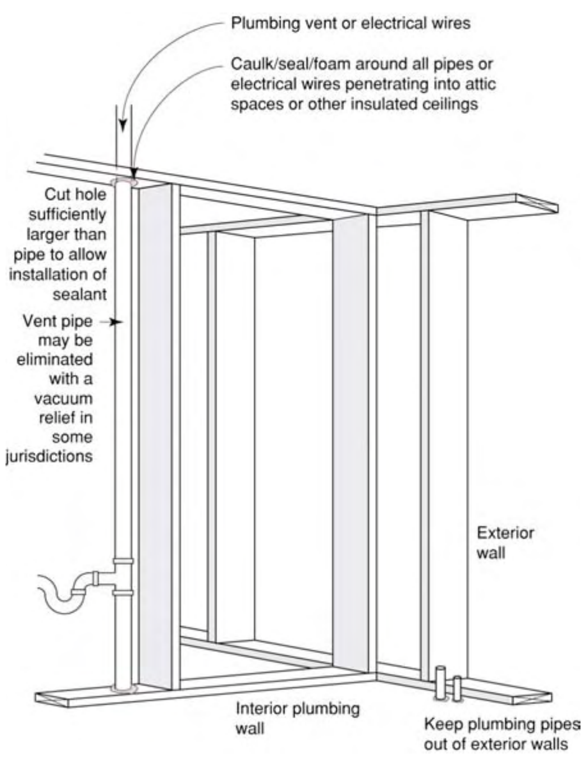
for All Climates

Air Sealing Rim Closure Penetrations



- Penetrating pipes, conduits, ducts, projecting beams etc, are sealed to the air barrier element that they penetrate.

Air Sealing at Vertical Plumbing Penetrations



- Plumbing penetrations through the floor plane are sealed either to the subfloor or to the bottom plate.
- Penetrations through the top plate must also be sealed if the top plate is in the plane of an intended air, smoke or fire separation

Sealing Air Barrier Penetrations

Most air barrier systems will require supplemental air sealing to seal around penetrations. Typical penetrations through the primary components of the air barrier system include plumbing pipes and vents, electrical wires and conduits, electrical fixtures, other mechanical services, and, in some cases, structural members.

Penetrations through Rain Shedding Assemblies

Penetrations through building enclosure elements that also perform rain water management functions must be properly flashed. It is critical that air sealing not interfere with drainage (see Information Sheet 302, and 303).

Typical Plumbing Penetrations within the Building Enclosure

Vertical plumbing runs are typically sealed at the floor plane or bottom plate for floors over unconditioned space or over a separate dwelling unit. While holes to accommodate pipes, conduits and wires represent potential breaches in the air barrier, serious lapses can result from utility chases. Utility chases must be draftstopped wherever these intersect an intended air barrier plane. In colder climates this is also an important freeze-protection measure. Diagrams on the following page illustrate measures to draftstop the utility chase.

While plumbing should not be located in exterior walls, demising walls (or party walls) represent a situation where plumbing may penetration an air barrier assembly laterally. Demising walls should be constructed as airtight assemblies for reasons of sound, smoke, fire and air quality control. Therefore, any penetrations through the drywall surface of demising walls should be sealed air tight. Ensure that the sealant material used complies with any required fire resistance rating and that it is compatible with the pipe, conduit or wire materials.

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Sealing penetrations for sprinkler heads requires special attention as the air sealing must not interfere in anyway with operation of the fire suppression system. The air seal should be between the pipe and the air barrier, not between the sprinkler head itself and the air barrier.

Typical Electrical Penetrations within the Building Enclosure

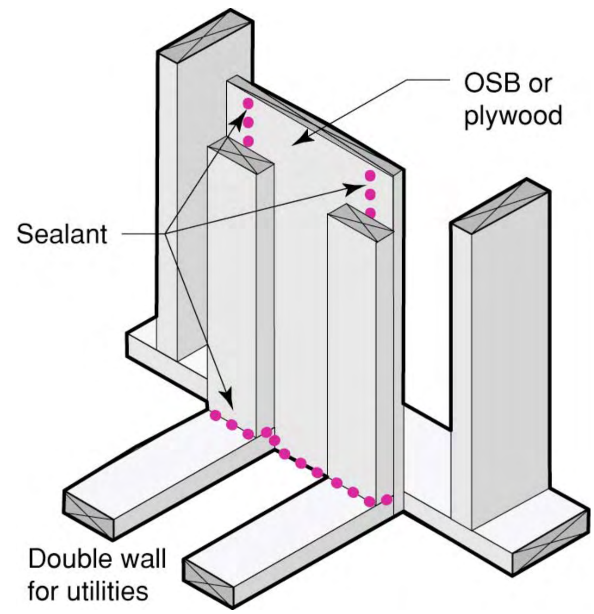
Vertical wiring or conduit runs are typically sealed at the floor plane or bottom plate for floors over unconditioned space or over a separate dwelling unit (i.e., similar to vertical plumbing runs described above). Holes to accommodate electrical services must also be sealed where interior partitions intersect an exterior wall or demising wall.

Typical penetrations in exterior wall, demising wall and ceiling drywall assemblies include electric penetrations – electric boxes and recessed fixtures.

Electric boxes can be made air tight by caulking or sealing all openings in the box (including around wire penetrations) and by sealing the face of the box to the drywall. Specially designed airtight electric boxes with flexible boot seals at wire penetrations and a gasketed flange at the face can also provide air barrier continuity.

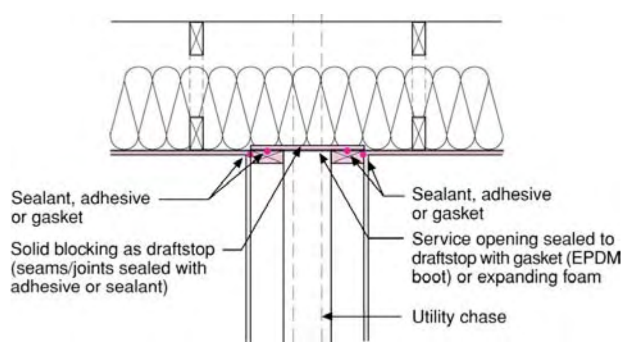
Gasketed Electric Box

Draftstop of Utility Chase at Exterior Wall or Demising Wall



- Solid draftstop material sealed to framing to isolate utility chase cavity

Utility Chase at Insulated Ceiling

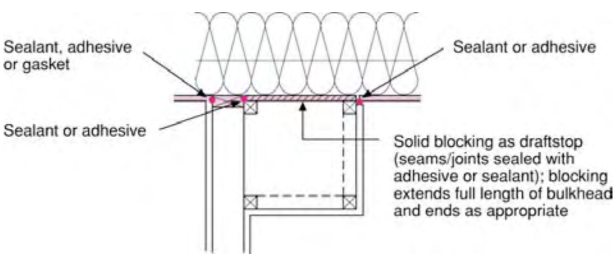


- Flexible gasket sealed to top plate or other solid blocking allows movement of penetrating element without loosing the air seal

Recessed ceiling fixtures in insulated ceiling should be both insulation contact ("IC")- and air tight rated. The housing of the recessed fixture should also be sealed (with caulk or an effective gasket) to the ceiling gypsum board.

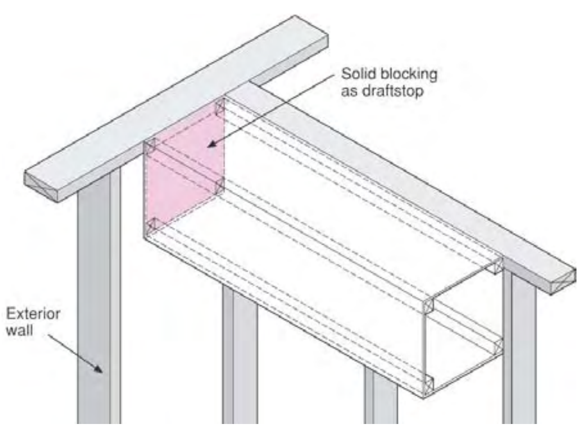
Interior soffits that are not constructed entirely inside of the air barrier may result in lapses in the air barrier if not treated properly. In terms of air barrier performance, such soffits are similar to utility chases: they must be thoroughly draftstopped wherever these intersect an intended air barrier plane.

Interior Soffit at Ceiling Air Barrier



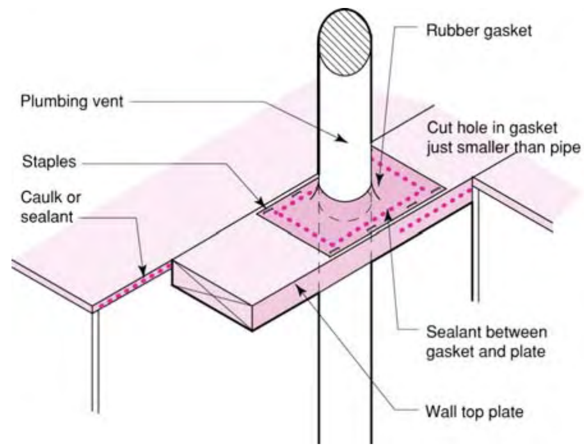
- Solid draftstop material is sealed to framing and surrounding air barrier material.
- Alternatively, the soffit may be constructed after the sealing gypsum board is installed and sealed

Interior Soffit at Exterior or Demising Wall



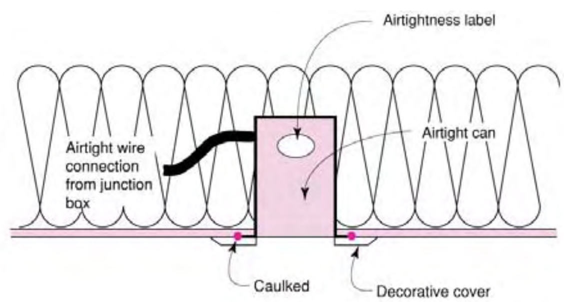
- Solid draftstop material is sealed to framing and surrounding air barrier material.
- Alternatively, the soffit may be constructed after the sealing gypsum board is installed and sealed

Plumbing Penetration through Top Plate with Unconditioned Space Above



- Flexible gasket sealed to top plate or other solid blocking allows movement of penetrating element without loosing the air seal

Recessed Fixture in Insulated Ceiling



- Fixture labeled IC-rated and airtight as determined by ASTM E-283 air leakage test
- Housing (not decorative trim piece) sealed to ceiling with caulk or gasket

Suggestions for Further Research:

"Understanding Air Barriers", Building Science Digest-104, www.buildingscience.com.

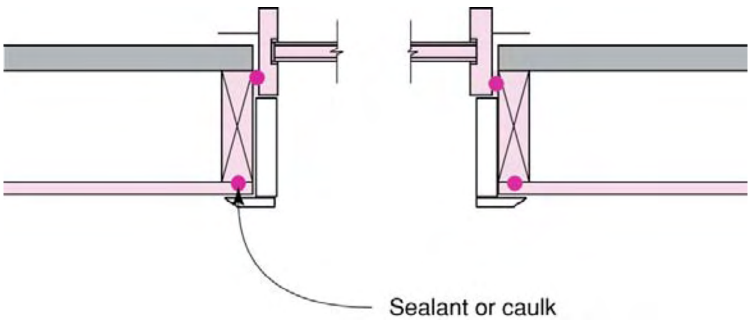
"READ THIS: Before You Design, Build, or Renovate," Building Science Primer-040, www.buildingscience.com.

Lstiburek, Joseph W.; *Builder's Guide Series*, Building Science Press, 2006.

Air Sealing Windows

for All Climates

Location of Air Seal Relative to Window Frame



- Air seal toward the interior edge of the window frame permits drainage of leakage through the window frame
- The diagram above depicts an interior air barrier. Note that the air barrier would also transition to the rough opening framing with cavity air seal or exterior air barrier approaches

Air Sealing Windows

Windows are elements of the building enclosure system that perform many building enclosure functions. One of the building enclosure functions that windows must fulfill is that of an air barrier. As a component of the air barrier system, the connection between windows and other air barrier components is critical to the overall air barrier performance. The air barrier connection between windows and other components must be made in a way that does not compromise other building enclosure functions. Also, the window is the sole air barrier at its opening, unlike walls (which have some redundancy of layers, in terms of airtightness).

While this Information Sheet specifically addresses windows, it may also be applied to doors and other pre-assembled elements installed in building enclosures that also perform an air barrier function.

Location

The air seal between the window unit and the rough opening should be toward the interior edge of the window unit frame. There are two reasons for this. First, at this location, the seal is less likely to interfere with drainage (remember the other building enclosure functions). This is especially important at the sill where the pan flashing must be able to drain to the exterior. The second benefit of sealing toward the interior of the unit is that the remaining gap toward the exterior would be pressure equalized with the exterior. There is then no air pressure difference to drive moisture into the joint (note that water may still be driven into the joint by other forces).

Materials

The window unit should be sealed to the rough opening (or material lining the rough opening) with an air impermeable material. Chinking the gap between window units and rough opening with fibrous insulation does not provide an air barrier connection.

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Materials used to seal the window in the rough opening should be permanently flexible so as to maintain the seal as components move due to thermal expansion and changes in humidity. Finally, the material used to make the seal must not cause the window framing to bow or bend. If foams are used, it must be a low, or no expansion foam and the application should be tested before being applied to the whole building. Caulking may be a suitable air sealing material if gaps are _" or less. Backer rod and sealant may be suitable if the gap between the window unit and framing is of relatively uniform width.

Suggestions for Further Research:

"Understanding Air Barriers", Building Science Digest-104, www.buildingscience.com.

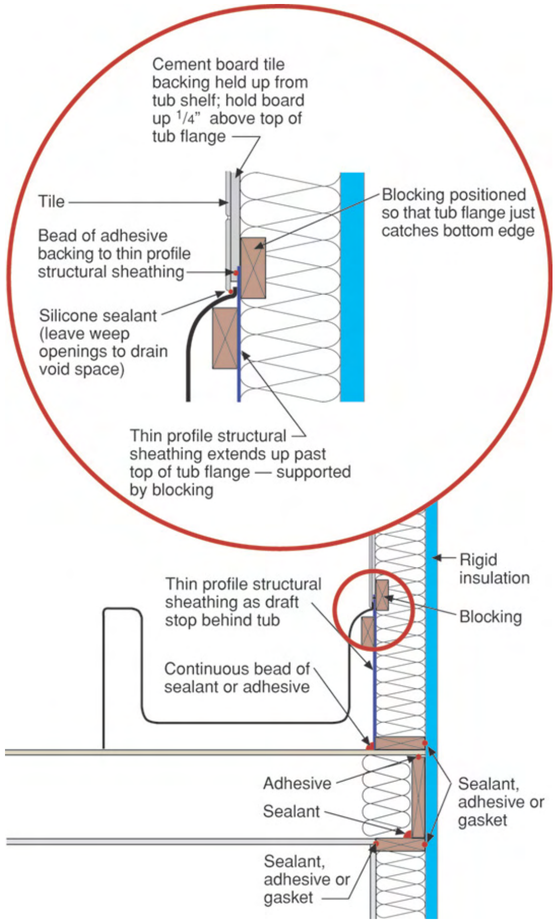
"READ THIS: Before You Design, Build, or Renovate," Building Science Primer-040, www.buildingscience.com.

"Drainage, Holes and Moderation", Building Science Insight 004, www.buildingscience.com.

Lstiburek, Joseph W.; *Builder's Guide Series*, Building Science Press, 2006.

Air Barriers–Tub, Shower and Fireplace Enclosures *for All Climates*

Draft Stopping and Air Barrier at Tub Enclosure - Section



- Entire perimeter of draft stop material sealed to framing and subfloor with adhesive or sealant
- Seams in draft stop material sealed
- Bottom plate sealed to subfloor
- Flat blocking for draft stop and tub flange support allows cavity insulation to be installed behind draft stop
- Cement board, fiber cement board or paperless gypsum board tile backing is recommended in place of moisture-resistant gypsum board ("green board")
- Note: cement board is not waterproof: it must be coated with a fluid applied waterproofing, or a water resistive barrier applied behind it and drained

Air Barriers—Tub, Shower and Fireplace Enclosures

To create an effective air barrier in a building, it is first necessary to cover the big holes. Some common locations for large holes in the air barrier include bathtubs, showers, fireplace enclosures, and chimneys. Holes behind tub and shower enclosures are common, as these enclosures are often installed before the interior-side air barrier of the exterior wall. Similarly, the enclosure behind a prefabricated fireplace is often left incomplete. Where the chimney flue penetrates through an insulated assembly, it is critical to maintain clearances to combustibles materials. But a non-combustible, airtight closure around this penetration is also important.

Bathtub and Shower Enclosures

The diagrams below and to the right provide an example of draft stopping using thin profile sheathing that is installed before the tub enclosure.

Other air barrier sheathings or membranes may also be used to create an airtight draft stop behind tub and shower enclosures. If spray foam insulation is used to create an air barrier in the framing cavities, the bottom plate must still be sealed to the subfloor.

Fireplace Enclosures

Ideally, chimneys for natural draft fireplaces are located within the interior of the building enclosure. Alternatively, chimney enclosures attached to exterior walls should be insulated full height to keep the chimney flue pipes warm to support sufficient draft.[1] If air barrier continuity is not maintained in the chimney enclosure the chimney could create a serious hole in the building enclosure.

Because finishes are generally brought to the face of prefabricated fireplace units, providing an air barrier in the enclosure behind the

[1] Note: use of sealed combustion, direct vent gas fireplaces eliminates the need for chimneys.

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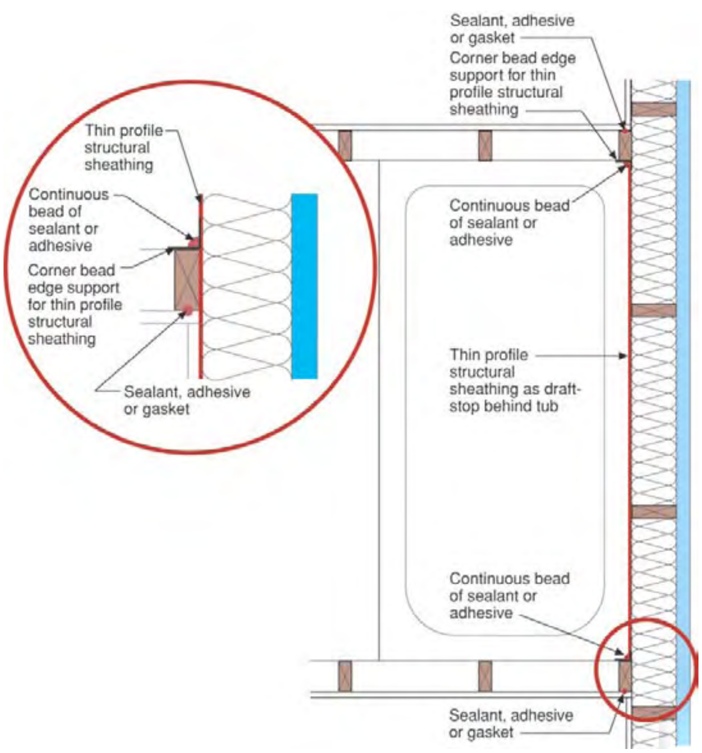
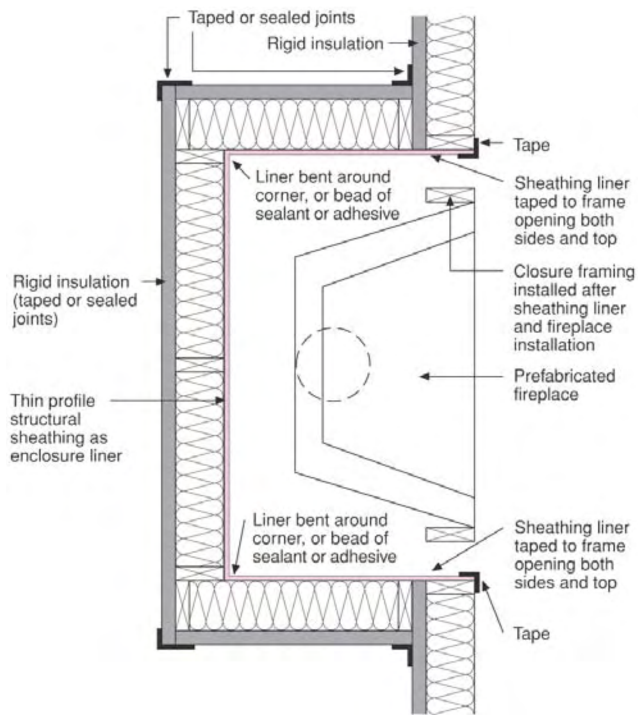
fireplace unit can create a sequencing challenge. The diagrams to the right and on the following page demonstrate one method of maintaining air barrier continuity by installing airtight draft stopping on the inside of the chimney enclosure and by installing an airtight flue closure.

Draft Stopping and Air Barrier at Tub Enclosure - Plan

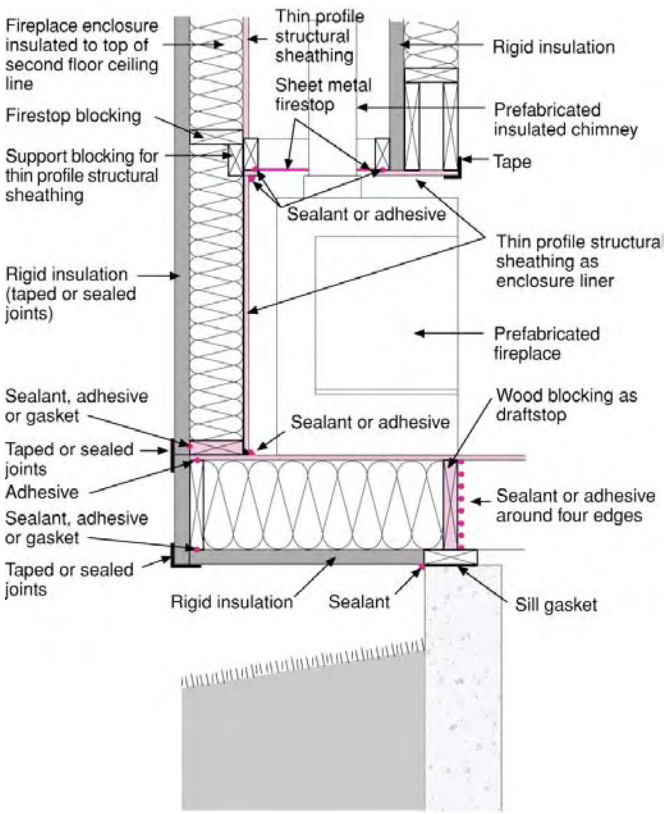


Fireplace Enclosure – Plan



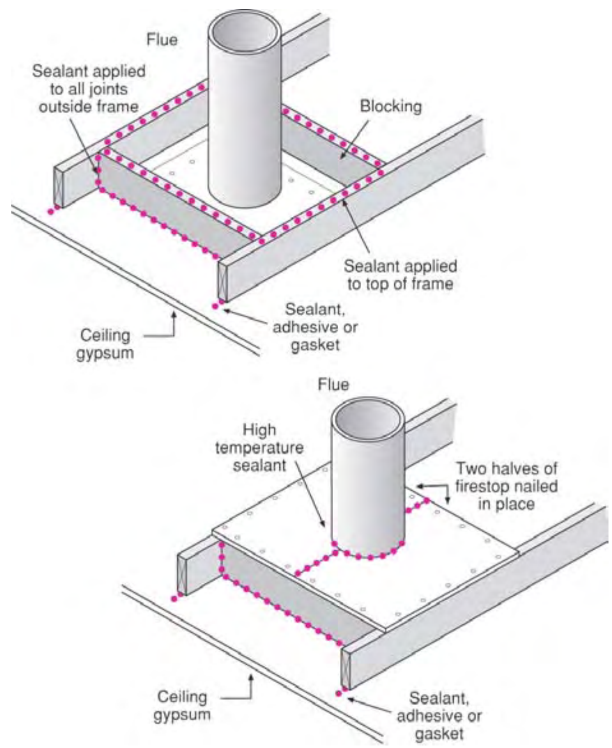
- Clearances around chimney and fireplace unit to be determined by manufacturer's recommendations and local codes
- Exterior combustion air with a damper should be provided to all fireboxes
- Draft stopping material is sealed at perimeter to framing or subfloor
- Seams in draft stopping material sealed

Fireplace Enclosure - Section



- Flue closure needed at top of insulated assembly
- Draft stopping material is sealed at perimeter to framing or subfloor
- Seams in draft stopping material sealed

Flue Closure



- Only approved high temperature sealants to be used at firestopping
- Flue closure also needed at the insulated ceiling for chimneys within the interior of the building enclosure

Suggestions for Further Research:

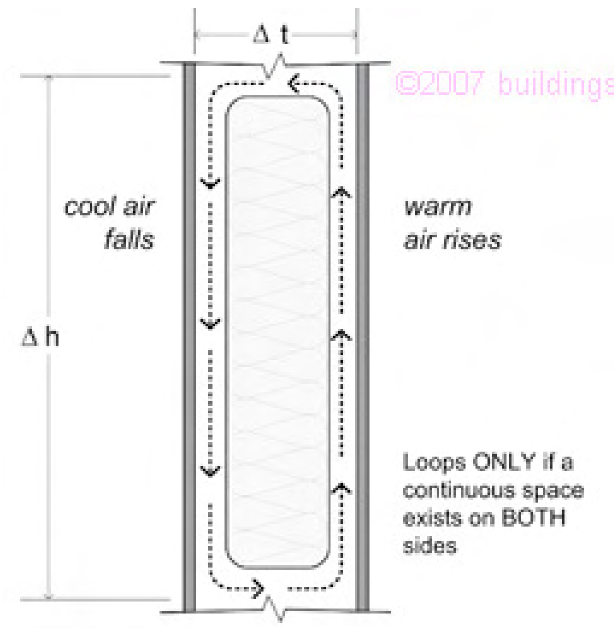
"Understanding Air Barriers", Building Science Digest-104, www.buildingscience.com.

"READ THIS: Before You Design, Build, or Renovate," Building Science Primer-040, www.buildingscience.com.

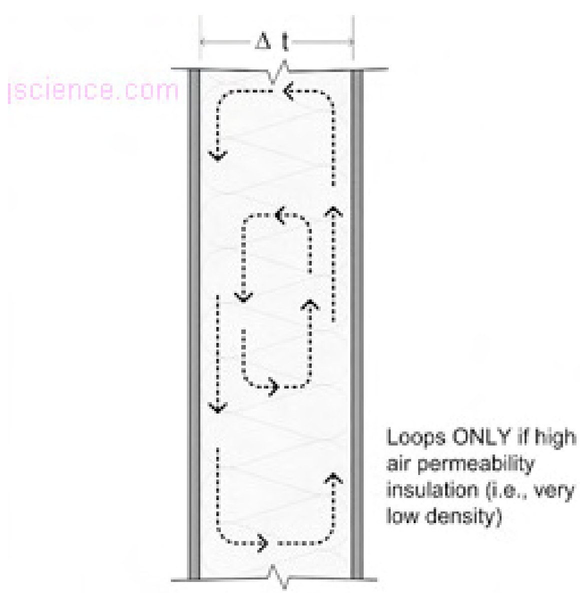
Lstiburek, Joseph W.; *Builder's Guide Series*, Building Science Press, 2006.

BSC Information Sheet 501
Installation of Cavity Insulation
for All Climates

Convective Air Loops that Reduce Thermal Control of Insulation



A: Air Loops Around Insulation



B: Air Loops Through Insulation

Installation of Cavity Insulation

Cavity insulation combined with insulating sheathings are common in residential wall construction. Cavity insulations can be categorized as rolled batt; blown-in or loose-fill (fibrous insulation – cellulose, fibreglass, rock or slag wool – supported by netting or reinforced polyethylene or blown into closed cavities); damp spray (fibrous insulation with moisture activated adhesive or binder); and spray foam. Insulating sheathings are typically extruded and expanded polystyrenes, foil and fiber-faced isocyanurates, and rigid fibreglass. Roof/attic insulations are typically blown fibreglass, blown cellulose, fibreglass batt, and spray foam.

For insulation to perform as intended, it must be installed correctly. Correctly installed insulation forms a continuous thermal barrier that is as even as practical.

This information sheet will address the installation techniques important to the effective performance of cavity insulation. It bears reminding that health and safety precautions must be followed for insulation installers and those remaining in the vicinity of the insulation installation. Performance of cavity insulations are degraded primarily by two factors:

1. Absence of insulation
2. Convective looping in and around the insulation

The fist factor is a contributor to the second. Gaps, voids, and incomplete cavity fills leave spaces in which convective looping can occur.

An omission or degradation in any type of insulation will reduce the insulating performance of the overall assembly.

One of the heat exchange mechanisms that cavity insulations are intended to control is convection. When convective looping is able to occur in or around the insulation, its function is subverted. Also, air moving through insulation because of wind or other pressures can also

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subvert its performance. Therefore, low density fibrous insulations should be covered by air barriers in areas subject to air movement.

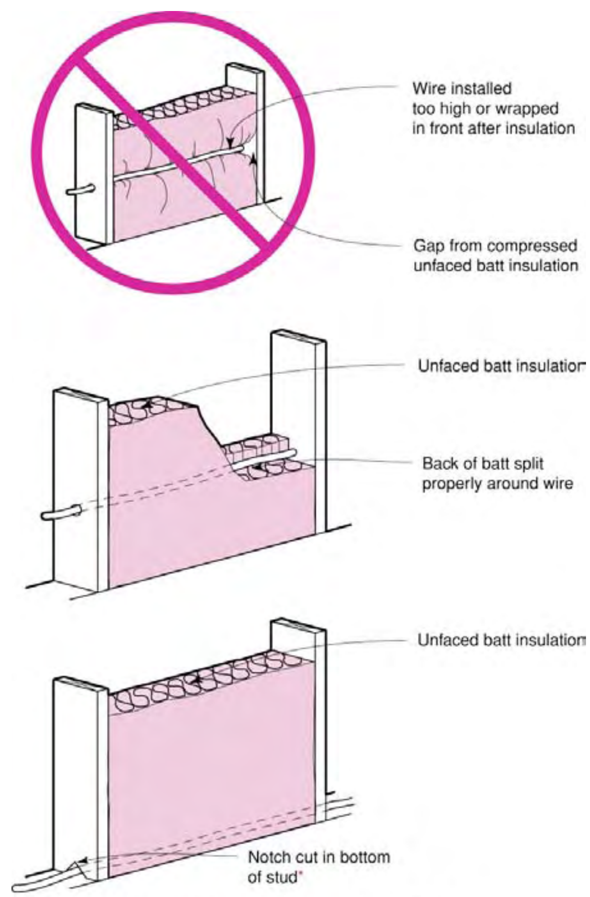
Rolled Batt Insulation:
Batt insulation can be a very cost effective option where the framing cavities are of uniform size and where the width and depth matches that of the rolled batt insulation. With rolled batt insulation care must be taken to cut the insulation to fit snugly in cavities and around all obstructions without compression. When batts are cut too short, too narrow, or too wide around obstruction, gaps and the associated problems result. Also when batts have been cut too big for the cavity or have not been cut to adequately accommodate obstructions there will tend to be compression *and* gaps of incomplete thickness ("rolled shoulders" at framing or wrinkles in the field of the batt). Compressing batt insulation also reduces its thermal resistance (effectively, its R-value). Batts should also be fluffed to full thickness so that they will be in contact with the cavity enclosure on all six sides and not leave gaps for convective looping. Higher density rolled batts are more effective at inhibiting convective looping within the insulation.

Blown-in or Loose-fill Insulation:
Blown-in insulations can be very effective at filling irregularly shaped framing cavities, inaccessible cavities, and completely filling cavities around obstructions. At sufficient densities, blown-in insulations can also inhibit convective air flow. Care must be taken to completely fill cavities without leaving holes or voids. The blown-in insulations must be applied at sufficient density to protect against settling which would also leave holes and voids.

Damp Spray Insulation:
Damp spray insulations can effectively fill open cavities and then be trimmed to be flush with framing. With sufficient adhesive/binder strength, some damp-spray insulations can be used in cavities that will not be enclosed such as attic knee walls and tricky areas such as rim joist areas. At sufficient densities, damp spray insulations can also inhibit convective air flow. Care must be taken to completely fill cavities without leaving holes or voids as the adhesive properties of the insulation can prevent the insulation from "flowing" in behind obstructions.

Damp spray insulations should only be used in wall assemblies that are able to dry toward the interior or exterior. Generally, where the assembly will require a vapor retarder to the interior of the assembly, the insulation should be allowed to dry before application of the vapor retarder.

Installing Batt Insulation in Cavity with Electrical Wiring



Alternate Wiring with Batt Insulation Detail

- Roll batt insulation should not be shoved behind obstructions
- Insulation materials should be slit, cut or notched to fit neatly around obstructions
- Insulation material should be fluffed to full thickness

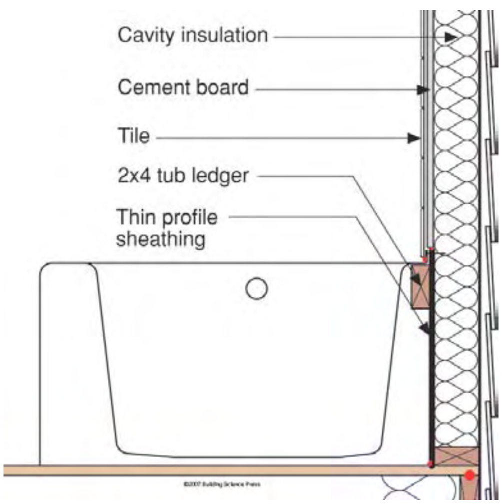
Spray Foam Insulation:
Spray foam insulations can effectively fill framing cavities, irregular spaces, and around obstructions. The adhesion of spray foams (provided substrates are compatible and clean) allow spray foams to be

applied in cavities that will be left open. Spray foam insulations provide excellent air sealing characteristics and can be used to provide air barrier continuity at difficult details such as across rim joist/band joist assemblies. Use of low density foams result in flexible installations, forgiving of movement. Higher density foams are more abuse-resistant but are not as tolerant of movement.

Because of the rapid expansion of spray applied insulation during curing – particularly most low-density spray foams – care must be exercised in insulating behind obstructions or in confined cavities.

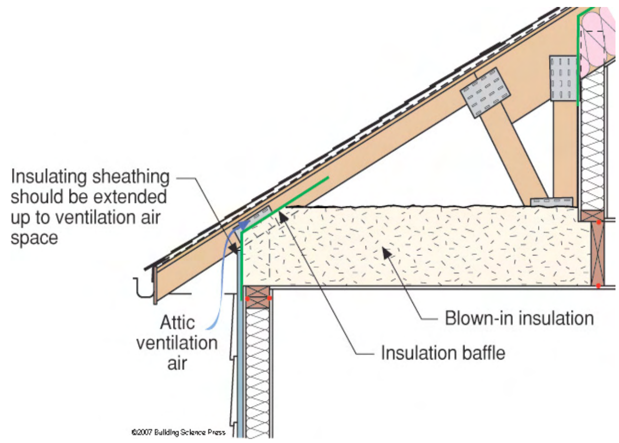
Spray foams must be mixed at the proper chemistry to achieve the intended performance.

Insulation Cavity Enclosure Behind Tub



- Thin profile sheathing protects insulation from convective looping and prevents insulation from slumping out of cavity

Insulated Knee-Wall with Vented Attic



- House wrap or rigid sheathing material on the attic side of the knee-wall insulation protects the insulation from wind washing.

Suggestions for Further Research:

"ENERGY STAR Thermal Bypass Checklist Guide", U.S. Environmental Protection Agency, www.energystar.gov.

"National Home Energy Rating Technical Guidelines", Residential Energy Services Network, 2005 (<Appendix A to 2006 Mortgage Industry National Home Energy Rating System Standards, www.resnet.us.)

Mathis, R. Christopher, *Insulating Guide,* Building Science Press, 2007

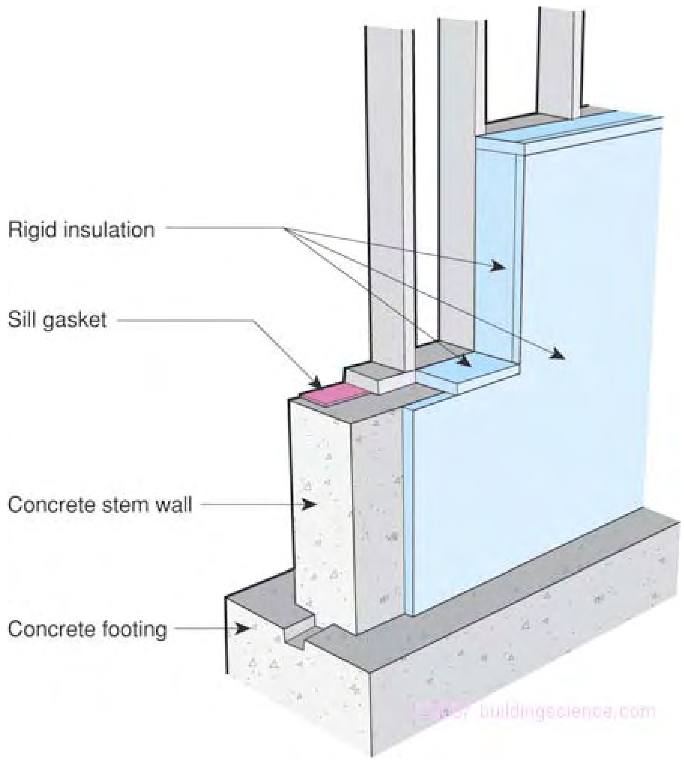
Lstiburek, Joseph W.; *Builder's Guide Series*, Building Science Press, 2006.

BSC Information Sheet 511

Basement Insulation

for All Climates

Rigid Insulation Wraps Concrete Surfaces



- Cold concrete foundation wall must be protected from interior moisture-laden air in summer and winter
- Rim joist assembly must be insulated with air impermeable insulation or insulated on the exterior
- Rigid insulation completely wraps exposed concrete preventing interior air from contacting potential concrete condensing surface
- Seams in rigid insulation and joints to other materials sealed to provide air barrier
- Rigid insulation is vapor semi-impermeable or vapor semi-permeable (foil facing or plastic facing not present)
- Rigid insulation provides bond break between foundation wall and slab when insulation is installed before slab is poured

Basement Insulation

Basements are part of a home, within the building boundary — despite repeated attempts over the years to disconnect them from the living space. Because of this, basements should be designed and constructed to be dry and conditioned. This is particularly important for basements that contain mechanical equipment – a situation that is practically guaranteed in buildings that have a basement. Mechanical systems must not be installed outside of a home in unconditioned space unless there is no practical alternative.

Basements need to be dry for reasons of indoor air quality, pest control, and durability of the building. A dry basement or crawlspace is less likely to have pests and termites. If a basement is being used for storage or as living space, it needs to be kept dry to avoid mold and dust mites.

The most important strategies for keeping basements dry are those of groundwater and rainwater control. Refer to BSC Information Sheet 1, "Groundwater Control" for further guidance. Once these groundwater control strategies are employed, the basement should be insulated to minimize cold surfaces that can condense water and elevate local relative humidity.

Basements should be insulated on their perimeters — they should not be insulated between floors.

Walls

Basement walls should be insulated with non-water sensitive insulation that prevents interior air from contacting cold basement surfaces – the concrete structural elements and the rim joist framing. Allowing interior air (that is usually full of moisture, especially in the humid summer months) to touch cold surfaces will cause condensation and wetting, rather than the desired drying. The structural elements of below grade walls are cold (concrete is in direct contact with the ground)– especially when

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insulated on the interior. Of particular concern are rim joist areas – which are cold not only during the summer but also during the winter. This is why it is important that interior insulation assemblies be constructed as airtight as possible.

The best insulations to use are foam based and should allow the foundation wall assembly to dry inwards. The foam insulation layer should generally be vapor semi impermeable (greater than 0.1 perm), vapor semi permeable (greater than 1.0 perm) or vapor permeable (greater than 10 perm) (Lstiburek, 2004). The greater the permeance the greater the inward drying and therefore the lower the risk of excessive moisture accumulation.

Up to two inches of unfaced extruded polystyrene (R-10), four inches of unfaced expanded polystyrene (R-15), three inches of closed cell medium density spray polyurethane foam (R-18) and ten inches of open cell low density spray foam (R-35) meet these permeability requirements.

In all cases, a capillary break should be installed on the top of the footing between the footing and the perimeter foundation wall to control "rising damp". It is also necessary to install a capillary break between the foundation wall and framing.

In certain situations, foil-faced insulations may be used on the interior of foundation walls. However, such requires careful attention to supplemental moisture management strategies. Consult the *Builder's Guide* listed among the Suggestions for Further Research below for specific guidance.

In most basement wall situations, the foam plastic insulation material will need to be covered by a fire/ignition barrier. _" gypsum board usually provides sufficient ignition barrier (check your local building code). When this ignition barrier is supported on a stud wall, the cavities of this wall may be filled with supplemental insulation. It is important that the airtight foam insulation assembly be continuous behind the framed wall. No interior vapor barriers should be installed in order to permit inward drying.

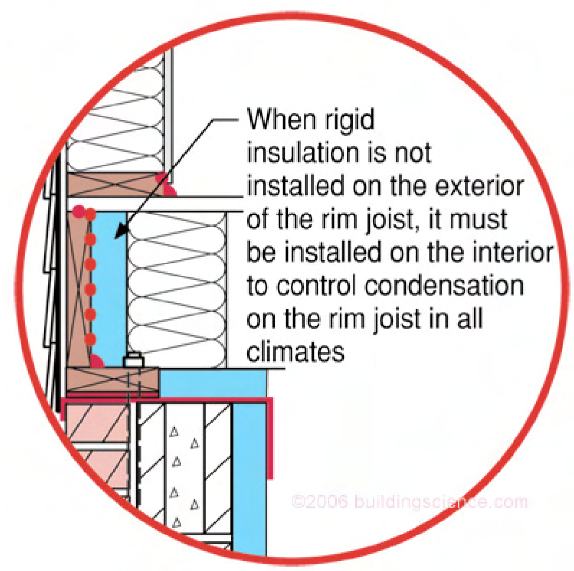
Floors

Basement floor slabs are best insulated underneath with rigid insulation: both extruded or expanded polystyrene have been widely used with success. Although the energy savings of sub-slab insulation are not as significant as basement wall insulation, such insulations do offer a significant improvement in comfort and moisture damage resistance (including against summertime condensation).

When slab insulation is provided, a sheet polyethylene vapor barrier should be located over the rigid insulation and in direct contact with the concrete slab. As the slab will only be able to dry upward, the slab should be allowed to dry before finishes are applied. Impermeable interior floor finishes such as vinyl floor coverings should also be avoided.

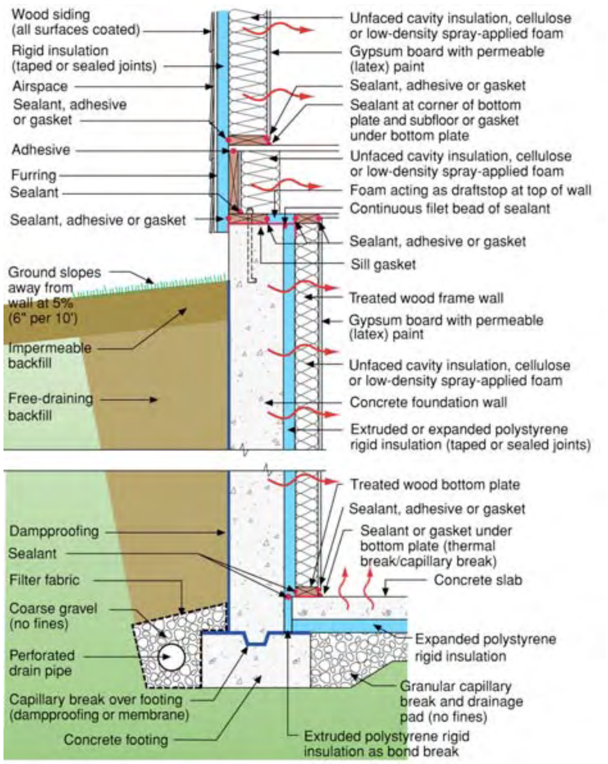
A sand layer should never be installed between the sheet polyethylene vapor barrier and the concrete slab. Sand layers located between the slab and the vapor barrier can become saturated with water, which are then unable to dry downwards through the vapor barrier. In this scenario, drying can only occur upward through the slab which typically results in damaged interior floor finishes (Lstiburek, 2002).

Interior Rim Joist Insulation



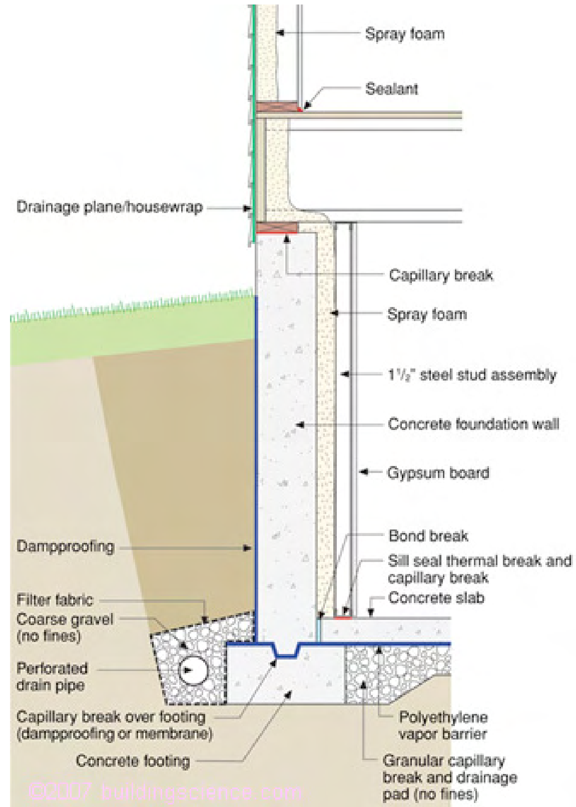
- Air barrier needed to protect the rim joist from interior moisture-laden air in summer and winter
- Seams in rigid insulation and joints to other materials sealed to provide air barrier

Rigid Insulation with Supplemental Insulated Frame Wall Assembly



- Rigid foam insulation board assembly must provide continuous air barrier and capillary break around concrete foundation
- Rigid insulation assembly must be continuous behind wood frame wall
- Rigid insulation is vapor semi-impermeable or vapor semi-permeable (foil facing or plastic facing not present)
- Wood frame wall cavity to be insulated with unfaced fiberglass or damp spray cellulose
- No interior vapor barrier installed
-

Interior Spray Foam Encapsulates Concrete Surfaces



- Least risky interior wall insulation approach
- Cold concrete foundation wall must be protected from interior moisture-laden air in summer and winter
- Rim joist assembly must be insulated with air impermeable insulation
- Interior air cannot access concrete condensing surface or rim joist condensing surface due to spray foam layer
- Spray foam insulation layer is vapor semi-permeable permitting inward drying
- Spray foam must be covered with fire/ignition barrier

Suggestions for Further Research:

"Understanding Basements," Building Science Digest-103, www.buildingscience.com.

"READ THIS: Before You Design, Build, or Renovate," Building Science Primer-040, www.buildingscience.com.

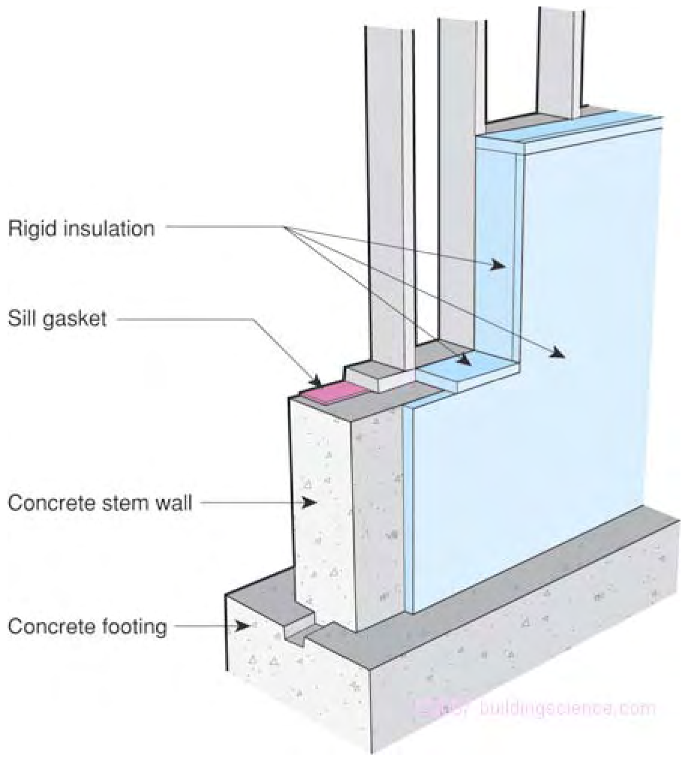
Lstiburek, Joseph W.; *Builder's Guide Series*, Building Science Press, 2006.

Lstiburek, Joseph W.; "Investigating and Diagnosing Moisture Problems," ASHRAE Journal, December 2002.

Lstiburek, Joseph W.; "Understanding Vapor Barriers," ASHRAE Journal, August 2004.

BSC Information Sheet 512
Crawlspace Insulation
for All Climates

Rigid Insulation Wraps Concrete Surfaces



- Cold concrete foundation wall must be protected from interior moisture-laden air in summer and winter
- Rim joist assembly must be insulated with air impermeable insulation or insulated on the exterior
- Rigid insulation completely wraps exposed concrete preventing interior air from contacting potential concrete condensing surface
- Seams in rigid insulation and joints to other materials sealed to provide air barrier
- Rigid insulation is vapor semi-impermeable or vapor semi-permeable (foil facing or plastic facing not present)
- Rigid insulation provides bond break between foundation wall and slab when insulation is installed before slab is poured

Crawlspace Insulation

Crawlspaces should be designed and constructed as mini-basements. Crawlspaces are connected to the living space and therefore must be be dry, conditioned, and pest free. This is particularly important for crawlspaces that contain mechanical equipment – a situation that is practically guaranteed in buildings that have a crawlspace. Mechanical systems must not be installed outside of a home in unconditioned space unless there is no practical alternative. Crawlspaces need to be dry for reasons of indoor air quality, pest control and durability of the building. The crawlspace is conditioned so that the mechanical system can control the temperature and relative humidity of the air in the crawlspace. The crawlspace is insulated to control heat flow and to minimize cold surfaces that can condense water and elevate local relative humidity.

If it is not possible to treat the crawlspace as a part of the house such as in flood zones in costal areas or in dry climates where it is not necessary, it is important to construct the house such that the crawlspace is isolated from the house — outside of the building boundary. These situations should follow recommendations for homes built on piers.

Crawlspaces should not be used for storage. Builders and contractors should use designs that discourage the use of crawlspaces for storage, and provide clear guidance to owners and occupants to avoid using this area for storage.

Crawlspaces should not be vented to the exterior (see FAQ on Crawlspace Venting). They should have a continuous sealed groundcover such as taped polyethylene or a poured concrete slab with perimeter and control joints sealed. They should have perimeter drainage just like a basement (when the crawlspace ground level is below the ground level of the surrounding grade). There must be good drainage away from crawlspaces (refer to BSC Information Sheet 1, "Groundwater Control"). Crawlspace design and construction

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should also provide drainage for potential plumbing leaks or flooding incidents.

Crawlspaces should be insulated on their perimeters — they should not be insulated between floors. Crawlspaces insulated on the perimeter are warmer and drier than crawlspaces insulated between the crawlspace and the house.

Crawlspace walls should be insulated with non-water sensitive insulation that prevents interior air from contacting cold basement surfaces – the concrete structural elements and the rim joist framing. Allowing interior air (that is usually full of moisture, especially in the humid summer months) to touch cold surfaces will cause condensation and wetting, rather than the desired drying. The structural elements of below grade walls are cold (concrete is in direct contact with the ground)– especially when insulated on the interior. Of particular concern are rim joist areas – which are cold not only during the summer but also during the winter. This is why it is important that interior insulation assemblies be constructed as airtight as possible.

The best insulations to use are foam based and should allow the foundation wall assembly to dry inwards. The foam insulation layer should generally be vapor semi impermeable (greater than 0.1 perm), vapor semi permeable (greater than 1.0 perm) or vapor permeable (greater than 10 perm) (Lstiburek, 2004). The greater the permeance the greater the inward drying and therefore the lower the risk of excessive moisture accumulation.

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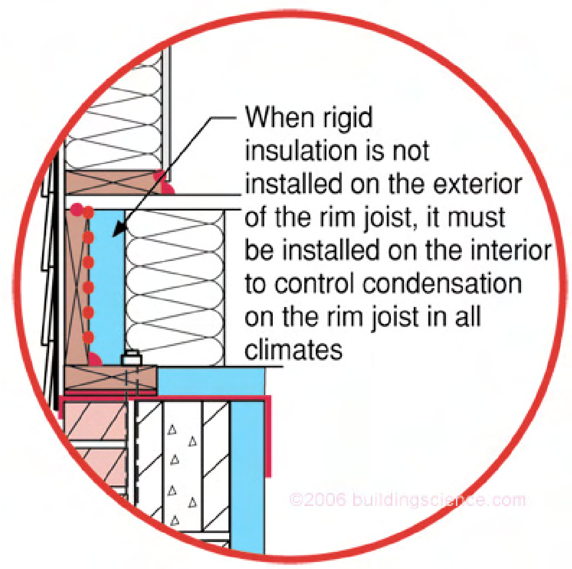
In all cases, a capillary break should be installed on the top of the footing between the footing and the perimeter foundation wall to control "rising damp". It is also necessary to install a capillary break between the foundation wall and framing.

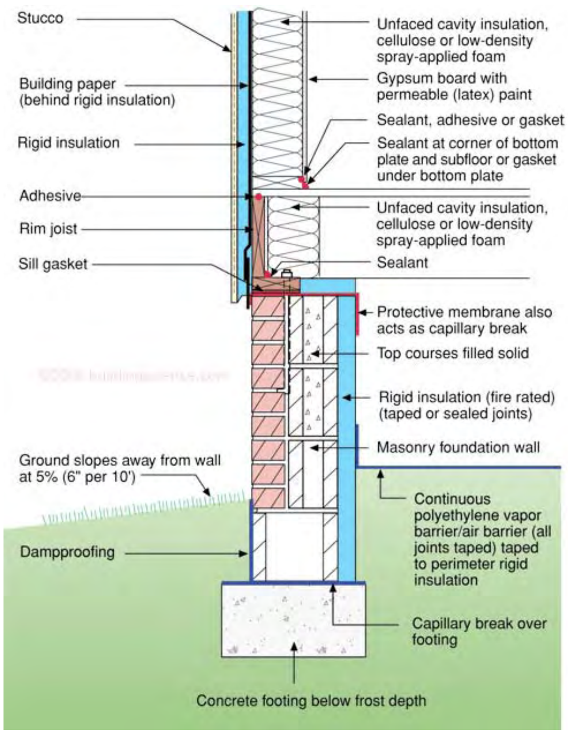
Interior Rim Joist Insulation



- Air barrier needed to protect the rim joist from interior moisture-laden air in summer and winter
- Seams in rigid insulation and joints to other materials sealed to provide air barrier

In crawlspaces where the insulation material will need to be covered by a fire/ignition barrier, it may be acceptable to use fire-rated foil-faced insulations. However, such requires careful attention to supplemental moisture management strategies. With vapor impermeable facings on interior insulation, it is possible that water may accumulate between the insulation facing and the inside surface of the foundation wall. The airtightness of the assembly is, therefore, extremely important to prevent the exchange of air between this damp interface and anywhere else in the building. Consult the resources listed below for specific guidance.

Rigid Insulation with Supplemental Insulated Frame Wall Assembly



- Rigid foam insulation board assembly must provide continuous air barrier and capillary break around concrete foundation
- Rigid insulation is vapor semi-impermeable or vapor semi-permeable (foil facing or plastic facing not present)
- Protective membrane adhered to top of foundation wall and wrapped over top of insulation
- Insulation material non-moisture sensitive and not subject to degradation with ground contact

Suggestions for Further Research:

"Understanding Basements", Building Science Digest-103, www.buildingscience.com.

"READ THIS: Before You Design, Build, or Renovate," Building Science Primer-040, www.buildingscience.com.

Lstiburek, Joseph W.; *Builder's Guide Series*, Building Science Press, 2006.

Lstiburek, Joseph W.; "Understanding Vapor Barriers," *ASHRAE Journal*, August 2004.

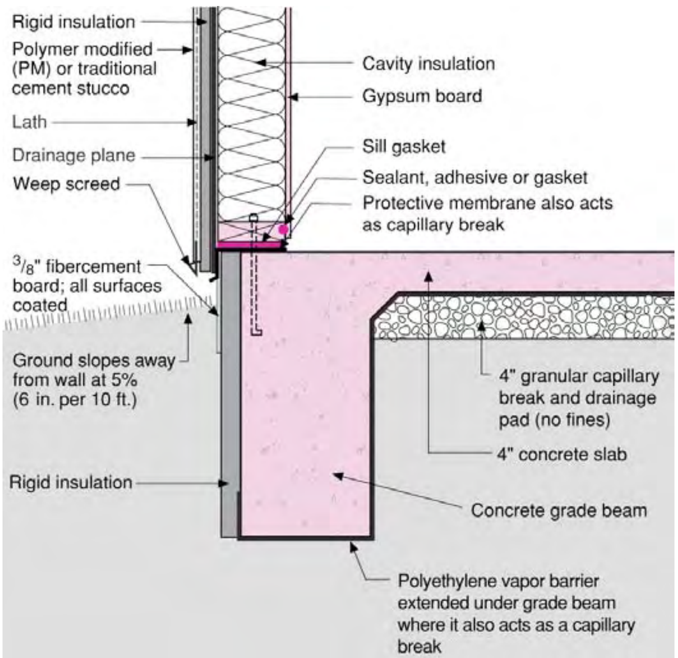
Lstiburek, Joseph W.; "New Light in Crawlspaces," *ASHRAE Journal*, May 2008.

BSC Information Sheet 513

Slab Edge Insulation

for All Climates

Perimeter Insulation of Monolithic Slab-Grade Beam



- Insulation extends to bottom of grade beam
- Protection board over above grade portion of rigid insulation
- Protection board of non-water sensitive material and coated to control absorption of water
- Protective membrane adhered to slab and wrapped over top of insulation
- Insulation material non-moisture sensitive and not subject to degradation with ground contact

Slab Edge Insulation

For slab on grade construction, the slab edge represents a significant heat loss potential. This is important not only to the energy performance of a building but moisture management of the building as well. In climates where the average monthly temperature for the coldest month of the year goes below 45°F, the temperature of the slab perimeter may be below the dew point of interior air for a significant period of time.

Even when condensation conditions are not present on the slab surface, relatively cool temperatures near an uninsulated slab edge will tend to elevate the local relative humidity. As relative humidity rises above acceptable human control conditions (30-60% RH), so too do the risks associated with mold and mildew, fungal growth, dust mites and other pests. This is a particular concern for carpeted slabs as these tend to also provide media and cover for "biologicals."

Adding insulation outside of the slab edge will allow the inside surface temperature of the slab perimeter to more closely track interior conditions thereby reducing the potential for condensation and elevated relative humidity. The strategies available for insulating the slab edge depend upon whether the slab on grade is 1) monolithic with a grade beam, or 2) supported on grade and independent of the foundation wall.

When the slab is monolithic with a grade beam, the insulation must be installed to the exterior of the slab edge/grade beam and continue vertically to the bottom of the grade beam as shown in the example to the right. The insulation material must be appropriate for ground contact. XPS, rigid fiberglass and rock wool are examples of acceptable materials. The exterior insulation will need to be protected from impact damage during construction and, subsequently, the above grade portion must be protected from UV and impact damage on the above grade portion.

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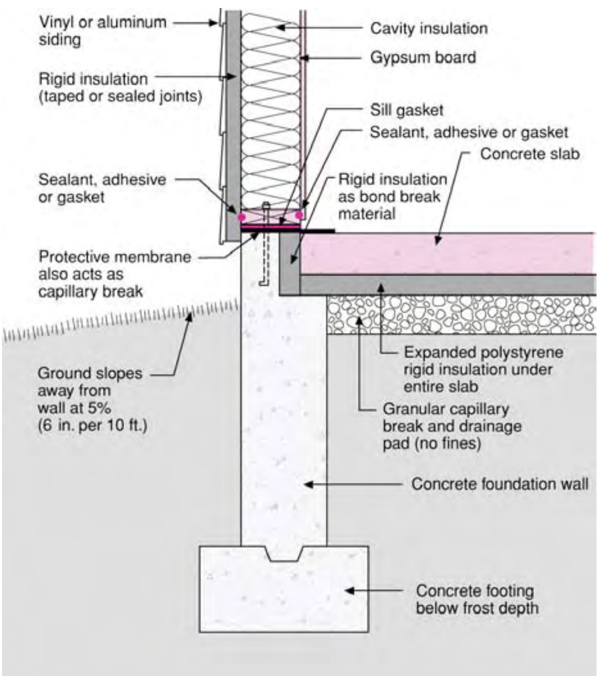
When the slab is independent from a perimeter foundation wall, insulation may be installed either on the exterior of the foundation wall or between the foundation wall and the slab. In order for the slab to be independent of the foundation wall, a bond break is needed between the slab, which is supported on grade, and the foundation wall that supports the exterior wall structure and its loads. Insulation at the vertical slab edge and under the slab perimeter provides this bond break. The diagram to the right shows and example of a slab on grade that is structurally and thermally isolated from the perimeter foundation wall. Limiting factors on the width of the slab edge insulation in this situation are determined by attachment of floor finishes and width of foundation wall needed to support the wall structure.

Whenever insulation is used in contact with ground or near ground, appropriate insect control measures must be used. Appropriate measures will vary by location.

Slab on Grade Independent of Perimeter Foundation Wall



- Slab is insulated vertically at the edge and horizontally at the perimeter or under the entire slab
- Rigid insulation provides bond break between slab and foundation wall
- Protective membrane adhered to both slab and top of foundation wall

Suggestions for Further Research:

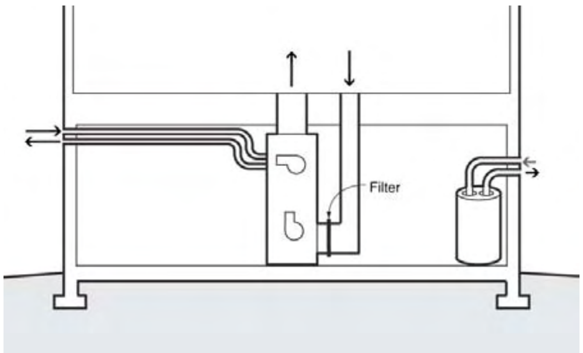
"Understanding Basements," Building Science Digest-103, www.buildingscience.com.

"READ THIS: Before You Design, Build, or Renovate," Building Science Primer-040, www.buildingscience.com.

Lstiburek, Joseph W.; *Builder's Guide Series*, Building Science Press, 2006.

Sealed Combustion

for All Climates



- Water heater combustion air supplied directly to water heater from exterior via duct; products of combustion exhausted directly to exterior also via duct
- Furnace flue gases exhausted to the exterior using a fan; combustion air supplied directly to furnace from exterior via duct

Sealed Combustion

In order to ensure good indoor air quality, all combustion appliances are recommended to be sealed combustion units, as opposed to naturally aspirated units. These systems are completely decoupled from the interior environment through the use of dedicated outdoor air intake and exhaust ducts connected directly to the unit. This change completely disconnects the combustion process from the interior environment, and eliminates concerns of back-drafting of the unit. In addition, it allows the elimination of the usual make-up air ducts. These make-up air ducts (required for naturally aspirated units) are a source of uncontrolled air leakage through the building enclosure, and therefore increase energy use. Finally, the sealed combustion appliances tend to be more efficient than the naturally aspirated units.

Spillage or backdrafting of combustion appliances is unacceptable. Only sealed combustion, direct vented, power vented or induced draft combustion appliances should be installed inside conditioned spaces for space conditioning or for domestic hot water. Traditional gas water heaters with draft hoods are prone to spillage and backdrafting. They should be avoided. Gas ovens, gas stoves or gas cooktops should only be installed with an exhaust range hood directly vented to the exterior. Wood-burning fireplaces or gas-burning fireplaces should be supplied with glass doors and exterior combustion air ducted to the firebox. Wood stoves should have a direct ducted supply of combustion air. Unvented (ventless) gas fireplaces or gas space heaters should never be installed. Sealed combustion direct vent gas fireplaces are an acceptable alternative. Portable kerosene heaters should never be used indoors.

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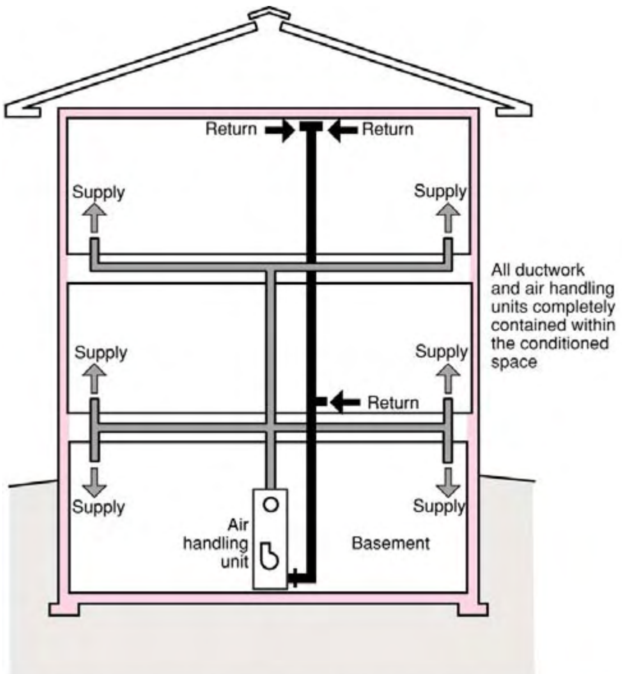
BSC Information Sheet 602

Ducts in Conditioned Space

for All Climates

Vented and Unconditioned Attic



Note: Colored shading depicts the building's thermal barrier and pressure boundary. The thermal barrier and pressure boundary enclose the conditioned space.

- The air handling unit is located in a conditioned basement
- Low efficiency gas appliances that are prone to spillage or backdrafting are not recommended in this type of application; heat pumps, heat pump water heaters or sealed combustion furnaces and water heaters should be used
- A hot water-to-air coil in an air handling unit can be used to replace the gas furnace/heat exchanger. The coil can be connected to a sealed combustion (or power vented) water heater located within the conditioned space.
- Ductwork is not located in exterior walls or in the vented attic

Ducts in Conditioned Space

The location of the duct system can have a significant impact on the overall performance of the system–both the utility use and the ability to provide comfort. The energy loss from the ducts for forced air heating and cooling systems can be significant, depending on the location of the ducts, and how well the ducts are sealed against air leakage. Though it is conceptually easy to imagine sealed duct systems, tight duct systems are unfortunately all too rare - duct leakage values of 20% of system flow are common. In many houses, the distribution duct work is located either in a vented crawlspace or in a vented attic – effectively outdoors. With the ducts located outside of the thermal envelope of the home, any leakage and conductive losses from the duct work is lost directly to the outside. Even worse, whenever air is leaking out or the ducts due to the system running, air is coming into the house to replace the lost air—resulting in forced air leakage whenever your furnace or air conditioner runs.

Moving the duct work and air handlers inside the thermal enclosure can be used to help prevent this energy loss to the exterior. Alternately, the thermal enclosure can be extended to include areas such as crawlspaces and attic as part of the conditioned space of the house.

In general, the placement of the mechanical equipment will depend on the design of the house. For houses with conditioned crawlspaces and basements, it is often logical to place the air handler or furnace in those locations. For slab on grade designs or elevated floors, available space can become a limitation. In these cases, unvented conditioned and semi-conditioned attics provide for a convenient location for the mechanical equipment and ducts. Otherwise, the equipment and / or ducts can be located in a dropped ceiling or in closets.

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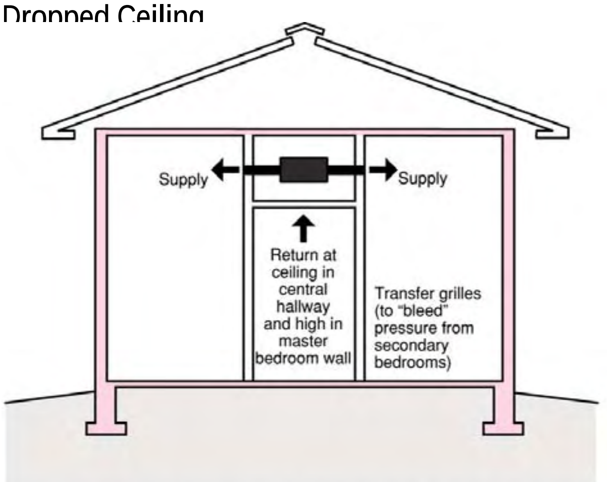
Consideration for space requirements for the mechanical equipment should be made early in the design.

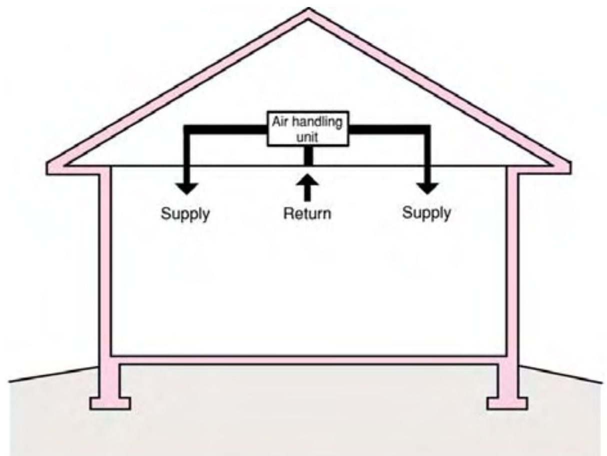
Vented and Unconditioned Attic with a Dropped Ceiling



Note: Colored shading depicts the building's thermal barrier and pressure boundary. The thermal barrier and pressure boundary enclose the conditioned space.

- In this approach, exterior wall heights are typically increased to 9-feet or more leaving hallway ceiling heights at 8-feet
- The air handling unit is located in an interior closet and the supply and return ductwork are located in a dropped hallway
- Transfer grilles "bleed" pressure from secondary bedrooms
- Ductwork does not have to extend to building perimeters when thermally efficient windows (low-E, spectrally selective) and thermally efficient (well-insulated 2x6 frome walls with 2" of insulating sheathing) building enclosure construction is used; throw-type registers should be selected
- Low efficiency gas appliances that are prone to spillage or backdrafting are not recommended in this type of application; heat pumps, heat pump water heaters or sealed combustion furnaces and water heaters should be used
- A hot water-to-air coil in an air handling unit can be used to replace the gas furnace/heat exchanger. The coil can be connected to a sealed combustion (or pwer vented) water heater located within the conditioned space.
- Ductwork is not located in exterior walls or in the vented attic

Vented and Conditioned Attic



Note: Colored shading depicts the building's thermal barrier and pressure boundary. The thermal barrier and pressure boundary enclose the conditioned space.

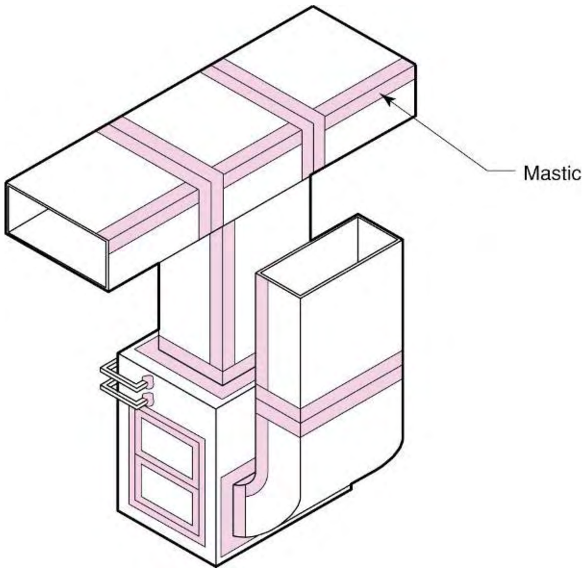
- The air handling unit is located in an unvented, conditioned attic; the attic insulation is located at or above the roof deck
- Low efficiency appliances that are prone to spillage or backdrafting are not recommended in this type of application; heat pumps, heat pump water heaters or sealed combustion furnaces and water heaters should be used
- A hot water-to-air in an air handling unit can be used to replace the gas furnace/heat exchanger. The coil can be connected to a sealed combustion (or power vented) water heater located within the conditioned space
- Ductwork is not located in exterior walls

BSC Information Sheet 603

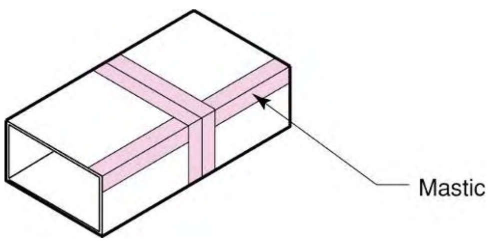
Duct Sealing

for All Climates

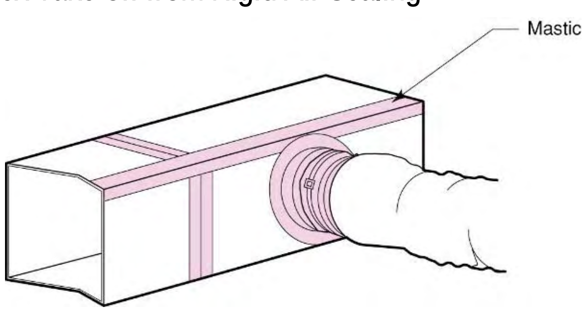
Air Handler Air Sealing



Rigid Duct Air Sealing



Flex Take-off from Rigid Air Sealing



Duct Sealing

Ductwork, furnaces and air handlers should be sealed against air leakage. The only place air should be able to leave the supply duct system and the furnace or air handling unit is at the supply registers. The only place air should be able to enter the return duct system and the furnace or air handling unit is at the return grilles. A forced air system should be able to be pressure tested the way a plumber pressure tests a plumbing system for leaks. Builders don't accept leaky plumbing systems, so they should not accept leaky duct systems.

Supply systems should be sealed with mastic in order to be airtight. All openings (except supply registers), penetrations, holes and cracks should be sealed with mastic or fiberglass mesh and mastic. Fabric/rubber duct tape (common duck tape developed for temporary repair of cotton duck tarps and raingear has thousands of uses. Sealing ducts is not one of them) should not be used: after hot and cold cycling, the adhesive dries out and fails. Tapes meeting UL 181A or 181B may provide reasonable performance. These must be applied only to clean, dry, and dust-free surfaces. Sealing of the supply system includes sealing the supply plenum, its attachment to the air handler or furnace, and the air handler or furnace itself. Joints, seams and openings on the air handler, furnace or ductwork near the air handler or furnace should be sealed with both fiberglass mesh and mastic due to greater local vibration and flexure.

Return systems should be "hard" ducted and sealed with mastic in order to be airtight. Building cavities should never be used as return ducts. Stud bays or cavities should not be used for returns. Panned floor joists should not be used. Panning floor joists and using stud cavities as returns leads to leaky returns and the creation of negative pressure fields within interstitial spaces. Carpet dustmarking at baseboards, odor problems, mold problems and pollutant transport problems typically occur when building cavities are used as return ducts.

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The longitudinal seams and transverse joints in sheet metal ducts should be sealed. The inner liner of insulated plastic flex duct should be sealed where flex ducts are connected to other ducts, plenums, junction boxes and boots/registers.

The recommended procedure to connect insulated flex duct to a metal collar is as follows:

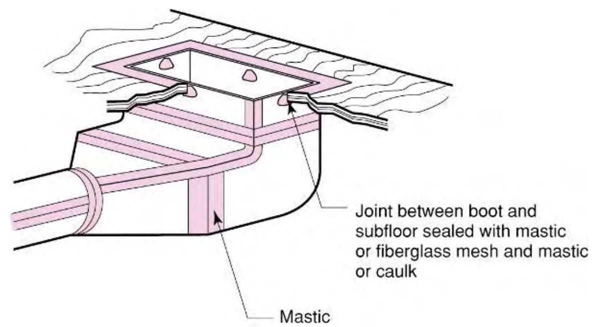
1. brush a thick coat of mastic around the collar;
2. slide the inner liner over the collar;
3. tie wrap the collar with a tensioning tool (not just by hand);
4. pull the outside liner over the boot;
5. tape the outside liner to the boot with appropriate tape;
6. brush mastic over the tape bridging from the outside liner vapor barrier to the vapor barrier of the boot.

When flex ducts are used, care must be taken to prevent air flow restriction such as those resulting from "pinching" ducts or from kinks caused by bending them at a tight radius.

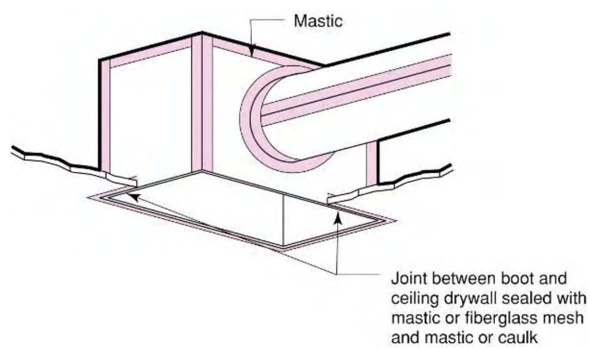
Connections between grilles, registers and ducts at ceilings, floors or knee walls typically leak where the boot does not seal tightly to the grille or gypsum board. Air from the attic, basement, or crawlspace can leak in or out where the ducts connect to the boot.

If the gap between boots and gypsum board opening or subfloor openings is kept to less than 3/8-inch, a bead of sealant or mastic may be used to seal the gap. Where gaps are larger than 3/8-inch, fabric and mastic should both be used. The optimum approach is to keep the gaps to less than 3/8-inch and use a bead of sealant. This requires careful coordination with the drywall contractor to make sure that the rough openings for the boots are cut no more than 3/8-inch bigger than the actual boot size on all sides.

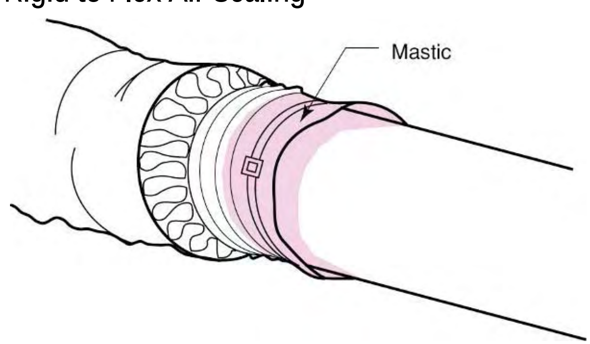
Floor Boot Air Sealing



Ceiling Boot Air Sealing



Rigid to Flex Air Sealing



Retrofit Sealing of Air Handler and Plenum

Metal duct system with mastic joints

Suggestions for Further Research:

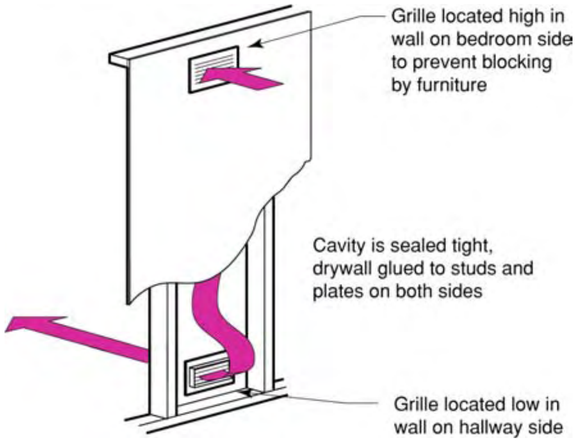
Frequently Asked Questions. RCD Corporation, www.rcdmastics.com/faq.asp

BSC Information Sheet 604

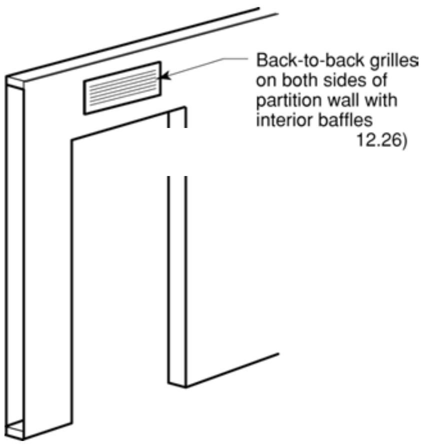
Transfer Ducts and Grilles

for All Climates

Transfer Grille

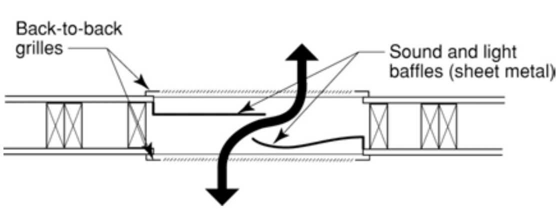


Transfer Grille—Over Door Opening



- Relieves pressure differences between spaces
- Interior baffles control sound and light transfer
- Door undercut of 1” minimum still required

Transfer Grille—Section



Transfer Ducts and Grilles

The ductwork systems in these houses are designed to supply air to the individual rooms, and to have the air return to a central return grille. The Manual J (i.e. heating and cooling load) calculations typically yield the airflow requirements to the various rooms to meet those design loads. These airflow volumes are then used to size and lay out the ducts.

With any distribution system, there must be a return path for the energy distributing fluid. In the case of an air-based duct system, there is a central return that is open to the primary living space, with transfer means from bedrooms to the main space. The return path from the bedrooms needs to allow sufficient return flow to prevent room pressurization and prevent supply flow from being “choked” off. While undercutting doors can create part of the return air path, wall transfer grilles or jump ducts should be installed to prevent the return problems stated above.

All supply registers should have clear access to a return grille in order to prevent the pressurization of bedrooms and the depressurization of common areas. Bedrooms should either have a direct-ducted return or a transfer grille. Undercutting of bedroom doors rarely works and should not be relied upon to relieve bedroom pressurization. A central “hard” ducted return that is airtight and coupled with transfer grilles to relieve bedroom pressurization significantly outperforms a traditional return system, which has leaky ducted returns in every room, stud bays used as return ducts, and panned floor joists.

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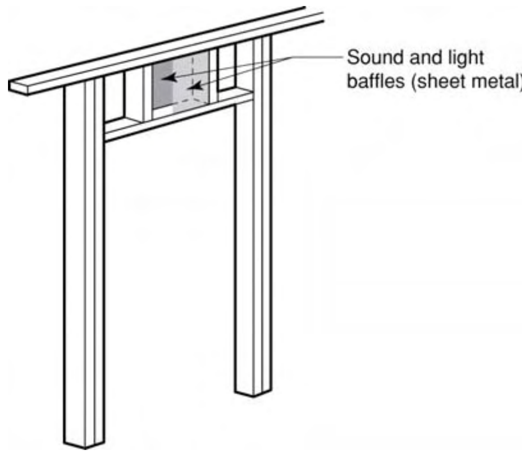
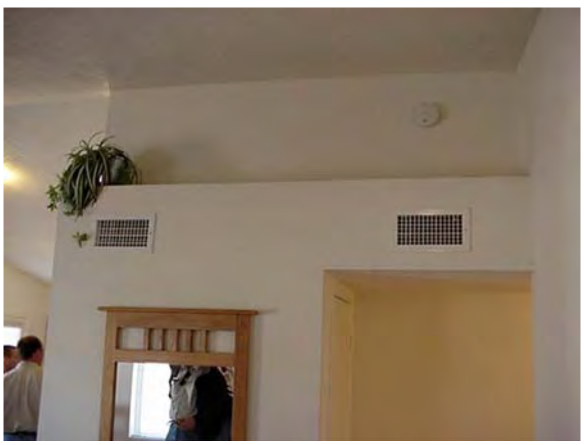
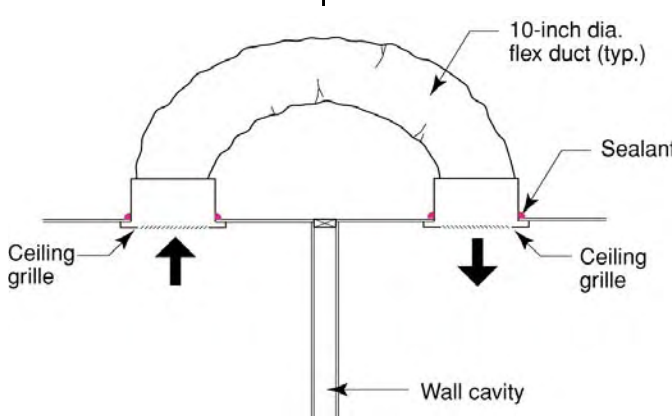
Transfer Grille—Construction





Jump Ducts



BSC Information Sheet 606

Placement of Intake and Exhaust Vents

for All Climates

Outdoor Air Intake Grille Location

- Intake located 2 feet above grade.
- Area around intake location is free of vegetation.

Placement of Intake and Exhaust Vents

Ventilation system intakes must be sufficiently separated away from potential contaminant sources, and locations of dust and debris. Mechanical sealed combustion equipment intake should also be located away from likely sources of dust and debris. Both intakes and exhaust vents must not be located where they can be obstructed by drifting snow. Measures must also be taken to reduce the risk of pest entry or obstruction caused by plants or animals. Location of exhaust vents, particularly for combustion equipment exhausts must consider whether air currents at the location will be sufficient to convey moisture and other contaminants safely away from the building and its occupants.

Ventilation System Intake

A supply-only or balanced ventilation system offers control over the source of dilution ventilation air. This is a considerable advantage *if* the outdoor intakes are located where they will not likely entrain contaminants, dust, debris, odours or other substances that would degrade indoor air quality. The following rules are offered to govern location of outdoor air intakes.

- Intake must draw through an intake grill or register located on an outside wall or soffit and not the roof.
- Wall intakes must be located at least 10 feet from any appliance vent or any vent opening from a plumbing drainage system. Wall intakes must also be 10 feet from any exhaust fan discharge outlet unless that outlet is 3 feet or more *above* the intake location. (IRC 2006, Section M1602.2)
- Intakes should not be located directly above any wall exhaust or vent.
- Intakes must be protected against rain and pest entry with durable rust- and rodent-proof materials.

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- Intakes must not be located within 10 feet above any paved surface or roof.
- Intakes must not be located in proximity to an area where vehicles or motorized equipment is likely to idle for any length of time.
- Intakes must not be located where they might be obstructed by drifting snow (consult local experience as to the height of snow drifts against buildings)
- Intakes must not be located within a zone of significant ground-level dust and debris generation (e.g. mowing, leaf blower use). At a minimum, intakes should be 2 feet above grade.
- Intakes must not be allowed to be obscured or hidden by vegetation. Vegetation must not be allowed to grow within 3 feet of a ventilation system intake.

Sealed Combustion Equipment Intake
Safe operation of sealed combustion equipment requires that combustion air intakes remain clear. For the durability of this equipment, it is also important to minimize the possibility for dust and debris to be drawn into the equipment. The following rules are offered to govern location of sealed combustion air intakes.

- Intakes must be protected against rain and pest entry with durable rust and rodent-proof materials.
- Intakes must not be located where they might be obstructed by drifting snow (consult local experience as to the height of snow drifts against buildings)
- Intakes must not be located within a zone of significant ground-level dust and debris generation (e.g. mowing, leaf blower use). At a minimum, intakes should be 3 feet above grade.
- Intakes must not be allowed to be obscured or hidden by vegetation. Vegetation must not be allowed to grow within 3 feet of a combustion intake.

Exhaust Vent Locations
Combustion exhaust and appliance exhaust are likely to contain elevated levels of moisture and other airborne contaminants. While building codes and manufacturer instructions establish minimum standards of care, builders and designers must also be aware of other building features that could prevent effective dissipation of exhausted contaminants. The following guidelines are offered to reduce the risk to occupant health and building durability from combustion exhaust and appliance exhaust:

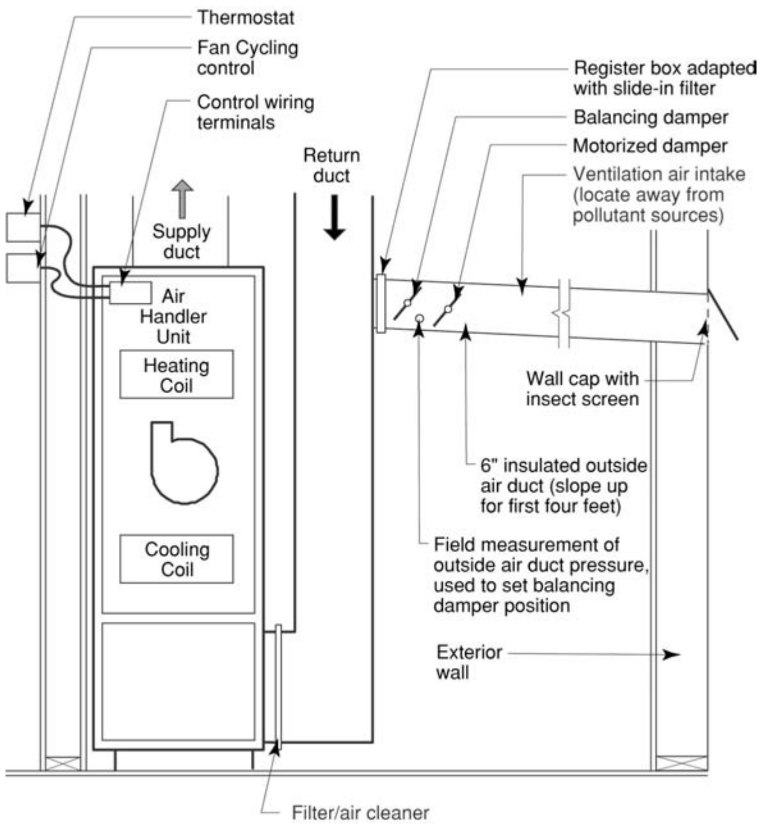
- Exhaust vents must not be located where they might be obstructed by drifting snow (consult local experience as to the height of snow drifts against buildings). In all areas, exhaust vents should be at least 1 foot above grade.
- Exhaust vents must be protected against rain and equipped with back flow prevention features (e.g., flap dampers).
- Exhaust vents must not be allowed to be obscured or hidden by vegetation. Vegetation must not be allowed to grow within 3 feet of an exhaust vent.

- Combustion vents must be located at least 3' above any building opening within 10 feet.
- Non-combustion appliance vents should be located 3 feet from any building opening.
- Avoid locating exhaust vents within 10 feet above outdoor living areas (e.g. deck, patio, play yard)
- Avoid locating exhaust vents beneath canopies, overhangs or within recessed openings.
- Avoid locating exhaust vents in enclosed courtyards.
- Avoid locating exhaust vents on relatively wind sheltered walls facing predominant heating-season wind direction.
- Do not locate exhaust vents under decks, porches, stoops or similar areas.

Suggestions for Further Research:

"READ THIS: Before You Design, Build, or Renovate," Building Science Primer-040, www.buildingscience.com.
Lstiburek, Joseph W.; *Builder's Guide Series*, Building Science Press, 2006.

BSC Information Sheet 610
Ventilation System
for All Climates



- Outside air duct should be insulated and positioned so that there is a fall/slope toward the outside to control any potential interior condensation. Avoid using long lengths of flex duct, which may have a dip and could create a reservoir for condensation
- Motorized damper allows control of ventilation air duty cycle (i.e., run time) separate from air handler duty cycle
- Controller can be mounted on the air handler, or in the main space near the thermostat
- Balancing damper adjusted to provide required flow
- Mixed return air temperatures (return air plus outside air) should not be allowed to drop below 50° Fahrenheit at the design temperature in order to control condensation of combustion gases on heat exchanger surfaces

Ventilation System
All buildings require controlled mechanical ventilation, or the controlled, purposeful introduction of outdoor air to the conditioned space. Building intentionally leaky buildings and installing operable windows does not provide sufficient outside air in a consistent manner. Building enclosures must be “built tight and then ventilated right.” Why? Because before you can control air you must enclose it. Once you eliminate big holes it becomes easy to control air exchange between the inside and the outside.

With a tight building enclosure, both mechanical ventilation and pollutant source control are required to ensure that there is reasonable indoor air quality inside the house. These approaches are shown schematically in figure Integrated Supply Ventilation System.

An example of a ventilation system design includes a central fan integrated system, which is made up of a 6-inch outdoor air intake duct connected to the return side of the air handler. This duct draws outdoor air in to the air distribution system and distributes it to the various rooms in the house. The intake duct has a motorized damper controlled by a fan cycling control to close the damper to prevent over ventilation of the house during times of significant space conditioning demands. An example of the central fan ventilation system with 6-inch motorized damper is shown in figure *Outdoor Air Duct Connected to the Return of the Air Handler.*

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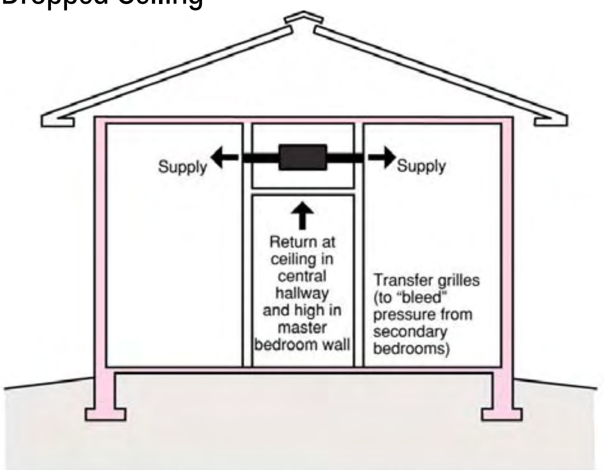
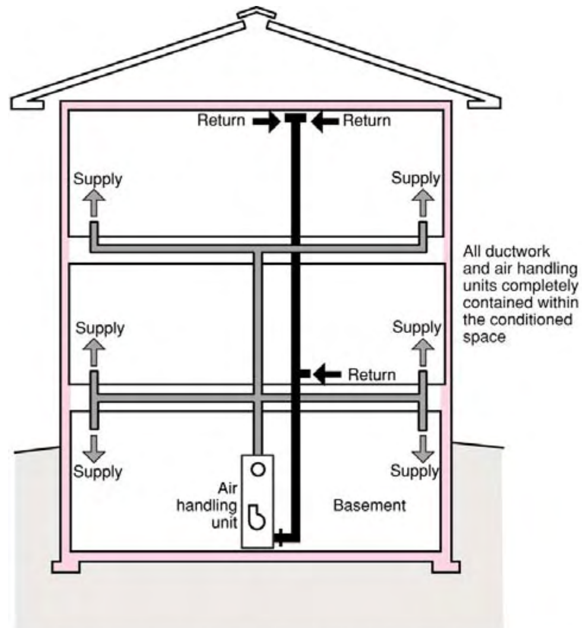
Vented and Unconditioned Attic with a Dropped Ceiling



Note: Colored shading depicts the building's thermal barrier and pressure boundary. The thermal barrier and pressure boundary enclose the conditioned space.

- In this approach, exterior wall heights are typically increased to 9-feet or more leaving hallway ceiling heights at 8-feet
- The air handling unit is located in an interior closet and the supply and return ductwork are located in a dropped hallway
- Transfer grilles "bleed" pressure from secondary bedrooms
- Ductwork does not have to extend to building perimeters when thermally efficient windows (low-E, spectrally selective) and thermally efficient (well-insulated 2x6 frome walls with 2" of insulating sheathing) building enclosure construction is used; throw-type registers should be selected
- Low efficiency gas appliances that are prone to spillage or backdrafting are not recommended in this type of application; heat pumps, heat pump water heaters or sealed combustion furnaces and water heaters should be used
- A hot water-to-air coil in an air handling unit can be used to replace the gas furnace/heat exchanger. The coil can be connected to a sealed combustion (or power vented) water heater located within the conditioned space.
- Ductwork is not located in exterior walls or in the vented attic

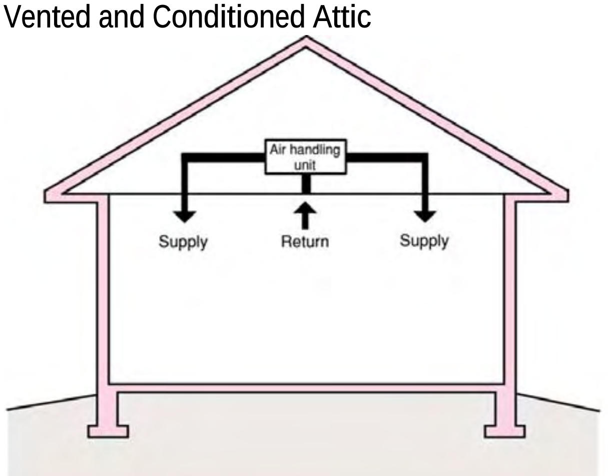
Vented and Unconditioned Attic



Note: Colored shading depicts the building's thermal barrier and pressure boundary. The thermal barrier and pressure boundary enclose the conditioned space.

- The air handling unit is located in a conditioned basement
- Low efficiency gas appliances that are prone to spillage or backdrafting are not recommended in this type of application; heat pumps, heat pump water heaters or sealed combustion furnaces and water heaters should be used
- A hot water-to-air coil in an air handling unit can be used to replace the gas furnace/heat exchanger. The coil can be connected to a sealed combustion (or power vented) water heater located within the conditioned space.
- Ductwork is not located in exterior walls or in the vented attic

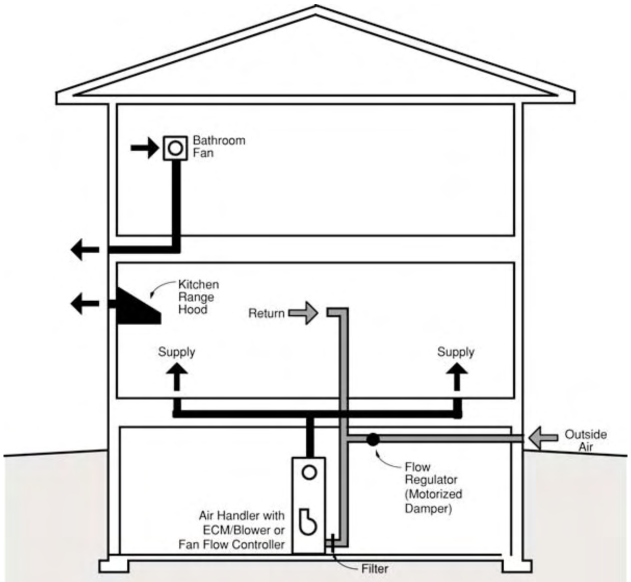
Vented and Conditioned Attic



Note: Colored shading depicts the building's thermal barrier and pressure boundary. The thermal barrier and pressure boundary enclose the conditioned space.

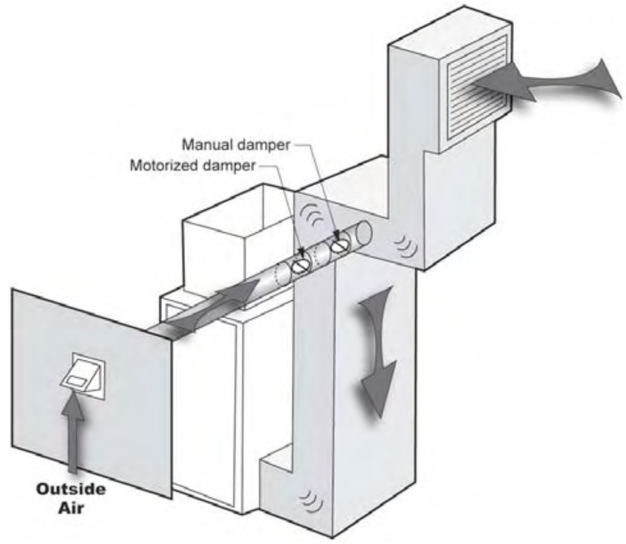
- The air handling unit is located in an unvented, conditioned attic; the attic insulation is located at or above the roof deck
- Low efficiency appliances that are prone to spillage or backdrafting are not recommended in this type of application; heat pumps, heat pump water heaters or sealed combustion furnaces and water heaters should be used
- A hot water-to-air in an air handling unit can be used to replace the gas furnace/heat exchanger. The coil can be connected to a sealed combustion (or power vented) water heater located within the conditioned space
- Ductwork is not located in exterior walls

Integrated Supply Ventilation System



- Air handler with ECM/blower runs continuously (or operated based on time of occupancy) pulling outside air into the return system
- A flow regulator (motorized damper) provides fixed outside air supply quantities independent of air handler blower speed
- House forced air duct system provides circulation and tempering
- Point source exhaust is provided by individual bathroom fans and a kitchen range hood
- In supply ventilation systems, and with heat recovery ventilation, pre-filtration is recommended as debris can affect duct and fan performance reducing air supply
- Kitchen range hood provides point source exhaust as needed
- Outside air duct should be insulated and positioned so that there is a fall/slope toward the outside to control any potential interior condensation. Avoid using long lengths of flex duct that may have a dip that could create a reservoir for condensation
- Mixed return air temperatures (return air plus outside air) should not be allowed to drop below 50° Fahrenheit at the design temperature in order to control condensation of combustion gases on heat exchanger surfaces

Outdoor Air Duct Connected to the Return of the Air Handler



BSC Information Sheet 620

Supplemental Humidity Control

for Hot-Humid Climates

High performance homes - due to superior insulation, better performing windows and more efficient lighting and appliances, can be expected to have smaller sensible cooling loads than typical new homes in the same geographic region. However, measures to improve the energy performance of the home generally do not affect internal humidity loads related to occupancy. Furthermore, under conditions where the moisture content of exterior air is higher than that of interior air – a condition that occurs for a significant portion of hours in hot and humid climates – dilution ventilation has the effect of increasing moisture levels within the building. The result is that latent cooling loads (the energy required to cool/remove moisture in the air) will typically be higher than sensible cooling loads for high-performance homes in humid climates. Most air conditioning equipment will not have the capability of removing the moisture load without over cooling the space – a condition likely to result in other problems.

Supplemental dehumidification can compliment the capability of the air conditioning system to remove moisture from air within the conditioned space. This information sheet offers general recommendations on supplemental humidity control and outlines viable system configurations.

General Recommendations

All homes, whether built to high performance standards or minimally code compliant, constructed in Hot-Humid climates require supplemental dehumidification. Additionally, high performance homes in Mixed Humid climates require supplemental dehumidification. Other homes, particularly small to modest sized high performance homes, may also benefit from supplemental humidity control.

The air conditioning and dehumidification system should be designed to maintain indoor relative humidity below 60%. Outdoor air dilution ventilation must be delivered in a controlled manner so as to deliver the ventilation required without over-ventilating. Over-ventilating introduces more load than is necessary. The ventilation system should be integrated with the central air conditioning distribution system to ensure effective distribution. The ventilation system controls ensure that the central air conditioning system fan cycles a fraction of every hour to promote adequate mixing within the conditioned space. Mixing tends to even out differences in relative humidity and temperature between different spaces in the house thereby promoting greater control.

For a description of central fan integrated ventilation, refer to Information Sheet 610, Ventilation System.

Stand-Alone Dehumidifier

Combined with a central fan integrated ventilation system, an "off the shelf" dehumidifier can provide effective whole-house humidity control. The dehumidifier is installed in a centrally located closet within the conditioned space. The door on the closet must be louvered or otherwise allow air flow. The dehumidifier condensate collection must be connected to a drain line. A supplemental drain pan is installed beneath the dehumidifier and also connected to a drain line. The dehumidifier should be ENERGY STAR qualified with an efficacy of at least 1.5 Litres/kWh to avoid excessive energy consumption. The central fan integrated ventilation system ensures mixing of conditioned air and, hence distribution of the humidity control.

Recommended enhancements to this simple system include adding a small return duct to the dehumidifier closet and providing remote humidistat control. The ducted return (20-30% of the system airflow) in the dehumidifier closet will enhance the whole house humidity control by circulating air through the dehumidifier closet when the central fan operates. A remote dehumidistat control (e.g. dehumidistat controlling a relay operating the dehumidifier power supply) allows the dehumidifier to respond to conditions in a location removed from the dehumidifier location.

Dehumidifier with Dedicated Distribution System

This dehumidifier configuration includes an air distribution fan and air ducts to provide distribution of dehumidified air and some degree of mixing for homes that do not otherwise have a central ducted system. This type of equipment is available with dehumidifier efficacy above that of a typical high-efficiency stand-alone dehumidifier but at a cost that is also significantly higher. The need to install

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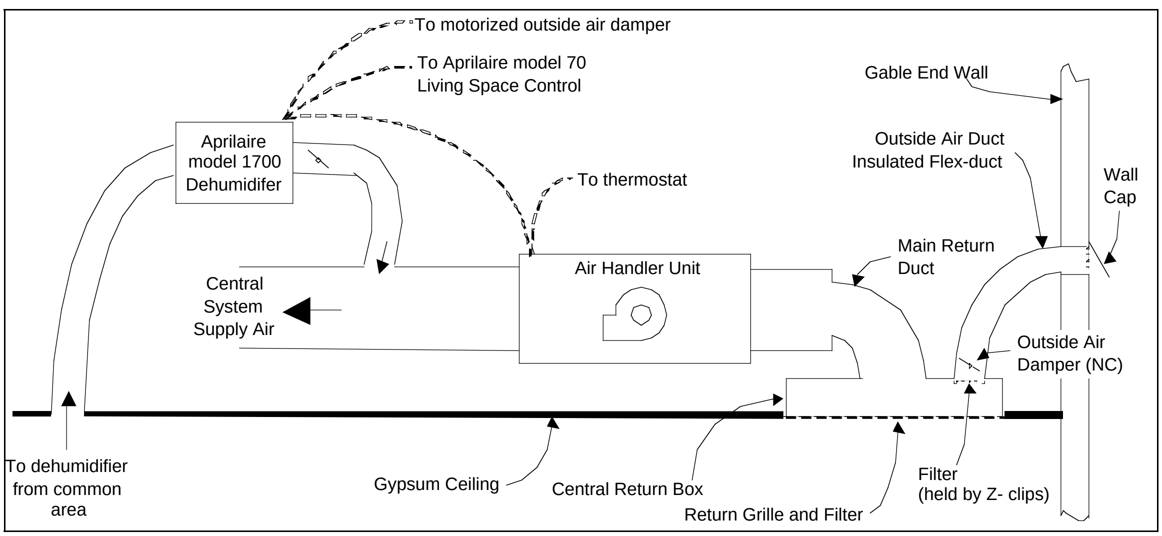
ductwork also represents an added first cost. A remote dehumidistat located in the living space controls the dehumidifier.

Integrated Ducted Dehumidifier
A ducted dehumidifier can be integrated with the central air conditioning distribution system as illustrated in schematic below. The fan inside the dehumidifier unit draws air from the living space or from the air handler plenum and returns it to the supply plenum. The dehumidifier controls include a remote dehumidistat located in the living space. Controls cycle the air handler fan on when the dehumidifier is activated. Controls could also be configured to operate the outside air damper or to link dehumidifier operation to outside air ventilation cycles.

Integrated Heat Pump Dehumidifier
In this configuration, the central air conditioning unit is also capable of providing dehumidification by using a portion of the condenser heat rejection for re-heat. This uses the same compressor for both dehumidification and cooling. While equipment cost is high, the equipment with this capability typically offers excellent energy efficiency in cooling and good efficiency in dehumidification. This configuration also offers the advantage of a pre-packaged system.

Integrated Ducted Dehumidifier



- Dehumidifier controlled by remote dehumidistat located in the conditioned space
- Air handler fan is operated with the dehumidifier for distribution
- Controls can be configured to operate the outside air damper with dehumidifier

Suggestions for Further Research:

"READ THIS: Before You Design, Build, or Renovate," Building Science Primer-040, www.buildingscience.com.

Lstiburek, Joseph W.; *Builder's Guide Series*, Building Science Press, 2006.

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Rudd, Armin, Joseph Lstiburek, P.Eng., and Kohta Ueno, "Residential Dehumidification Systems Research for Hot-Humid Climates," Research Report-0505, Building Science Press, 2008, www.buildingscience.com

Rudd, Armin, Hugh Henderson, Jr., 2007. "Monitored Indoor Moisture and Temperature Conditions in Humid Climate U.S. Residences." *ASHRAE Transactions* (17, Dallas 2007). American Society of Heating Refrigeration and Air-Conditioning Engineers, Atlanta, GA.