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Builder's Guide

Cold Climates

A systems approach to designing and building homes that are healthy, comfortable, durable, energy efficient and environmentally responsible.

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The building science information presented in this guide and the companion guides for other climates has evolved over the past 100 years. Many individuals and numerous institutions, organizations and agencies have contributed significantly, often anonymously, to the wealth of information and experience contained here. Fundamental research from the research establishments of four nations — Canada, Norway, Sweden and the United States — provides the foundation for the construction details and approaches presented. More significantly, the lessons learned from the construction of the Arkansas House, Saskatchewan Conservation House, Leger House and Canada's R-2000 program were applied, altered, improved, discarded, rediscovered and massaged by EEBA members throughout North America in thousands of field tests and experiments, sometimes referred to as home-building. The experience from these lessons can be found in the following pages.

Joseph Lstiburek,
Westford, MA
January, 1997

When we build, let us think that we build forever. Let it not be for present delight nor for present use alone. Let it be such work as our descendants will thank us for; and let us think, as we lay stone on stone, that a time is to come when those stones will be held sacred because our hands have touched them, and that people will say, as they look upon the labor and wrought substance of them, "See! This our parents did for us."

John Ruskin

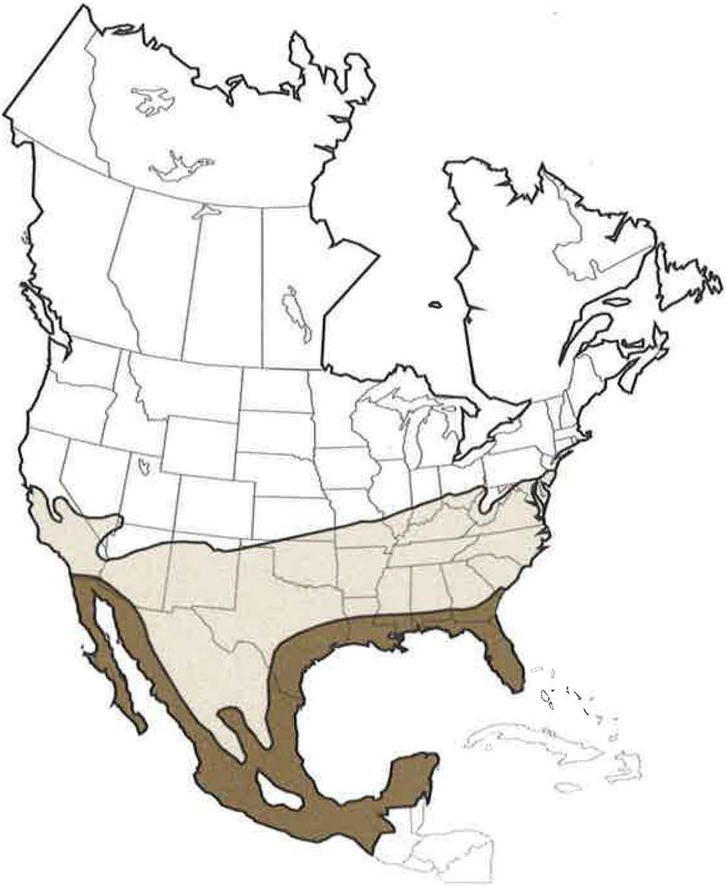
About this Guide

This guide contains information that is applicable to cold climates. A cold climate is defined as regions with approximately 4,500 heating degree days or greater. Figure A - Climate Zones illustrates the three major climate zones in North America used to distinguish the range of applicability of this guide and the companion guides for mixed and hot climates. Each climate zone specified is broad and general for simplicity. The climate zones are generally based on Herbertson's Thermal Regions (see Goode's World Atlas, 19th Edition, Rand McNally & Company, New York, NY, 1990) and the ASHRAE definition of hot, humid climates (see ASHRAE Fundamentals, ASHRAE, Atlanta, GA, 1993). For a specific location, designers and builders should consider weather records, local experience, and the micro climate around a building. Incident solar radiation, nearby water and wetlands, vegetation, and undergrowth can all affect the micro climate.

All illustrations are shown with exterior walls framed using 2x6 framing techniques. The red lines or red shading on illustrations represent materials that form the air flow retarder system.

Precise specification of materials and products is not typically provided on the illustrations or in the text to provide maximum flexibility. It is the responsibility of the designer, builder, supplier and manufacturer to determine specific material compatibility's and appropriateness of use. For example, there are wide range of performance and cost issues dealing with sealants, adhesives, tapes and gaskets. Cold weather construction, oily, damp or dusty surfaces affect performance. In addition, adhesives, sealants, tapes and gaskets must be matched to specific materials and joint geometry.

Generally, several different tapes, sealants, adhesives or gasket can be found to provide satisfactory performance when installed in the locations illustrated in this guide. Premium tapes, sealants, adhesives or gaskets typically (but not always) outperform budget tapes, sealants, adhesives or gaskets. It is always advisable to obtain samples and test compatibility and performance on actual material substrates prior to construction.



Cold		Mild summer and cool or cold winter
Mixed		Hot summer and cool winter
Hot		Hot summer and mild winter

Hot = above 68°F/20°C

Mild = 50°F/10°C to 68°F/20°C

Cool = 32°F/0°C to 50°F/10°C

Cold = below 32°F/0°C

Figure A
Climate Zones

- Based on Herbertson's Thermal Regions and the ASHRAE definition of hot, humid climates

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Introduction

People ask builders all the time, "Why can't you build homes the way you used to?" Builders can't help but notice that callbacks and warranty claim costs are rising more rapidly than they did in the past. Were older homes built better than we build today? Have we forgotten all we learned about quality and durability?

The homes of yesterday do perform better than homes built today, but not for the reasons most people think.

In fact, many builders today are obsessed with quality control. The quality revolution that has swept through North America has forced builders to focus on producing quality homes. When faced with the question of quality, a builder typically looks at two things:

- workmanship
- materials

It is assumed that if good workmanship can be achieved and good materials are used, a high quality home will result. Let's examine that assumption.

Countless homes across North America are being built with good workmanship and good materials but are not performing. We have better paints than we ever had before, but we have more paint problems today. Are today's painting contractors less skilled than yesterday's? We have better insulation than we ever had before, but we have more insulation problems today. Are today's insulation contractors that much worse than yesterday's? We have better windows than we ever had before, but we have more window problems today. Are today's window installers that much worse than yesterday's? The list goes on almost endlessly.

What's going on here? How can we have good workmanship and good materials and still have problems? What if we do the wrong thing with good materials and good workmanship? Do we still have quality?

The problem is not workmanship or materials; the problem is understanding. The pieces must be put together correctly. In order to do so, we must understand how homes work. Homes today work differently than they did in the past. The old solutions and old understandings don't apply.

Homes of yesterday were cold and drafty, but they stood the test of time. Houses of today are exceptionally comfortable but frequently experience serious problems long before the initial mortgage is fully paid. Can there be any connection between comfort and durability? The answer is, "Yes". In a strange way, what we do to homes to make them more comfortable has in fact made them less durable.

In the last fifty years there have been three important changes to the way we build homes:

- The introduction of thermal insulation
- The development of tighter building enclosures
- The advent of forced air heating and cooling systems

Each of these changes has made homes more comfortable, but also has made the same houses less durable.

Thermal Insulation

Thermal insulation was added to wall cavities and ceilings to keep the heat in and make a home more comfortable. However, by keeping the heat in, the insulation kept the heat out of the wall cavities and ceilings themselves. Wall cavities and attics became colder because the insulation did its job keeping so well. In doing so, the insulation made these assemblies more prone to condensation. In addition, the ability of these assemblies to dry when they get wet from either interior or exterior sources was reduced. How do you dry something? You heat it. No heat flow, no drying. The addition of thermal insulation increased the "wetting potential" of building enclosures while reducing their "drying potential."

Ironically, adding even more insulation in the form of insulating sheathing, compensated for this by warming up building cavities. Of coarse, this now caused the claddings to perform poorly.

Tighter Building Enclosures

Homes built today are much tighter than the homes of yesterday. We use plywood and gypsum board in place of board sheathing and plaster.

We platform frame instead of balloon frame. We use factory-made windows instead of site glazing our windows. Building papers come in 10 foot wide rolls instead of 3 foot wide rolls. We put more caulk and glue on our houses than ever before, and we can buy material that actually sticks and holds. The results are fewer holes and a lower air change. The lower the air change, the less the dilution of interior pollutants such as moisture (from people,soil and appliances), formaldehyde (from particle board, insulation, furniture and kitchen and bathroom cabinets), volatile organic compounds (from carpets, paints, cleaners and adhesives), radon (from basements, slabs, crawl spaces and water supplies) and carbon dioxide (from people).

This trend to lower air change occurred simultaneously with the introduction of hundreds of thousands of new chemical compounds, materials and products that were developed to satisfy the growing consumer demand for household goods and furnishings. Interior pollutant sources have increased while the dilution of these pollutants has decreased. As a result, indoor air pollutant concentrations have increased.

Additionally, chimneys don't work well in tight homes. In tight homes, other exhaust fans compete with chimneys and flues for available air. The chimneys and flues typically lose in the competition for available air, resulting in spillage of combustion products, and backdrafting of furnaces and fireplaces.

As air change goes down, interior moisture levels rise causing condensation problems on windows, mold on walls, dust mites in carpets and decay in wall cavities and attic spaces. Yet even though interior moisture levels are rising, builders continue to install central humidifiers rather than installing dilution ventilation.

Traditional chimneys in many new homes have been replaced with power vented, sealed combustion furnaces. Many new homes have no chimneys or flues at and rely on heat pumps or electric heating. Traditional chimneys ("active chimneys") acted as exhaust fans. They extracted great quantities of air from the conditioned space that resulted in frequent air changes and the subsequent dilution of interior pollutants. Eliminating the "chimney fan" has led to an increase in interior pollutant levels such as moisture.

Active chimneys also tended to depressurize conditioned spaces during heating periods. Depressurization led to a reduced wetting of building assemblies from interior air-transported moisture and therefore a more forgiving building envelope.

Heating and Cooling Systems

Today, forced air systems (heating and air conditioning) move large quantities of air within building enclosures of increasing tightness. The tighter the building enclosure, the easier it is to pressurize or depressurize. This has led to serious health, safety, durability, and operating cost issues.

Supply duct systems are typically more extensive than return duct systems. There are usually supply registers in each room, with common returns. Pressurization of rooms and depressurization of common areas is created by the combination of more extensive supply systems, leaky returns combined with interior door closure.

When supply ducts are run exterior to the building envelope in vented attic roof and crawl spaces, the supply ducts typically leak. This leads to the depressurization of the building enclosure. Depressurization can cause infiltration of radon, moisture, pesticides and soil gas into foundations as well as probable spillage and backdrafting of combustion appliances and potential flame roll-out resulting in fire.

Pressurization can lead to the exfiltration of warm moisture-laden air into wall and roof cavities that are at lower drying potentials because of higher levels of insulation.

Integration

The three important changes in the way we build homes today interact with each other. This is further complicated by the effects of climate and occupant lifestyle. The interrelationship of all of these factors has led to major warranty problems that include health, safety, durability, comfort and affordability concerns. Problems are occurring despite the use of good materials and good workmanship.

We cannot return to constructing drafty building enclosures without thermal insulation, without consumer amenities, and with less efficient heating and air conditioning systems. The marketplace demands sophisticated, high performance buildings operated and maintained intelligently. As such, buildings must be treated as integrated systems that address health, safety, durability, comfort and affordability .

Quality construction consists of more than good materials and more than good workmanship. If you do the wrong thing with good materials and good workmanship, it is still wrong. You must do the right thing with good materials and good workmanship. The purpose of this guide is to promote the use of good materials and good workmanship in a systematic way, so that all the parts work together, promoting good performance, durability, comfort and health.

1 The House System

Functional Relationships

Residential construction is a complex operation including thousands of processes by dozens of industries, bringing together hundreds of components and sub-systems into a house. A house is a complex, interrelated system of people, the building itself and the environment (Figure 1.1).

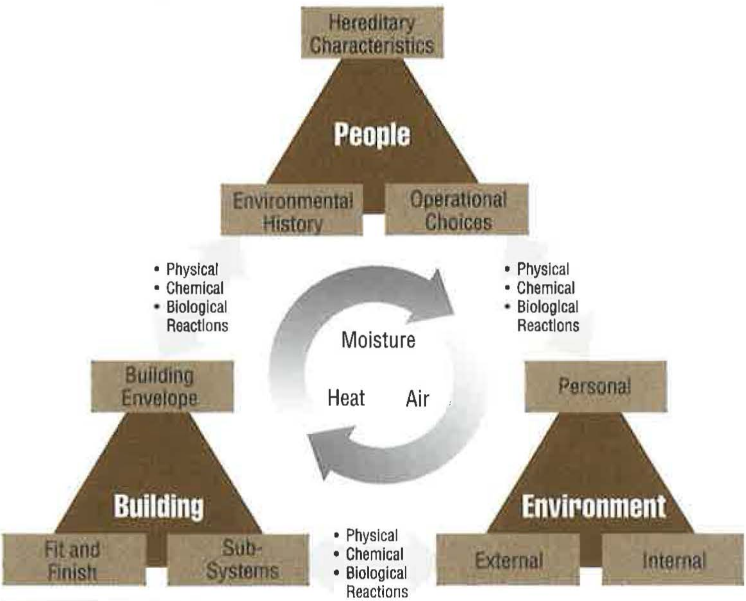


Figure 1.1
Analytical Model of the House System – Functional Relationships

A house consists of the building envelope, the sub-systems contained within it and the fit and finish. The building envelope is composed of assemblies. Assemblies are composed of elements. Sub-systems are composed of components. The fit and finish is composed of appliances, fixtures and the furnishings.

The building envelope, assemblies, elements, sub-systems, components and the fit and finish are all interrelated. A change in an element can change the performance of an assembly, affect building envelope and subsequently change the characteristics of the house. Similarly, a change in a sub-system can influence the house, an assembly or an element of an assembly.

The house, in turn, interacts with the people who live in the house and with the local environment where the house is located. The functional relationships between the parameters are driven by physical, chemical and biological reactions. The basic factors controlling the physical, chemical and biological reactions are:

- heat flow
- air flow
- moisture flow

Controlling heat flow, air flow and moisture flow will control the interactions among the physical elements of the house, its occupants and the environment.

Building houses is really about the durability of people (health, safety and well being of people), the durability of buildings (the useful service life of a building is typically limited by its durability) and the durability of the planet (the well being of the local and global environment).

The major elements of the residential construction process as well as continuing home operation are respresented in Figures 1.2, 1.3, and 1.4.

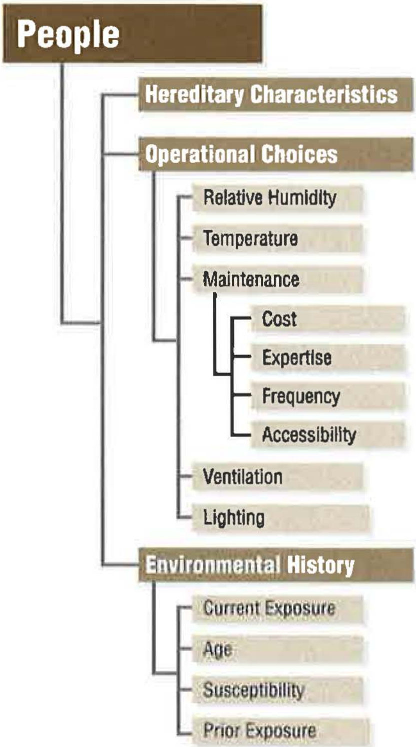


Figure 1.2
Hierarchical Relationships – People

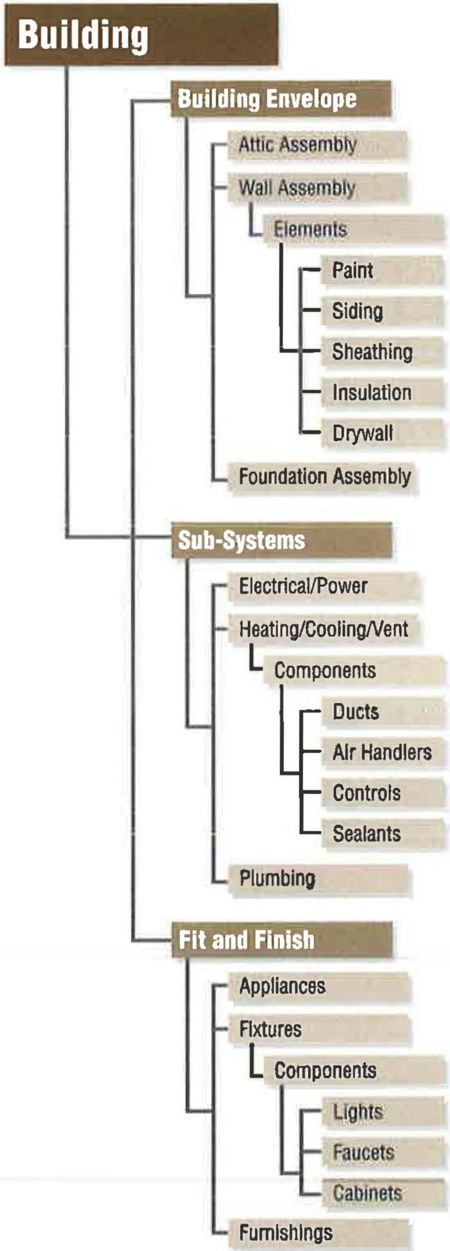


Figure 1.3
Hierarchical Relationships – Building

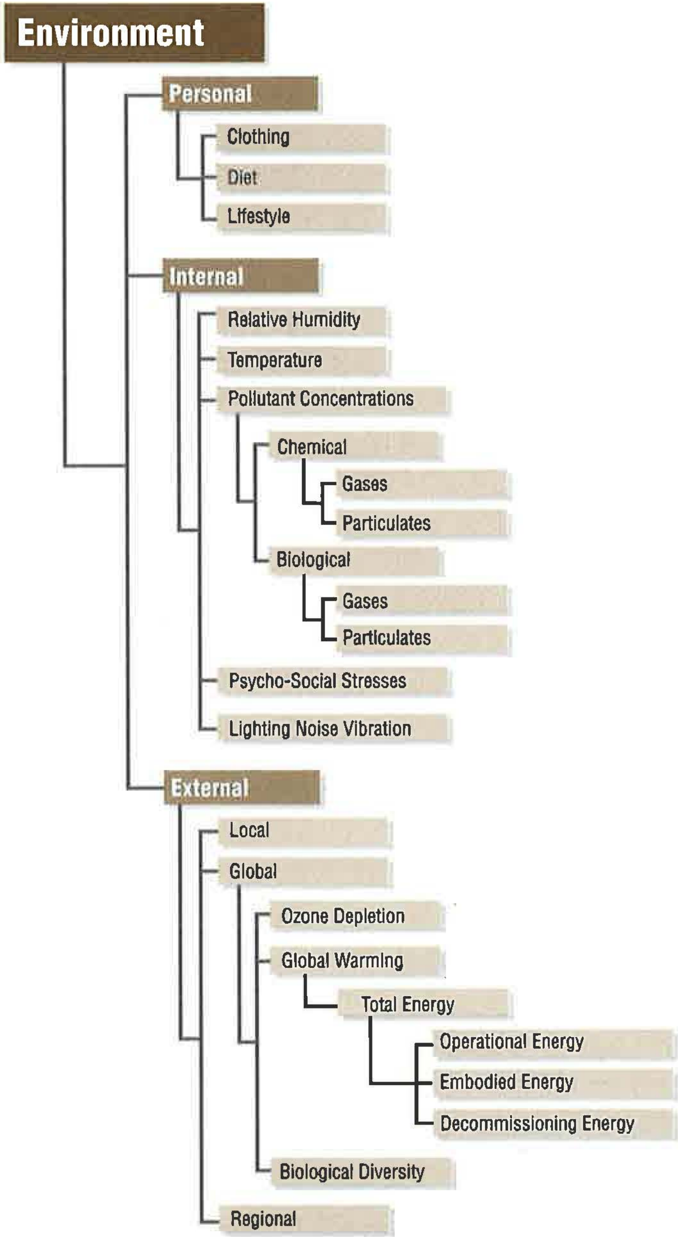


Figure 1.4
Hierarchical Relationships – Environment

Prioritization

The residential construction process should minimize needs for energy, water and materials and satisfy these needs in the least disruptive manner possible (Figure 1.5).

The interior environment, or conditioned space, should be safe, healthy and comfortable. The building should be both durable and affordable in terms of purchase price and operating costs. And the building should be built in a manner that does the least harm to the local environment, including the construction site and the land around it. The impact of home production on the global environment should also be considered. What resources will be used to build and operate the building? Are they renewable? What is the effect on the environment of extracting them?

Figure 1.5
Minimization of Needs

The sometimes conflicting needs among people, buildings and the environment should be prioritized. For example, the needs of people should be considered before the needs of a building. The internal environment created by a building should be considered before the planetary environment. Short-term concerns should be considered before long-term concerns (Figure 1.6).

Applying prioritization to residential construction would identify the immediate health risk from carbon monoxide poisoning as a result of improper installation of combustion appliances as more significant than long-term health concerns from the infiltration of radon gas.

Figure 1.6
Priorities

Extending the prioritization process further shows that job-site recycling and reducing construction waste should have precedence over a global concern such as ozone depletion in the upper atmosphere. Finally, ozone depletion — a global short-term risk — should have precedence over global warming — a global long-term risk.

People Priorities

Houses should be safe, healthy, comfortable and affordable. A safe, healthy home is one in which concerns about structural adequacy, fire and smoke spread, security and indoor air quality have been addressed. Comfort involves satisfying people's sensory perception. It implies dealing with thermal comfort, interior relative humidity, odors, natural light, sound and vibrations. Affordability means the designer, the builder and the various subcontractors and suppliers should be able to make a profit, and the occupant, for whom the home is built, should be able to purchase it and afford the operating and maintenence costs (Figure 1.7).

Building Priorities

Houses should be durable and capable of being maintained. The single most important factor affecting durability is deterioration of materials by moisture. Houses should be protected from wetting during construction and operation, and be designed to dry should they get wet.

Homeowners and occupants should be instructed on how to maintain and operate their buildings. Houses should be able to be renewed and renovated as new technologies, materials and products emerge. The house built today will likely be renovated at some point in the future. Houses should be able to be adapted as families and occupancy change. Finally, houses should be designed and constructed with decommissioning at the end of the useful service life in mind. This means taking into consideration how the materials that go into the house will ultimately be disposed of (Figure 1.7).

Environmental Priorities

Houses should be constructed in a manner that reduces construction waste and operated in a manner that reduces occupancy waste. Recycling of construction and operating waste should be encouraged. Use of construction water, domestic water and irrigation water should be minimized. Erosion of soil during site preparation and the construction process should be controlled. Storm water should be infiltrated back into the site.

Activities that contribute to air pollution during construction, such as painting and burning of trash, should be minimized. Materials and systems that contribute to ozone depletion by releasing chlorofluorocarbons (CFCs) into the air should be avoided.

Biological diversity of plant and animal species should be protected by using materials from managed forests and managed mineral extraction processes. Finally, the use of energy to operate the building and to make and transport building products (embodied energy) should be minimized to reduce the production of greenhouse gases (e.g., carbon dioxide) that contribute to global warming (Figure 1.7).

People Priorities	Building Priorities	Environmental Priorities
Health & Safety	**Durability**	**Local Environment**
• fire and smoke spread • indoor environment (air quality) • security • structural	• deterioration due to moisture and chemical and biological reactions • operation, housekeeping and maintenance	• construction waste • operating waste • construction water • operating water • rain water run-off and local hydrology • erosion of soil
Comfort	**Renewal, Reuse and Renovation**	**Regional Environment**
• temperature • moisture (relative humidity) • odors • sound/vibrations • light • aesthetics	• future sub-system upgrading, such as communications, space conditioning and power • adaptability	• contamination of groundwater, streams and lakes (acid rainfall and acidification of lakes) • regional air pollution • regional recycled materials and waste disposal
Affordability	**Decommissioning/ Disassembly**	**Global Environment**
• capital cost, financing • operating cost from energy, water and maintenance	• benign materials • disposable and further recyclable materials	• global warming impacted by operating and embodied energy • ozone depletion impacted by CFC-containing materials and systems • biological diversity impacted by utilizing materials from non-sustainable forests

Figure 1.7
People, Building and Environmental Priorities

2 Home Designer

The designer makes fundamental decisions about the siting, massing, layout and design of the house. The designer is often the general contractor but can be an architect or the home buyer. In many cases, design decisions are shared among the designer, general contractor, and home buyer. The designer must be aware of the limitations of the project budget, the needs of the home buyer and the requirements of the general contractor. The designer must also understand the local climate and the specific limitations of the proposed site. Furthermore, the designer must understand the project time, labor, construction sequence, material characteristics and the process of construction (Figure 2.1).

Site Planning

The ideal site is seemingly never available, and there is never enough money. However, where flexibility exists, sites facing southeast, south or southwest provide the best opportunities for optimizing a building's orientation with respect to daylighting and passive solar gain. Sites sheltered from winter winds and open to summer breezes are warmer in winter and cooler in summer. Bodies of water and areas of vegetation moderate air temperature. Sites shaded by deciduous trees are cooler in summer. Sites that are well drained reduce the stress on drainage systems and water management. Building in a swamp is always more difficult than building on the top of a hill.

The site access, site clearing, excavation, site manipulation and shaping, construction process, site development and landscaping all need to be considered with respect to soil erosion and the existing hydrology. Sculpting the ground to permit a slab-on-grade rather than a walkout basement or elevated crawl space can save thousands of dollars.

2
Home Design

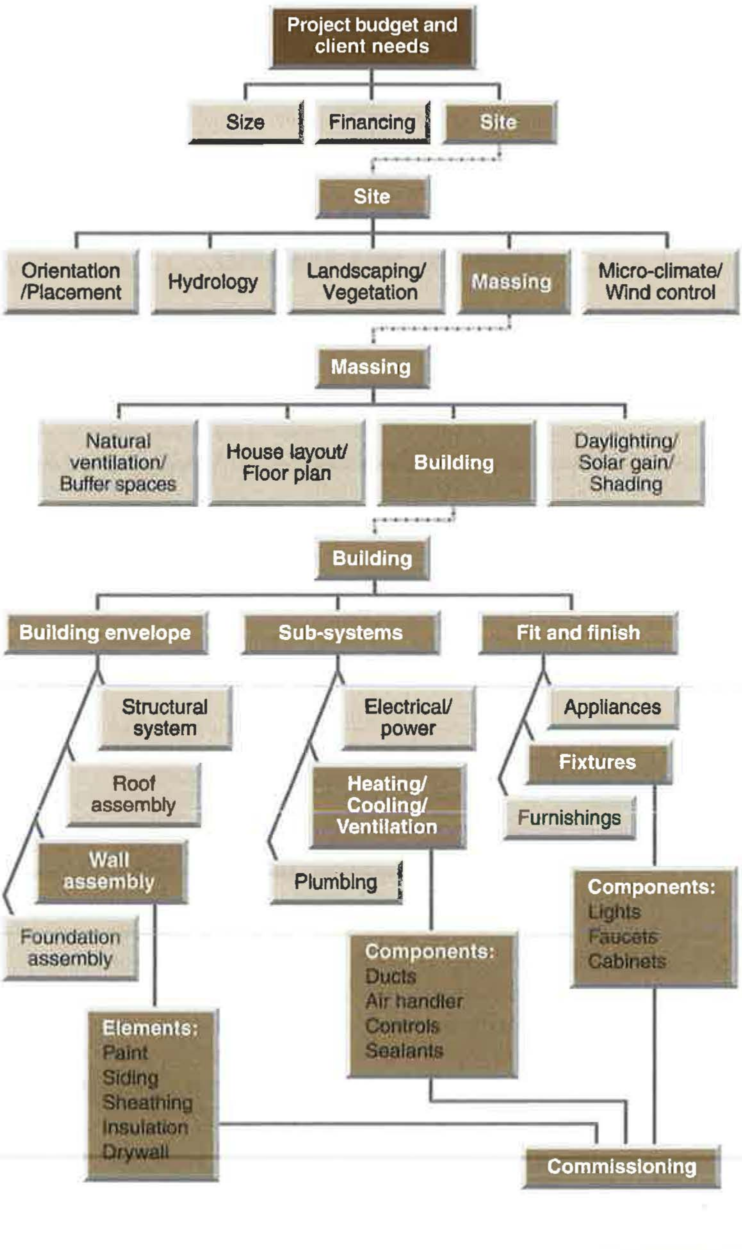


Figure 2.1
Process of House Construction

Landscaping should be used to buffer the house from winter winds, allow winter solar gain and daylighting, and provide summer shading and cooling. Vegetation, walls, fences and other buildings can be used as wind breaks. Wind breaks can be used to channel breezes into buildings and outdoor spaces. Overhead structures can be used to provide shade for outdoor use areas. East and west facades, that provide the greatest potential for summer overheating, should be shaded from low-angled sun. Light-colored walls or fences can be used to assist daylighting by reflecting sunlight into north windows. Paving should be minimized and shaded from the sun. Understory vegetation should be cleared and maintained to admit summer breezes.

Site hydrology and the management of storm water have a major environmental impact. Under natural conditions most rainfall percolates into the ground upon which it falls, whereas almost all the rain that falls on a built-up area contributes to surface run-off. The principle advantage of vegetation is that it controls soil erosion from run-off water. Grass encourages percolation to the water table and is effective vegetation for erosion control. In fact, many grasses work to reduce the impact of pollutants by breaking them down before they reach the water table. Turf grass requires considerably more water than other ground covers. Xeriscaping should be considered.

An ideal situation would be one in which no increase in run-off occurs as a result of development, so that problems are localized rather than passed on to others. This concept can be promoted by reducing the amount of paving and other impervious surfaces in order to permit a greater portion of the storm water to seep into the ground. Vegetation can be increased and/or retained in order to maximize the amount of storm water consumed and stored by plants. Storm water can be drained to temporary or permanent storage areas by means of surface collection and low volume underground systems. It's okay to have puddles of water after a rain. Just don't have those puddles right next to the house.

House Layout

The building form and layout are major factors influencing cost and performance. Heat gain and heat loss occur across building surfaces. Maximizing volume while minimizing surface area will increase operating efficiencies. Building forms that are compact are more resource and energy efficient than those that are spread out. In terms of floor plans, locating the most actively used spaces where they will benefit most from daylighting makes the most sense. In cold climates, kitchens, living rooms and family rooms should be located to the south side.

Buffer spaces should be used both within a building (vestibules) and external to a building (porches, sunspaces, sheltered patios) to temper weather extremes.

In cold climates, outdoor use areas should be located adjacent to the south side of the buildings and southern exposures should remain free from obstructions except with respect to shading from the summer sun. Large paved surfaces should be avoided on windward sides of buildings. Such surfaces, if necessary, should be located to the lee side of use areas with respect to summer breezes so as to minimize summer thermal mass effects.

Open floor plans allow for air flow and ventilation efficiencies, increased daylighting and summer cross ventilation. During heating, heat is more evenly distributed.

Windows should be sized and positioned so as to decrease heat loss during the winter and decrease heat gain in the summer while providing daylighting year round. Moderate amounts of southern glazing provide improved comfort during heating (sun tempering) while providing views without an energy penalty. Substantial south-facing glass can lead to overheating in summer as well as winter. As a minimum, Low E glass should be installed throughout (see Appendix IV).

In designing for cooling load, east- and west-facing windows should be minimized as they cause the most summertime overheating. Spectrally selective glazing should be considered for extensive east- and

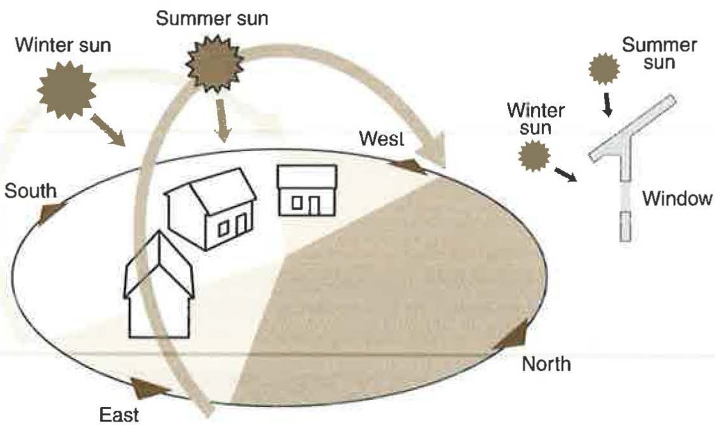


Figure 2.2
Summer vs. Winter Sun Angle

west-facing glazing. Large areas of glazing overhead (large skylights) should be avoided. Overhangs (Figure 2.2) and vegetation such as deciduous trees should be considered to shade windows during the summertime while leaving windows unshaded in wintertime. Fencing and/or a trellis can also be used to shade glazing, particularly on east and west exposures.

Light-colored walls, floors and ceilings should be used to reflect incoming light deep into a room. A small skylight can be used to get the light to the back of a room. Light ground colors should be avoided in front of south-facing windows to minimize reflected summer heat gain, but should be considered for walls and fences on north exposures to reflect sunlight into north windows for improved daylighting.

Basic Structure and Dimensions

The house layout and massing define the basic structure. The type of foundation system (crawl space, slab or basement), roof system (attic, cathedral ceiling or flat), floor system (joist, truss or slab) and structural system (wood frame, steel frame, concrete or masonry) is selected by the designer based on costs, availability of materials, regional practices and preferences, site conditions and micro-climate, environmental impact and availability of experienced trades.

Plywood, oriented strand board (OSB), and insulating sheathings all come in 4 ft. by 8 ft. sheets. It makes sense to design out-to-out dimensions on 2 ft. increments to reduce sheet good waste and to maximize the efficiency of the structural frame (Figure 2.3).

Roof slopes and overhangs should also be selected and dimensioned to take advantage of 2 ft. increments. We often specify 4:12, 6:12 or 8:12 roof pitches when we can just as easily specify a 4.217:12 roof pitch and minimize sheet good waste (Figure 2.3).

Roof framing should line up with wall framing and floor framing. Windows and doors should be located on 2 ft. grid increments to eliminate extra studs on the sides of openings.

Fireplaces should not be located on exterior walls, they should be totally contained within the conditioned space. A warm chimney drafts much better than a cold one. In addition, masonry chimneys that are located within the conditioned space have thermal mass that stores the heat created by a fire and continue to warm the space even after the fire has gone out.

Mechanical equipment, ductwork and plumbing must not be located in exterior walls, vented attics or vented crawlspaces. All air distribution systems must be located within the conditioned space. Interior chases

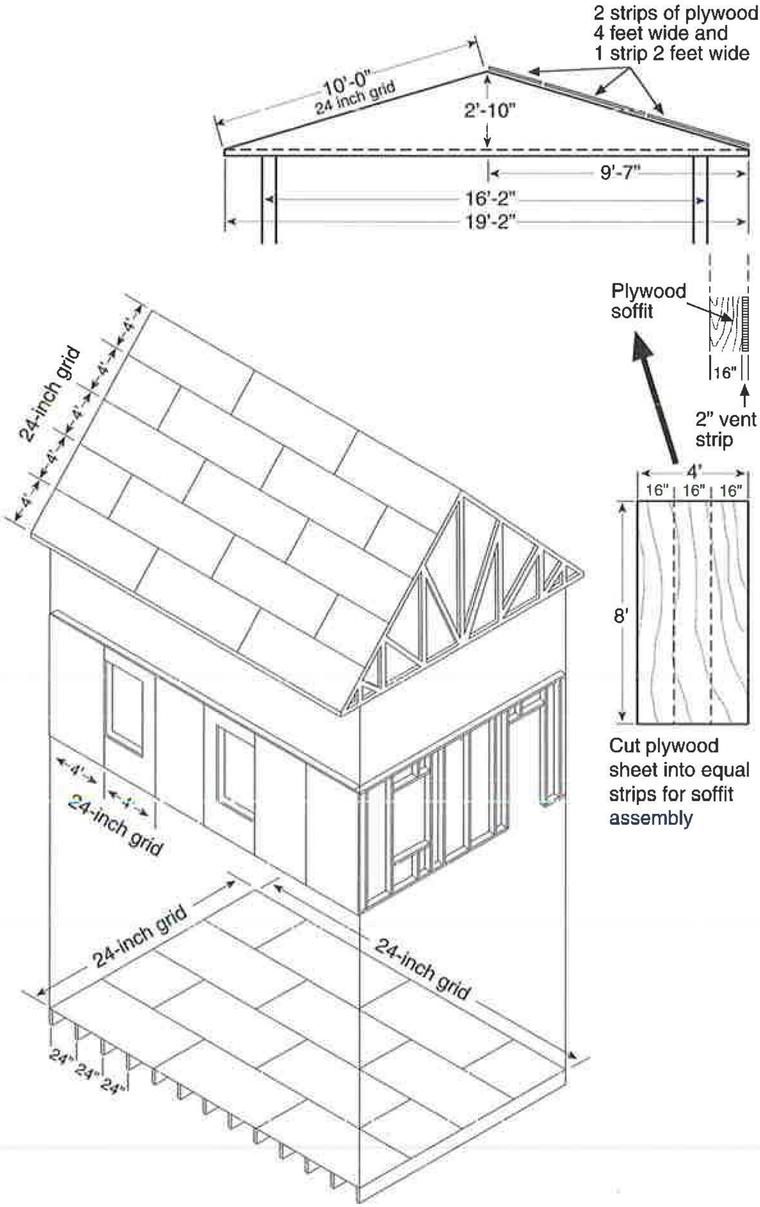


Figure 2.3
Efficient Material Use by Design

must be considered and provided during the schematic design phase to make it easy to install services (Figure 2.6). A designer must think about stair locations and openings while allowing ductwork and plumbing to get by them as it goes from one side of the house to the other.

Complaints on how plumbers and sheet metal workers butcher framing during rough-in are often heard. However, if the designer does not leave them space, or make it easy for them to install equipment, piping and ductwork, it is often the only way to install the services. The designer almost never talks to the plumber or heating contractor during the design phase about locating soil stacks, ductwork layouts and equipment locations. It's time we start the dialog, or stop complaining about cut floor framing, having to pad-out walls to hide plumbing and ducts and paying for tortured ductwork layouts that don't deliver any air.

Building Envelope

The building envelope must:

- hold the building up
- keep the rain water out
- keep the groundwater out
- keep the wind out
- keep the moisture vapor out
- keep the soil gas out
- let the moisture vapor out if it gets in
- keep the heat in during the winter
- keep the heat out during the summer

The designer has to chose materials, equipment and systems to make all this work. Will exterior sheathings be permeable or impermeable? Will building papers or housewraps be used? What type of air flow retarder systems will be used? What will the thermal resistance of the building envelope be?

A key concept should be used at this point in the design approach — the concept of "break points." A break point denotes the situation where an increase in cost in one area is balanced by a reduction in cost in another area.

For example, increasing the thermal resistance of the building envelope by using insulating sheathing and high performance glazing will result in an increased cost. However, the heating and cooling system can be made much smaller with a resulting decrease in the size and cost of ductwork and equipment. Open-web floor trusses cost more than floor joists. However, it takes much less time, effort and money to install plumbing, electrical work and ductwork within floor trusses than within floor joists. A 2x6 costs more than a 2x4, but if you use far fewer 2x6s than 2x4s, the building frame can be put up faster and, therefore, less expensively.

Material Selection

There are only a few inherently bad materials, but there are many bad ways to use materials. The use of a material should be put into the context of a system. In general, the system is more important than the material. Once the system is selected, you must determine if the material can perform its intended function as part of that system? What is the

Figure 2.4
Material Selection

risk of using the material to the occupants, to the building and to the local and global environment when used in that system? (Figure 2.4)

Extending the argument further, there are no truly benign materials, only degrees of impact. Nothing is completely risk free. However, risk can be managed. There may be no alternative to a particular toxic material in a specific system, but the use of that material may pose little risk when used properly and provide significant benefits to that system. For example, bituminous dampproofing is a toxic material, but if it is installed on the exterior of a concrete foundation wall enclosing a pressurized basement (one that has a positive air pressure relative to the surrounding soil), there is little risk to the occupants, but there are substantial moisture control benefits to the foundation assembly.

The risk to occupants from a particular synthetic or natural agent in a building product, system or assembly is generally low if that agent is not inhaled or touched. In any case, building products and materials that do not off gas are preferable to those that do. Less toxic alternatives should be used in place of more toxic materials (Figure 2.5). Remember that these material choices need to be placed in the context of the system or assembly of which it is a part. Is the toxic material being used in roofing? If so, it may pose little hazard to the occupants.

In addition to the specific concerns about material and product use on

Figure 2.5
Product Substitution and Context

the interior environment of a building and the occupants, are the concerns relating to the local and global environment. Is it more appropriate to use a recycled, refurbished or remanufactured product or material in place of a new material or product? Is the new material or product obtained or manufactured in a non-disruptive or the least-disruptive manner to the environment? Can the cost of a product justify its use? How far was the material transported? How much energy was used to make it?

Sub-Systems

All buildings require controlled mechanical ventilation. Building intentionally leaky buildings and installing operable windows does not provide sufficient fresh air in a consistent manner. Building envelopes 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. Controlled mechanical ventilation can be provided in many forms (See Chapter 6), but what is important at this stage is that the designer recognize that a controlled mechanical ventilation system is necessary and that controlled mechanical ventilation works only in a tight building envelope. You can't control anything in a leaky building.

Selecting a fuel source is usually based on availability, regional practices and customer preference. Natural gas is the most common choice where it is available. If gas heating or a gas water heater is selected, the appliances must be power vented or sealed combustion. Gas appliances should not interact aerodynamically with the building. If a gas cooktop or gas oven is installed, it must be installed in combination with a kitchen range hood directly ducted to the exterior (exhaust fan).

Air change through mechanical ventilation can be used during heating periods to control interior moisture levels. Dehumidification through the use of mechanical cooling (air conditioning) can be used during cooling periods to control interior moisture levels.

Furnaces or air handlers should be located within the conditioned space and provide easy access to accommodate servicing, filter replacement, drain pan cleaning, future upgrading or replacement as technology improves. Hostile locations (extreme temperatures and moisture levels) such as attics and unconditioned (vented) crawl spaces should be avoided.

Appliances

The designer is responsible for the selection of appliances, typically with home owner input. If home owners assume the responsibility of selecting some or all of the appliances, it is the responsibility of the designer to provide the necessary information to the home owner so that an informed decision can be made within the context of the house system.

Appliances should be selected and installed in such a manner that they do not adversely impact the building envelope or building sub-systems. For example, gas cooktops and ovens should provide for their own exhaust of combustion products by installing vented range hoods or exhaust fans.

Fireplaces and wood stoves should be considered appliances. They should be provided with their own air supply independent of the other air requirements of the building enclosure. The location of combustion appliances should take into consideration air pressure differentials that may occur due to the stack affect or competition for air from other combustion appliances. Indoor barbecues should be considered similarly. Air supply, air pressure differentials and combustion product venting need to be addressed.

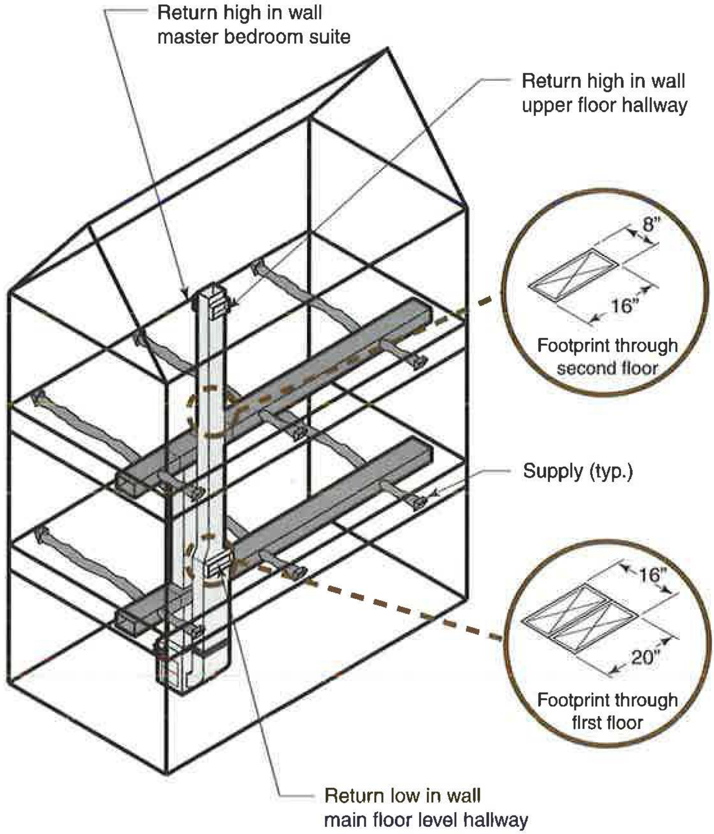
Energy consumption should be a prime consideration in the selection of refrigerators, freezers, light fixtures, washers and dryers. Dryers should be vented directly to the exterior and should not adversely affect the air pressure dynamics of the building enclosure when they are operating.

Commissioning

The home designer must ensure that commissioning of the home occurs that the home functions as intended by the design. The commissioning can be done by the designer, the contractor or someone else but should include:

- testing of the building envelope leakage area
- testing of the leakage of duct systems
- testing of the air pressure relationships under all operating conditions
- testing for proper venting of all combustion appliances under all operating conditions
- testing of the carbon monoxide output of all combustion appliances (gas oven, range, water heater, gas fireplaces)

As part of the commissioning process, the home owner or occupants should be educated and informed as to the correct operation, maintenance and housekeeping requirements of the building. What are appropriate temperature, relative humidity and ventilation ranges for the building? How do owners or occupants identify a system failure as distinct from the improper operation of a system? How do owners or occupants monitor the building conditions (temperature sensors, humidity sensors, ventilation sensors)?



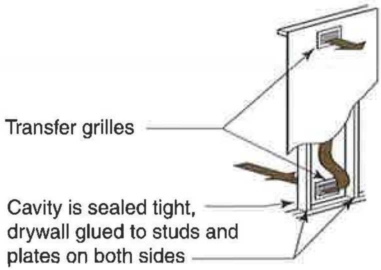


Figure 2.6
New Construction Air Distribution Systems

- Use fully ducted returns or transfer grilles for return airflow paths. Do not use panned floor joists or other building cavities.

3

General Contractor

All the general contractor has to do is construct the building on time and under budget using imperfect materials and imperfect trades, under less than ideal conditions. The client even expects the building to work. There never seems to be enough time or money, but the job still has to get done. In this line of work, Murphy is an optimist.

In the old days, all you needed was good workmanship and good materials. Getting good workmanship today is hard enough given the state of the trades, but it is not enough. Good workmanship cannot compensate for bad design. A general contractor cannot just follow the plans. Plans rarely provide enough information to get the job done, and many times the plans are wrong, in which case, the general contractor has to catch the mistakes. When the plans don't provide enough information, the general contractor has to fill in the gaps. "Not my fault, I was just following the plans," or "Nobody told me I had to do it that way," doesn't work anymore. It's not fair, nor is it right, but often the way it is. In order to protect himself or herself, the general contractor has to know everything about everything. Easy, right?

Concerns

Everything is a concern to the general contractor, but of all the concerns, there is one that towers above the rest. Getting the right information to people when they need it is more important than anything else. Getting the materials and equipment to the people when they need it comes next. General contracting is all about the flow of information, materials and equipment to the right people at the right time.

Most mistakes happen because of a lack of information, followed by a lack of attention. Understanding comes from having the right information. Once there is understanding, problems can be caught early and corrected by the people actually doing the work. It helps the general contractor to employ workers who understand how their jobs fit into the entire process.

Unfortunately, nowadays it is difficult to find fully trained and knowledgeable trades people. It seems that trades people don't take courses or classes anymore and that apprenticeship programs have fallen by the wayside. The depth of experience in the trades is often missing and the workforce is very transient. Even when there has been training, it is often out of date or just plain wrong. In order to get the job done right, the general contractor has to train the trades himself, everyday, day in and day out.

The most effective training approach is on-site training, beginning with the first day of work. This should occur during a one-hour period prior to commencing work. "This is what I want and why." "This is how I think you should do it, but I'm open to any suggestions on how to do it simpler." "I'm available all day to answer questions."

Training is always easier if you have the right tools. Simple training tools, like visual aids posted on site for easy reference and use, work well. Posters illustrating key details can be developed for framers, electricians, insulators and drywallers.

Detailed framing drawings can be created that illustrate the location of each stud and framing member. These drawings can significantly reduce construction time as well as potential confusion. Supervisory time can also be reduced.

The better, the quicker and the simpler the training, the better the subcontractors' prices the next time a job is bid.

The detailed framing drawings and the posters developed for the framers, electricians, insulators and drywallers, coupled with checklists and addresses of suppliers, become key elements in developing "competitive pricing" during bid negotiations.

No one likes surprises. The better the information and the better the training, the fewer the surprises. When there are no surprises, you get good prices. Now we're talking.

4 Foundations

The three foundation approaches common to residential construction are crawl spaces, slabs and basements. Each can be built with concrete, masonry or wood. Each can be insulated on the inside, on the outside or from below. However, they all have to:

- hold the building up
- keep the groundwater out
- keep the soil gas out
- keep the moisture vapor out
- let the moisture vapor out if it gets inside
- keep the heat in during the winter

Concerns

Concrete cracks. Concrete has always cracked. Concrete will always crack. Reinforcing concrete will not prevent it from cracking. It is not possible to build a crack-free concrete slab or foundation wall. However, it is possible to control the cracking process by deliberately cracking the concrete (Figure 4.1). These deliberate cracks are called control joints. Cracks do not naturally occur in straight lines, nor do they happen in predictable places; but control joints cause concrete to crack along straight lines and in predictable locations where builders can better deal with them. Home owners get annoyed at cracks in concrete, but home owners don't have a problem with control joints. Cracks are bad. Control joints are good.

Concrete also shrinks, creeps and moves. This is also true for masonry and brick, only more so. Masonry and brick swell when they get wet. Concrete can shrink while brick is swelling. Concrete moves. Masonry moves. Brick moves. Let them move.

When wood gets wet it expands; when it dries it shrinks. Wood is almost always in the process of either getting wet, absorbing moisture or drying. Therefore, wood is almost always moving. Wood has always moved and will always move. Nailing wood, screwing wood and gluing wood will not prevent it from moving. It is not possible to build a wood wall, floor, roof or foundation and not have it move. Let it move.

Mixing wood with concrete, masonry and brick makes building interesting but also makes buildings move. Buildings will always move. It is not possible to build buildings that do not move. Let them move.

Since buildings move, it is not possible to build one without holes. Builders can reduce the number of holes; builders can control the size of holes. Builders can control the types of holes. But make no mistake about it, there will be holes. The trick is to keep the water out, even though you have holes. Fortunately, water is lazy. Water will always choose the easiest path to travel. If you provide an easy path for water to travel to a foundation drain, it will follow that path rather than a path through a foundation wall, even if the foundation wall has holes. And we know the foundation wall will have holes despite our best efforts.

Water Managed Foundations

Water managed foundation systems rely on two fundamental principles (Figure 4.2):

- keep rainwater 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 buildup 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.

Frost Movement

Frost exacerbates foundation movement. The key to frost management is also the key to water management. Keep water away from the foundation wall so that there is no water to freeze. Garages are most susceptible to frost damage due to lack of heat in a garage. Keep the water away from a garage foundation wall. If water freezes in the ground anyway, let the garage foundation move in a manner that won't destroy the house foundation (Figures 4.3 and 4.4).

Soil Gas

Keeping soil gas (radon, moisture vapor, herbicides, termiticides, methane, etc.) out of foundations cannot be done by building hole-free foundations. 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 basement floors 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 (Figure 4.5). An exhaust fan can be added later, if necessary.

Moisture

Controlling moisture vapor in foundations relies first on keeping it out, second, and on letting it out when it gets in. Make no mistake, it will get in. The issue is complicated by the use of concrete and masonry because there are thousands of pounds of water stored in freshly cast concrete and freshly laid masonry to begin with. This moisture of construction has to dry somewhere, and it usually (but not always) dries to the inside.

For example, we put coarse gravel (no fines) and a polyethylene vapor diffusion retarder under a basement concrete slab to keep the moisture vapor and water in the ground from getting into the slab from underneath. The gravel and polyethylene do nothing for the water already in the slab. This water can only dry into the basement. Installing flooring, carpets or tile over this concrete before it has dried sufficiently and in a manner that does not permit drying, is a common mistake that leads to mold, buckled flooring and lifted tile.

Similarly, we install dampproofing on the exterior of concrete foundation walls and provide a water managed foundation system to keep moisture vapor and water in the ground from getting into the foundation from the exterior. Again, this does nothing for the water already in the foundation wall. When we then install interior insulation and finishes on the interior of a foundation wall in a manner that does not permit drying to the interior, mold will grow.

Foundation wall and slab assemblies must be constructed so that they resist moisture vapor and water from getting in them, but they also must be constructed so that it is easy for moisture vapor to get out when it gets in or if the assembly was built wet to begin with (as they typically are).

Insulating under a concrete slab with vapor permeable or semi-vapor permeable rigid insulation will cause the concrete slab to dry into the ground as well as into the basement. By insulating under the slab, the slab becomes much warmer than the ground. Moisture vapor flows from warm to cold. If the under slab insulation is not a major vapor diffusion retarder, the slab will be able to dry into the ground, even if the ground is saturated. Using a polyethylene vapor diffusion retarder with under slab insulation is counterproductive. You should use either a polyethylene vapor diffusion retarder or under slab insulation, but not both.

This approach can also be applied to foundation walls that are insulated on the exterior. By warming the foundation walls relative to the ground, the moisture moves outwards into the ground. Again, the exterior insulation must not be a major vapor diffusion retarder, and dampproofing cannot be installed. The exterior insulation used must also be a capillary break and provide drainage. Only rigid fiberglass, rock and slag wool insulation have these two properties.

Drying a foundation wall assembly or floor slab after it is insulated and after surface finishes have been installed should only be done using diffusion ("letting them breathe"), not air flow ("ventilation"). Allowing interior air (that is usually full of moisture, especially in the humid summer months) to touch cold foundation surfaces will cause condensation and wetting, rather than the desired drying. It is important that interior insulation assemblies and finishes be constructed as airtight as possible (but vapor permeable). This will prevent interior moisture-laden air from accessing cold surfaces during both the winter and summer and still allow the assemblies to dry.

Crawl Spaces

Constructing vented crawl spaces is a bad idea for reasons similar those explained above. Venting a crawl space with exterior, humid air during summer months leads to the wetting of crawl space assemblies, rather than drying, since crawl space surfaces will be cooler than the outside air. Crawl spaces should be constructed like mini basements. They should be heated during the winter and cooled during the summer. They should be enclosed like any other conditioned space, such as a bedroom or a living room.

If, for unavoidable reasons, a crawl space must be vented, the crawl space floor assembly should be constructed like any exterior wall assembly with impermeable insulating sheathing, only with the assembly lying flat—horizontal (Figure 4.18).

Polyethylene Under Slabs

A sand layer is sometimes installed over a polyethylene vapor diffusion retarder located under a concrete slab. It is thought by some that the sand layer will protect the polyethylene from damage and act as a receptor for excess mix water in the concrete slab when the concrete is cast. This is an extremely bad idea. If ground water rises sufficiently to contact the underside of the polyethylene, water will enter the sand layer and be held in the sand layer by capillary forces, even after the groundwater level drops. Since the polyethylene is between the water-soaked sand and the ground, the only way for the water to get out is up into the building through the concrete slab by diffusion. The wetting of the sand by groundwater can take only minutes, but the drying out may take a decade.

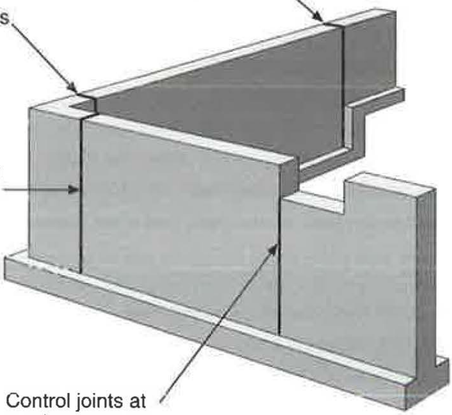
The polyethylene under a concrete slab can function as an effective vapor diffusion retarder even if it has holes. It does not need to be protected. The best way to deal with excess mix water is to not have any. Use low water-to-cement ratio concrete with an accelerator or a superplasticizer. It is faster and easier and, therefore, less expensive. The concrete costs a little more, but the labor is much less.

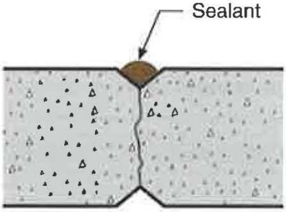
Carpets

Installing carpets on cold, damp concrete floor slabs can lead to serious allergic reactions and other health-related consequences. It is not recommended that carpets be installed on concrete slabs unless the carpets can be kept dry and warm. In practice, this is not possible unless floor slab assemblies are insulated and basement areas are conditioned.

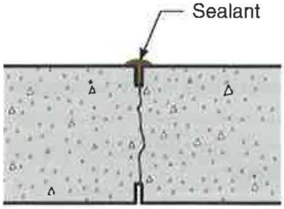
Insects

There is no good way of dealing with termites. Using a protective membrane as a termite barrier coupled with soil treatment seems to work on the few projects that have used the approach. However, there is no universal consensus on this matter as no long term performance information is available. The protective membranes used have been adhesive backed roll roofing, waterproofing membranes or ice dam protection membranes. Urethane based sealants are also used to seal the gaps between basement floor slabs and perimeter foundation walls. Their long term effectiveness in controlling termite entry is also unknown.





Diagonally cut 2 x 2's in forms provide goose neck joint



Saw cut joint

Figure 4.1
Control Joints in Concrete Foundation Walls

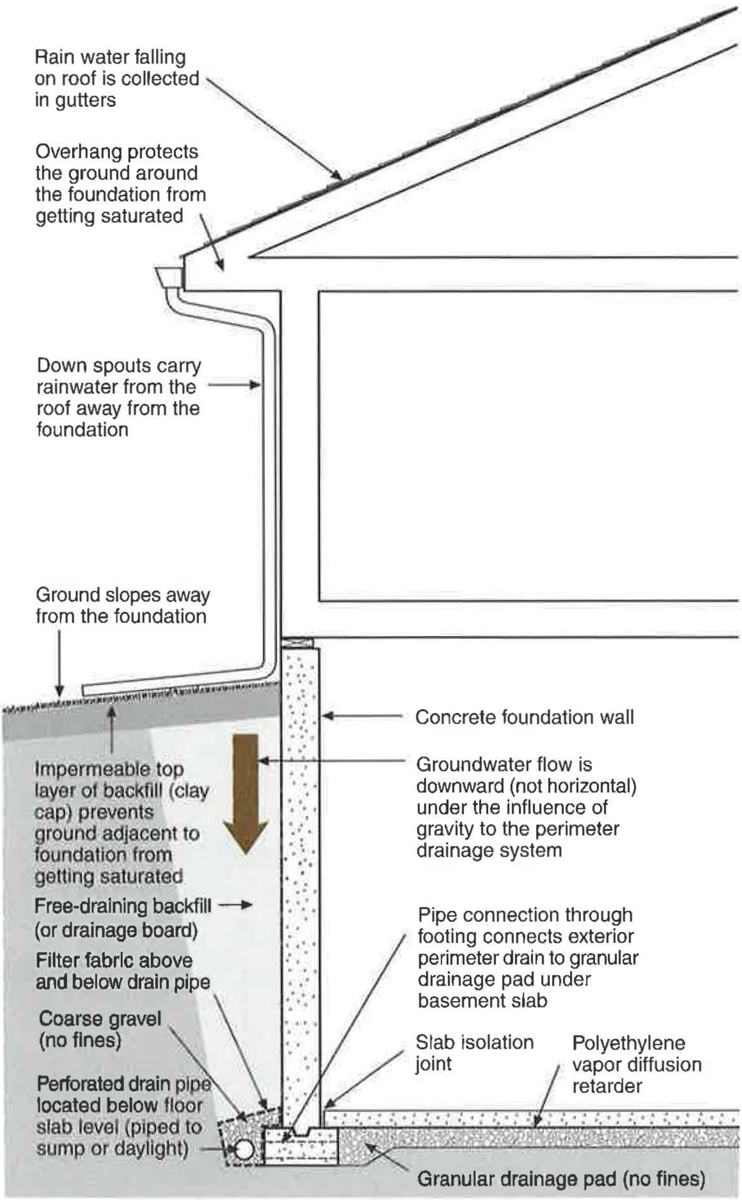


Figure 4.2
Water Managed Foundations

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

4 Foundations

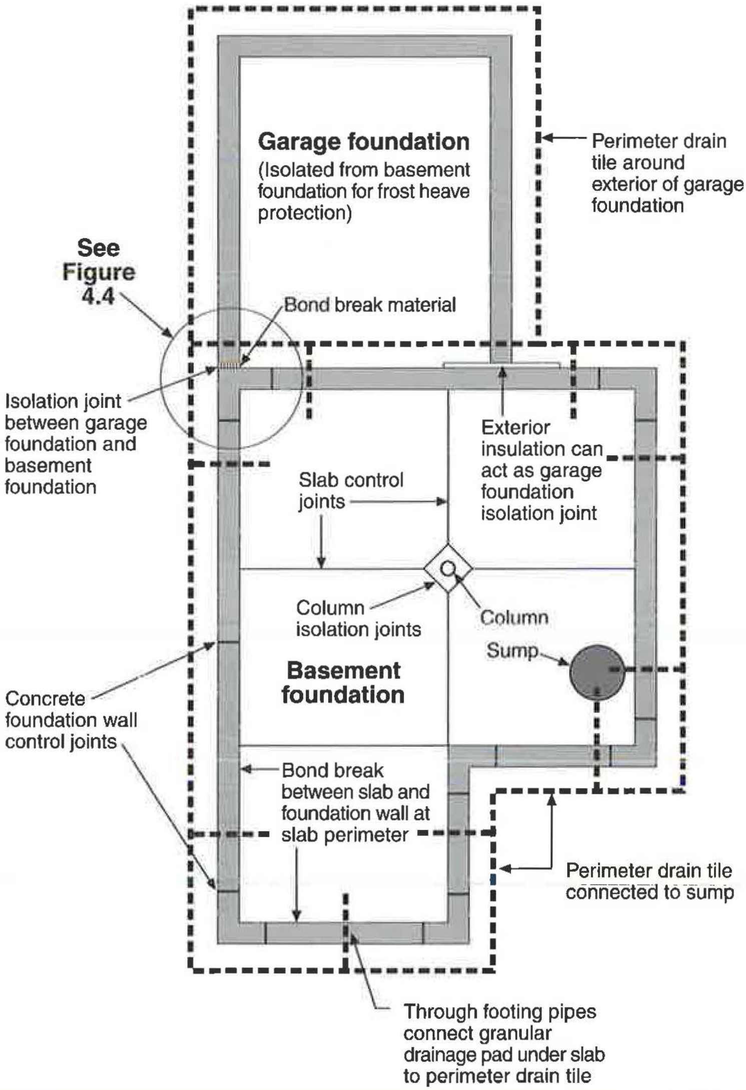


Figure 4.3
Sub Grade Drainage System

- Garage foundation isolated from basement foundation for frost protection
- Perimeter drain also protects garage foundation
- Joints should be sealed

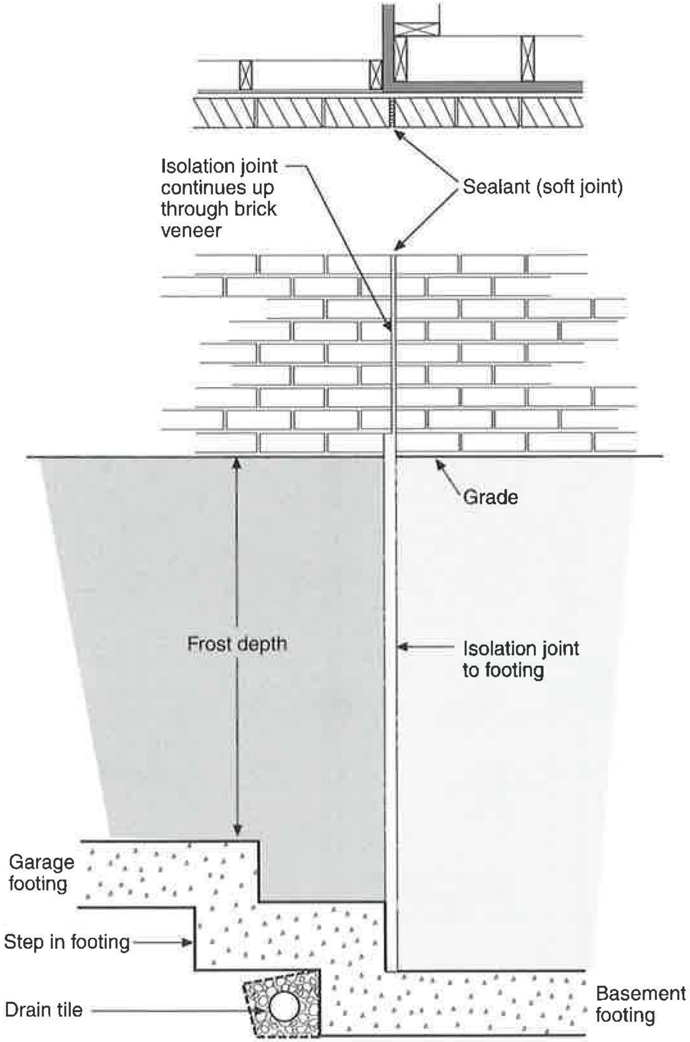


Figure 4.4
Isolation Joint Between Garage and Basement Foundation

- If frost heave moves garage – basement remains unaffected

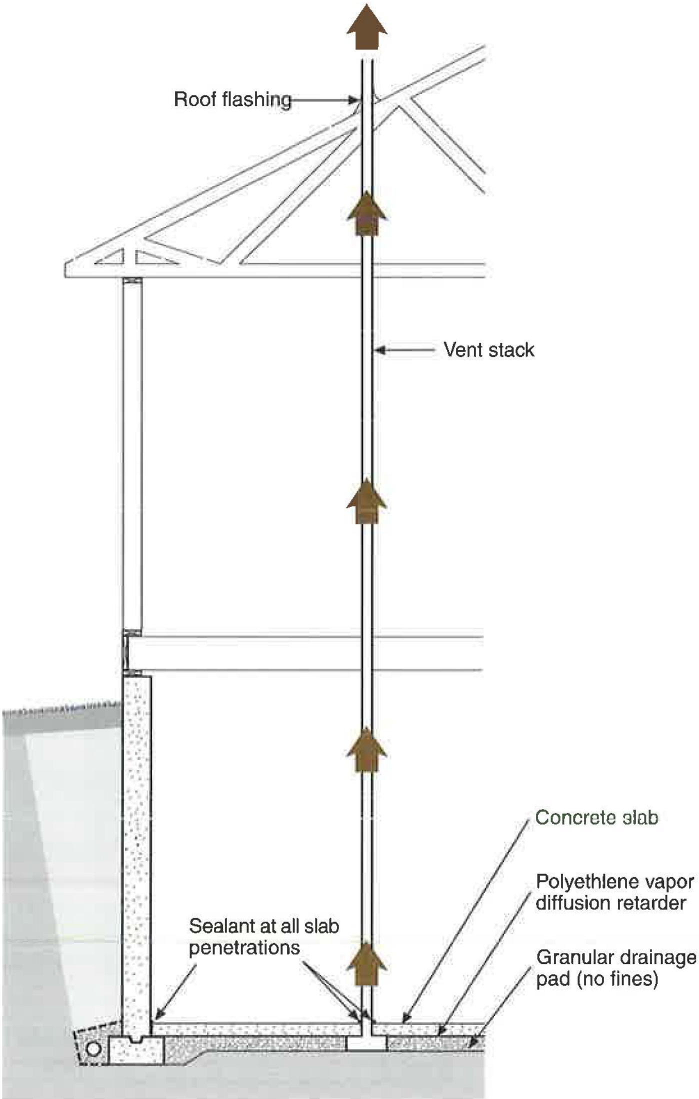


Figure 4.5
Soil Gas Ventilation System

- Granular drainage pad depressurized by active fan located in attic or by passive stack action of warm vent stack located inside heated space

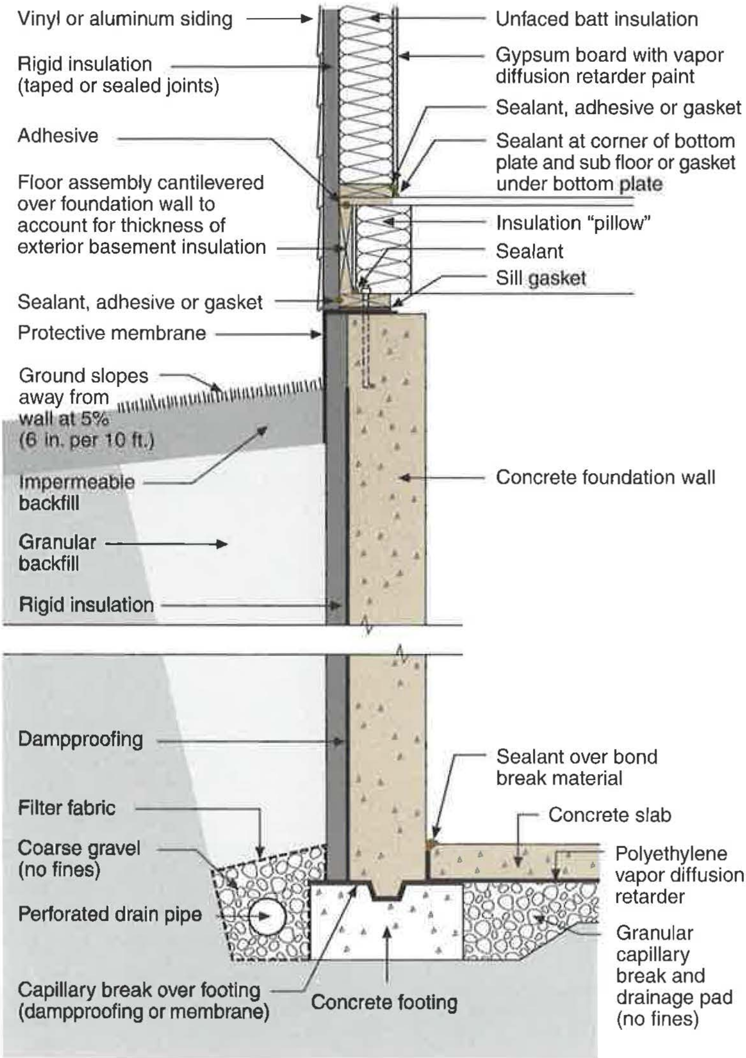


Figure 4.6
Externally Insulated Concrete Basement — Vinyl or Aluminum Siding

- Concrete wall warm, can dry to the interior; extremely low likelihood of mold
- Basement floor slab can dry to the interior
- Protective membrane acts as termite barrier
- Insulation pillow is batt insulation placed in a plastic bag and snugly fit between joists

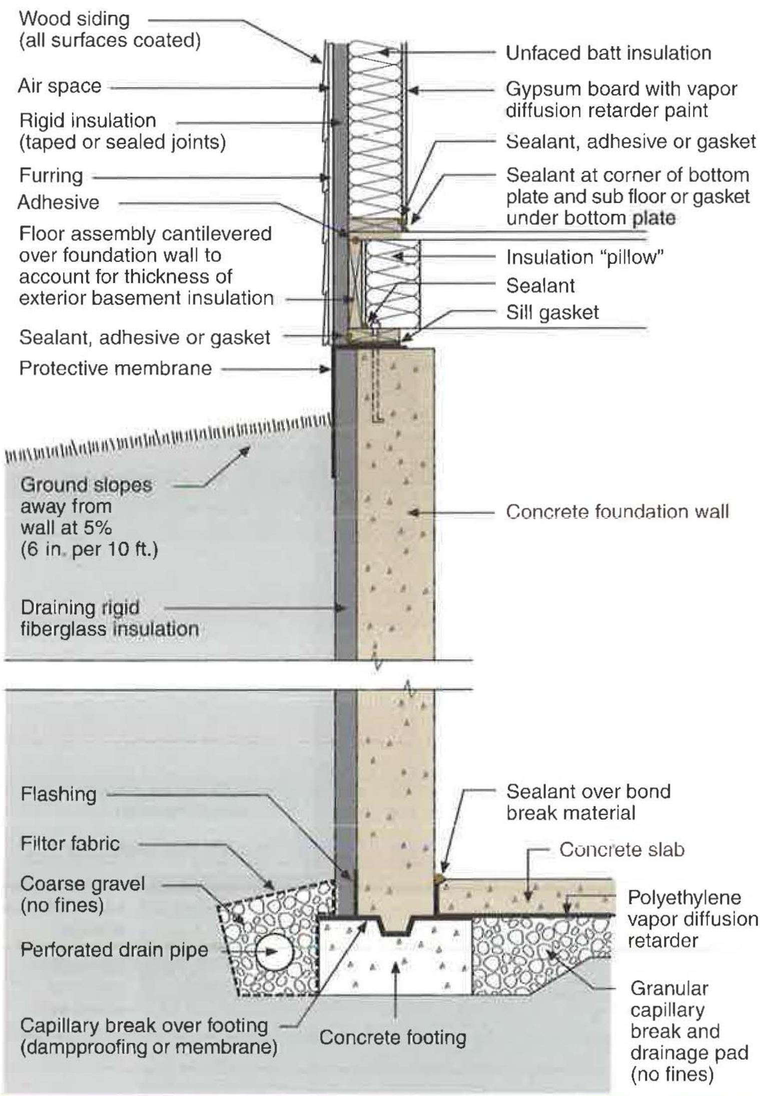


Figure 4.7
Externally Insulated Concrete Basement — Wood Siding

- Draining rigid fiberglass insulation also acts as capillary break (no dampproofing required)
- Concrete wall warm, can dry to the interior and exterior (since no dampproofing); lowest likelihood of mold
- Basement floor slab can dry to the interior
- Protective membrane acts as termite barrier

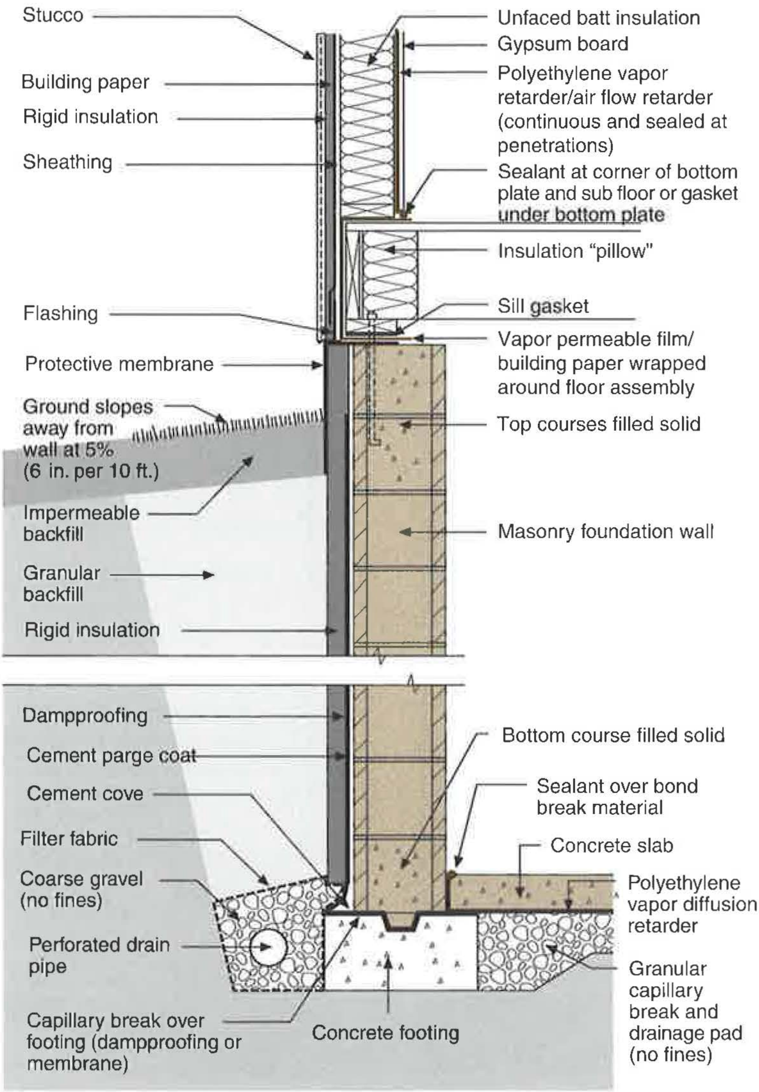


Figure 4.8
Externally Insulated Masonry Basement — Stucco

- Masonry wall warm, can dry to the interior; extremely low likelihood of mold
- Basement floor slab can dry to the interior
- Protective membrane acts as termite barrier
- Insulation pillow is batt insulation placed in a plastic bag and snugly fit between joists

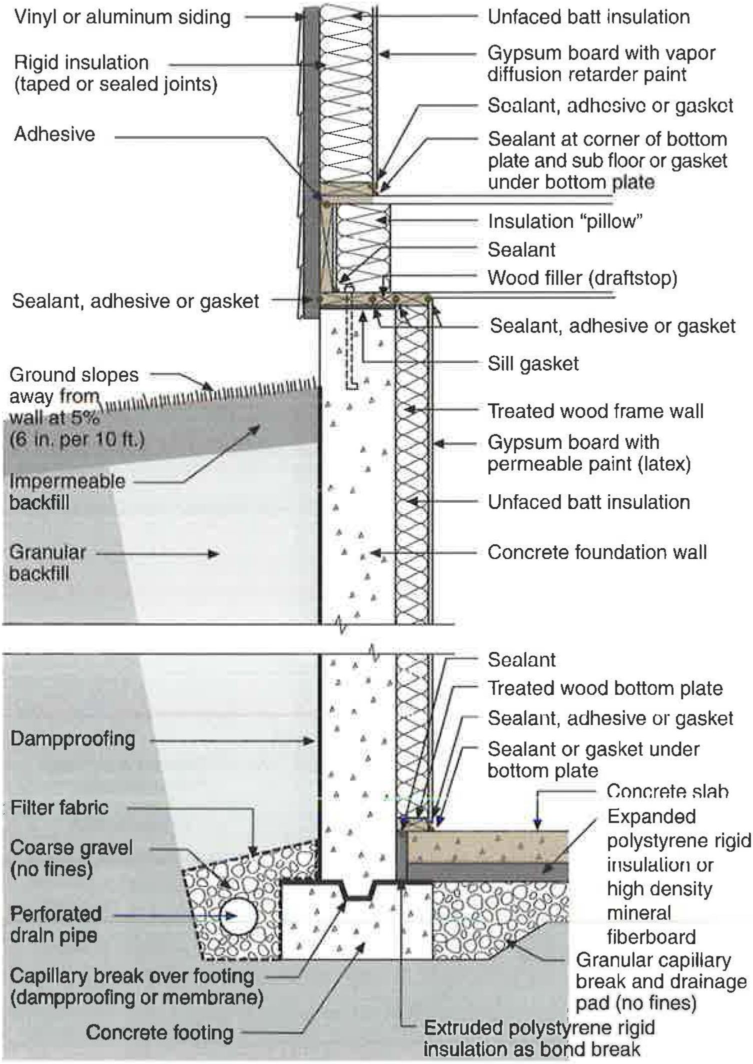


Figure 4.9
Internally Insulated Concrete Basement — Vinyl or Aluminum Siding

- Concrete wall cold, can only dry to the interior if interior assemblies are vapor permeable, mold possible if interior assemblies do not permit drying
- Cold concrete wall must be protected from interior moisture-laden air in winter and in summer
- Basement floor slab is warm, can dry to the ground (since no under slab vapor diffusion retarder) as well as to the interior; lowest likelihood of mold

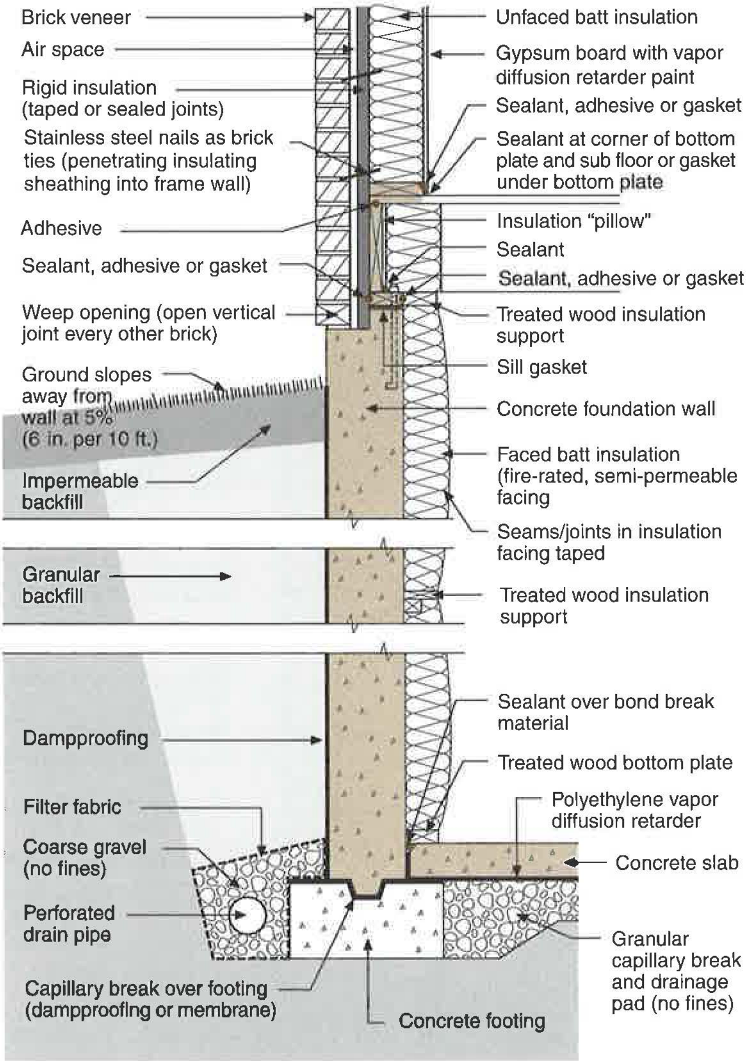


Figure 4.10
Internally Insulated Concrete Basement — Brick Veneer

- Concrete wall cold, can only dry to the interior if interior assemblies are semi-vapor permeable; mold possible if interior assemblies do not permit drying
- Cold concrete wall must be protected from interior moisture-laden air in winter and in summer
- Basement floor slab can dry to the interior
- Airspace behind brick veneer can be as small as 3/8", 1" is typical

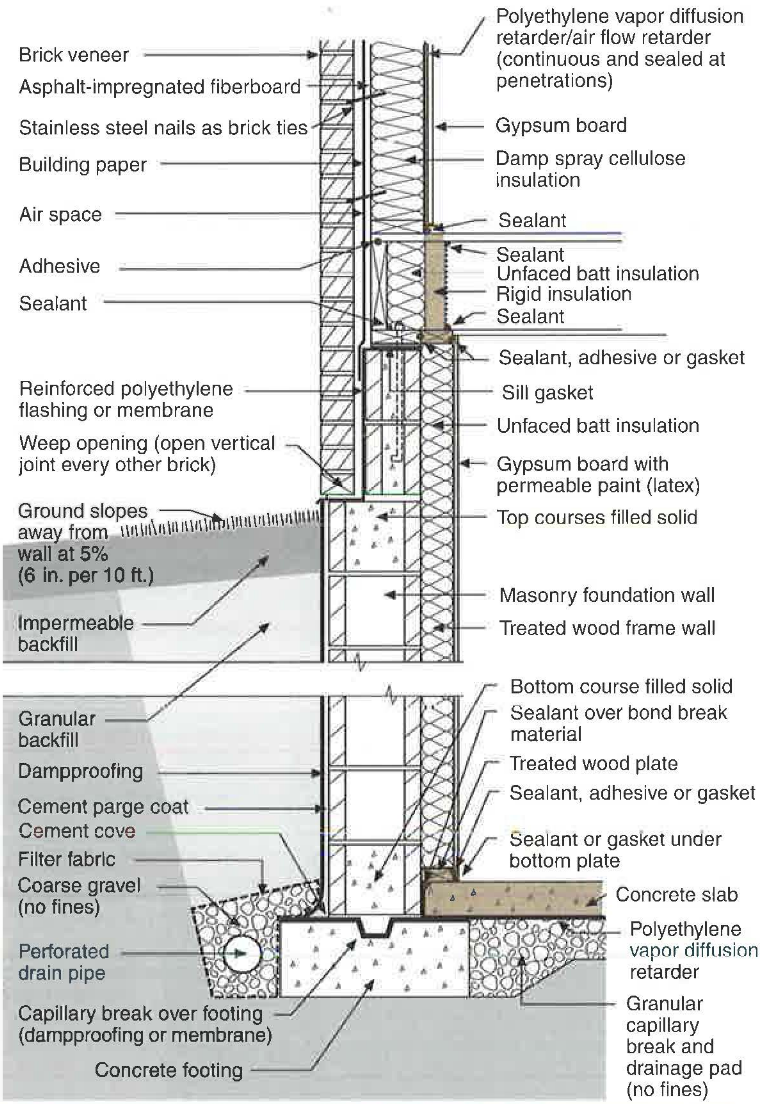


Figure 4.11
Internally Insulated Masonry Basement — Brick Veneer

- Masonry wall cold, can only dry to the interior if interior assemblies are vapor permeable; mold possible if interior assemblies do not permit drying
- Cold masonry wall must be protected from interior moisture-laden air in winter and in summer
- Basement floor slab can dry to the interior
- Airspace behind brick veneer can be as small as $^3/_8$", 1" is typical

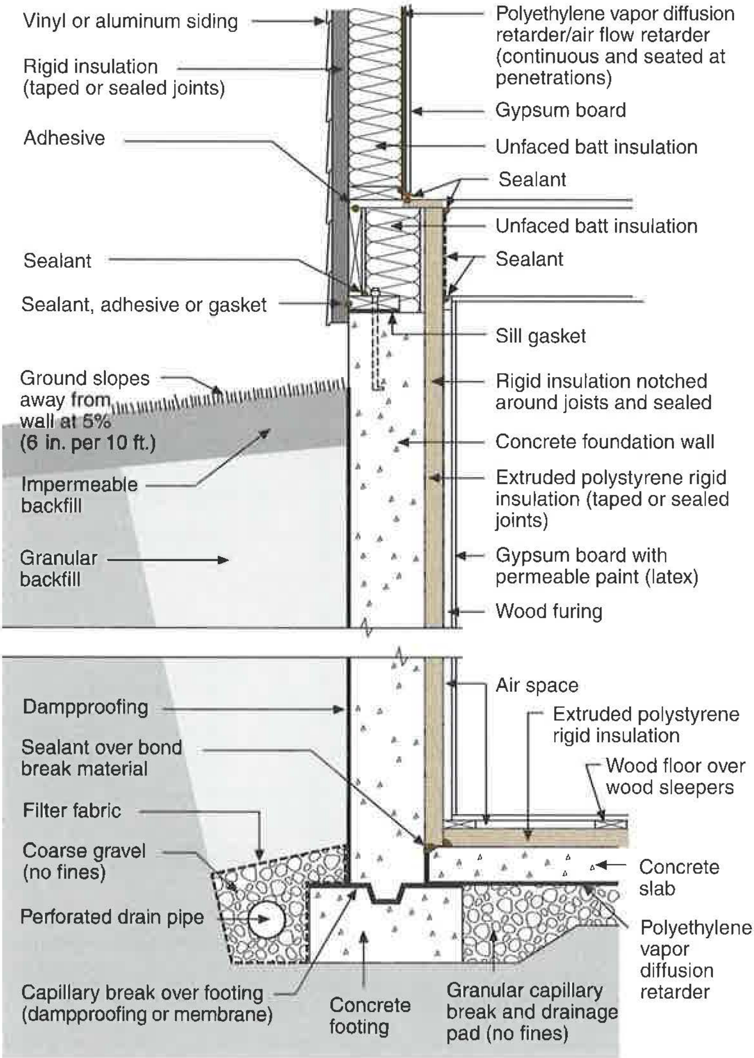


Figure 4.12
Internally Insulated Concrete Basement — Vinyl or Aluminum Siding

- Concrete wall cold, can only dry to the interior if interior assemblies are semi-vapor permeable; low likelihood of mold
- Cold concrete wall must be protected from interior moisture laden air in winter and in summer
- Basement floor slab can dry to the interior if interior assemblies are semi-vapor permeable; low likelihood of mold

4
Foundations

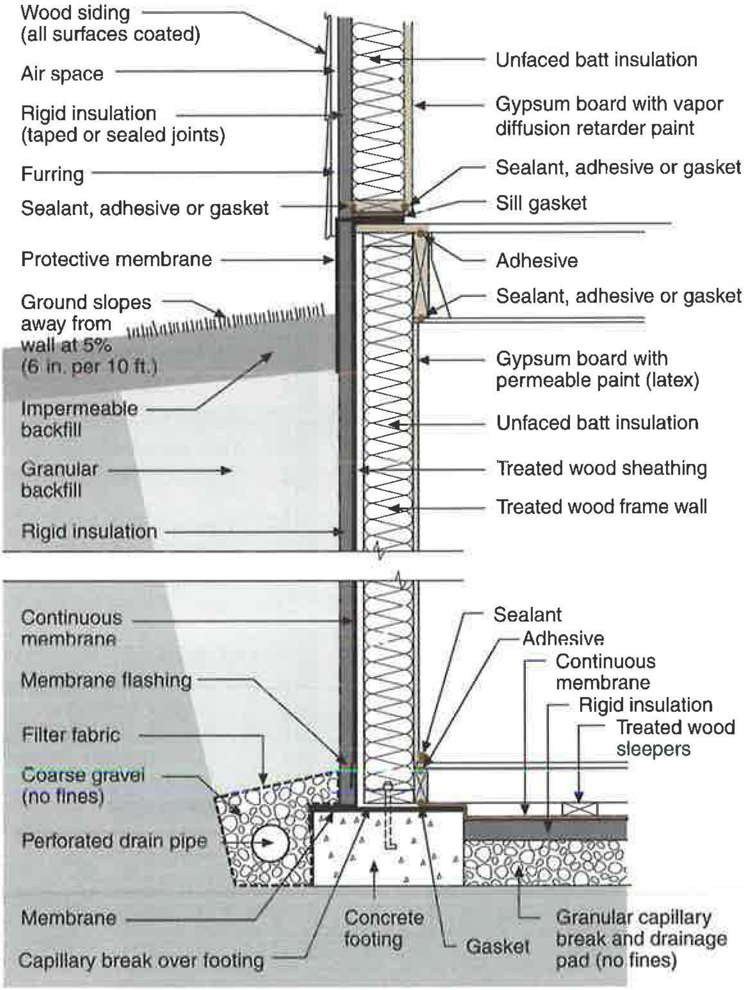


Figure 4.13
Externally Insulated Wood Basement — Wood Siding

- Wood frame warm, can only dry to the interior if interior finishes are vapor permeable; low likelihood of mold
- Wood floor assembly is warm, can dry to the interior; low likelihood of mold
- Protective membrane acts as termite barrier

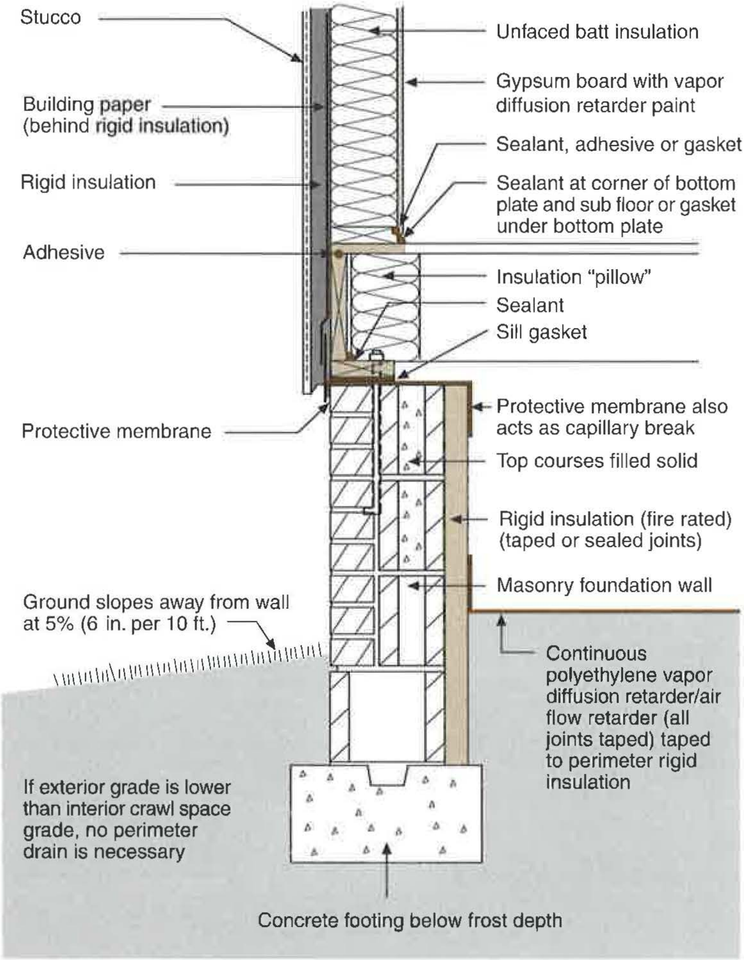


Figure 4.14
Internally Insulated Masonry Crawl Space — Stucco

- Masonry wall cold, can dry to the exterior; low likelihood of mold
- Protective membrane acts as termite barrier
- Rigid insulation must be fire rated if it is left exposed on the interior
- Building paper installed shingle fashion acts as draining plane located behind rigid insulation
- Capillary break over footing can be omitted if sufficient drying to exterior is provided above grade

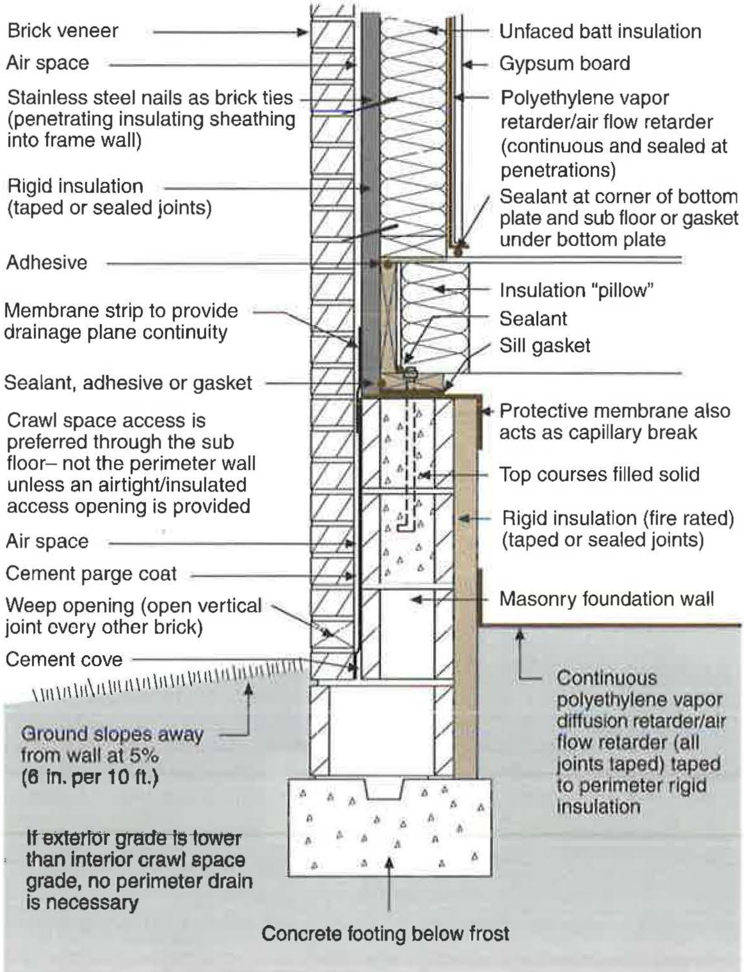


Figure 4.15
Internally Insulated Masonry Crawl Space — Brick Veneer

- Masonry wall cold, can dry to the exterior; low likelihood of mold
- Protective membrane acts as termite barrier
- Rigid insulation must be fire rated if it is left exposed on the interior
- Capillary break over footing can be omitted if sufficient drying to exterior is provided above grade
- Airspace behind brick veneer can be as small as $^3/_8$", 1" is typical

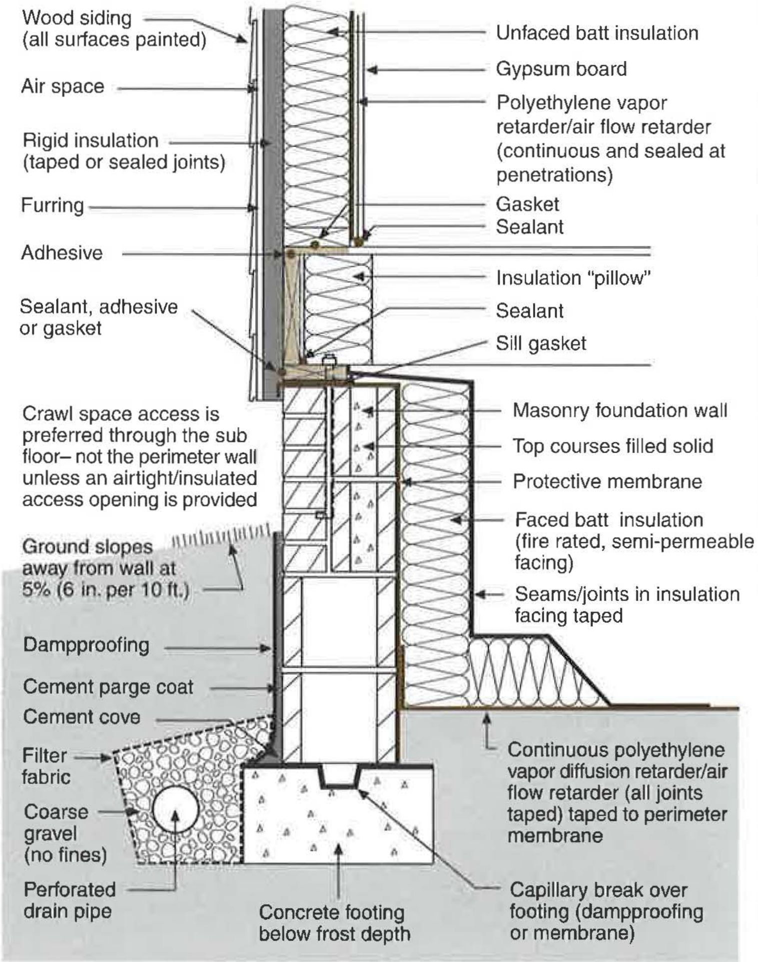


Figure 4.16
Internally Insulated Masonry Crawl Space — Wood Siding

- Masonry wall cold, masonry can dry to the exterior, insulation can only dry to the interior if interior insulation surface is semi-vapor permeable; mold possible if interior insulation surface does not permit drying
- Faced batt insulation must be fire rated if it is left exposed on the interior
- Insulation pillow is batt insulation placed in a plastic bag and snugly fit between joists

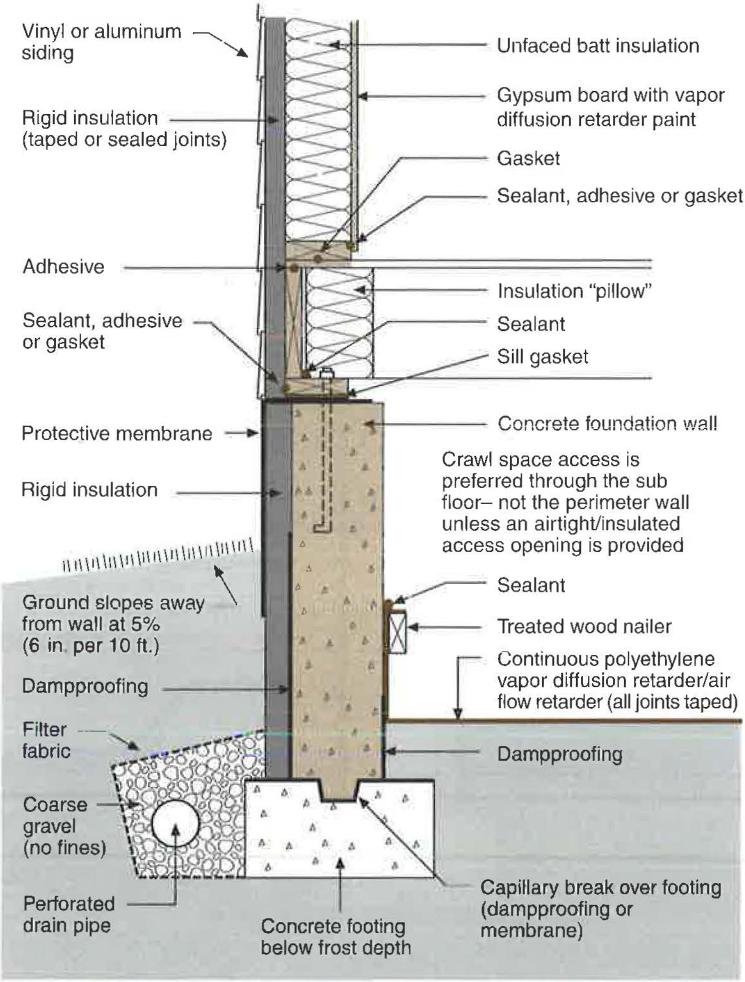


Figure 4.17
Externally Insulated Concrete Crawl Space — Vinyl or Aluminum Siding

- Concrete wall warm, can dry to the interior; extremely low likelihood of mold
- Protective membrane acts as termite barrier
- Perimeter drain is necessary since interior grade is lower than exterior grade
- Insulation pillow is batt insulation placed in a plastic bag and snugly fit between joists

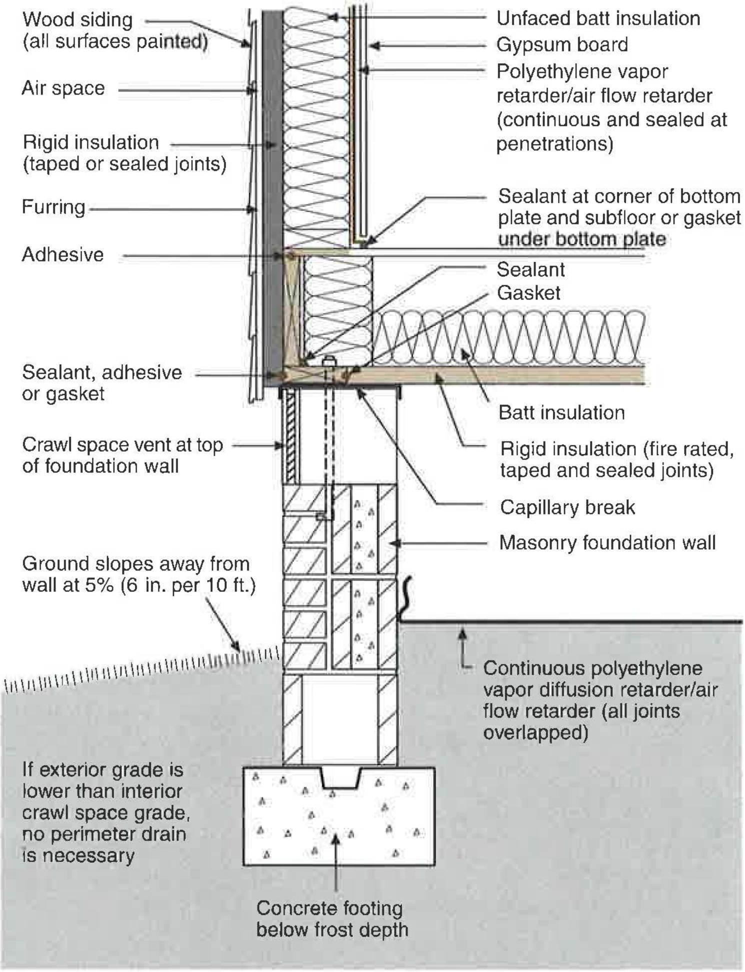


Figure 4.18
Vented Masonry Crawl Space — Wood Siding

- Rigid impermeable insulating sheathing protects underside of floor assembly from wetting during summer. Structural wood beams must also be similarly protected.
- Rigid insulation must be fire rated if it is left exposed under the floor framing in the crawl space
- Band joist assembly must be tight or entry of outside air will compromise the effectiveness of the floor cavity insulation

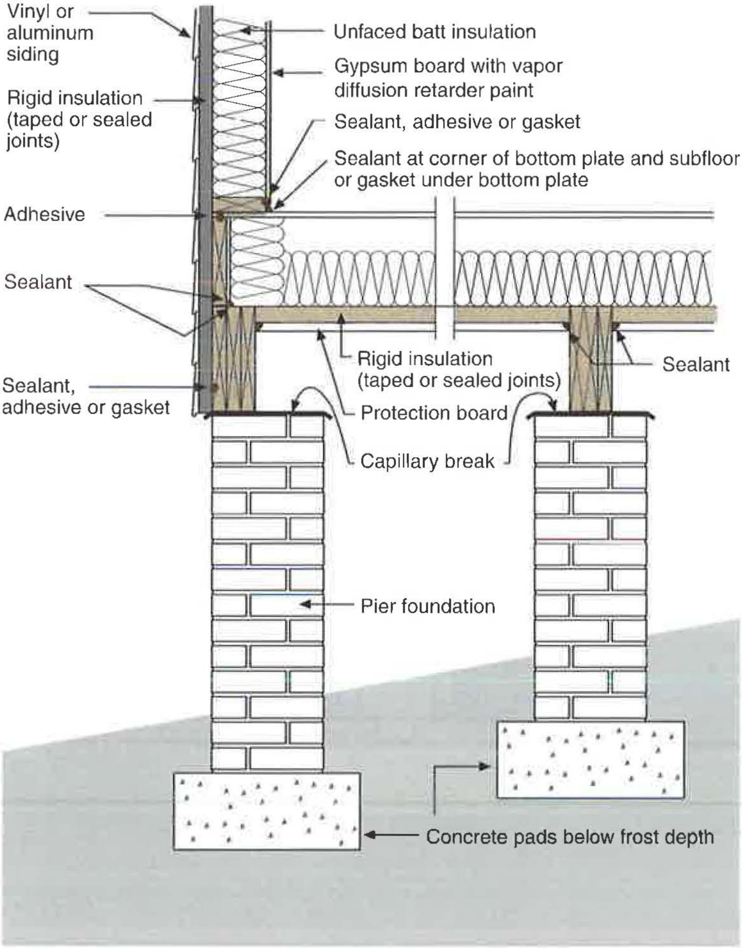


Figure 4.19
Pier Foundation — Vinyl or Aluminum Siding

- Rigid impermeable insulating sheathing protects underside of floor assembly from wetting during summer
- Floor cavity insulation held down in contact with rigid insulation – air space above insulation provides warm floor during winter

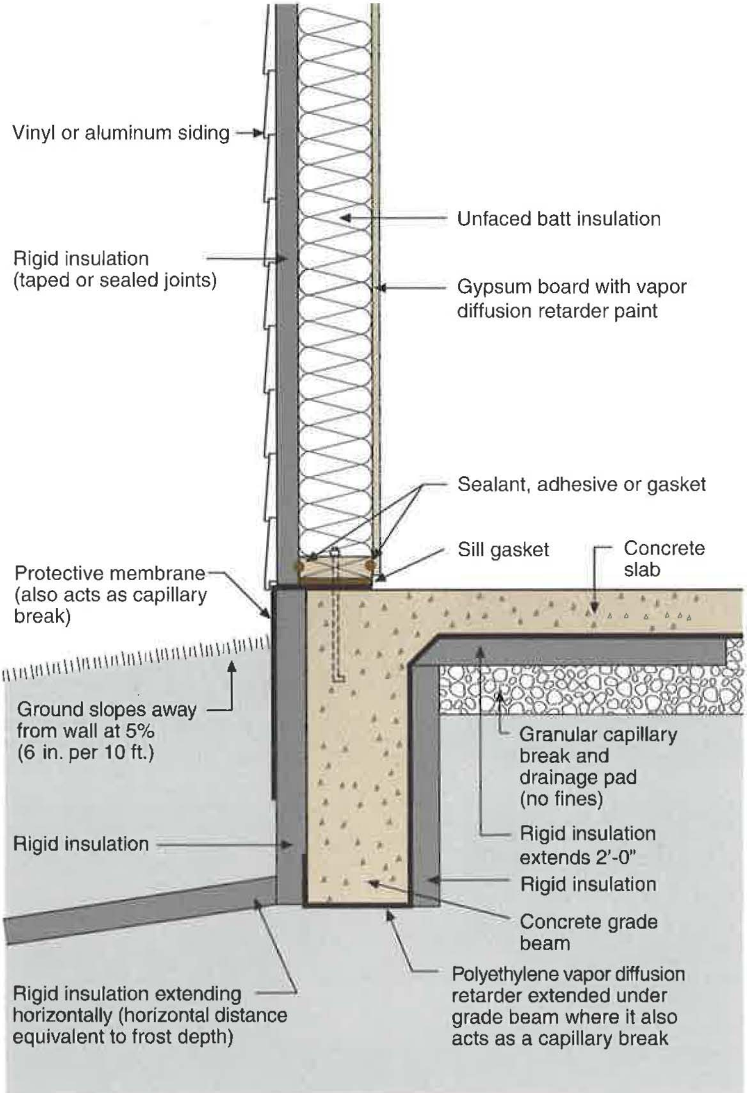


Figure 4.20
Monolithic Slab — Vinyl or Aluminum Siding

- Protective membrane acts as termite barrier
- Exterior horizontal rigid insulation provides frost protection

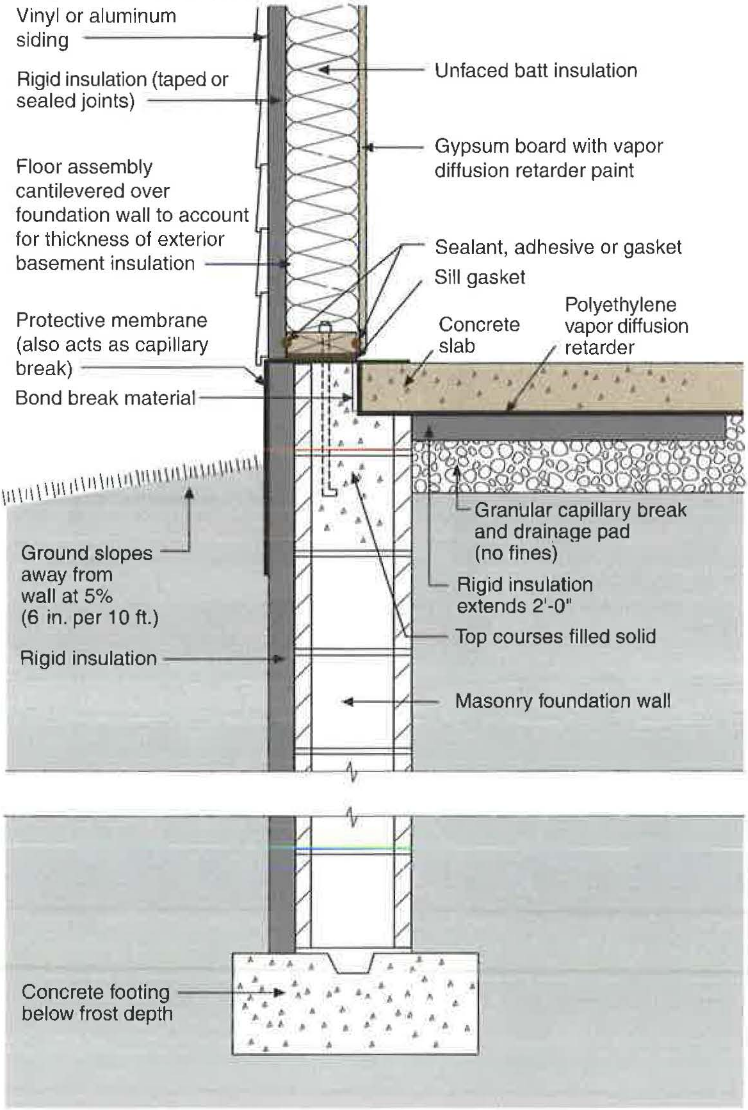


Figure 4.21
Slab with Masonry Perimeter — Vinyl or Aluminum Siding

- Protective membrane acts as termite barrier – sealed to slab
- Polyethylene acts as capillary break at masonry perimeter

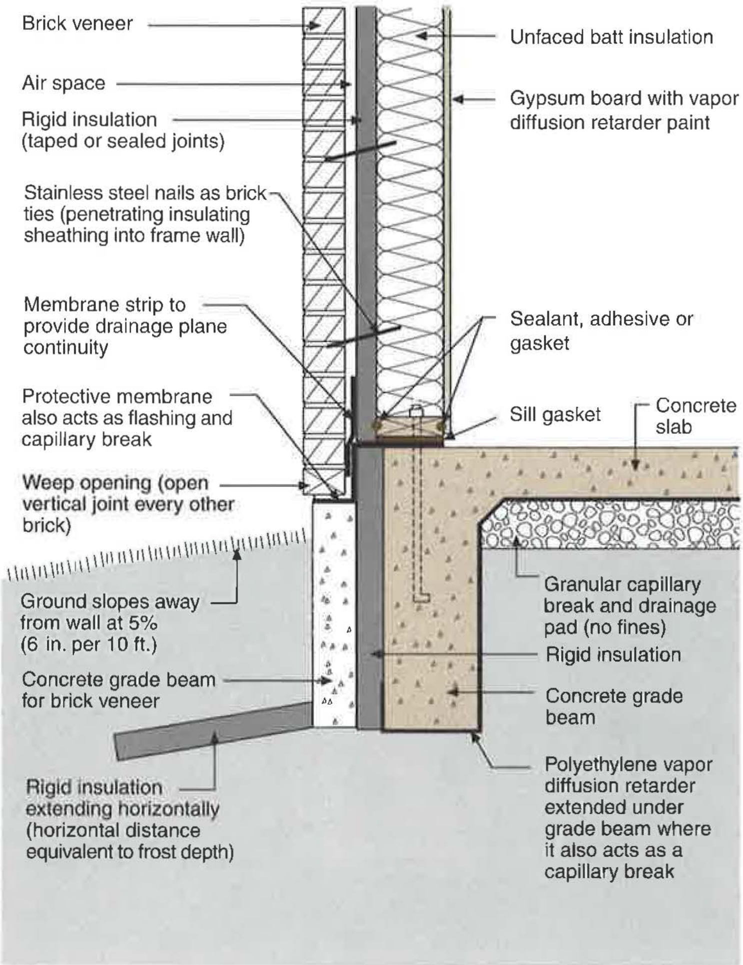


Figure 4.22
Monolithic Slab — Brick Veneer

- Protective membrane acts as termite barrier and acts as flashing at base of brick veneer
- Grade beam for brick veneer cast simultaneously with monolithic slab
- Exterior horizontal rigid insulation provides frost protection
- Airspace behind brick veneer can be as small as 3/8", 1" is typical

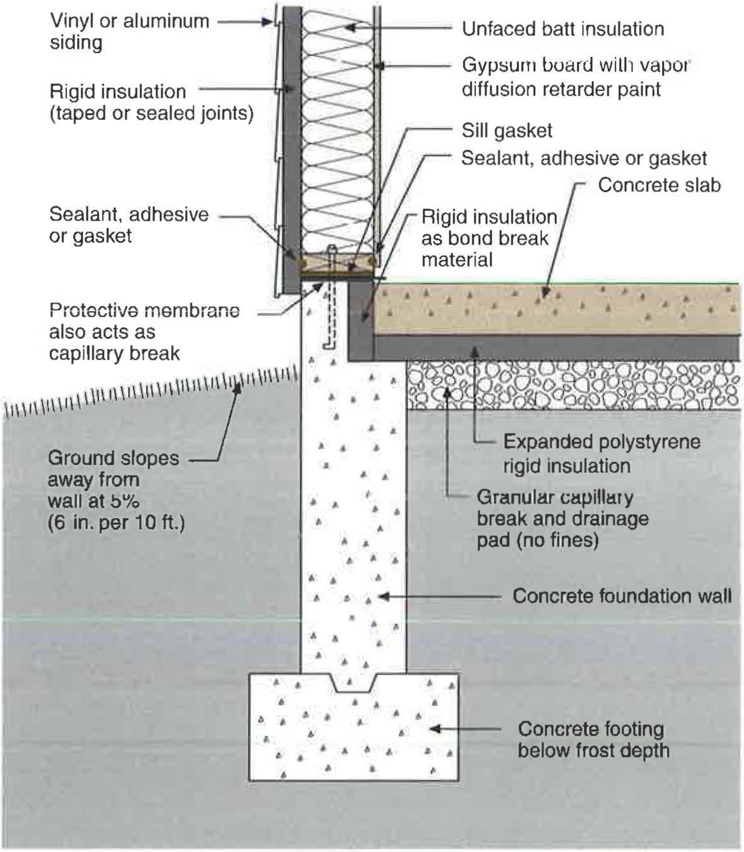


Figure 4.23
Slab with Concrete Perimeter — Vinyl or Aluminum Siding

- Protective membrane acts as termite barrier – sealed to slab
- Rigid insulation extends downward below top of concrete foundation wall to shelter horizontal joint
- Basement floor slab is warm due to sub-slab rigid insulation under entire floor; can dry to the ground (since there is no under slab vapor diffusion retarder, retarder insulation selected is semi-permeable) as well as to the interior, lowest likelihood of mold

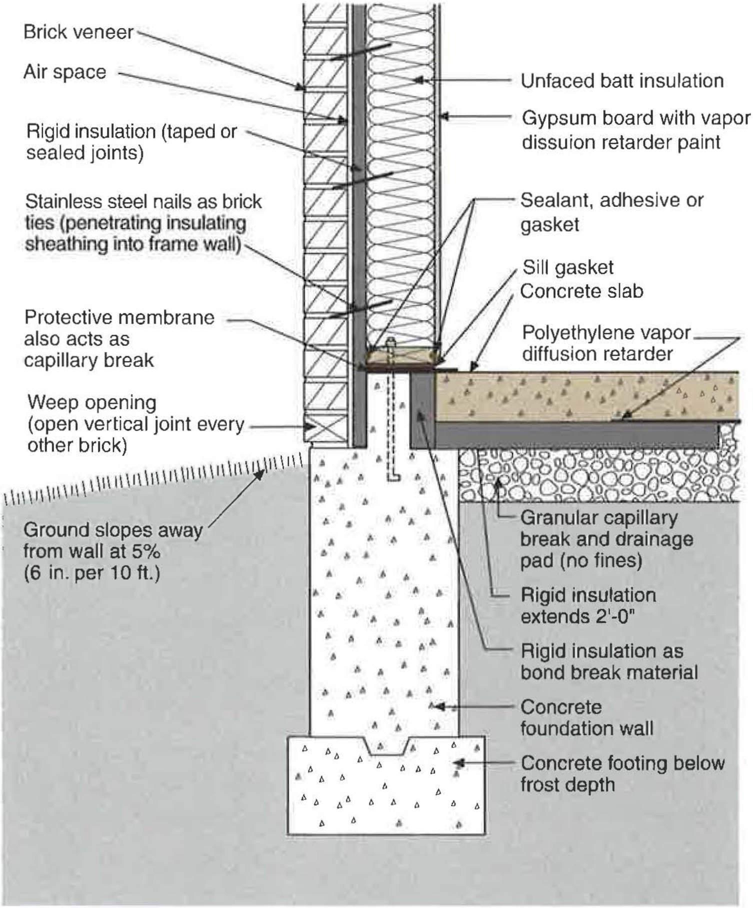


Figure 4.24
Slab with Concrete Perimeter — Brick Veneer

- Protective membrane acts as termite barrier – sealed to slab
- Airspace behind brick veneer can be as small as $^3/_8$", 1" is typical

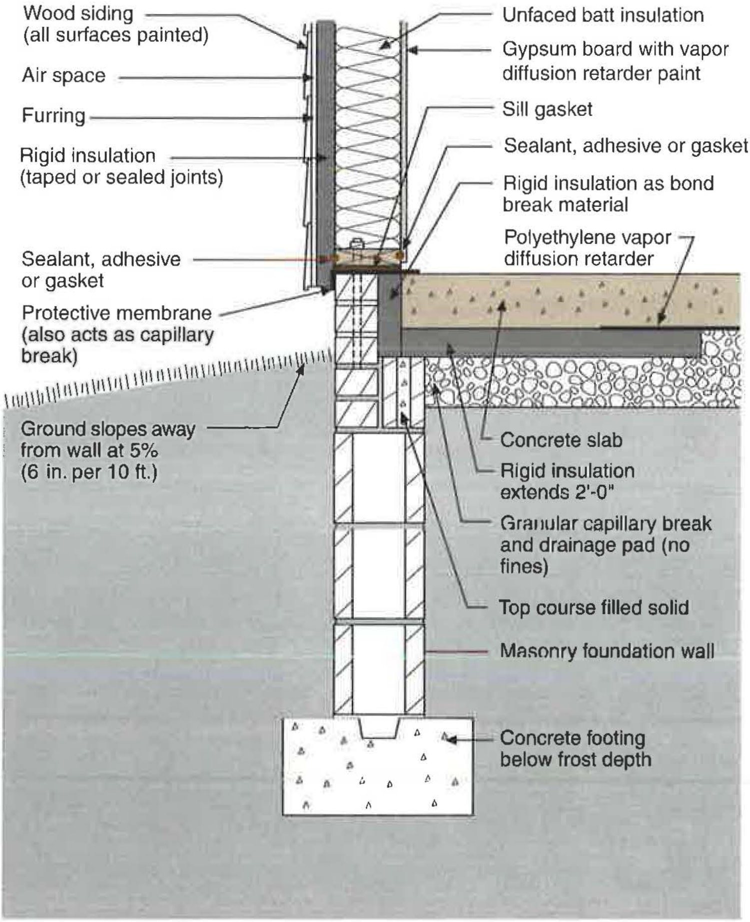


Figure 4.25
Slab with Masonry Perimeter — Wood Siding

- Protective membrane acts as termite barrier – sealed to slab

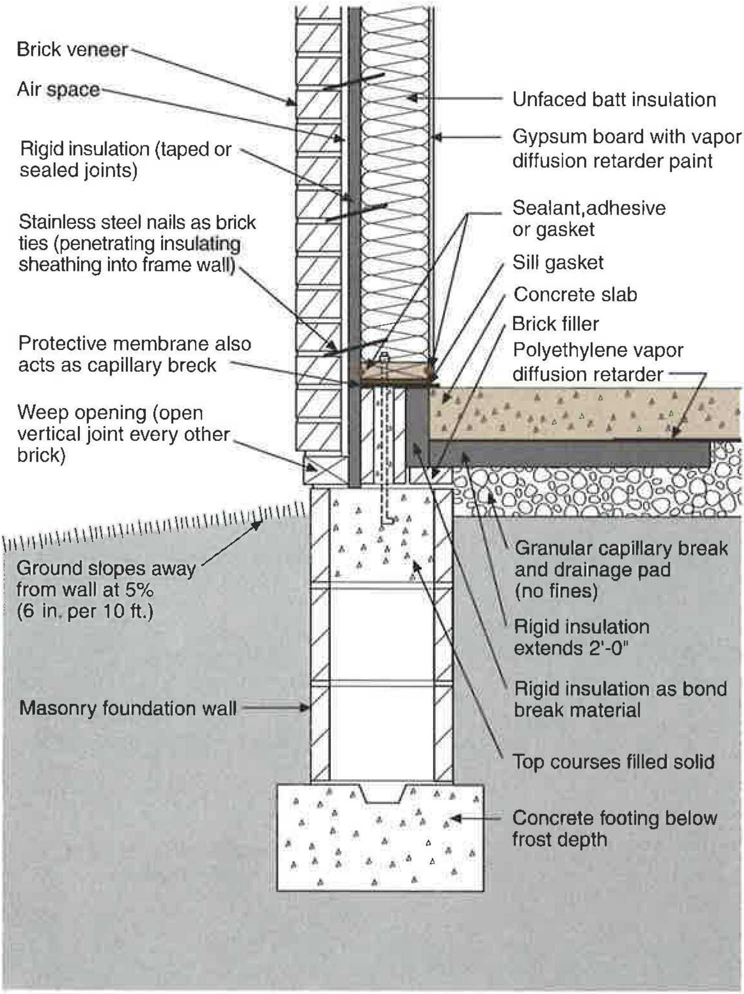


Figure 4.26
Slab with Masonry Perimeter — Brick Veneer

- Protective membrane acts as termite barrier – sealed to slab
- Brick veneer corbelled outwards at base to provide drainage space
- Airspace behind brick veneer can be as small as 3/8", 1" is typical

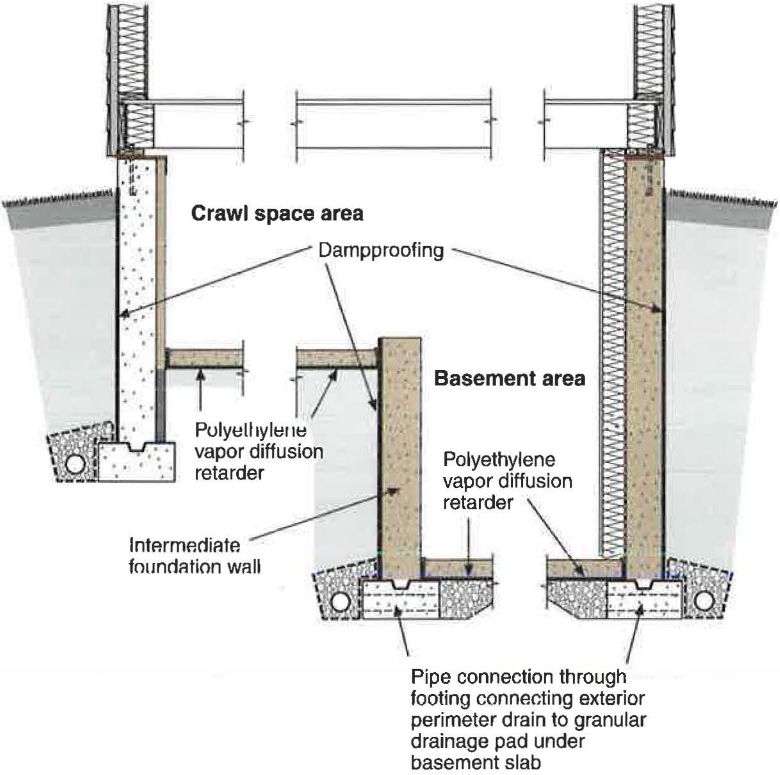


Figure 4.27
Crawl Space to Basement Continuity

- Crawl space area open to basement area and conditioned
- Slab cover or polyethylene air flow retarder over slab continuous with foundation perimeter and intermediate foundation wall

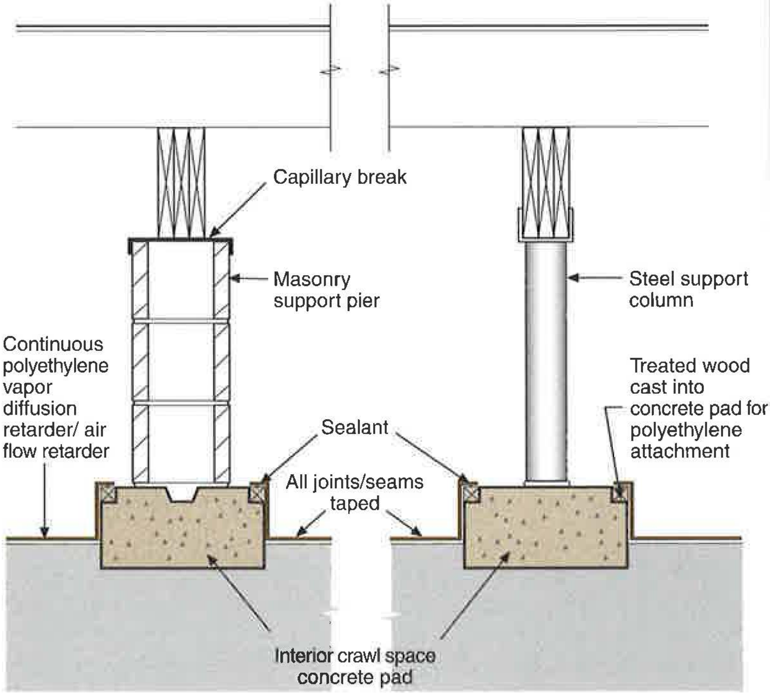


Figure 4.28
Air Flow Retarder Continuity at Piers

- All joints and seams in the polyethylene are taped

5
Framing

Three framing approaches are common in residential construction: platform frame, balloon frame, and post and beam. They can use combinations of wood, wood products, steel, masonry and concrete. They can be insulated on the inside, on the outside or in between. However, all have to:

- hold the building up
- keep the rain water out
- keep the wind out
- keep the moisture vapor out
- let the moisture vapor out if it gets inside
- keep the heat in during the winter
- keep the heat out during the summer

Concerns

If someone today invented wood, it would never be approved as a building material. It burns, it rots, it has different strength properties depending on its orientation, no two pieces are alike, and most cruelly of all, it expands and contracts based on the relative humidity around it. However, despite all of these problems, wood is the material of choice when building houses. In fact, we can use wood better than we can use steel, masonry and concrete.

We can compensate more easily for wood's poor qualities than those of steel, masonry and concrete. Steel is worse in a fire than wood because it twists and bends; steel rusts more easily than wood rots; and it is expensive and difficult to compensate for its thermal inefficiencies in an exterior wall. Masonry is too expensive in most applications to use structurally, as is concrete. In an earthquake, the most dangerous buildings are made of masonry and insufficiently reinforced concrete. Needless to say, it is expensive to reinforce masonry and concrete.

We are a wood dominated industry and will likely remain so. We have learned how to work with wood over the past several hundred years to overcome its inherent deficiencies. However, despite our vast experience, we must use wood better.

We use wood inefficiently. We put too much of it in our buildings in the wrong places and in the wrong ways. And then, in the presence of all this waste, we don't put it where it is needed.

Not enough wood in the right place is obviously a problem. Oops, it fell down. But how can too much wood hurt? Well, wherever you put wood, you can't put insulation. Where you don't have insulation, you have cold spots or hot spots. Cold spots and hot spots always cause trouble. Wood is also expensive; use too much of it and you hurt your wallet.

Frame Movement

Remember, wood always moves. How to attach things to something that is always moving becomes real important. Gypsum board doesn't crack all by itself. It cracks because what it is attached to moves more than the gypsum can. Use too much wood in the wrong places, use too much attachment of gypsum board to wood that is moving in the wrong places, and presto, you have cracks. Lots of them. It's better to use less wood with fewer attachments. One of life's least appreciated ironies is the more you attach gypsum board to wood, the more cracks you get. Longer nails, more nail pops. More nails, more cracks. More about this in the Drywall Chapter (See Chapter 10). In the meantime, in this chapter, we will show ho to eliminate as much wood as possible, by making sure we put it only where we really need it — for structure, draftstopping and firestopping.

In the past, framers have used wood much like drunken sailors on leave spend money. They felt they could never run out of wood and they put it everywhere, even where it was not needed. We do still. Look around your job site. Headers can be found in non-load bearing interior and exterior walls. Double plates are everywhere because we have not taken the time to figure out how to line up roof framing with wall and floor framing. Three stud corners to support gypsum board that doesn't need or want support. Cripples under window framing even though we hang windows. Studs on 16 in. centers rather than 24 in. centers to support gypsum board and siding that don't need it. Figures 5.1 through 5.5 and Figure 5.9 describe framing techniques that reduce wood waste, increase structural efficiency, promote thermally efficient walls and help reduce drywall cracking.

But where we really need wood, for draftstopping and firestopping we can't find it.

Rain

Another of life's ironies is that the strategy selected to keep rain out of a building will impact the how it is framed. So, maybe we should decide what the strategy is before we frame? Framers are responsible for installing building paper, sheathing and windows. The rain control strategy will decide whether building papers will be used or not, whether sheathing will be taped or glued or both, and whether window openings will be wrapped or not. Figures 5.46 through 5.49 show important flashing details when using taped insulating sheathing as a drainage plane. Keeping rain out of buildings is discussed in Appendix I.

Air Flow Retarder

The strategy selected to keep outside and inside air out of the building envelope will also impact the framing approach. Framers are responsible for installing exterior housewraps, insulating sheathings and maintaining the continuity of polyethylene air flow retarders (when used as the air flow retarder system), as well as the draftstops, firestops and framing used in rigid interior air flow retarders. Figures 5.6 through 5.8 and 5.10 through 5.14 show installation techniques for installing exterior insulating sheathings as exterior air flow retarders. Figures 5.17 through 5.39 show important air sealing details (draft stopping and fire stopping) that the framer must provide. Air flow retarders are discussed in Appendix II.

Moisture Vapor

The strategy selected to keep moisture vapor out of the building envelope yet allow moisture vapor out of the building envelope should it get in, will impact the framing approach since the approach selected will specify the type of sheathing used. Sheathings and vapor diffusion retarders are discussed in Appendix III. In addition, if a ventilated roof strategy is to be employed, the framer must install roofing members so that air can in fact flow from soffits to vents (Figures 5.40 through 5.43).

Paint and Trim

The manner in which wood siding and wood trim is installed determines the useful service life of paint and stain coatings as well as their useful service life. Wood siding and trim should always be coated on all six surfaces and should always be installed over spacers to promote drainage and drying (Figures 5.44 and 5.45). Paints and coatings are discussed in the Painting Chapter (See Chapter 11).

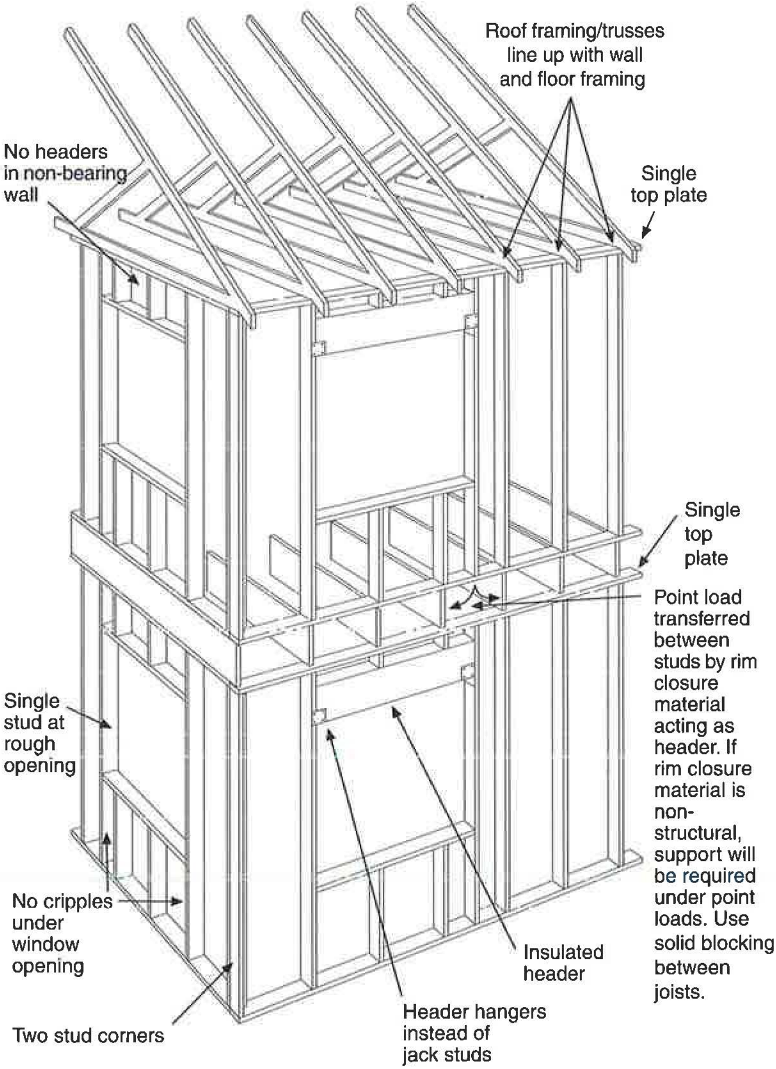


Figure 5.1
Stack Framing

- Eliminate headers in non-bearing interior walls

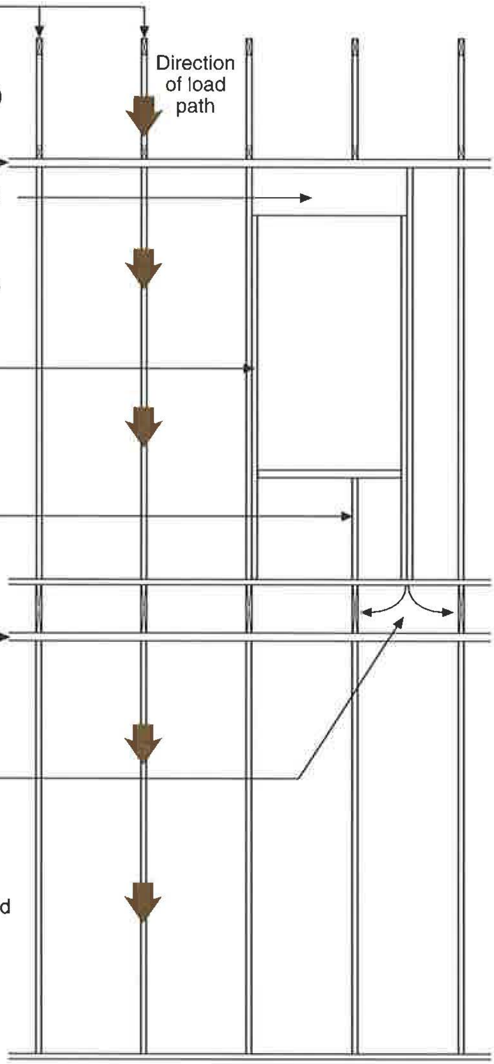


Figure 5.2
Stack Framing Elevation View

- Where single plates are used, floor to ceiling heights are affected (97" is standard). Custom cutting dimensional studs to 94" is recommended and results in no impact on gypsum board installation.

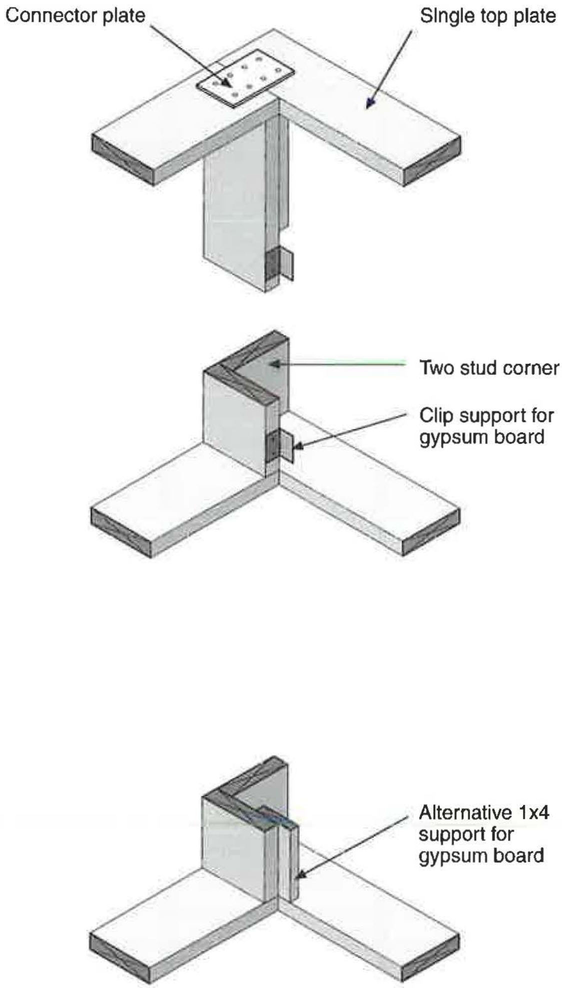


Figure 5.3
Corner Framing

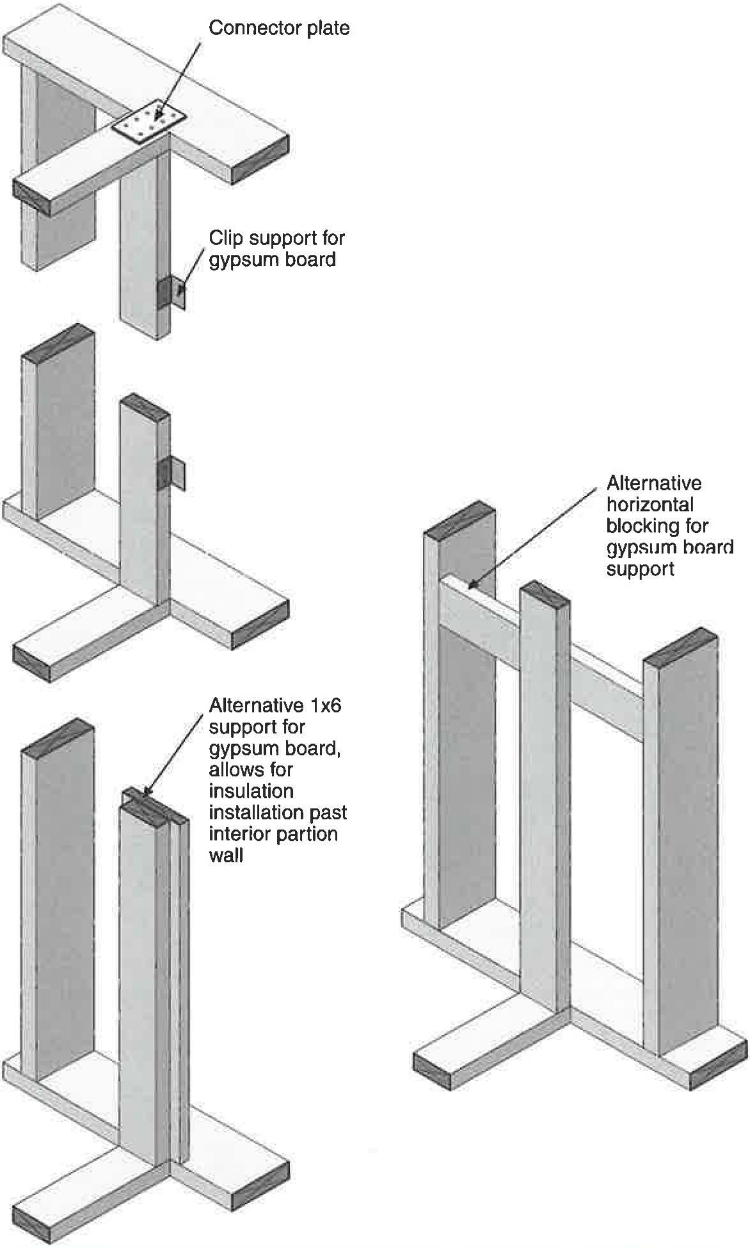
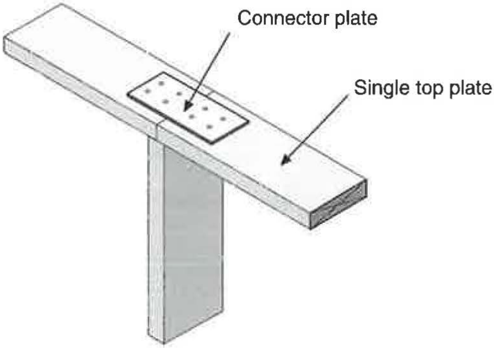


Figure 5.4
Interior Wall at Exterior Wall

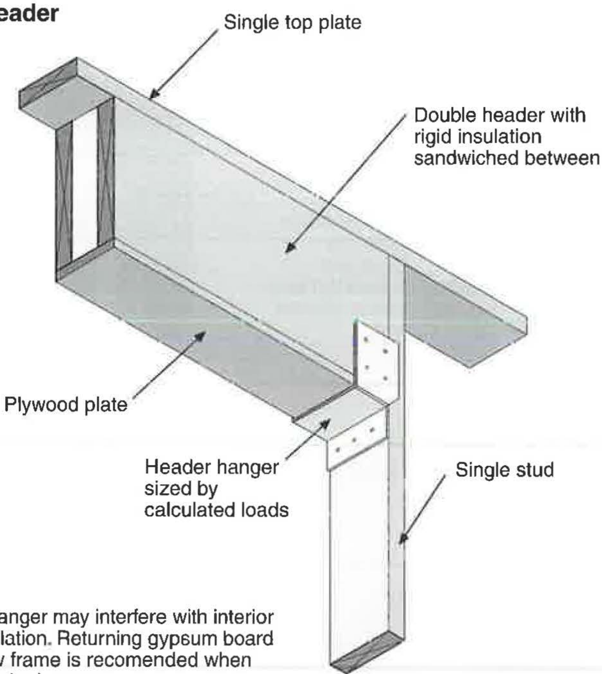
- See also Figure 10.7

5
Framing

Top plate splice

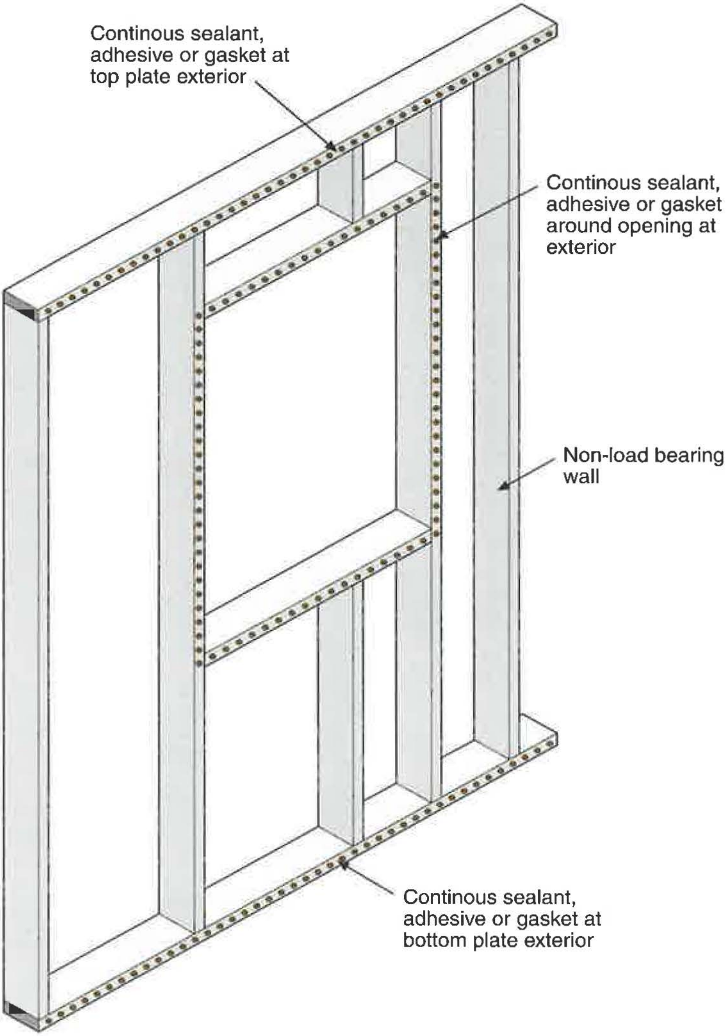


Insulated header



Header hanger may interfere with interior trim installation. Returning gypsum board to window frame is recomended when using header hangers.

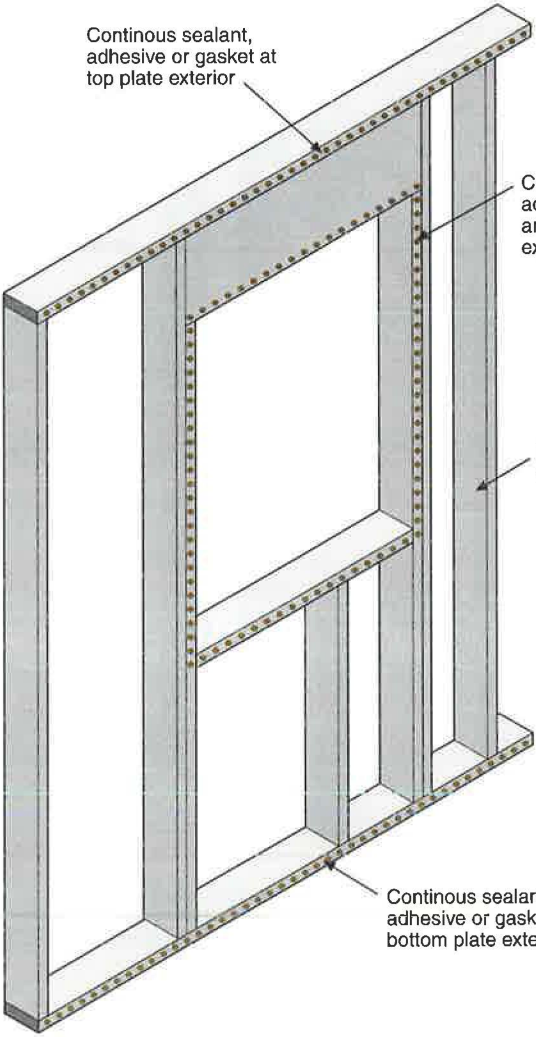
Figure 5.5
Top Plate Splice and Insulated Header



Exterior rigid insulation is sealed to exterior of wall framing at top plates, bottom plates and around openings.

Figure 5.6
Exterior Rigid Insulation Air Sealing on a Non-Load Bearing Wall

- A header is needed above window opening if wall is load bearing; see Figure 5.7.



Exterior rigid insulation is sealed to exterior of wall framing at top plates, bottom plates and around openings.

Figure 5.7
Exterior Rigid Insulation Air Sealing on a Load Bearing Wall

- A header is needed above window opening if wall is load bearing

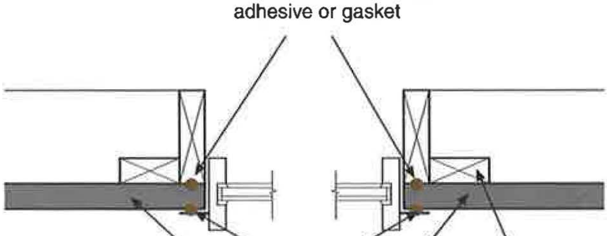


Figure 5.8
Window/Door Jamb Detail for Rigid Insulation

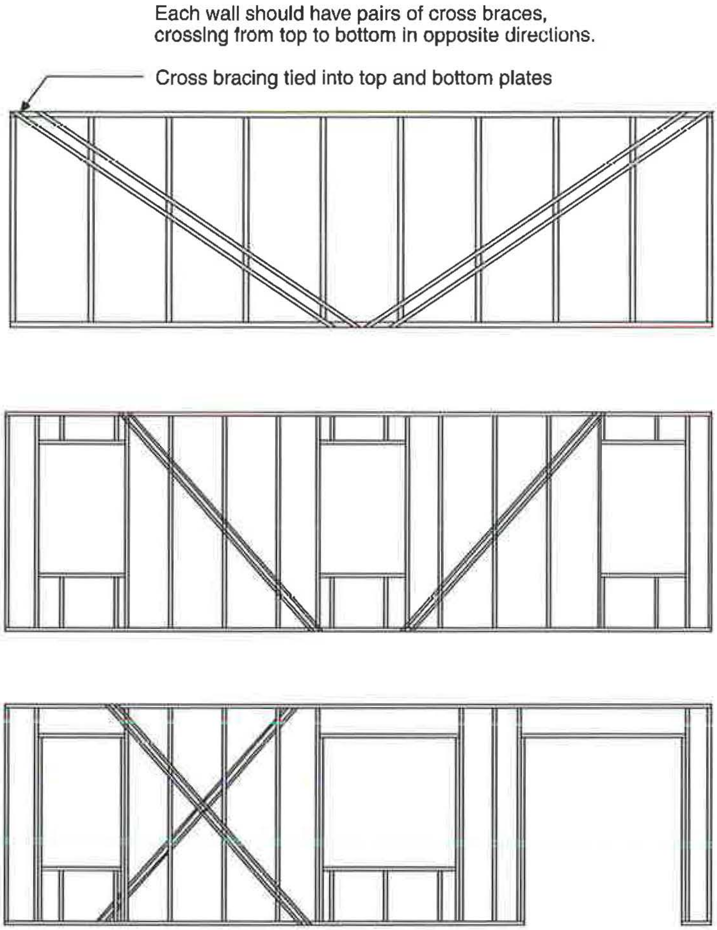


Figure 5.9
Cross Bracing

- Structural requirements and capacity should be determined on a case-by-case basis
- Interior partitions can also be designed to provide shear resistance

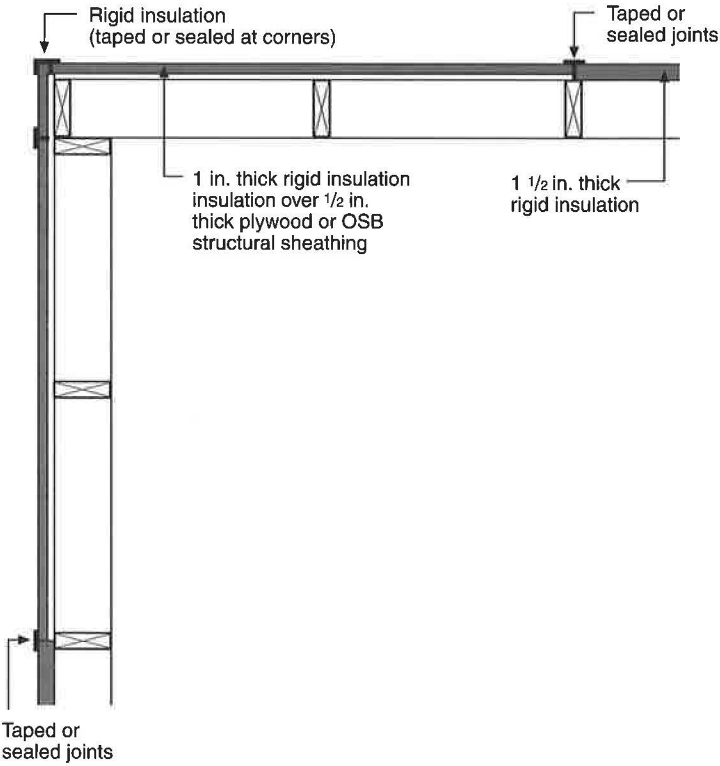


Figure 5.10
Rigid Insulation over Structural Sheathing at Corners

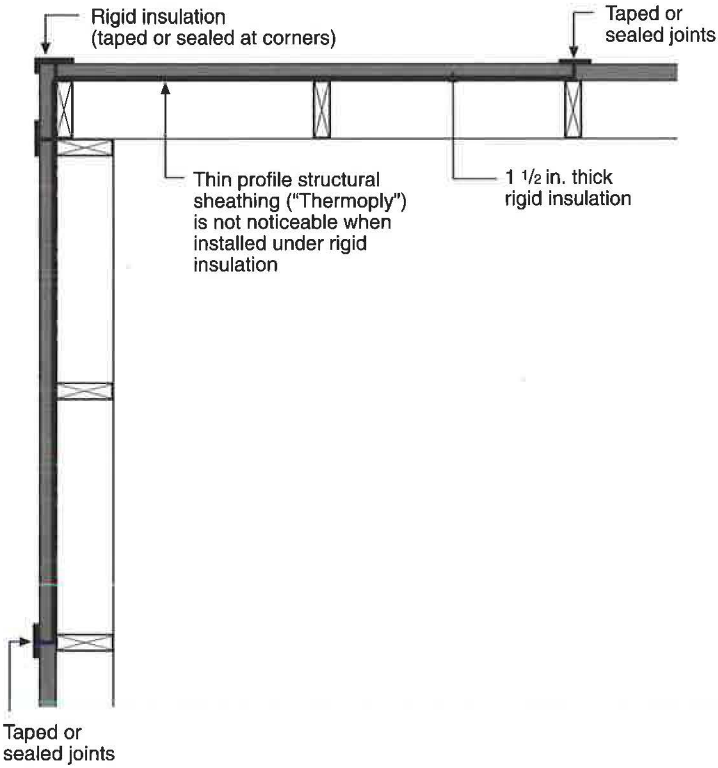


Figure 5.11
Thin Profile Structural Sheathing at Corners

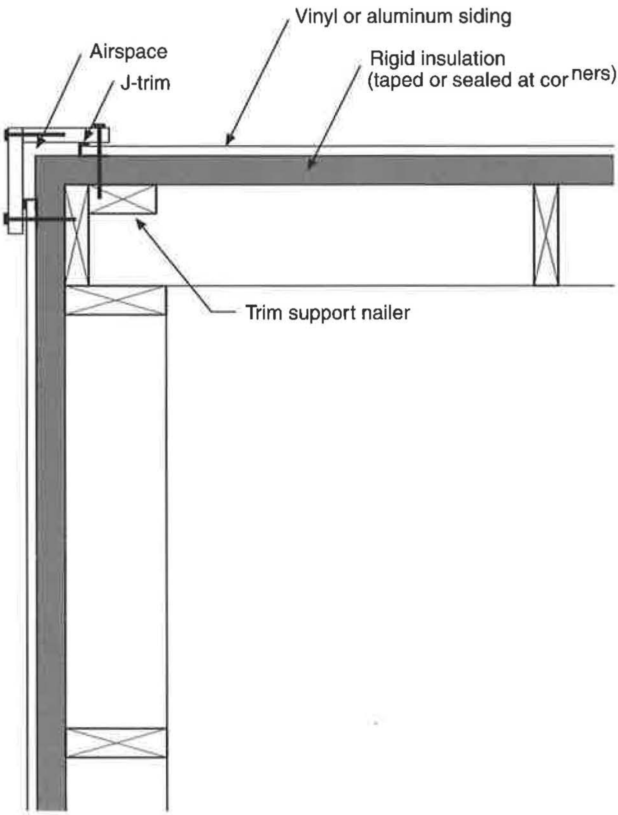


Figure 5.12
Exterior Corner Trim Detail for Rigid Insulation

- Vinyl or aluminum siding
- Trim back primed. All field cut ends in trim sealed with paint

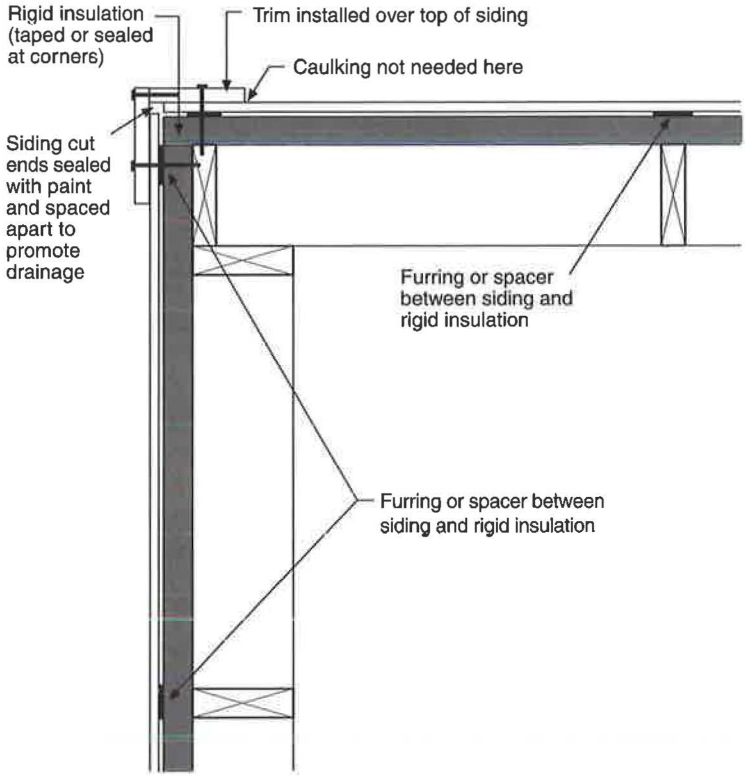


Figure 5.13
Exterior Corner Trim Detail for Rigid Insulation

- Siding and trim back primed. All field cut ends in siding and trim sealed with paint
- Furring strip can be cut strip of $^3/_8$" pressure treated plywood, wood lath, or 1x4

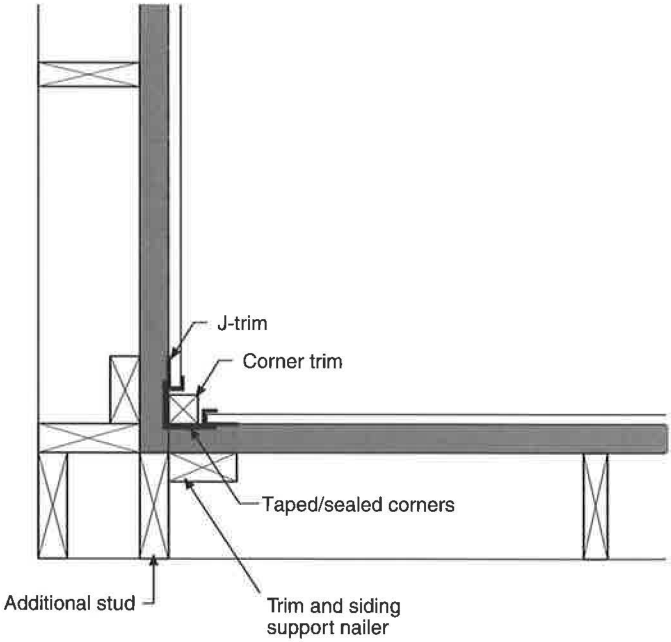


Figure 5.14
Interior Corner Trim Detail for Rigid Insulation

- Vinyl or aluminum siding
- Trim back primed. All field cut ends in trim sealed with paint

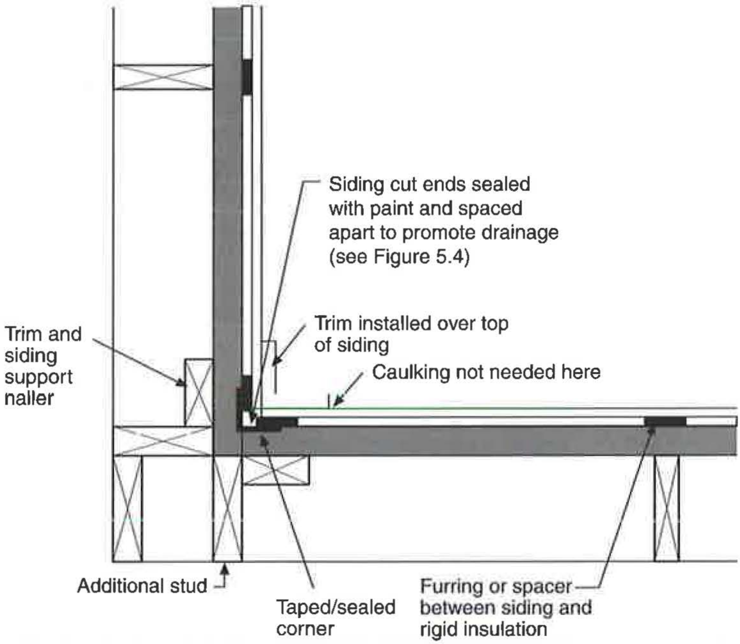


Figure 5.15
Interior Corner Trim Detail for Rigid Insulation

- Rigid insulation installed after wall erection
- Siding and trim back primed. All field cut ends in siding and trim sealed wtih paint
- Furring strip can be cut strip of 3/8" pressure treated plywood, wood lath, or 1x4

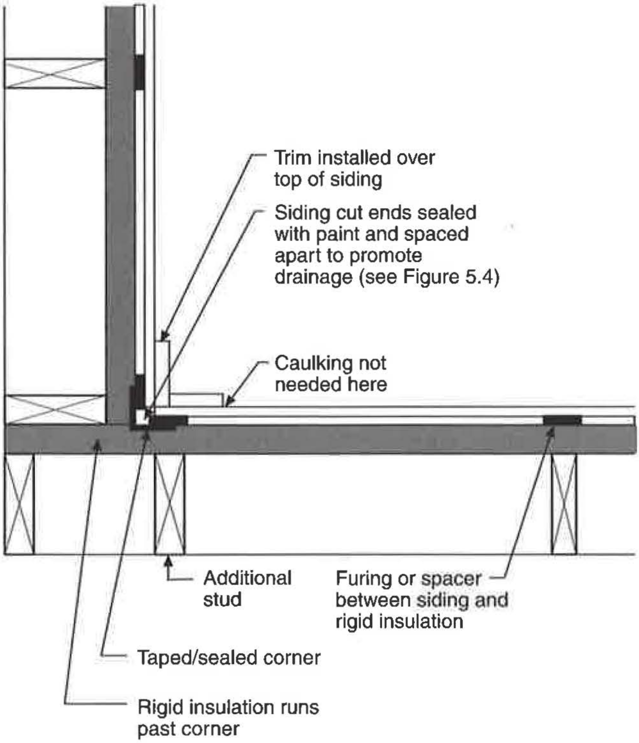


Figure 5.16
Interior Corner Trim Detail for Rigid Insulation

- Rigid insulation installed prior to wall erection
- Siding and trim back primed. All field cut ends in siding and trim sealed wtih paint
- Furring strip can be cut strip of $^3/_8$" pressure treated plywood, wood lath, or 1x4

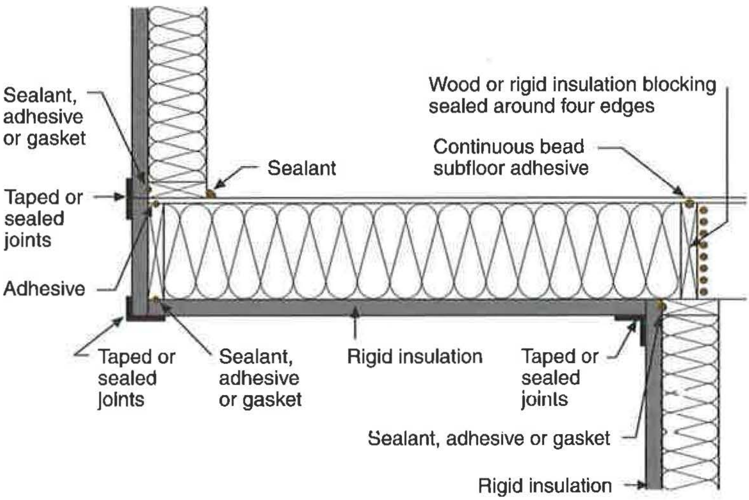


Figure 5.19
Cantilevered Floors

- Floor cavity insulation installed by framers prior to rigid insulation installation

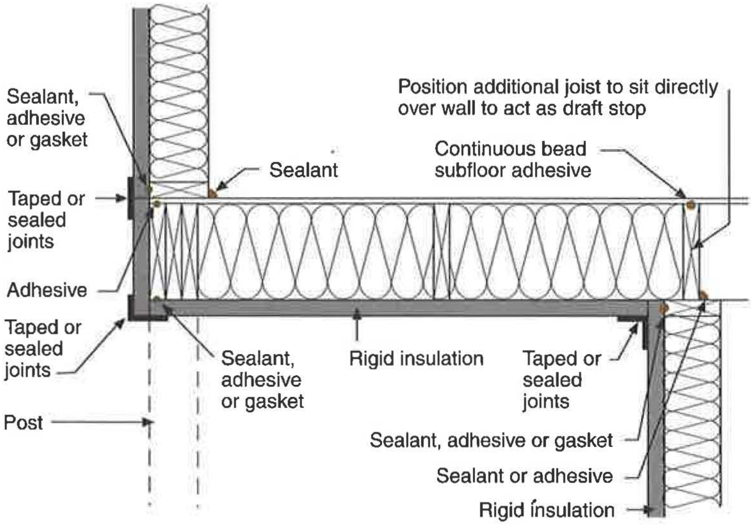


Figure 5.20
Cantilevered Floors

- Floor cavity insulation installed by framers prior to rigid insulation installation

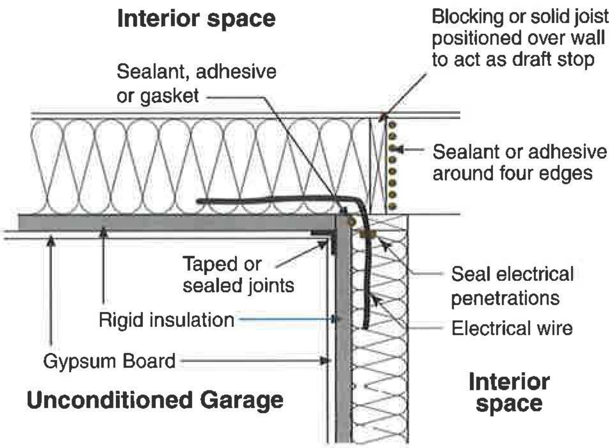


Figure 5.21
Floor over Garage

- Floor cavity insulation installed prior to rigid insulation installation by framers or insulators
- Electrical wires passing to exterior should be sealed with foam sealant or caulking

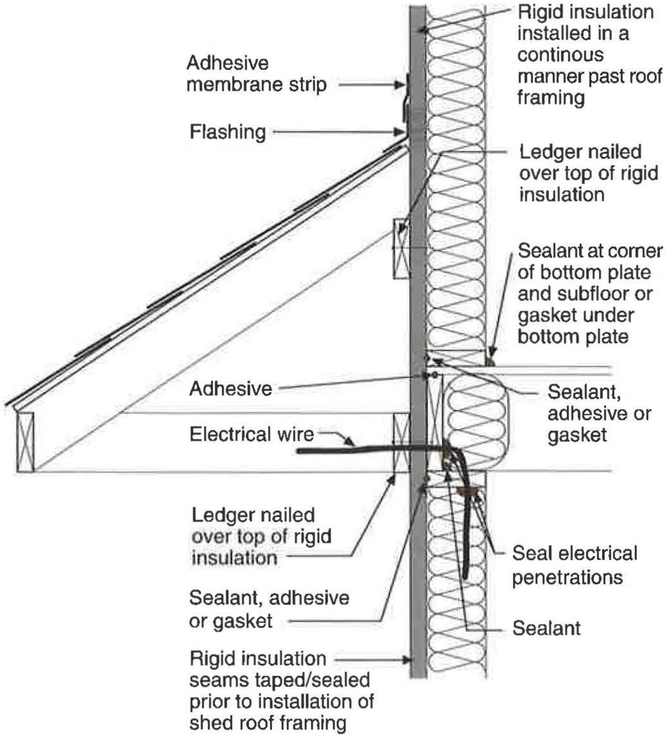


Figure 5.22
Shed Roof

- Electrical wires passing to exterior should be sealed with foam sealant or caulking

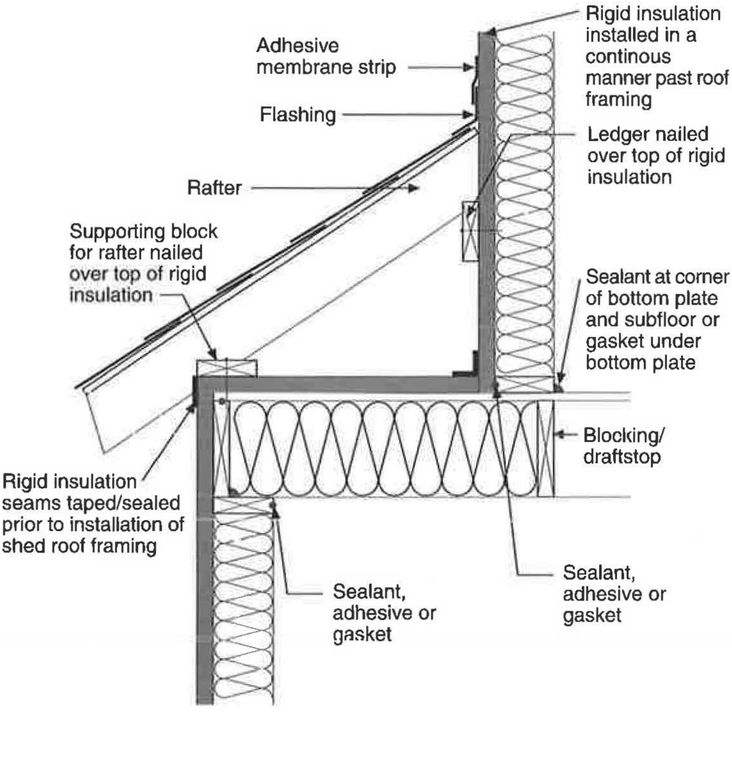


Figure 5.23
Set-Back Roof

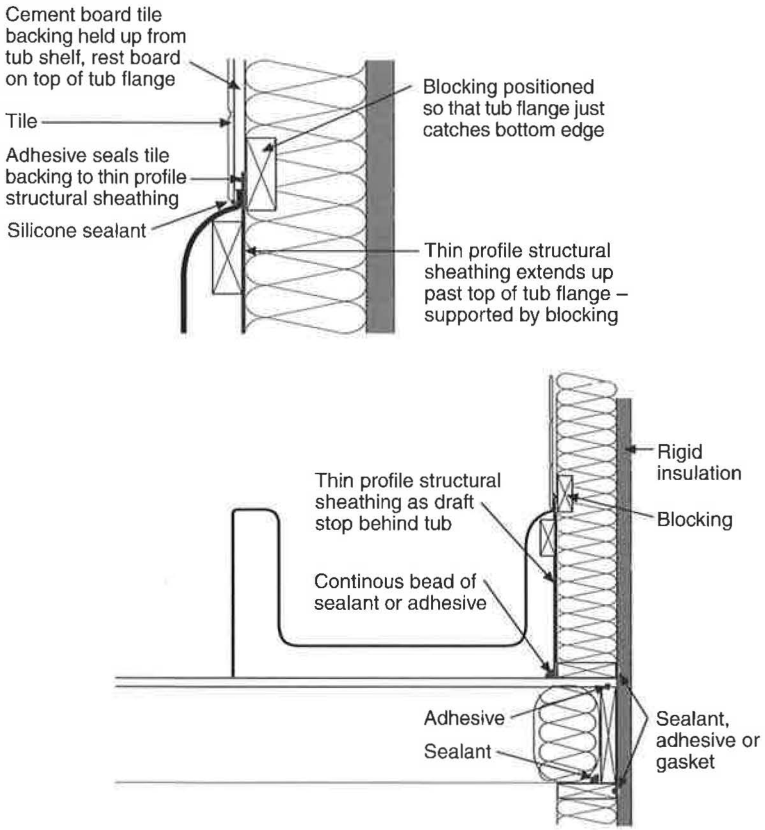


Figure 5.24
Tub Framing – Section

- Flat blocking allows cavity insulation to be installed behind tub draft stop

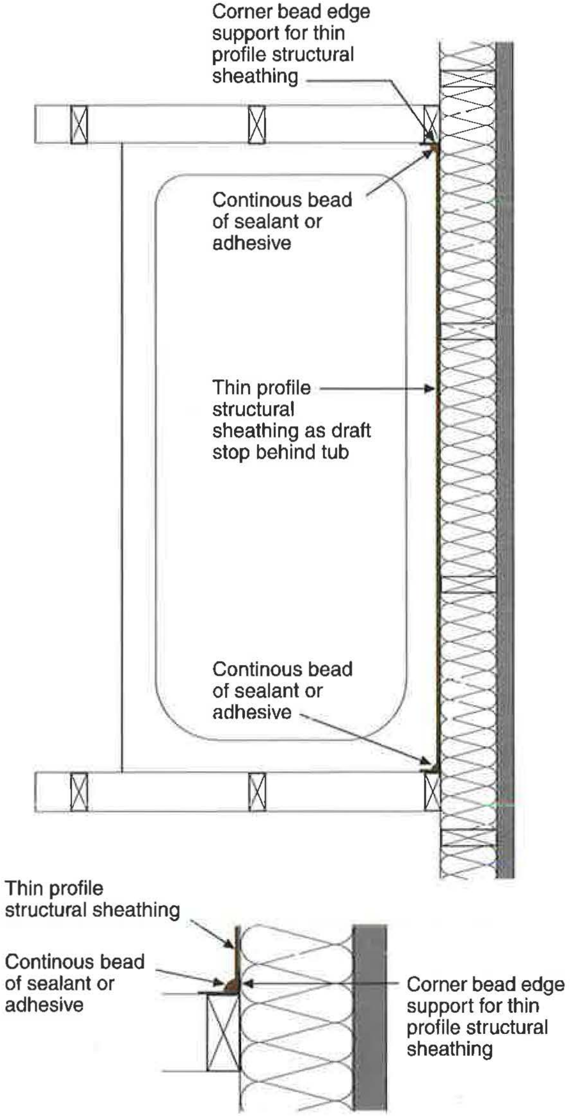


Figure 5.25
Tub Framing – Plan

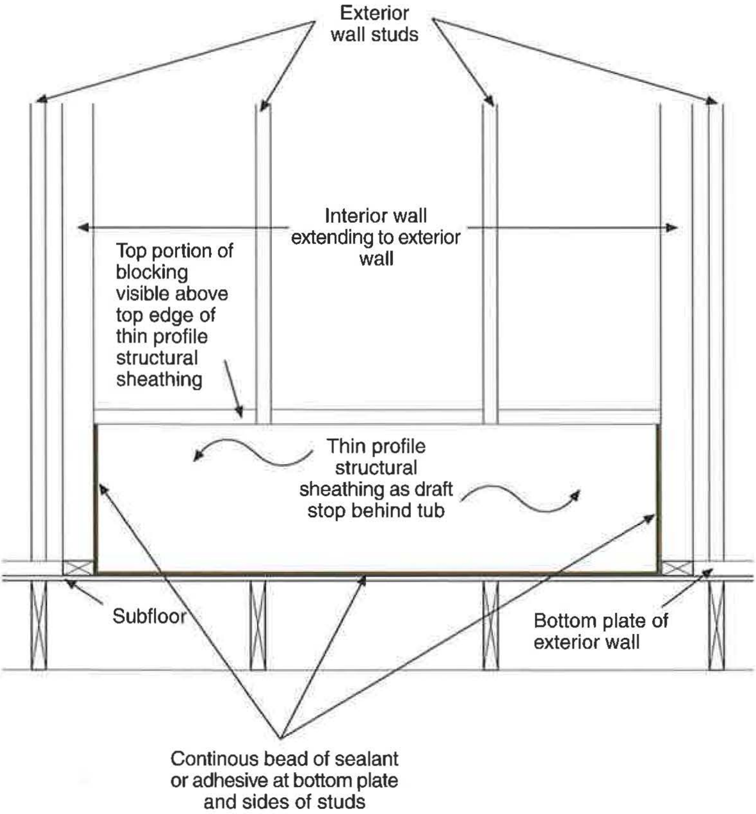


Figure 5.26
Tub Framing – Interior Elevation

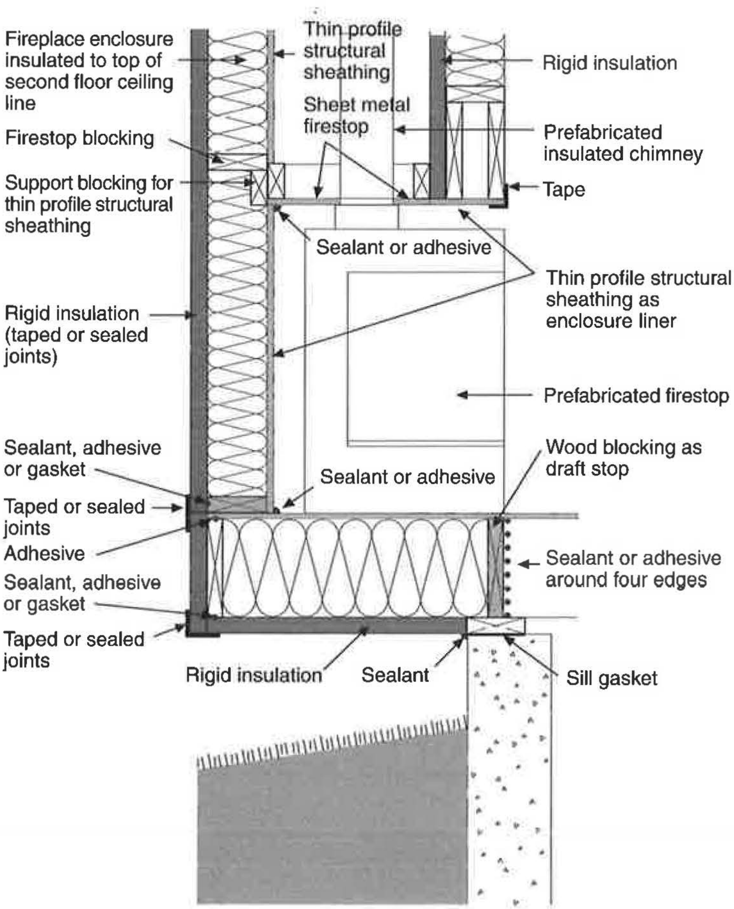


Figure 5.27
Fireplace Section

- Clearances around chimney to be determined by manufacturer's recommendations and local codes.
- Exterior combustion air with a damper should be provided to all fireboxes.
- Ideally, chimneys should be installed within the interior of the building envelope. Alternatively, chimney enclosures should be insulated full height to keep chimney flue pipes warm to ensure sufficient draft during the "die-down" stages of a fire. Insulated chimney flues are preferred.

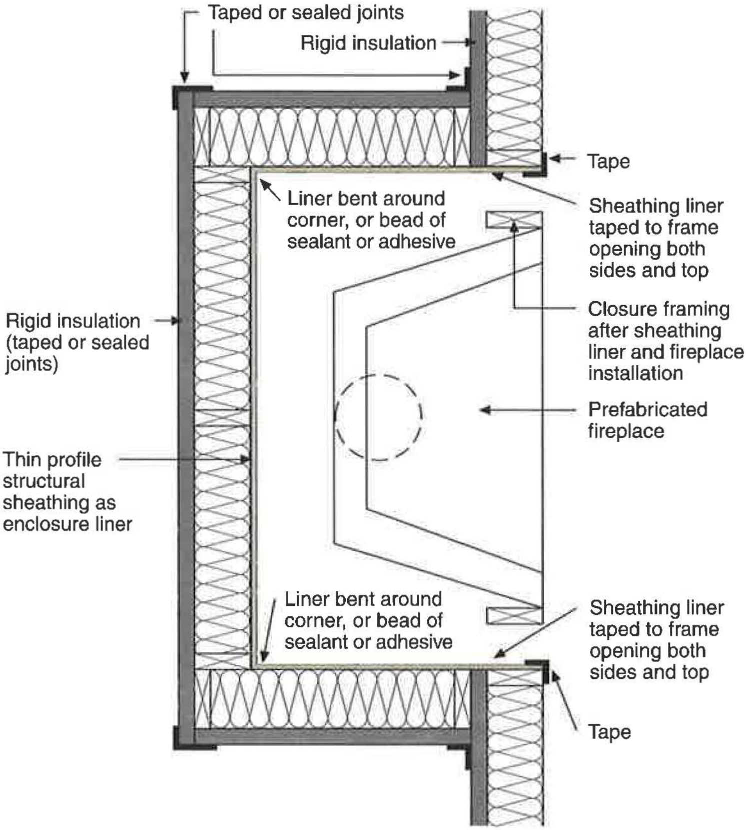


Figure 5.28
Fireplace Section

- Clearances around chimney to be determined by manufacturer's recommendations and local codes.
- Exterior combustion air with a damper should be provided to all fireboxes.
- Ideally, chimneys should be installed within the interior of the building envelope. Alternatively, chimney enclosures should be insulated full height to keep chimney flue pipes warm to ensure sufficient draft during the "die-down" stages of a fire. Insulated chimney flues are preferred.

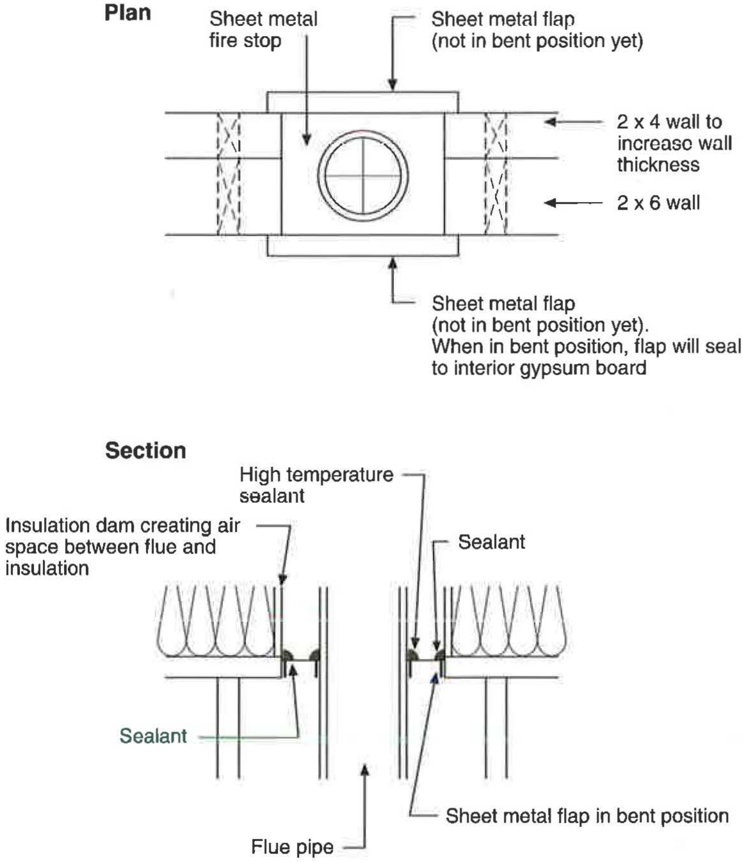


Figure 5.29
Flue Closure

- Interior gypsum board sealed with adhesive to sheet metal flap oa fire stop

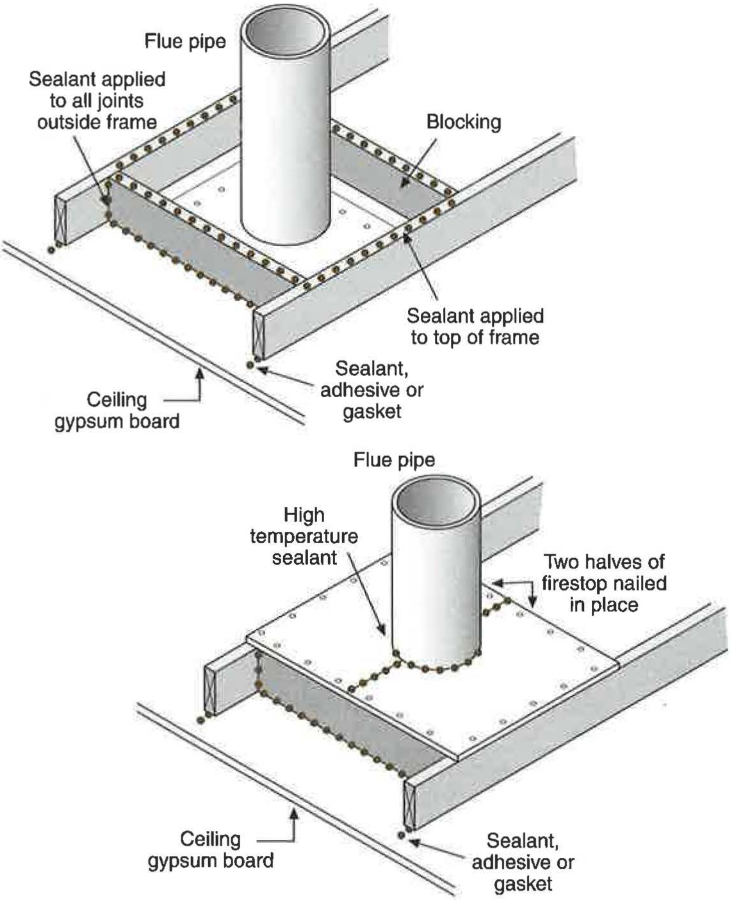


Figure 5.30
Alternative Flue Closure

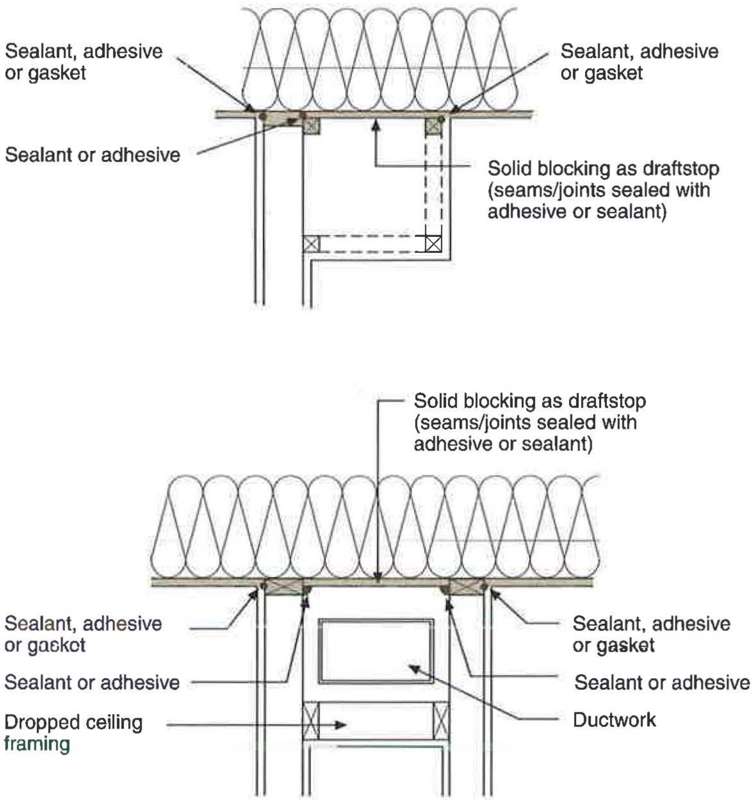


Figure 5.31
Interior Soffit

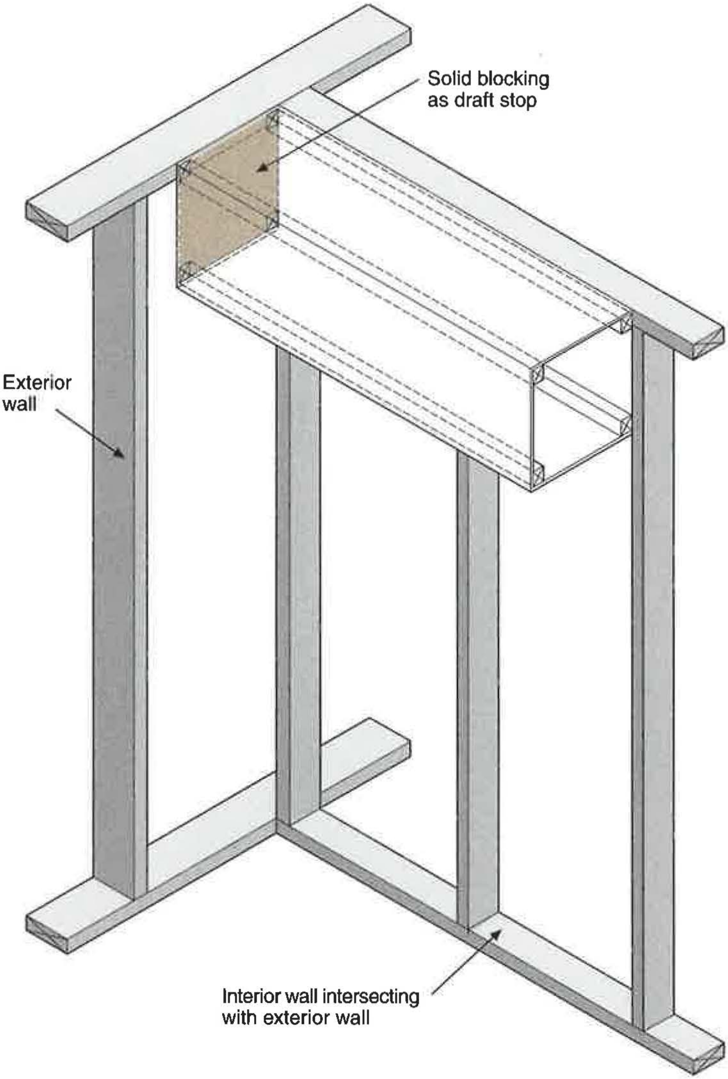
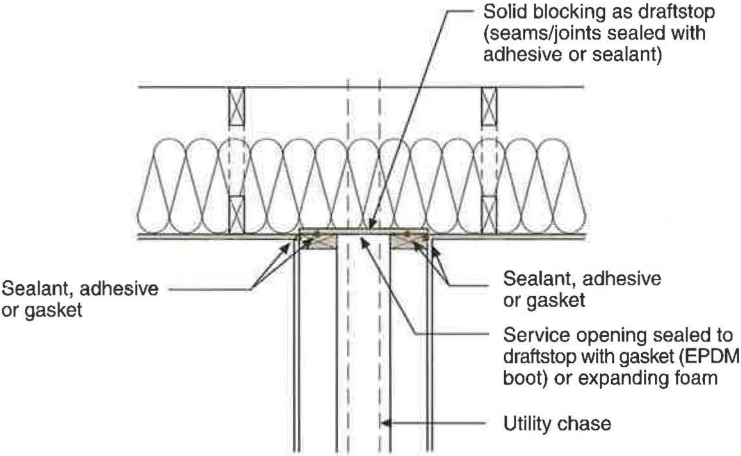


Figure 5.32
Interior Soffit Footprint Against Exterior Wall



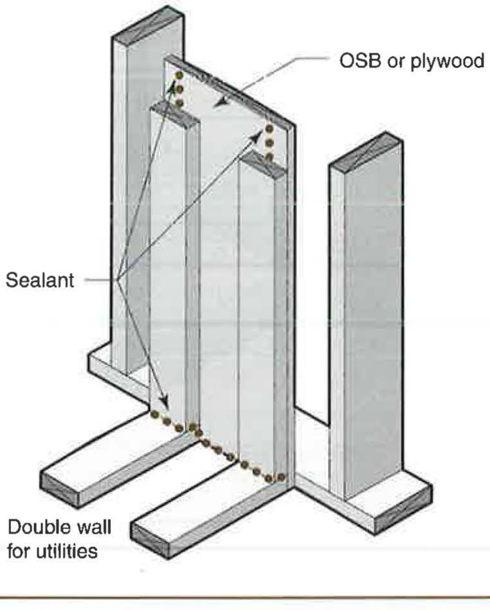


Figure 5.33
Utility Chase

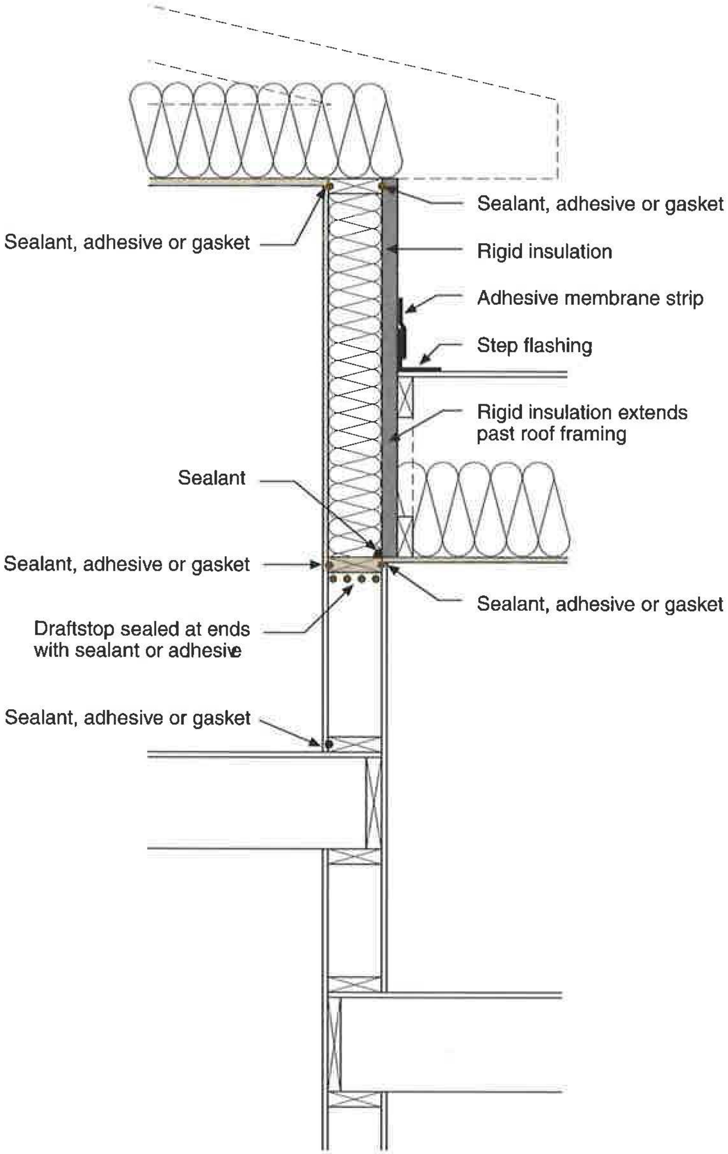


Figure 5.34
Split Level

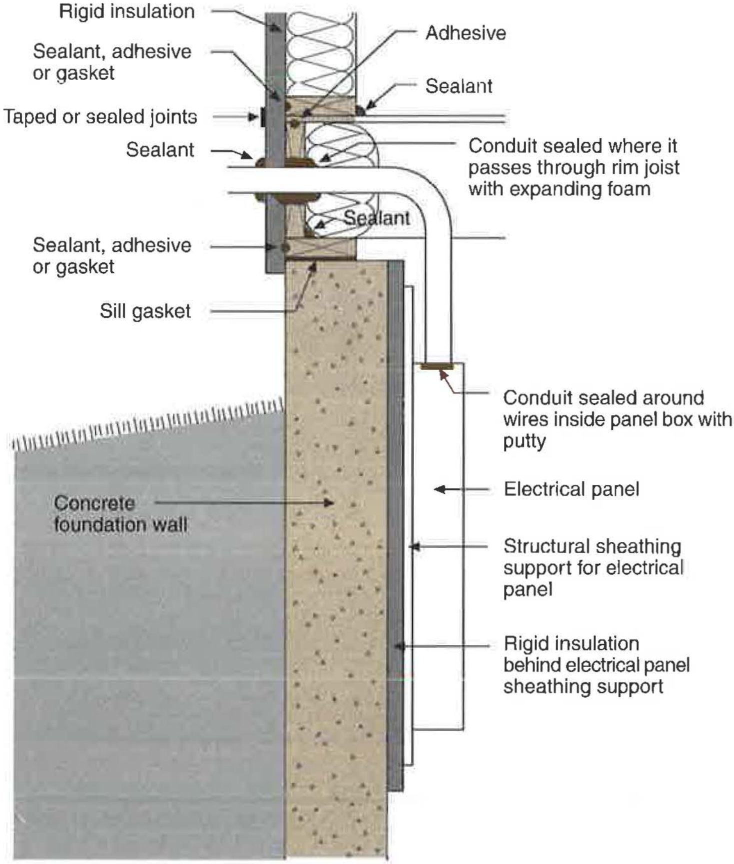


Figure 5.35
Electrical Panel

- Rigid insulation installed under electrical panel as a thermal break and to provide continuity for interior basement insulation

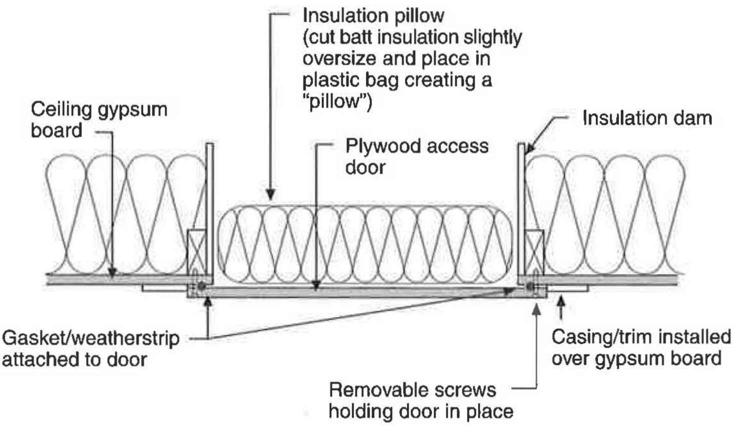


Figure 5.36
Attic Access or Removable Cover for Whole House Ventilation Fan

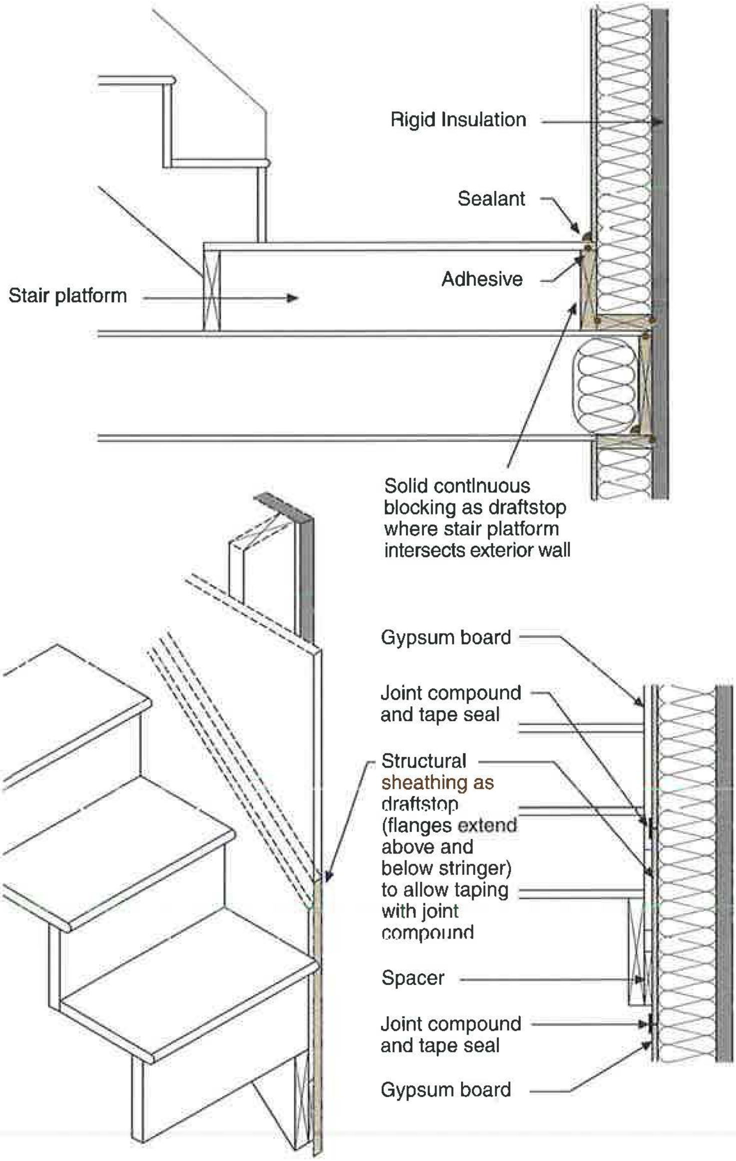


Figure 5.37
Stairs at Exterior Wall or Garage Wall

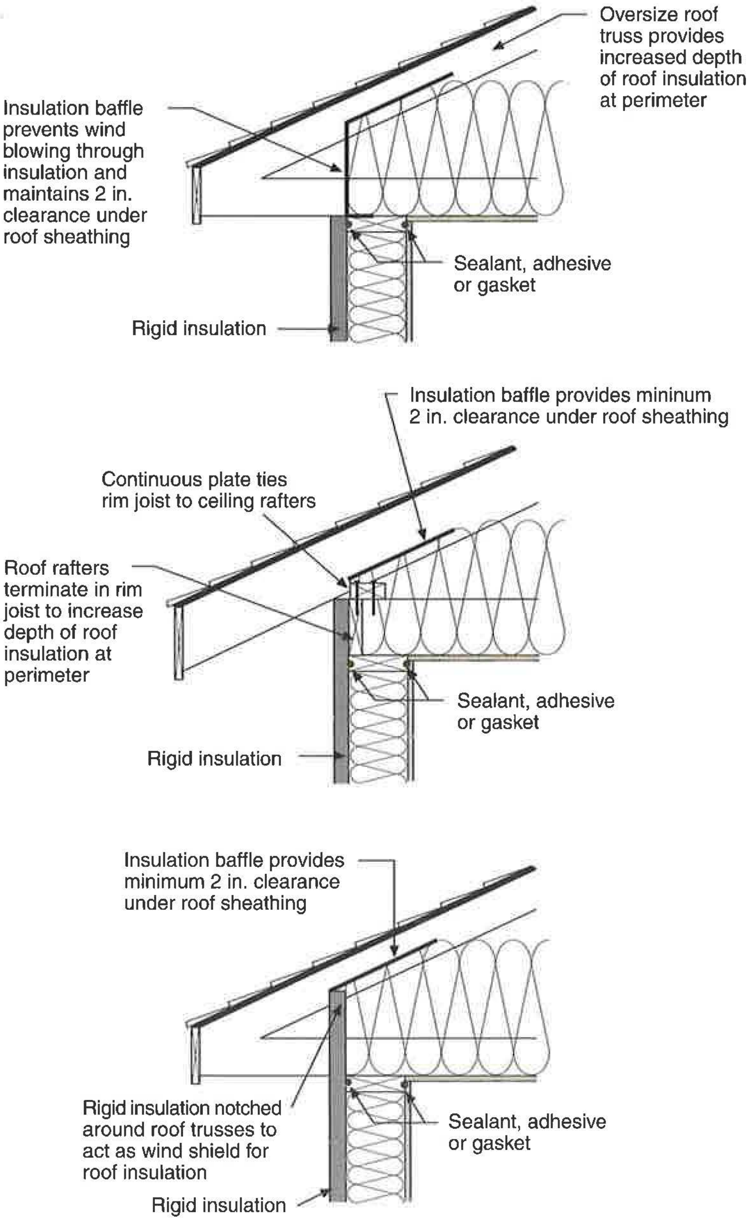


Figure 5.38
Roof Framing

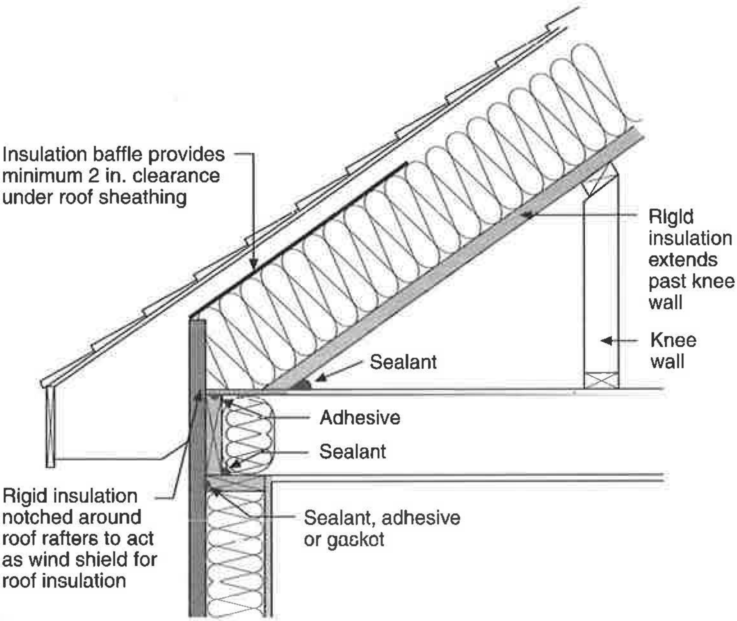


Figure 5.39
Roof Knee Wall

- Knee wall installed after rigid insulation

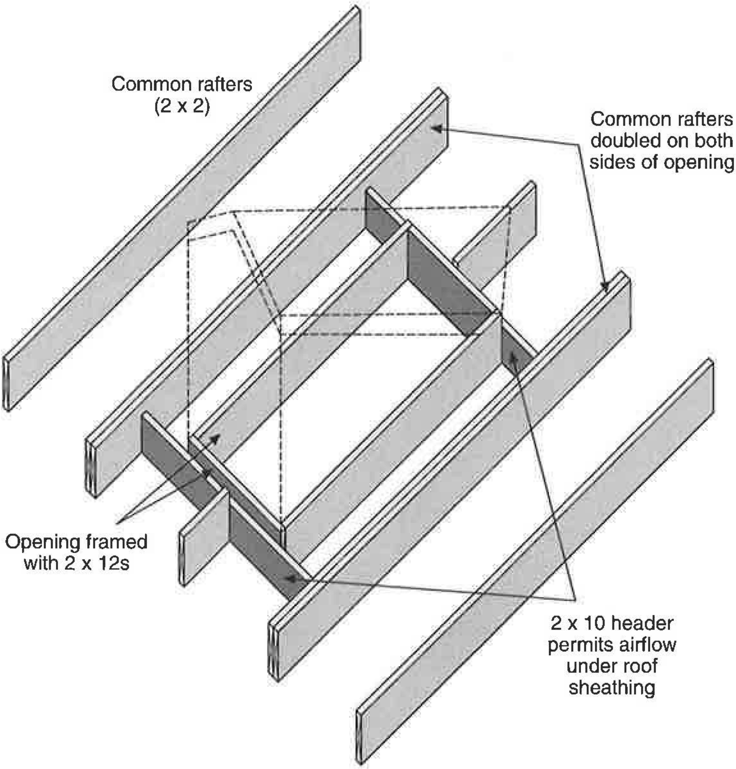


Figure 5.40
Skylight and Dormer Venting

- Reducing size of headers below that of rafters allows roof ventilation past opening

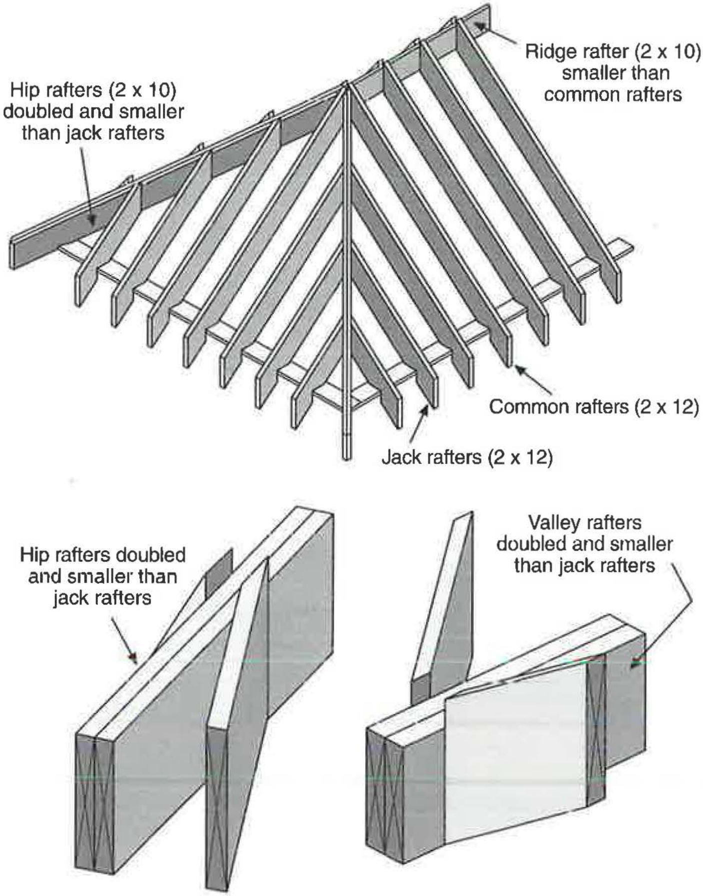


Figure 5.41
Venting Hip Roofs

- Smaller hip, ridge and valley rafters permit venting of hip roofs and valleys to ridge locations

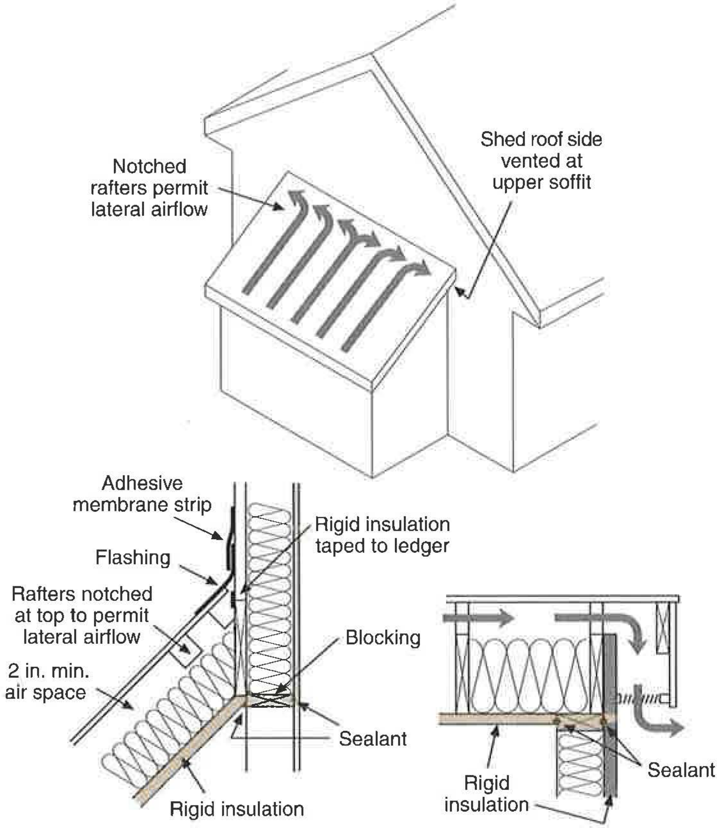


Figure 5.42
Venting Shed Roofs

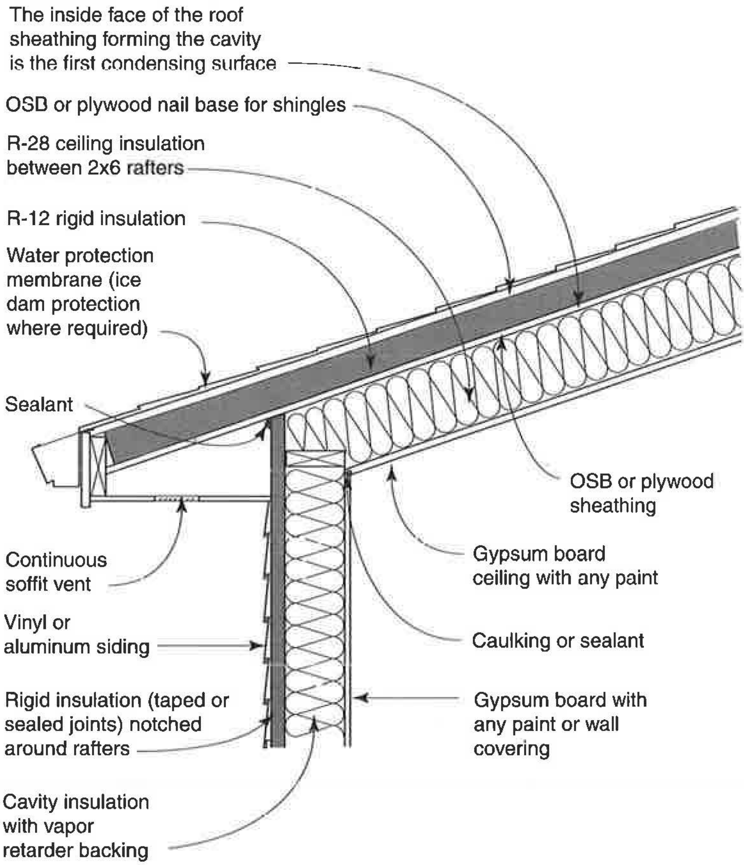


Figure 5.43
Hot Roof

- Rigid insulation raises dew point temperature of the first condensing surface
- This roof assembly is intended to be site constructed; premanufactured panels are not intended to be used in this assembly

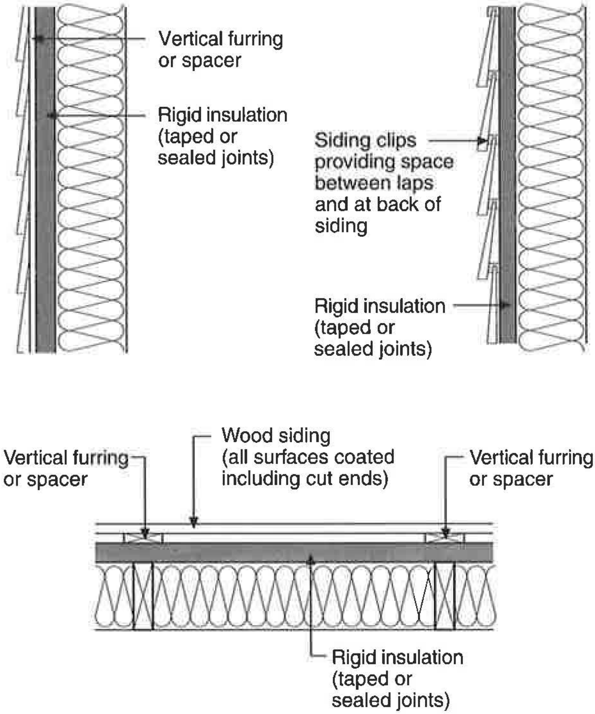


Figure 5.44
Wood Siding Installation

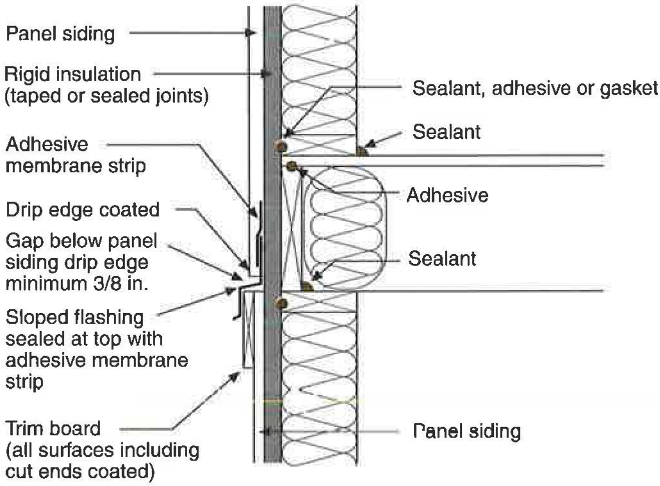


Figure 5.45
Panel Trim

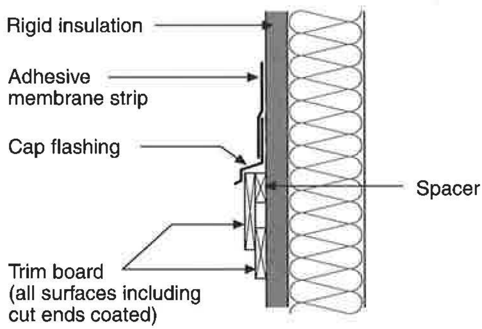


Figure 5.46
Flashing Installed Over Padded Horizontal Trim

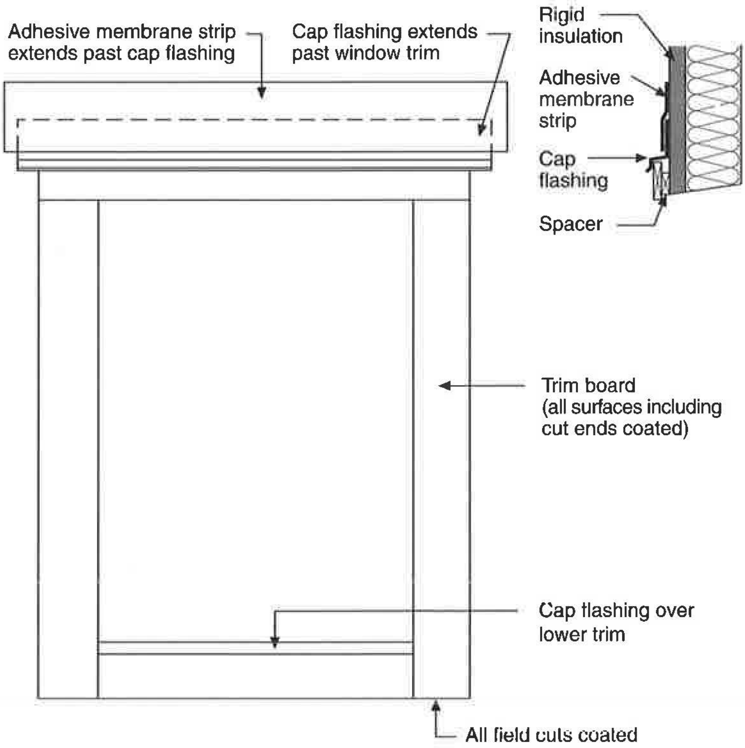


Figure 5.47
Flashing Over and Under Window Trim

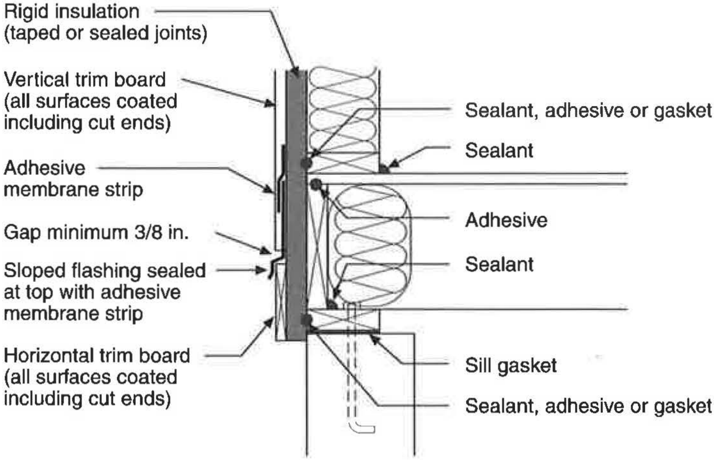


Figure 5.48
Vertical Trim and Flashing Installed Over Horizontal Trim

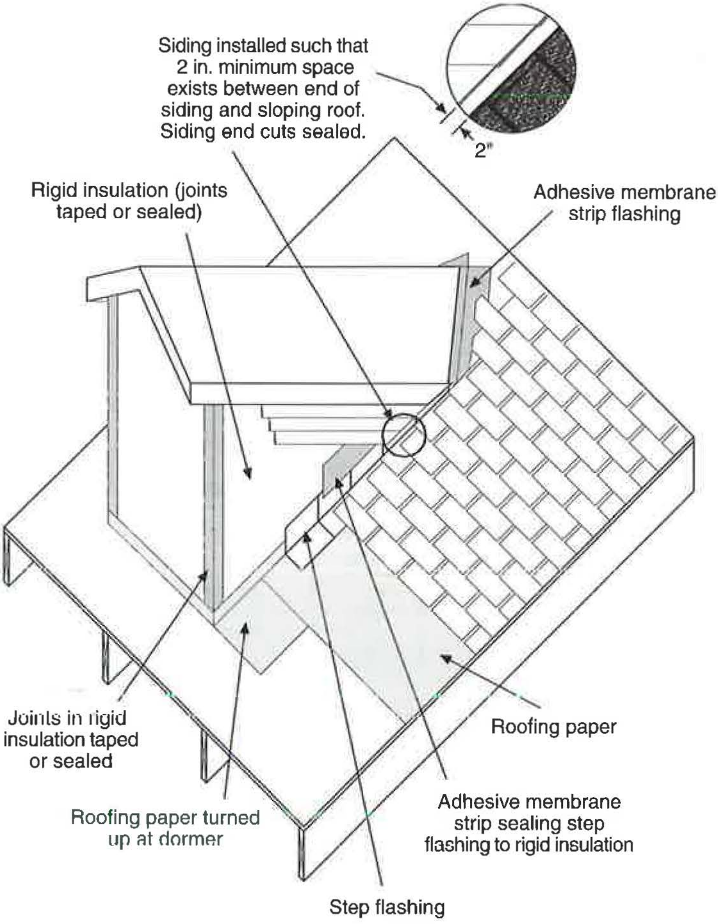


Figure 5.49
Dormer Siding Installation

6 HVAC

Two heating and cooling approaches are common in residential construction: those with forced air and those without. Three controlled ventilation approaches are common in residential construction: exhaust systems, supply systems and balanced systems (Figures 6.1, 6.2, 6.3). When mixed and matched all these systems have to:

- heat when it's cold
- cool when it's hot
- humidify when it's dry
- dehumidify when it's wet
- bring in outside air
- distribute outside air
- exhaust strong pollutant point sources
- do all this when needed

Concerns

The first choice a builder makes is which type of energy source to use: combustion, electricity or the sun (if we split hairs, the sun is the source of all energy, except nuclear generated electricity - where we split atoms). Choosing between combustion, electricity or the sun requires the wisdom of Solomon, the intelligence of Newton and the wit of Wilde (the reason we have trouble with this choice is that none of these people are alive to actually ask). Wars have been fought over less. Sometimes no choice is possible. We will assume that some type of rational choice will be made.

If a combustion energy source is selected, combustion appliances should not be subject to backdrafting or spillage of combustion products. If electricity is selected, resistance heating should be avoided ex-

Since most ventilation system airflow across the building envelope is in the 50 cfm or less range, the effect on building pressures is typically negligible. However, in general, exhaust ventilation systems have a slight depressurization effect on building enclosures; supply ventilation systems have a slight pressurization effect on building enclosures, and balanced ventilation systems have no effect on building air pressures. See Figures 6.4 through 6.10 for more detail on different types of ventilation systems.

Exhaust fans extracting less than 50 cfm will typically not increase radon ingress, soil gas ingress or backdrafting problems with fireplaces or wood stoves due to their negligible effect on building air pressures. Similarly, supply fans supplying less than 50 cfm will typically not increase wall and roof cavity interstitial moisture problems. Larger exhaust air flows may lead to unacceptably high negative air pressures (above five Pascals negative is considered unacceptable). Larger supply air flows may lead to moisture concerns in building envelope wall and roof assemblies that are not designed to dry towards the exterior or that do not have a provision to control condensing surface temperatures.

Combustion Appliances

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 exterior combustion air ducted to the firebox and glass doors. 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. Figures 6.17 through 6.22 describe several different systems for safely installing gas fired furnaces and hot water tanks.

Recirculating Fans

Recirculating range hoods and recirculating bathroom fans should be avoided due to health concerns. If recirculating range hood filters are not regularly replaced and units not regularly cleaned, they become a breeding ground for biologicals and a major source of odors.

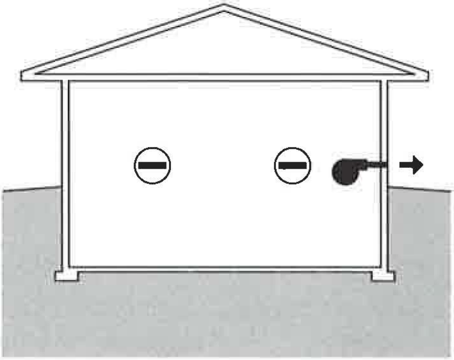


Figure 6.1
Exhaust Ventilation System

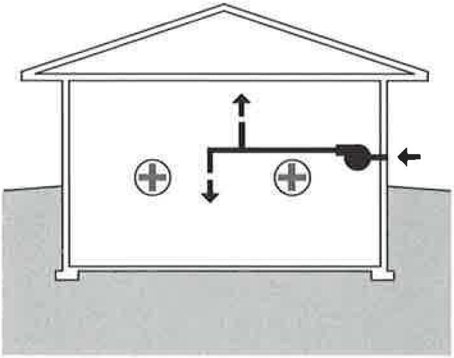


Figure 6.2
Supply Ventilation System

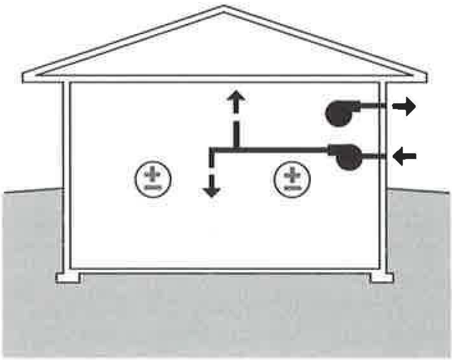


Figure 6.3
Balanced Ventilation System

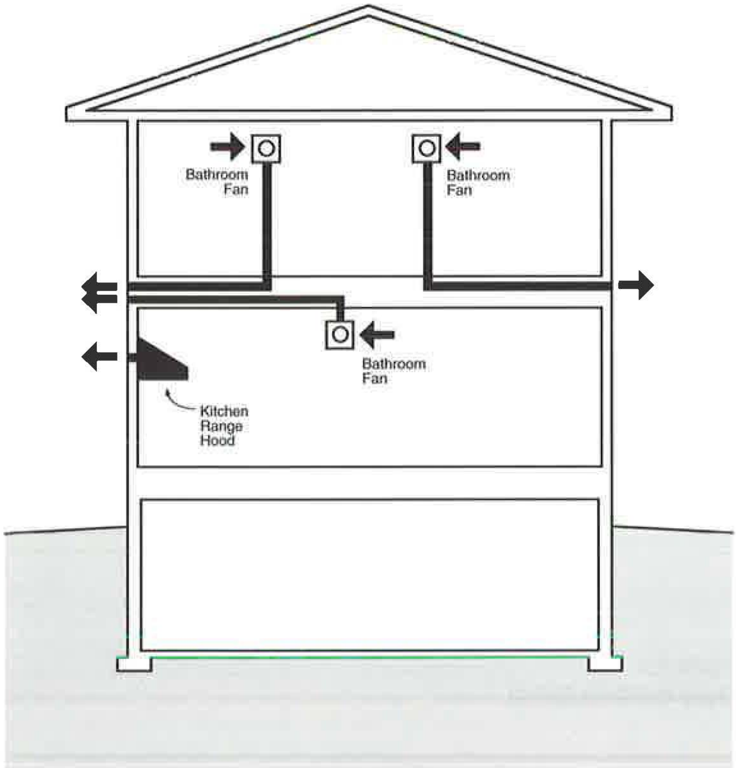


Figure 6.4
Exhaust Ventilation System with Point Source Exhaust

- Individual exhaust fans pull interior air out of bathrooms. One of these fans is selected to also serve as the exhaust ventilation fan for the entire building with a run time based on time of occupancy.
- Replacement air is drawn into bathrooms from hallways and bedrooms providing circulation and inducing controlled infiltration of outside air.

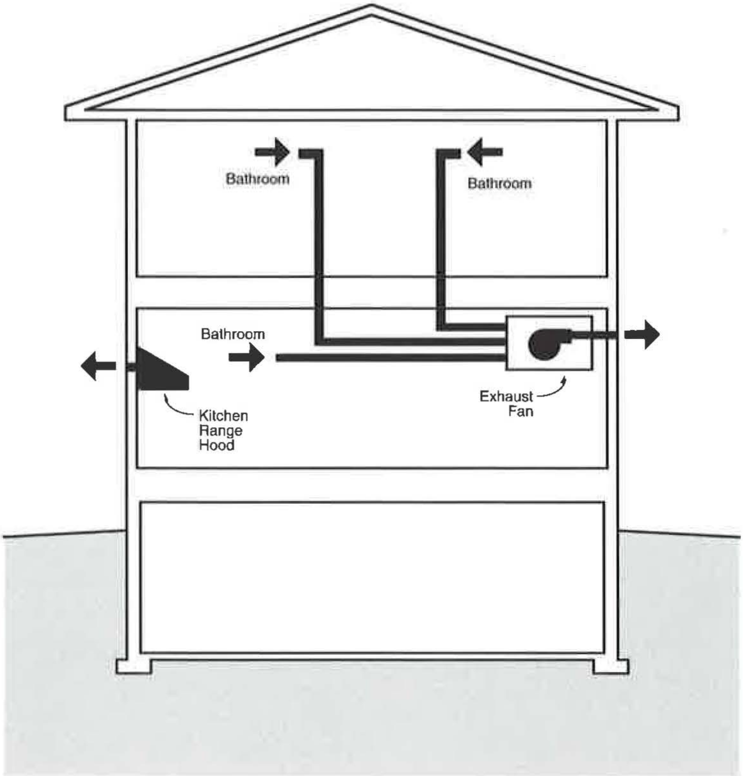


Figure 6.5
Central Exhaust Ventilation System

- Exhaust fan pulls interior air out of bathrooms.
- Replacement air is drawn into bathrooms from hallways and bedrooms providing circulation and inducing controlled infiltration of outside air.
- Run time is based on time of occupancy.
- Individual bathroom fans are eliminated.

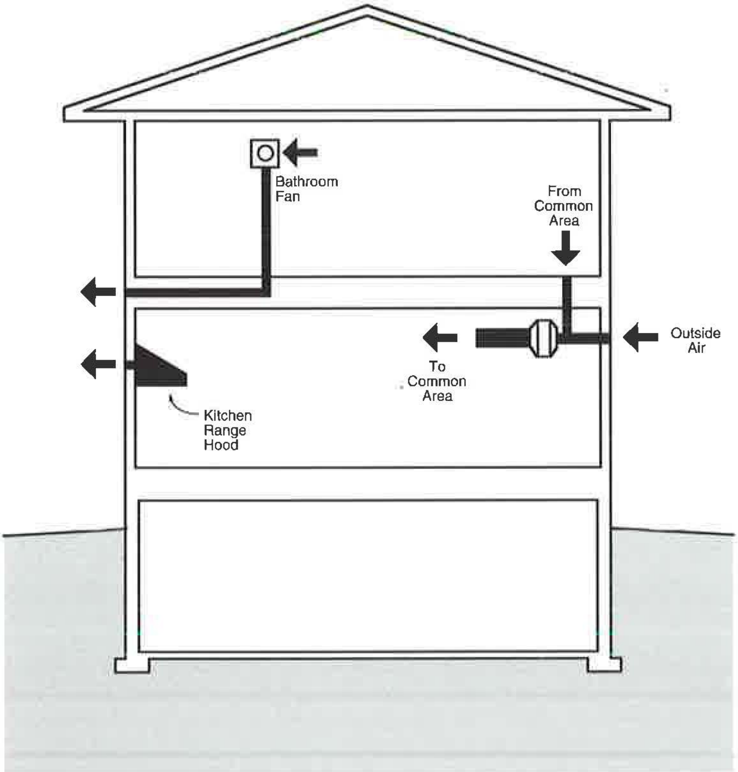


Figure 6.6
Supply Ventilation System with Point Source Exhaust

- Supply fan brings in outside air and mixes it with air pulled from a common area (living room, hallway) to provide circulation and tempering prior to supplying to common area.
- Run time is based on time of occupancy.
- In supply ventilation systems, and with heat recovery ventilation, pre-filtration is recommended as debris can affect duct and fan performance reducing air supply.

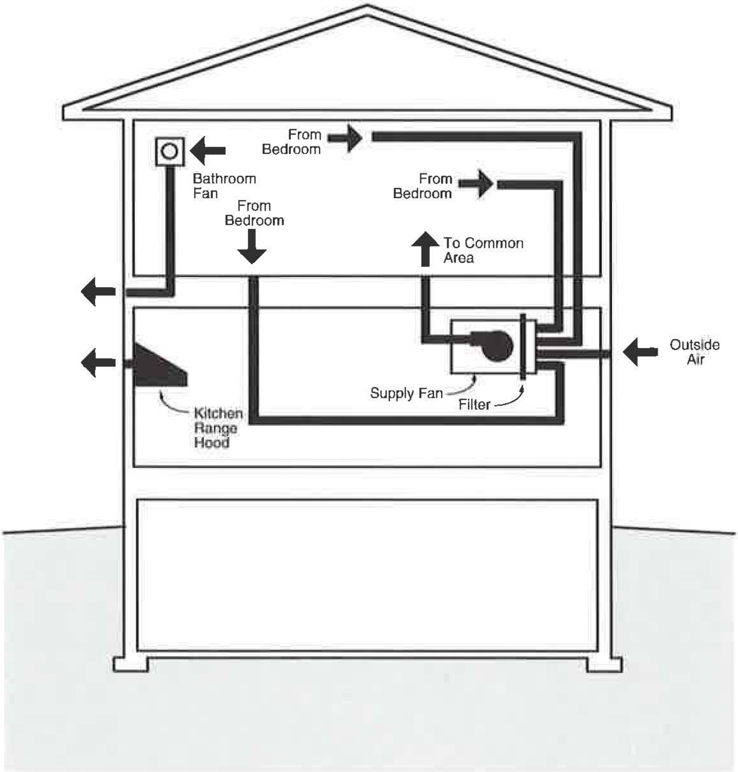


Figure 6.7
Supply Ventilation System with Circulation and Point Source Exhaust

- Supply fan brings in outside air and mixes it with air pulled from bedrooms to provide circulation and tempering prior to supplying to common area.
- Run time is based on time of occupancy.
- In supply ventilation systems, and with heat recovery ventilation, pre-filtration is recommended as debris can affect duct and fan performance reducing air supply.

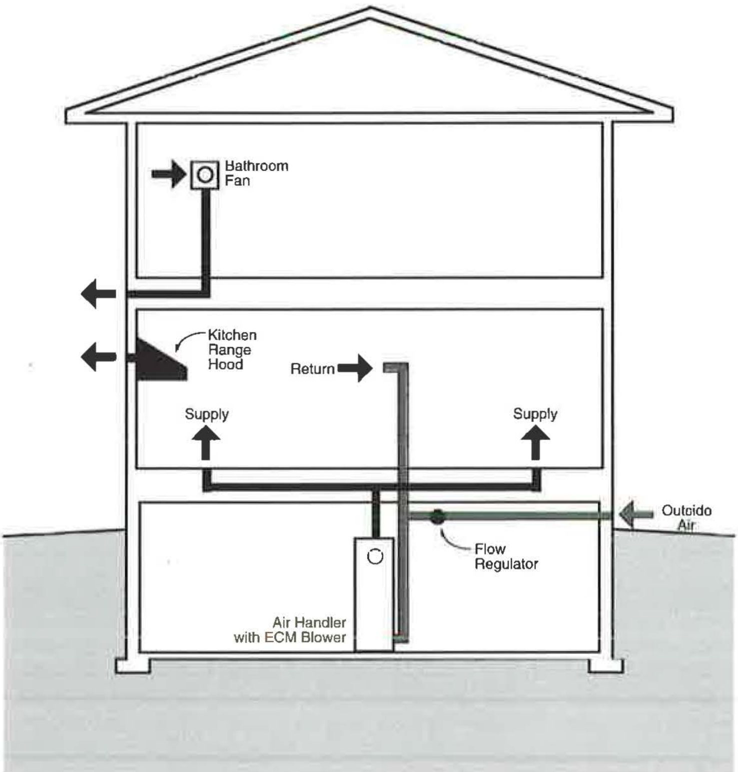


Figure 6.8
Supply Ventilation System Integrated with Heating and A/C

- Air handler runs continuously (or operated based on time of occupancy) pulling outside air into the return system.
- A flow regulator 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.

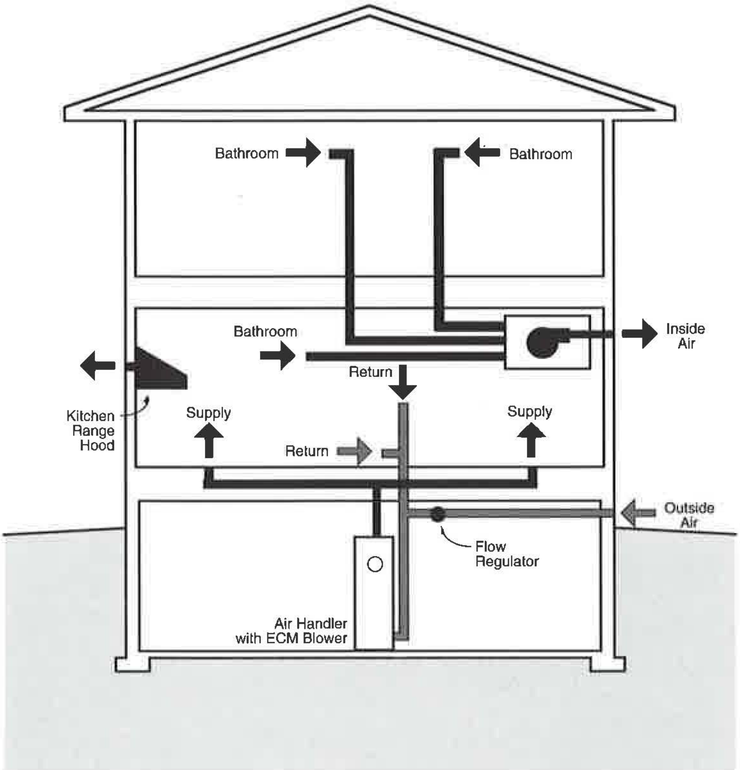


Figure 6.9
Balanced Ventilation System Using a Supply Ventilation System Integrated with Heating and A/C with a Stand Alone Central Exhaust

- The supply system integrated with heating and A/C as in Figure 6.5.
- A central exhaust system is added as in Figure 6.2. Both systems are operated simultaneously.
- Run time is based on time of occupancy.

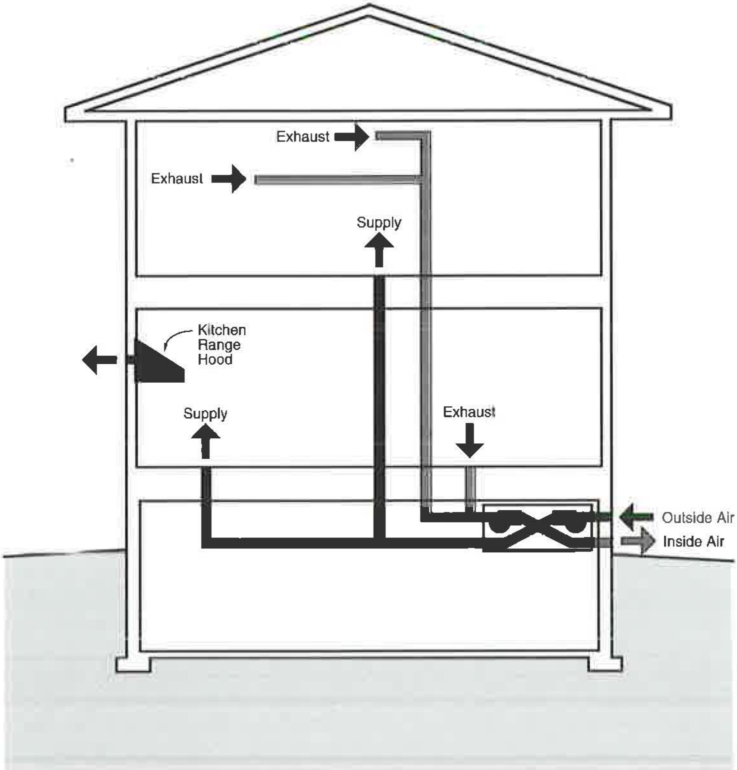


Figure 6.10
Balanced Ventilation System with Heat Recovery via an Air-to-Air Heat Exchanger

- The ventilation system has a separate duct system and is not integrated with the heating and A/C system.
- Run time is based on time of occupancy.
- Exhausts are typically from bathrooms and supplies are typically to bedrooms.
- In supply ventilation systems, and with heat recovery ventilation, pre-filtration is recommended as debris can affect duct and fan performance reducing air supply.

Air Handlers and Ductwork

Equipment should be sized correctly and return air flow paths should be planed. If a similar floor plan is constructed several times in a subdivision and sited with different orientations, heat gain and heat loss calculations should be done for each orientation. Equipment should be specifically selected for each orientation.

Furnaces, air handlers and ductwork should always be located within conditioned spaces and allow for easy access to facilitate servicing, filter replacement, drain pan cleaning, and future replacement as technology improves. Furnaces, air handlers and ductwork should not be located in vented attics, vented crawl spaces or garages. Ductwork should not be located in exterior walls or in concrete floor slabs. See Figures 6.25 and 6.26 for suggested conceptual ductwork layouts. In designs where ducts are unavoidably located in an unconditioned space, they should be sealed airtight and insulated (Figure 6.24).

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 grills. 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, 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. Tape, especially duct tape, does not work and should not be used. 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. See Figures 6.11 through 6.16 for suggested ways to air seal your ductwork.

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 dust marking at baseboards, odor problems, mold problems and pollutant transport problems typically occur when building cavities are used as return ducts.

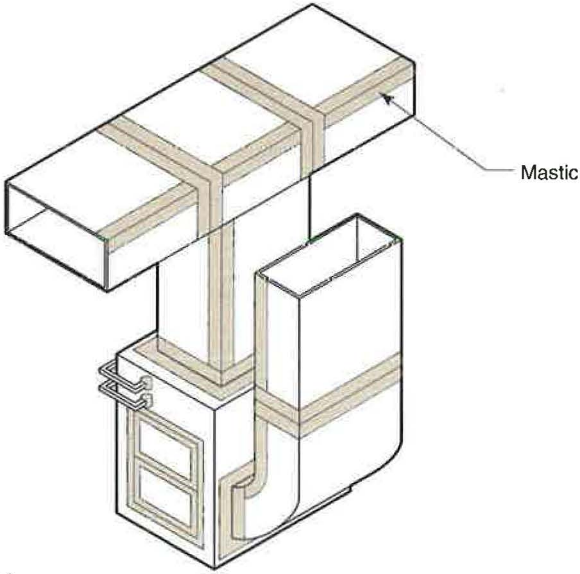


Figure 6.11
Air Handler Air Sealing

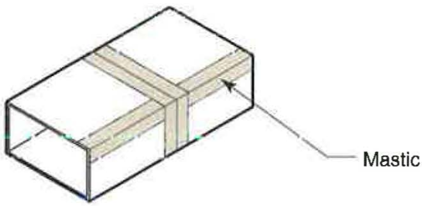


Figure 6.12
Rigid Duct Air Sealing

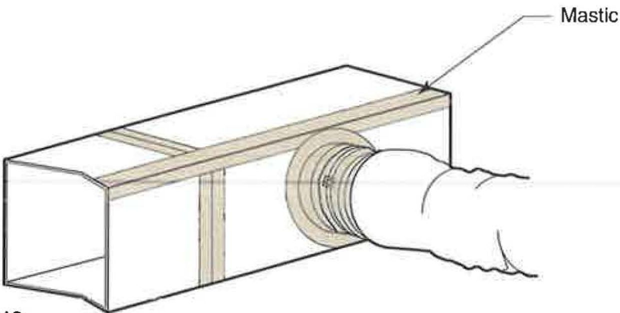


Figure 6.13
Flex Take-off from Rigid Air Sealing

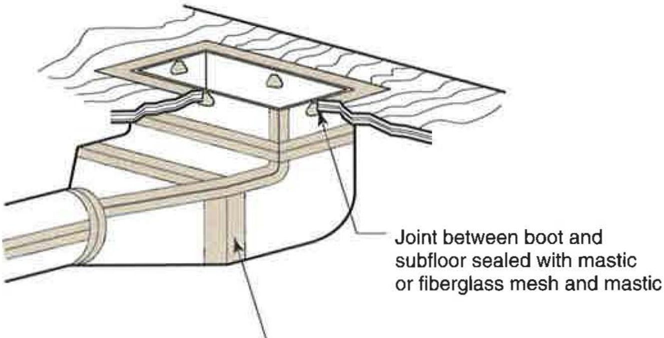


Figure 6.14
Floor Boot Air Sealing

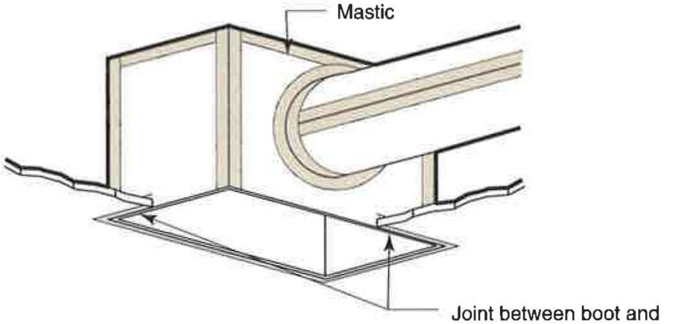


Figure 6.15
Ceiling Boot Air Sealing

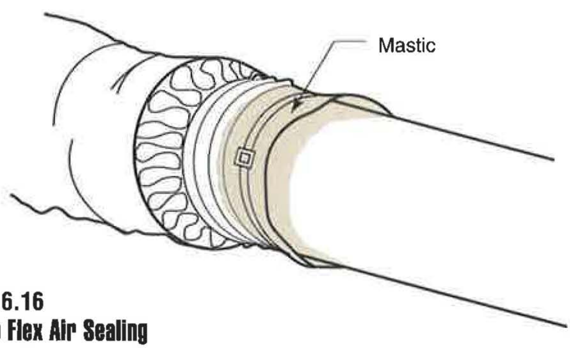


Figure 6.16
Rigid to Flex Air Sealing

The return side of the air handler or furnace also must be sealed, especially the filter access. The filter access should be sealed with aluminum tape to permit access. A roll of this tape should be left with the unit so that homeowners can re-tape access panels after filter replacement or other servicing.

All supply registers should have clear access to a return grill 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 grill. 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 grills to relieve bedroom pressurization significantly outperforms a return system with leaky ducted returns in every room, stud bays used as return ducts and panned floor joists. See Figure 6.23 for an effective transfer grill detail.

Large Exhaust Fans

Large exhaust fans and appliances such as whole house fans, attic ventilation fans, indoor grills, clothes dryers, fireplaces and kitchen exhaust range hoods can significantly depressurize buildings.

Whole house fans should only be used with windows open in order to relieve building pressures.

Attic ventilation fans should never be installed. A correctly constructed attic makes attic ventilation fans unnecessary. An incorrectly constructed attic should be repaired, not saddled with an energy wasting and problem-creating attic ventilation fan.

Kitchen exhaust range hoods should not be oversized. Anything larger than 100 cfm exhaust capacity for a kitchen exhaust range hood should be carefully integrated into the entire design of the building. Indoor grills should only be installed with a provision for make-up air.

Clothes Dryers

Nothing practical can be done with the large unbalanced air flows created by clothes dryers except to reduce the impact of the negative effects by installing only sealed combustion, direct vent, induced draft or power vented combustion furnaces and water heaters. By the way, never duct a clothes dryer into the house. The resulting moisture load is more difficult to deal with than an intermittent pressure imbalance. Additionally, lint and other particulates are known to aggravate allergies and contribute to dustmarking on interior finishes.

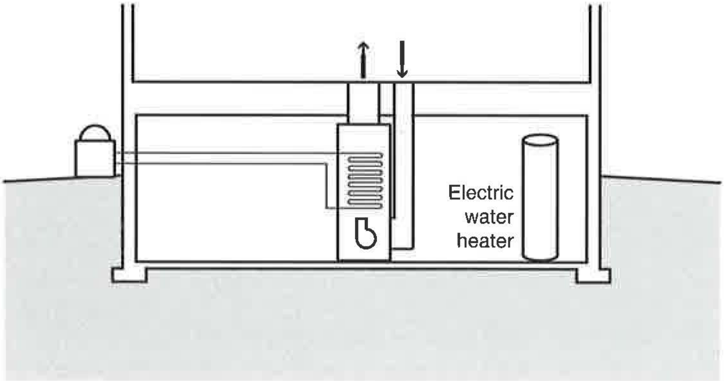


Figure 6.17
Air-to-Air Heat Pump

- Heating and cooling provided by an electrically driven heat pump with exterior air used as a heat source/sink

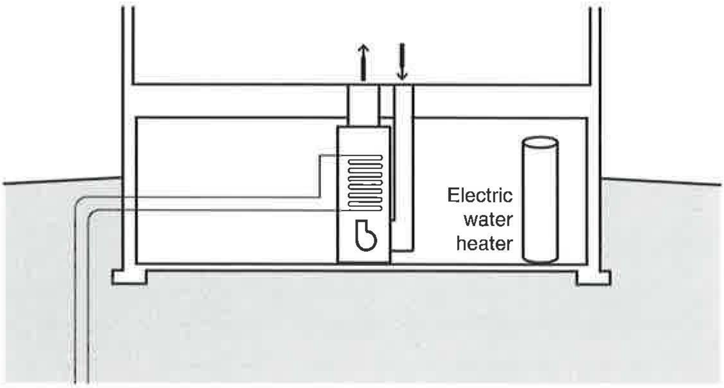


Figure 6.18
Ground Source Heat Pump

- Heating and cooling provided by an electrically driven heat pump with ground used as a heat source/sink

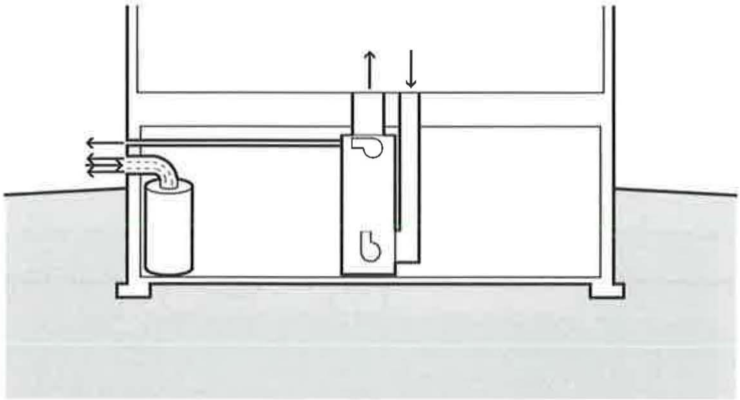


Figure 6.19
Direct Vented Gas Water Heater, Induced Draft Gas Furnace

- Water heater located against exterior wall; combustion air supplied directly to water heater from exterior via concentric duct; products of combustion exhausted directly to exterior also via concentric duct.
- Furnace flue gases exhausted to the exterior using a fan to induce draft; combustion air taken from the interior

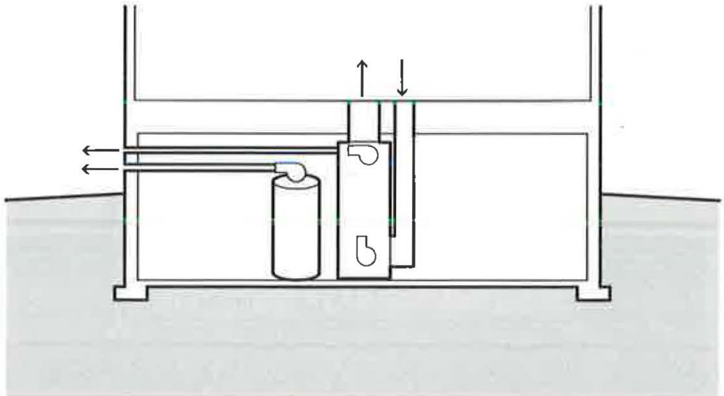


Figure 6.20
Power Vented Gas Water Heater, Induced Draft Gas Furnace

- Water heater flue gases exhausted to the exterior using a fan to maintain draft; combustion air taken from the interior
- Furnace flue gases exhausted to the exterior a fan to induce draft; combustion air taken from the interior

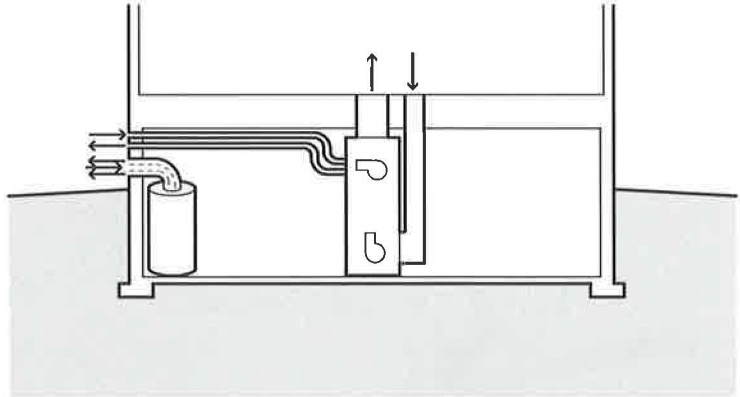


Figure 6.21
Direct Vented Gas Water Heater, Sealed Combustion Power Vented Furnace

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

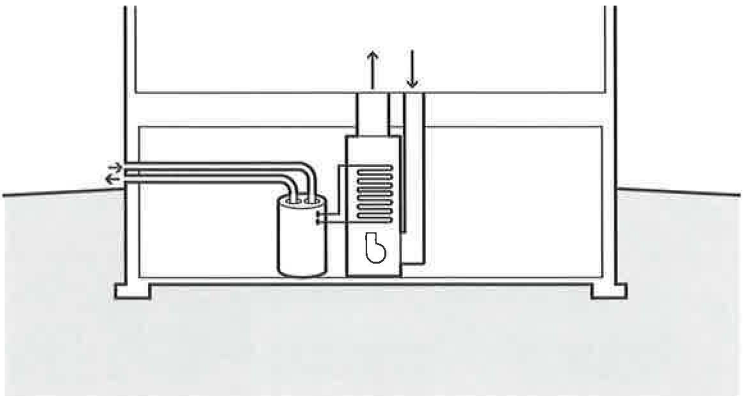


Figure 6.22
Sealed Combustion Power Vented Gas Water Heater

- Water heater flue gases exhausted to exterior using a fan; combustion air supplied directly to furnace from exterior via duct
- No furnace; heat provided by hot water pumped through a water-to-air heat exchanger (fan coil)

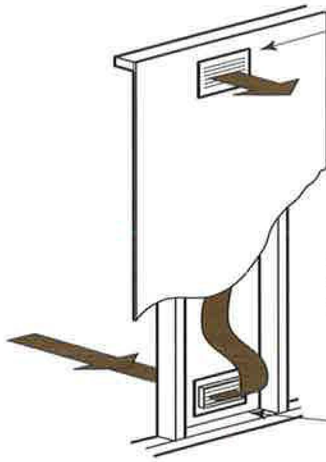


Figure 6.23
Transfer Grille

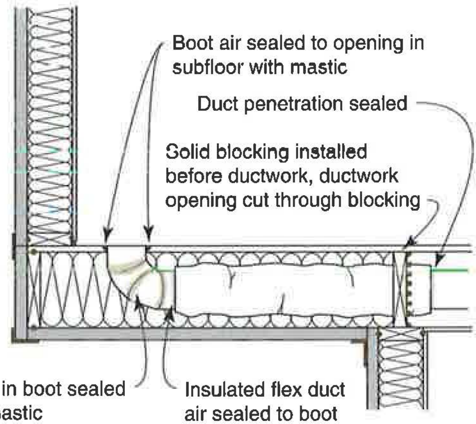


Figure 6.24
Ducts in Cantilevered Spaces or Serving Bedrooms Over Garages

- Avoid whenever possible
- Use insulated ducts
- Air seal all joints with mastic including boot penetrations through subfloors and duct penetrations through draft stops
- Consider spraying boot exterior with foam insulation

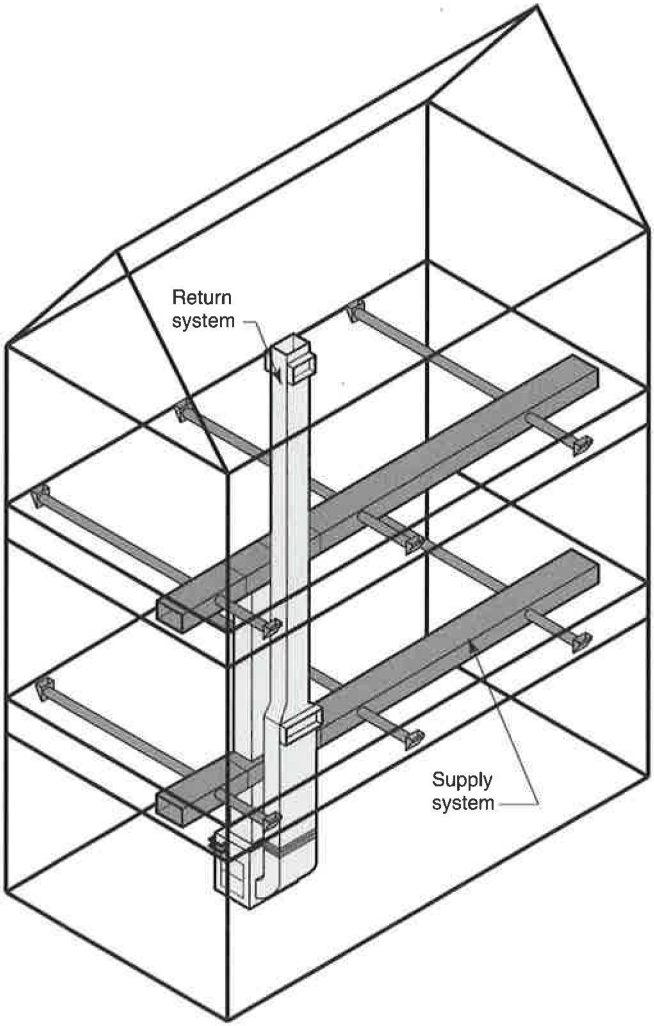


Figure 6.25
Air Handler and Duct Layout

- Air handler centrally located to minimize duct runs
- No ductwork in exterior walls or attic
- No returns in basement
- Return high in hallway of upper floor
- Return low in hallway of main level
- Only fully "hard"-ducted returns when connected directly to air handler; no panned floor joist returns; no stud cavity returns
- Either return ducts in bedrooms or transfer grilles

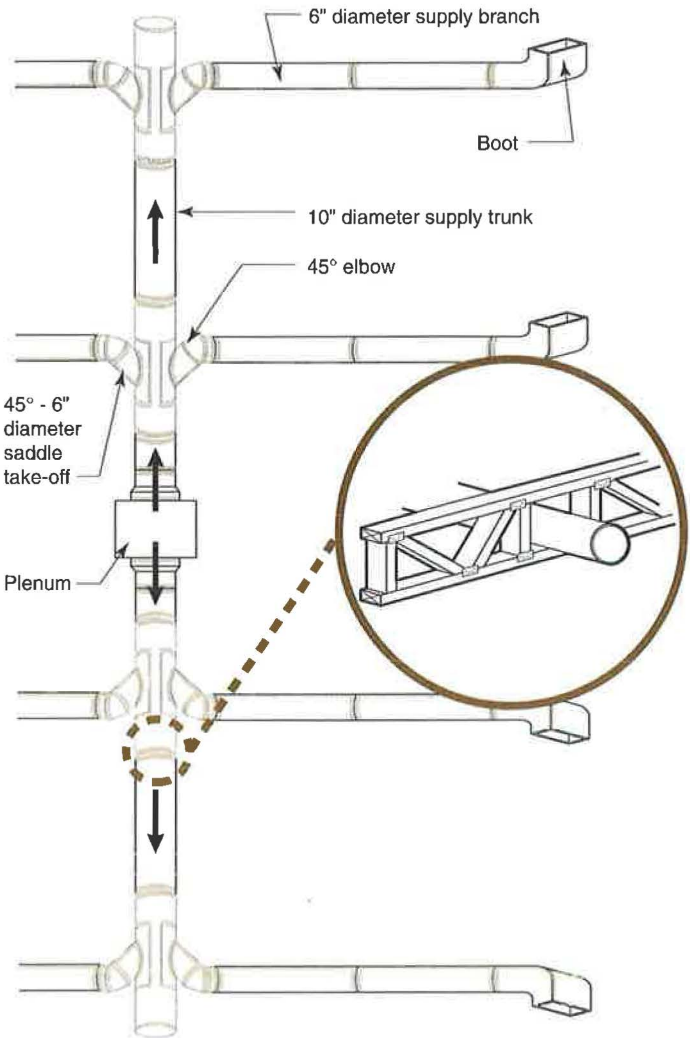


Figure 6.26
Supply Duct System

- Must be sized/designed on a case-by-case basis
- Supply duct system sized to fit within 14" deep or 12" deep open webbed floor trusses.
- Trunk ducts can be 10" diameter for 14" deep floor trusses or 8" diameter for 12" deep floor trusses depending on air flows and heat losses
- Branch supply ducts can be insulated flex
- Rounded ducts, 45° take-offs and 45° elbows reduce air flow resistance so ducts can be made smaller to fit in floor system

7 Plumbing

Plumbing systems have to:

- supply cold water
- supply hot water
- remove gray water and solid wastes
- not leak water, odors or air

Concerns

Plumbing system penetrations can be a major source of air leakage. Don't put plumbing in outside walls. Let us repeat that for those that may not get it. Don't put plumbing in outside walls. Holes in outside walls cause drafts; outside walls get cold. Pipes freeze. Owners get annoyed. Get it?

Plumbing penetrations through rim joists should be sealed with expanding foam or caulk. Vent stacks penetrating into attics should be sealed with flexible seals to handle expansion of pipes. See Figures 7.1 through 7.4 for details.

Tubs and Shower Stalls

Tubs, shower stalls, and one-piece tub-shower enclosures installed on exterior walls can be one of the single largest sources of air leakage across a building envelope. It is essential that rigid draft-stopping material is installed prior to tub and shower stall installation. With one-piece tub-shower enclosures, the entire height of the interior surface of the exterior wall should be insulated and sheathed prior to tub-shower enclosure installation. See Figures 5.21 through 5.23 for details.

Water Consumption

Low-flow toilets and shower heads should be installed to minimize water consumption. Pressure balanced shower controls should be used to reduce the dangers of scalding.

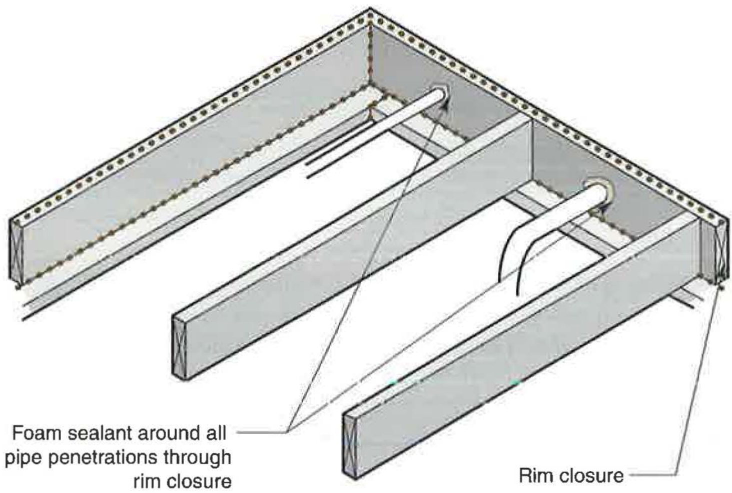


Figure 7.1
Rim Penetrations

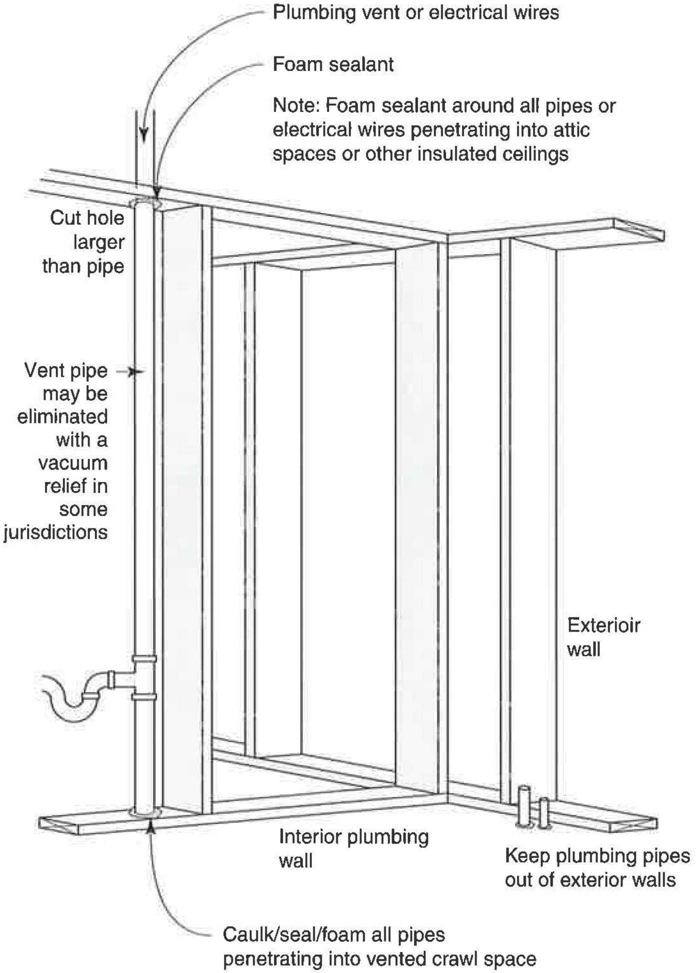


Figure 7.2
Locating Plumbing Pipes

- Where connections are made to toilets and pedestal sinks and exposed piping, chrome plated or other surface finished materials should be considered for aesthetic reasons.

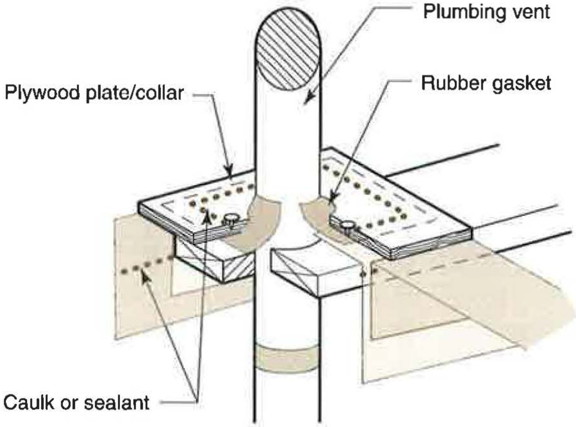


Figure 7.3
Neoprene Rubber Gasket or Roof Jack

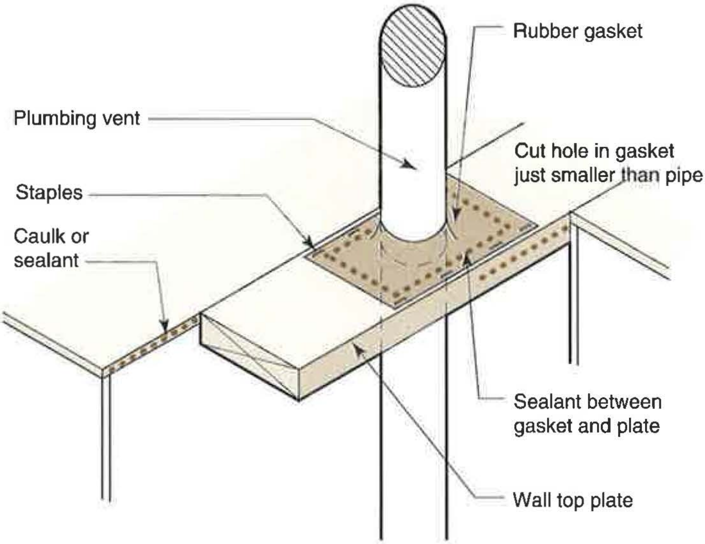


Figure 7.4
Vent Stack Penetration to Attic

8
Electrical

Electrical systems have to:

- supply electricity
- supply communication and control signals
- not leak air

Concerns

Electrical system penetrations through the building envelope can be a major source of air leakage.

Airtight outlet boxes should be installed in exterior walls and insulated ceilings. Specialized boxes are available. Alternatively, sealants can be used to seal penetrations in standard outlet boxes. See figures 8.2 and 8.3 for details.

Electrical penetrations through rim joists should be sealed with expanding foam or caulk. Wires penetrating into attics, and through top and bottom plates in exterior walls should be sealed with expanding foam or caulk. Air can also leak through service penetrations in studs where interior walls intersect exterior walls. These penetrations should also be sealed (Figure 8.4).

Recessed light fixtures in insulated ceilings should be insulation cover (IC) rated fixtures which are airtight and can be covered with insulation (Figure 8.5). Recessed light fixtures installed in dropped ceilings or soffits need to be draftstopped (Figure 8.6).

Where electrical panels are installed on exterior walls, air sealing of all penetrations is necessary (Figure 8.1).

Wires should be located along plates or against studs rather than through the center of insulated cavities to minimize insulation compression where batt insulation is used (Figure 8.4).

Lighting fixtures, locations and approaches should be selected in conjunction with daylighting design. Energy efficient lighting fixtures, bulbs and controls should be specified.

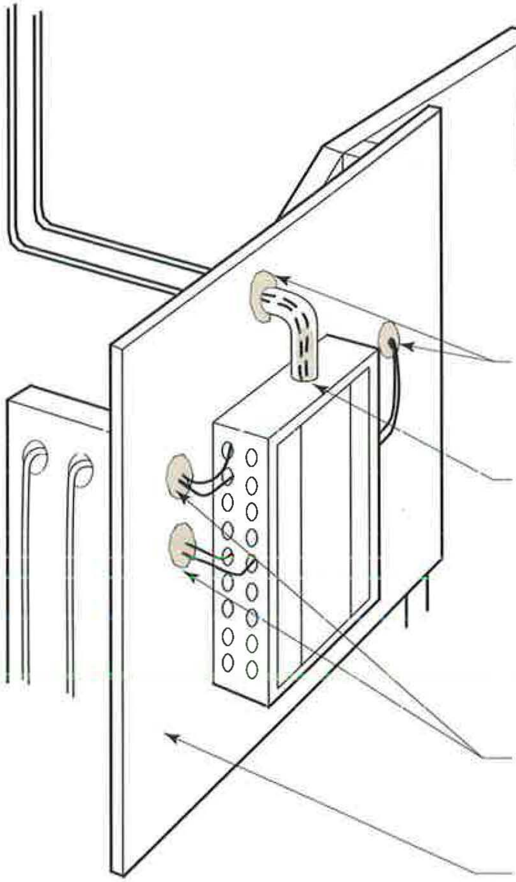
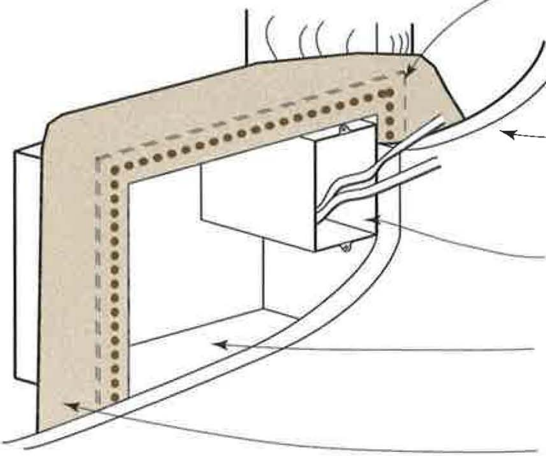


Figure 8.1
Electrical Panels



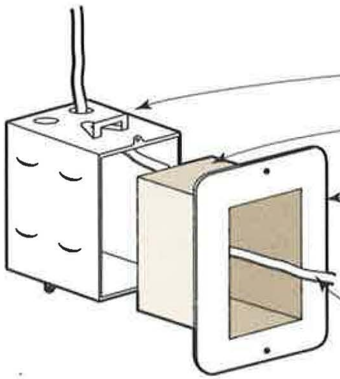


Figure 8.2
Electrical Boxes and Polyethylene Air Flow Retarders

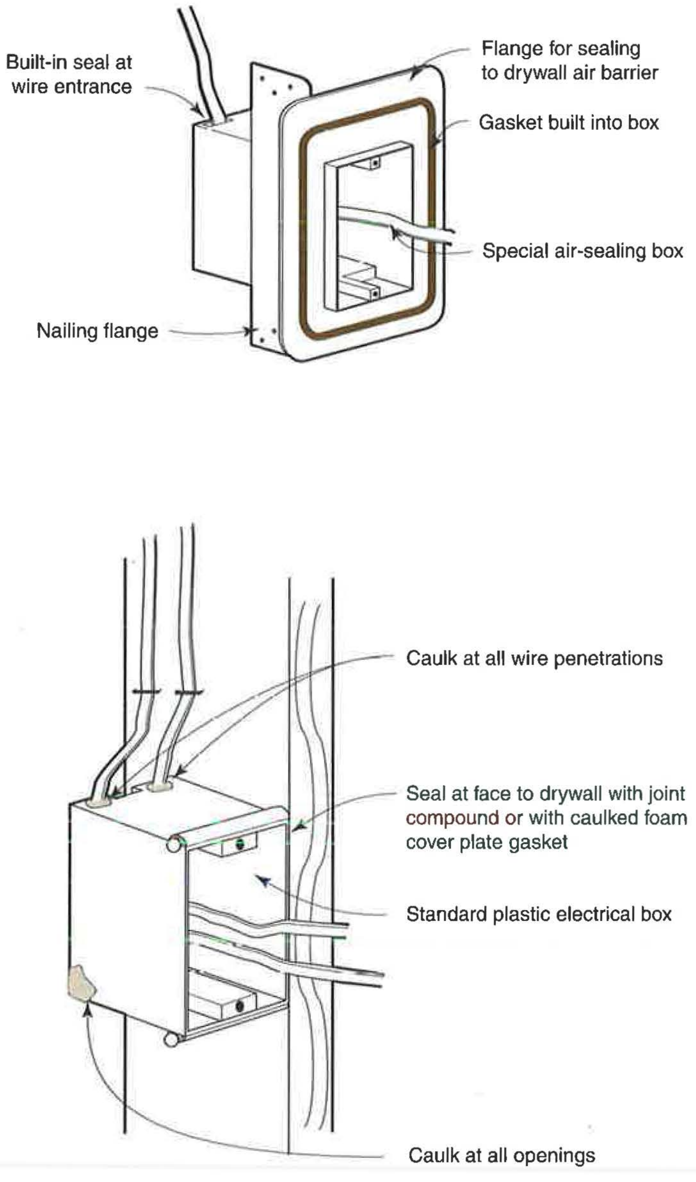


Figure 8.3
Electrical Boxes and Drywall Air Flow Retarders

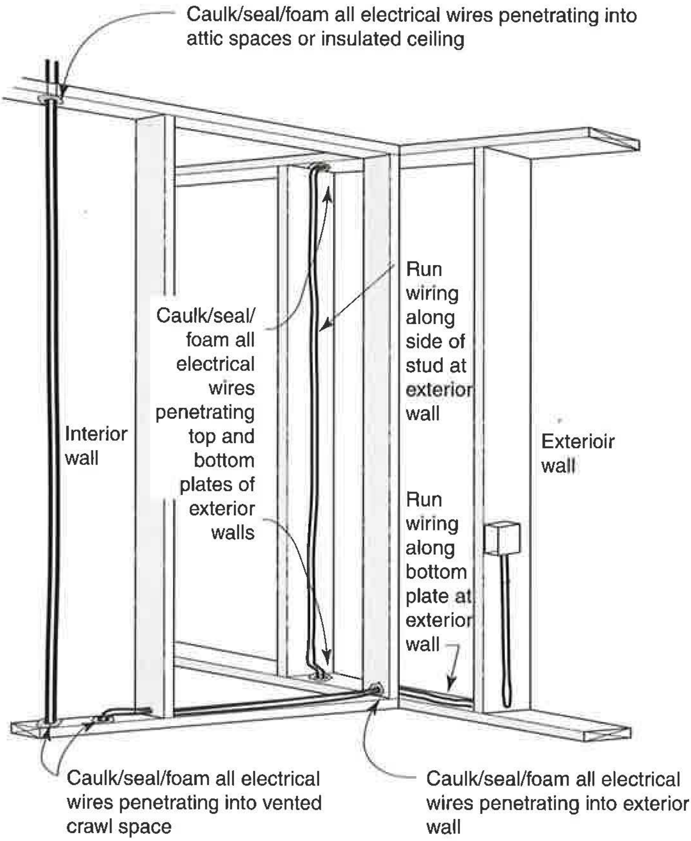
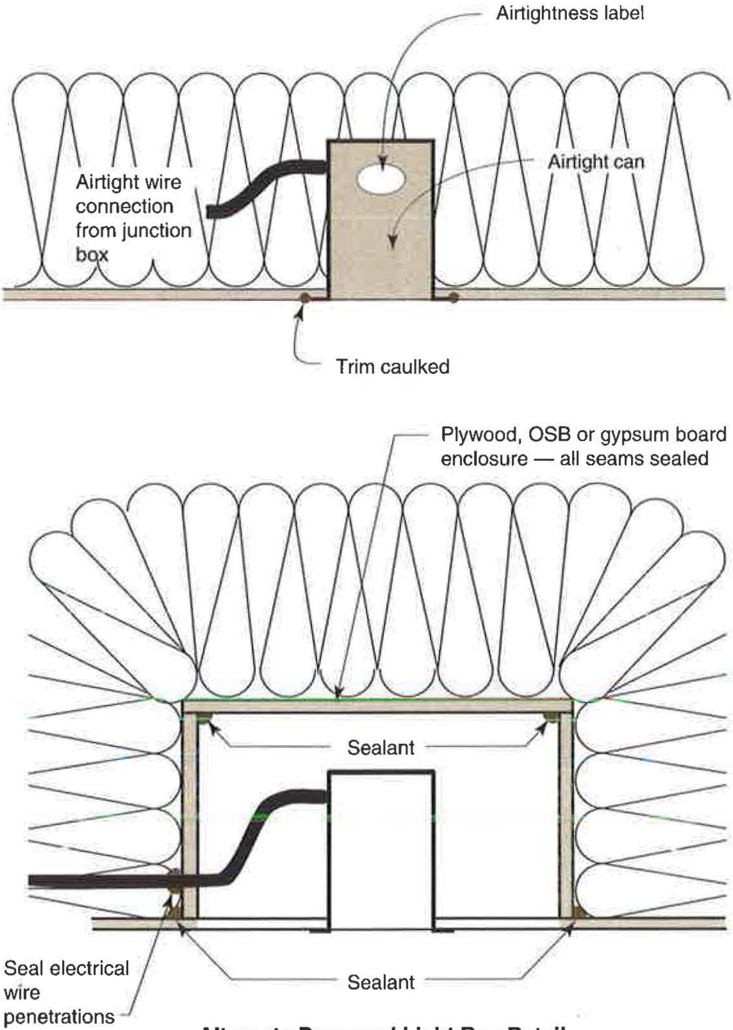


Figure 8.4
Sealing Electrical Wires

- Run low voltage wires in plastic conduit to allow for future upgrade or service

Avoid placing recessed lights in insulated ceilings unless they are specifically designed to be airtight. Install IC-rated fixtures that have passed the ASTM E-283 test for air leakage.



Alternate Recessed Light Box Detail

Figure 8.5
Airtight Recessed Light Box

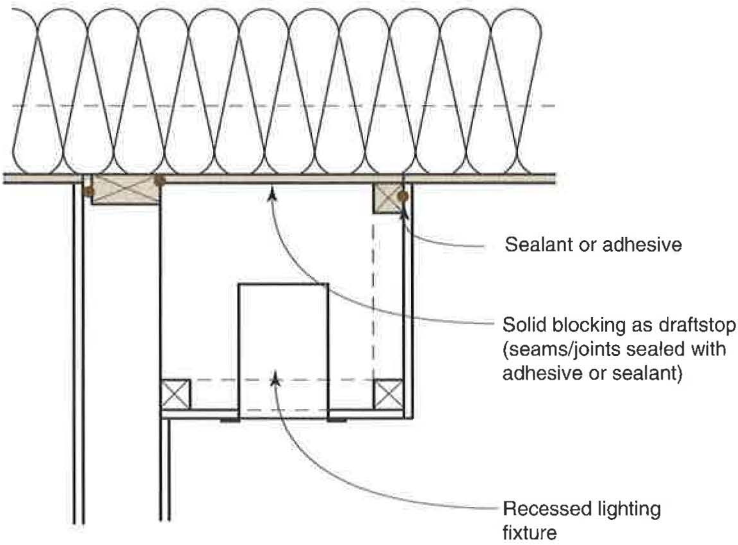


Figure 8.6
Blocking and Sealing Around Recessed Lights

9 Insulation

Cavity insulation combined with insulating sheathings are common in residential wall construction. Cavity insulations are typically fiberglass batt, damp spray cellulose, dry spray cellulose, fiberglass, rock or slag wool supported by netting or reinforced polyethylene and spray foam. Insulating sheathings are typically extruded and expanded polystyrenes, foil and fiber faced isocyanurates, and rigid fiberglass. Roof insulations are typically blown fiberglass, blown cellulose, fiberglass batt, and spray foam. All have to:

- keep the heat in during the winter
- keep the heat out during the summer

Concerns

Fiberglass batt, damp spray cellulose, dry spray cellulose, blown fiberglass, rock or slag wool and blown cellulose cavity and roof insulations are not air flow retarders. They should be used in conjunction with air flow retarders. Spray foams and rigid insulations (when their joints are sealed) are air flow retarders in their own right.

Just so that we are all clear, blowing a cathedral ceiling "solid" with cellulose will not eliminate the need for an interior air flow retarder or the need for roof ventilation if the temperature of the first condensing surface (underside of roof deck) is not controlled by the use of rigid insulation. Packing fiberglass around window frames or around plumbing stacks to reduce air flow, while better than nothing at all, does not effectively stop air flow. Foam sealants or caulks provide effective air sealing in these areas.

Let's also point out that properly treated cellulose is not, and we repeat, is not more of a fire hazard than fiberglass insulation. Furthermore regarding health related risks associated with different insulation types, loose fibers and particulates of many sizes and *many* materials (fiberglass, rock or slag wool, cellulose) have been known to irritate many people. As long as proper precautions are taken during installation and proper containment and air sealing of these insulations is made, the health risk is negligeable compared to the benefits provided by the energy savings.

To be perfectly clear: insulation is good. All insulation is good. More insulation is better. All insulation is environmentally friendly, even the rigid foams because of the shear quantity of energy (barrels of oil not burned, pounds of carbon not dumped into the atmosphere) they save over their useful service lives. The amount of energy used to make all insulation (the embodied energy, even in the rigid foams) is trivial compared to the energy they save when used in buildings that last at least one mortgage period (don't rot and fall down). So the key to environmentally friendly construction is durable building envelopes that are extremely well insulated.

Fiberglass

In wall cavities, fiberglass batt insulation should be cut to fit and carefully installed to completely fill the cavity. Batts should not be cut short or cut long and forced/compressed into small areas. Batts should be fluffed to full thickness and split around plumbing and wiring (Figure 9.2). Even better, move the wires so that insulation does not have to be split. It is preferable to face staple fiberglass batts, with integral vapor retarders as inset stapling can affect performance (Figure 9.1). Yes, face stapled batts can interfere with drywall installation. If you now need a vapor diffusion retarder because you are not using faced batts, use polyethylene or low perm paints. Use of higher density batts will typically improve quality of installation.

Cellulose

Damp spray cellulose insulation should only be used with permeable sheathings in cold climates (heating climates). Permeable means asphalt impregnated fiberboard, gypsum sheathing, plywood and OSB. It does not mean any of the rigid insulation's except rigid fiberglass. Dry spray cellulose can be used in wall cavities with netting and can be used with any type of sheathing. Cellulose is not a vapor diffusion retarder. That means if you need a vapor diffusion retarder you should use polyethylene or low perm (vapor retarder) paint. Wall assemblies in heating climates need interior vapor diffusion retarders unless insulating sheathings are installed in sufficient thickness to elevate temperature of condensing surfaces (see Appendix III).

Roofs

In all truss and roof assemblies, baffles should be installed at roof perimeters to prevent the wind washing of thermal insulation and to prevent insulation from blocking soffit vents in vented roof assemblies (Figure 9.3 and 9.4).

Ventilation can be used to remove moisture from roof assemblies and to control ice damming. Attic ventilation is most effective when half the vent area is near the ridge and half is near the eave. Typical practice requires 1 square foot of net free vent area for every 300 square feet of ceiling area (Figure 9.5).

Crawl Spaces

Crawl spaces should not be vented. Crawl spaces should be constructed as mini basements. They should be part of the conditioned space of the house.

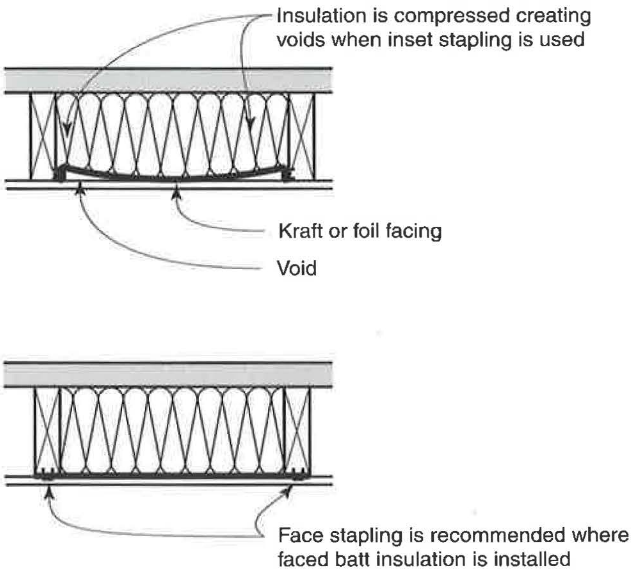
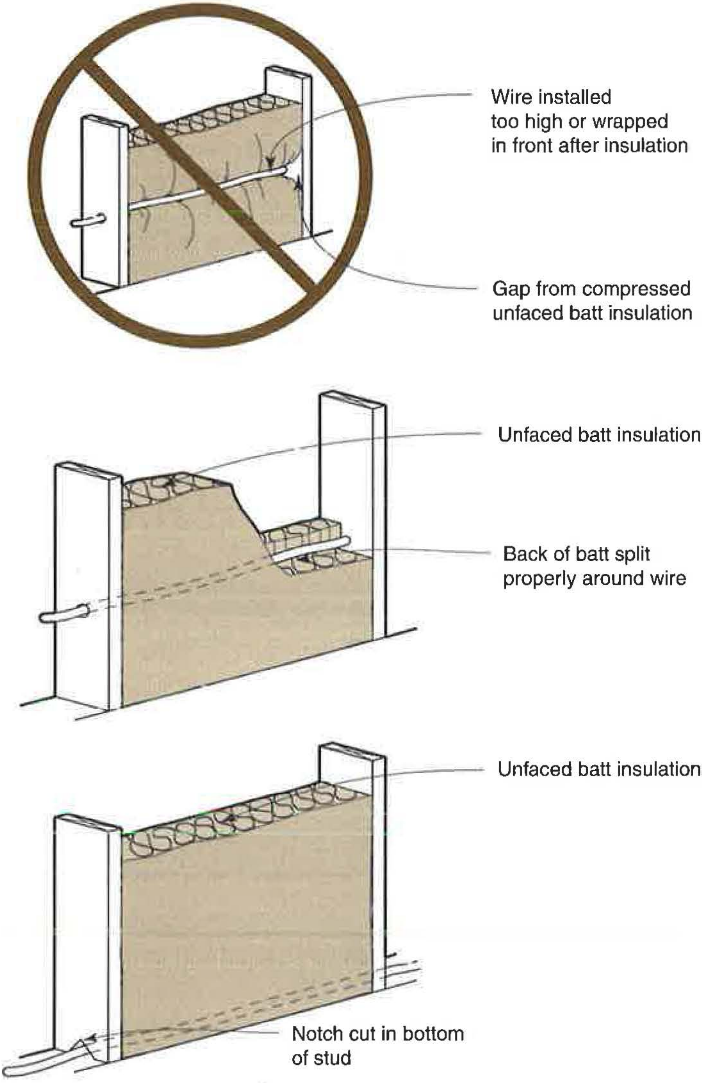


Figure 9.1
Face Stapling vs. Inset Stapling



Alternate Wiring with Batt Insulation Detail

Figure 9.2
Installing Batt Insulation in Cavity with Electrical Wiring

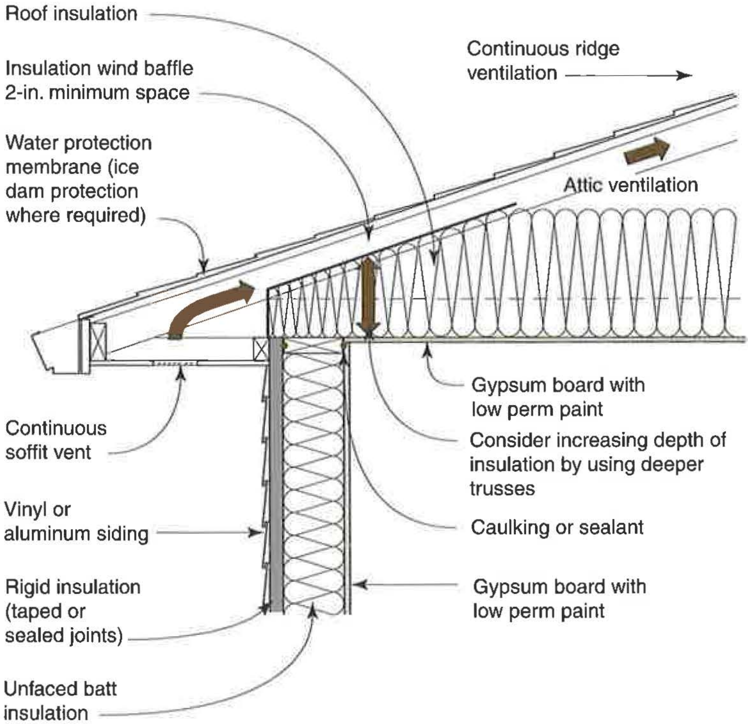


Figure 9.3
Baffle Installation

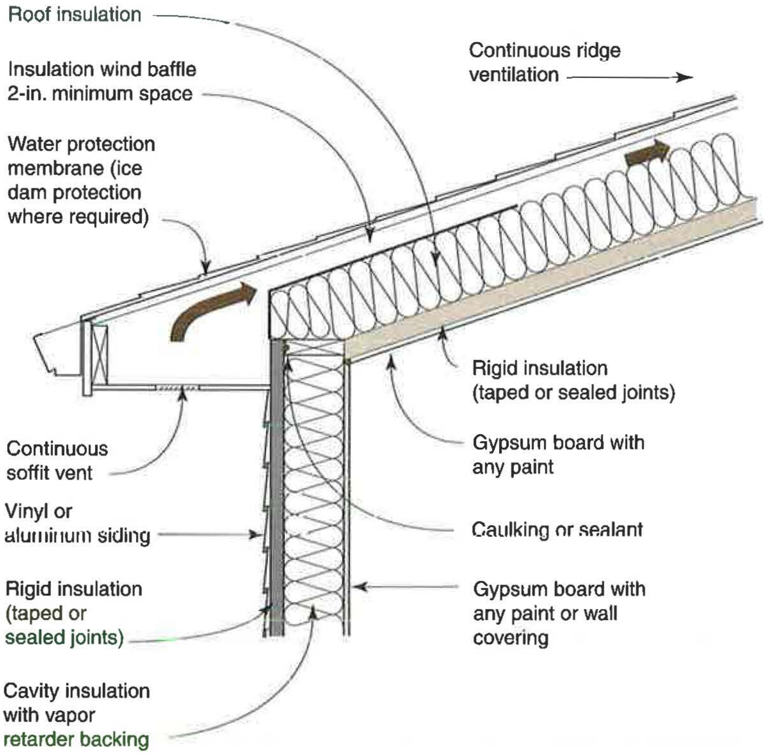
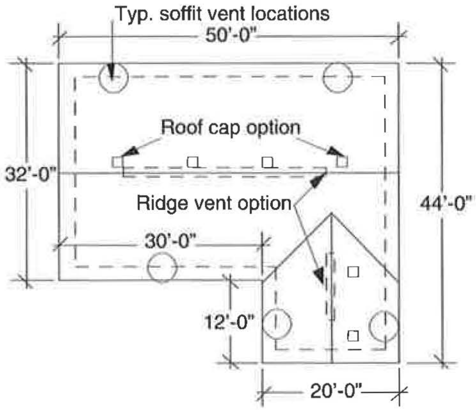


Figure 9.4
Baffle Installation in a Cathedral Ceiling



Obtain Local Code Requirement; E.G. 1:300*

1. total sq. ft. attic
   (32 x 50) + (12 x 20) = 1840 sq. ft.

2. total free vent required
   1850/300 = 6 sq. ft.

3. location of vents
   50% (3 sq. ft.) at ridge
   50% (3 sq. ft.) at eave

4. total vents at ridge (cap type)
   3 sq. ft./net free area per vent
   3 sq. ft./0.6** = 5 vents required

5. alt. vent at ridge (strip ridge vent)
   3 sq. ft./net free area per lin. ft. of vent
   3 sq. ft./0.125** = 24 linear ft. of vent

6. total vents at eave
   3 sq. ft./net free area per vent
   3 sq. ft./0.9** = 3 or 4 vents required

Continuous ridge combined with continuous soffit vents typically exceed code requirements for ventilated roof assemblies

Figure 9.5
Determining Attic Space Vent Area Requirements

* 1:300 requires 1 sq. ft. of vent area for every 300 sq. ft. of ceiling area divided between the ridge soffit

** See vent manufacturer's literature for net free vent area of particular vent

10 Drywall

Drywall (gypsum board) has to:

- provide rigidity
- provide aesthetics
- provide fire protection
- not leak air

Concerns

Wood moves. Drywall does not move. Interesting problem. The more you attach drywall to wood, the more cracks you have. Easy, attach the drywall to less wood, and, in a way, that allows the wood to move.

Nail pops happen because as wood dries, it shrinks. Nails do not shrink. Actually, nails do not pop. The wood shrinks away from the back face of the drywall as it dries. How about getting dry wood? Sure. Better to use shorter nails. Even better, use glue. With glue, as the wood shrinks, it pulls the drywall inwards with it. But, you can't only use glue, you've got to use something until the glue begins to work. Now, shorter nails don't hold very well, and we don't want to use more of them, so use shorter screws and glue.

Wood is weird. When it shrinks, it shrinks differently along the grain than perpendicular to the grain. It shrinks much more at right angles to the grain, than along the grain. Studs don't get shorter, but they get thinner in thickness and in width (Figure 10.1 and 10.2). When we attach drywall, we need to keep this in mind especially when we box in built-up beams made out of 2x10s and 2x12s. What's nice about engineered wood, is it doesn't shrink. Drywall likes engineered wood, especially above windows as header material. Drywall doesn't like big pieces of real wood.

Stairwells provide an interesting problem. With real wood floor joists (2x10s), you get more shrinkage in the 9-1/4 inches of floor framing (remember this is at right angles to the grain of the floor joists) than in the 8 feet of wall framing (along the grain of the studs) above and below. Old timers used to balloon frame two story spaces for this reason, or provide control joints between the floors in the plaster or drywall. Better to use floor trusses or engineered wood joists, they don't shrink.

Truss Uplift

What can we say about truss uplift? You can't prevent it. Truss uplift occurs because of moisture content differences between the upper and lower chords of wood trusses. Moisture content differences are inevitable if one member is cold and the other member is warm. If you insulate a wood roof truss, the lower chords will be warm and the upper ones will be cold. Remember, truss uplift is not truss uplift if the owner can't see it. Let the trusses move. Floating corners for drywall attachment is the way to go. The truss moves, the drywall bends, no crack, end of story (Figure 10.4). This is also the same principle to use at corners of exterior and interior walls. Why use three stud corners? If we attach the drywall to the wood on both sides of the corner, when the wood shrinks, the drywall cracks. Two stud corners are better. Don't attach the drywall (Figure 10.3). Let the wood move. If you are going to use a three stud corner, at least don't attach the drywall to one of the sides, just support the drywall until it is taped. Let the tape hold the corner together.

Air Flow Retarders

One of the really nice things about drywall is that air doesn't leak through it. It leaks around it, but not through it. Tape the joints of drywall together, glue it to top and bottom plates and around window openings and presto - you have an air flow retarder (Figures 10.5 through 10.7). Now paint it and shazzam - you have a vapor diffusion retarder. Add draft stops and fire stops out of rigid material to the framing package and we have an airtight building.

Now drywall is not the only air flow retarder. Polyethylene installed in a continuous fashion (seams taped or sealed) works as an air flow retarder. So does spray foam. If you are using polyethylene, it is very important that the installation of the drywall does not cause rips and tears in the poly.

Ceramic Tile Tub and Shower Enclosures

Treated gypsum board ("green board") is typically used as a base for ceramic tile enclosures around bathtubs and showers. This type of gypsum board (or any gypsum board) should not be installed over polyethylene in an exterior insulated wall under tile. Moisture becomes trapped between the tile and the poly. The gypsum board goes to mush (green board included, it just takes longer). Moisture gets in because grout joints are permeable to moisture. Cement boards or cement and wire lath should be used in place of gypsum board if poly is used.

Winter Construction

Drywall under insulated ceilings should be 5/8 inch thick. Interior and exterior walls should be framed on 24 inch centers and standard 1/2 inch drywall is fine. Don't tape under insulated ceilings in the winter if you haven't insulated. Big mistake. Try it and you will learn all about condensation and how expensive it is to put up new drywall. Yes, but I really like blown insulation and I can't blow until my drywall is up. Well, you can board first, then blow and then tape. Or, you can use a batt and blow strategy. Batt the ceiling with a little insulation when you do the walls, and then blow the loose stuff on top later.

Winter construction is always fun. Propane heaters release lots and lots of moisture. Interesting problem. You want to dry out your building while you are humidifying it. Okay, so we open some windows. Let's now heat a building with open windows. Propane heaters also release lots and lots of carbon dioxide. Joint compound does not like carbon dioxide. Bad things happen with lots of carbon dioxide, moisture and

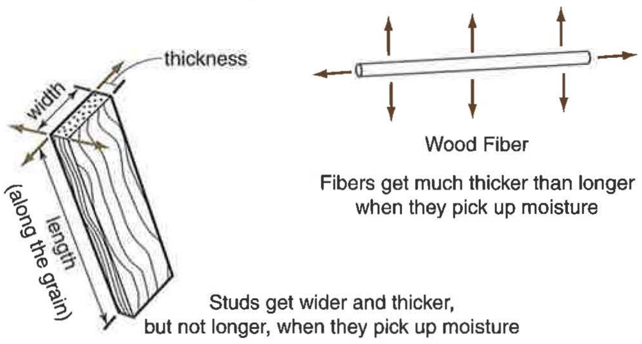


Figure 10.1
Wood Shrinkage

joint compound; carbonation. Carbonation is bad. Better to hook your heating system up. If you have gas heat, make sure you have a chimney. The alternative is to install temporary heat, properly vented. You still need air change to flush out the moisture, but not as much as before. Moisture is bad, carbon dioxide is bad, heat and ventilation are good. Use a setting type compund with humid or or cool conditions. These compounds can be selected for a range of specific properties.

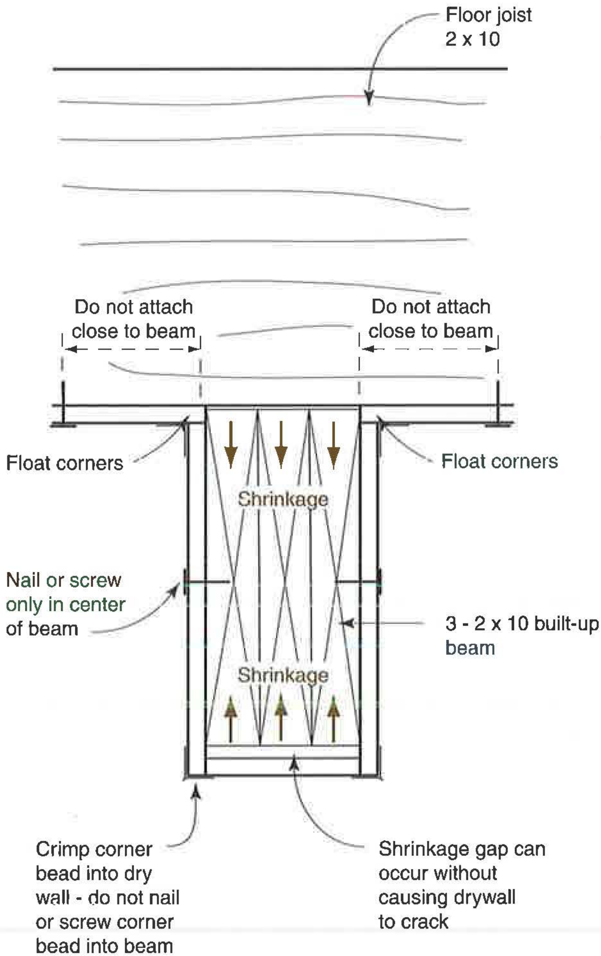
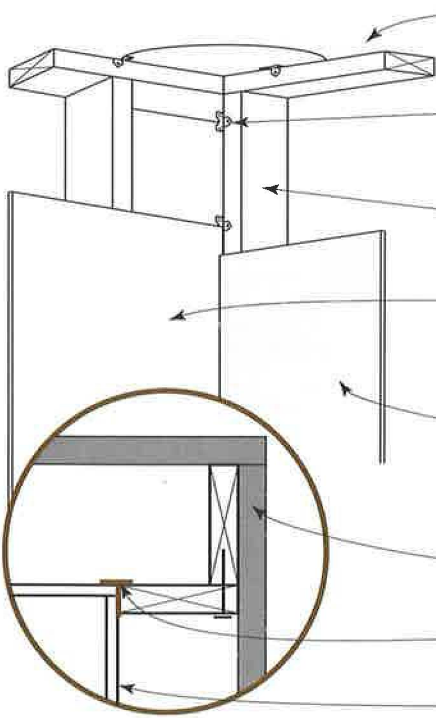


Figure 10.2
Built-up Beam Shrinkage

- Float corners and crimp corner bead without nails to allow for beam shrinkage



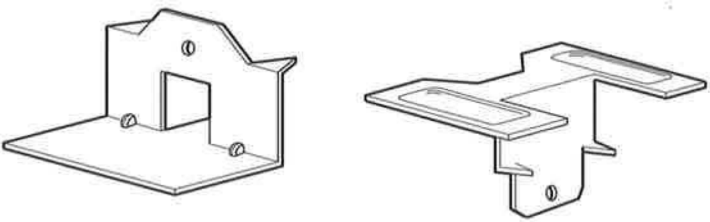
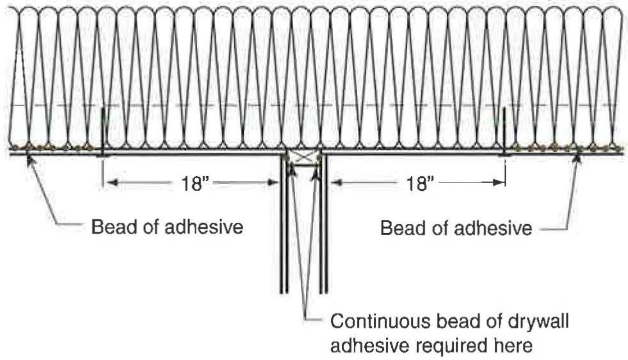


Figure 10.3
Typical Clip Support for Gypsum Board

- Use of clip support for gypsum board results in floating corners and significantly less drywall cracking



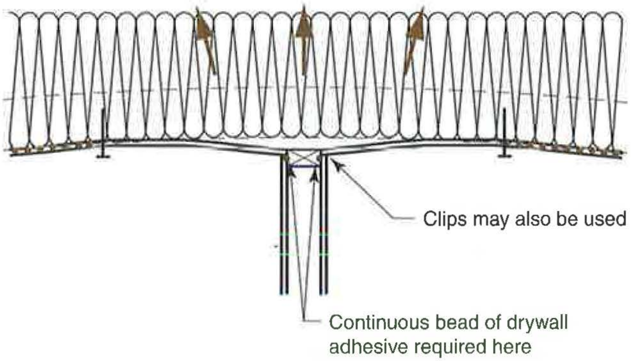


Figure 10.4
Truss Uplift

- Do not install ceiling drywall adhesive or ceiling drywall screws/nails closer than 18" to interior partition top plates in order to control drywall cracking from truss uplift.
- "Floating corners" of ceiling drywall allow truss movement without drywall cracking. Note that a continuous bead of drywall adhesive is required along both sides of top plates for wall drywall.

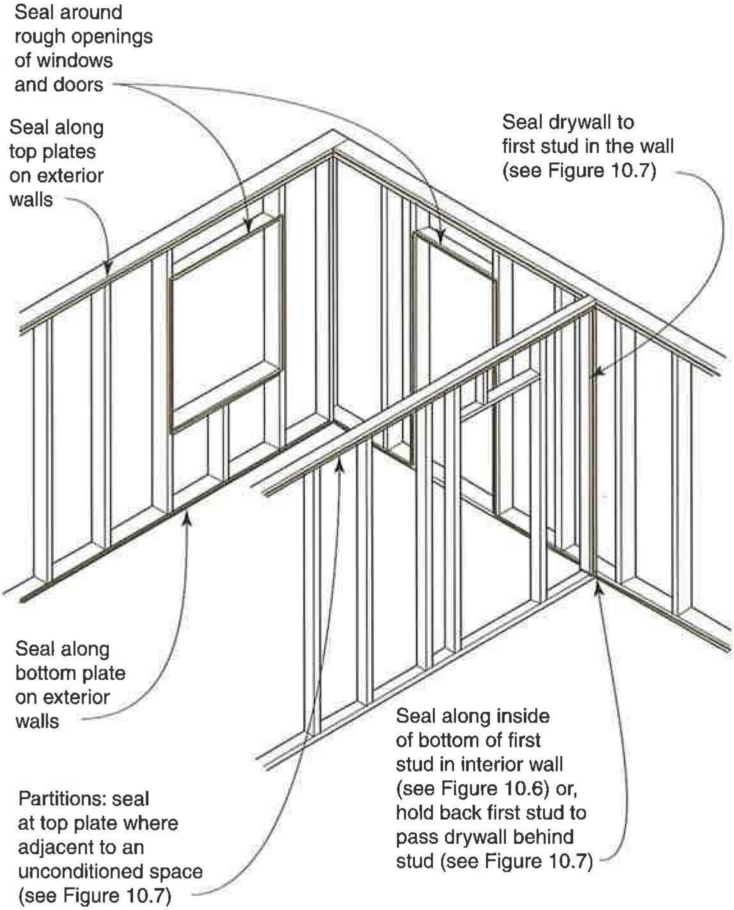


Figure 10.5
Interior Air Flow Retarder Details at Walls and Ceilings

- Use caution when installing drywall at gaskets or over polyethylene so that gaskets are not moved out of position or polyethylene is not cut or torn.
- Gasket can be used in place of sealants or adhesives

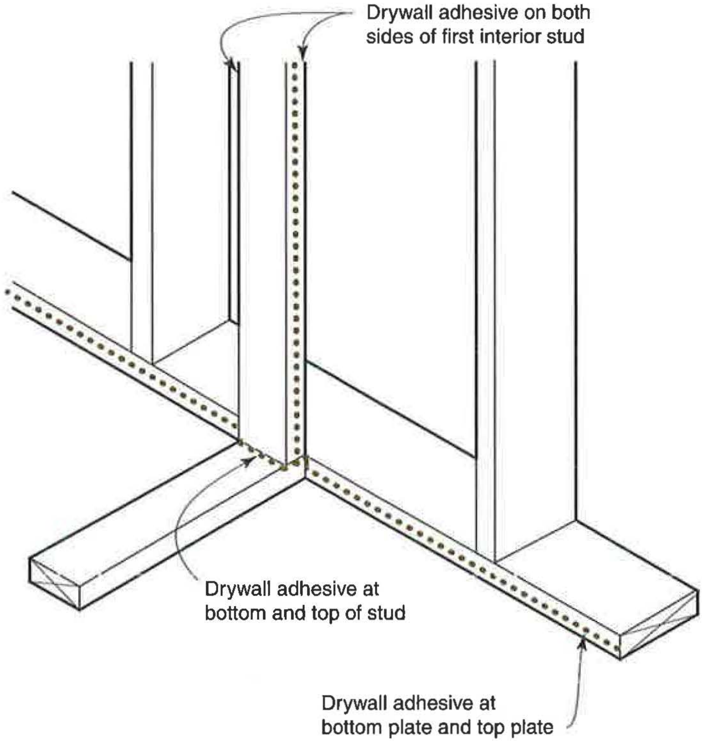


Figure 10.6
Interior/Exterior Walls

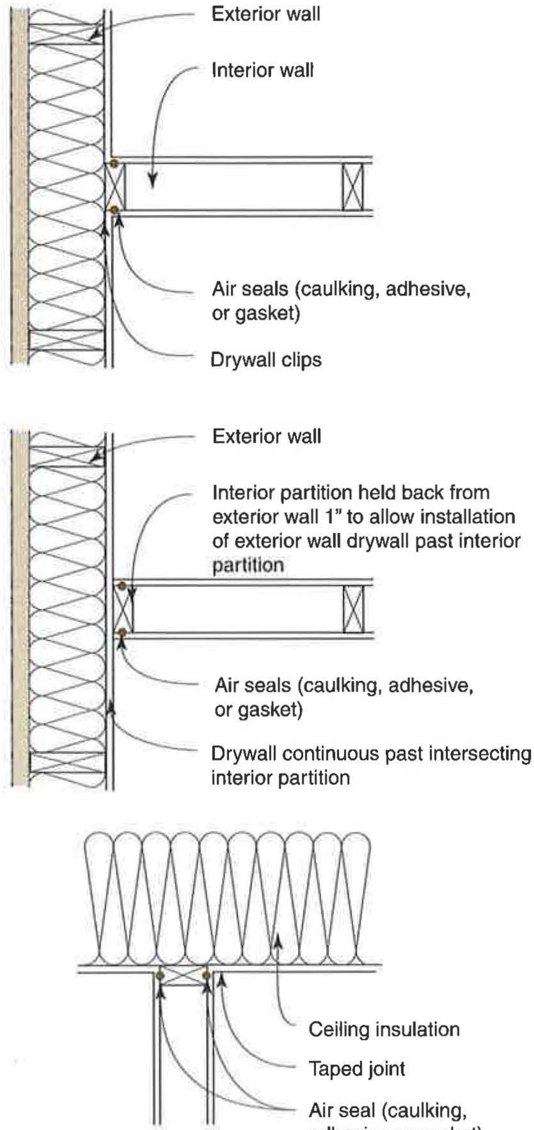


Figure 10.7
Intersection Interior Partitions

11 Painting

Paint has to:

- keep rain out of wood
- breathe when its on the outside
- protect wood from getting a sunburn
- look nice

Concerns

Exposure to sunlight (ultraviolet radiation) and moisture are the major factors affecting the durability of paint coatings and the durability of wood. Although, independently each factor can lead to deterioration, the effect of the combination of both factors is much more severe than either factor independently. Ultraviolet radiation and moisture can each lead to the breakdown of the resin in painted surfaces which binds (holds) the pigment to the surface. When the resin breaks down, pigment is lost (washed away from the surface) and fading occurs. In some instances, rubbing the surface with a cloth or a hand will remove a white powder from the paint surface (chalking). Ultraviolet radiation and moisture have a similar effect on wood. Wood breaks down under exposure to ultraviolet radiation and wood surface erosion is increased with exposure to ultraviolet radiation coupled with rain.

The ideal coating system for wood is a system which is hydrophobic (sheds water), vapor permeable (breathes), resistant to ultraviolet light (sunlight) and has good adhesion (sticks to wood) and cohesion (stretches) properties.

Acrylic latex top coats coupled with premium latex primers are recommended when they are applied over stable substrates (dry, dimensionally stable and able to hold paint) as they are more vapor permeable than other paint finishes while providing similar hydrophobic, UV resistance, adhesion and cohesion properties. Two coats of all-acrylic latex paint over a premium latex primer are recommended.

The optimum thickness for the total dry paint coat (primer and two topcoats) is 3.5 to 5 mils.

Oil based prime coats coupled with latex top coats do not provide as permeable a system as a latex prime coat based system. However, oil based prime coats provide superior adhesion and stain blocking characteristics for difficult substrates. For woods with water-soluble extractives, such as redwood and cedar, oil based prime coats are recommended. Do not use latex based prime coats with these type of substrates.

Exposure of unprotected wood to sunlight can adversely affect the adhesion of paint to wood within as little as 3 to 4 week exposures. Wood surfaces should be painted as soon as possible, weather permitting. All exterior wood (except decking materials) should be back primed or prime coated on all six surfaces. Ideally, wood should be pre-primed on all surfaces prior to arrival at the job site. Field cut edges should be sealed with primer during installation. Top coats should be applied within 2 weeks of field exposure of the prime coat. The sooner, the better. Some prime coats weather by forming a soap-like film that can interfere with adhesion with top coats. Washing of aged prime coats (exposed to sunlight) is recommended prior to top coat application. Re priming may be necessary if prime coats have excessively weathered. Ideally, the temperature should not drop below 50 degrees F for at least 24 hours after paint application. Winter, late fall or early spring topcoat application is not recommended.

Pre-primed material should be utilized during winter construction and not top-coated (finished) until weather permits.

A paint coating's resistance to ultra violet radiation and moisture is dependent on the ratio of resin to pigment in the paint. The more resin available to completely coat a pigment particle, the more forcefully the particle is bound to a surface. Premium paints have a high ratio of resin to pigment. A low cost paint typically has a high pigment content relative to resin content as pigment is less expensive than resin. Although a high pigment content paint has an excellent "hiding" ability, high pigment content paints with low resin contents are unable to resist exposure to sunlight and moisture. Gloss paints have more resin than semi gloss paints, and semi gloss paints have more resin than flat paints. Gloss paints have the most resistance to ultra violet radiation and moisture, flat paints have the least.

Stains are not as hydrophobic or resistant to ultraviolet light as paints but are more vapor permeable. As stains break down more rapidly due to ultraviolet light than do paints, re-coating more frequently with stains will be likely. Solid body stains are thin paints and should not be used. Do not use solid body stains.

Deck materials should never be painted as even vapor permeable paint coatings serve to inhibit drying of absorbed moisture beyond acceptable levels for such a hostile moisture environment (horizontal, exposed to rain and sun). However, deck materials can be coated with penetrating water repellents or stains. Both of these serve to reduce water absorption without reducing drying ability. Untreated deck materials will deteriorate from both water absorption and exposure to ultraviolet light. Even preservative treated deck materials deteriorate from exposure to ultraviolet light. Stains provide satisfactory protection against UV exposure (sunlight). Straight water repellents do not. Stains act as a type of "suntan lotion" for the wood. Like most typical sun tan lotions, stains must be regularly reapplied. Superior performance may be achieved when stains are applied over preservative treated decking materials.

Interior Surfaces

Paint coatings installed on interior surfaces can be either permeable or impermeable depending on the design of the wall assembly. On wall and basement assemblies which are designed to dry to the interior, only vapor permeable paint systems (latex paint) should be used.

On wall and roof assemblies which require a surface applied interior vapor diffusion retarder, a vapor impermeable paint system should be used. These coatings are available in both latex based and oil based systems.

12

Appendix I

Rain and Drainage Planes

Rain is the single most important factor to control in order to construct a durable structure. Although controlling rain has preoccupied builders for thousands of years, significant insight into the physics of rain and its control was not developed until the middle of this century by the Norwegians and the Canadians. Both peoples are blessed by countries with miserable climates which no doubt made the issue pressing.

Experience from tradition based practices combined with the physics of rain developed by the Norwegians and Canadians has provided us with effective strategies to control rain entry. The strategies are varied based on the frequency and severity of rain.

The amount of rain determines the amount of rain control needed. No rain, no rain control needed. Little rain, little rain control needed. Lots of rain, lots of rain control needed. Although this should be obvious, it is often overlooked by codes, designers, and builders. Strategies which work in Las Vegas do not necessarily work in Seattle. In simple terms, the amount of rainfall deposited on a surface determines the type of approach necessary to control rain.

Wind strength, wind direction, and rainfall intensity determine in a general way the amount of wind-driven rain deposited. These are factors governed by climate, not by design and construction. The actual distribution of rain on a building is determined by the pattern of wind flow around buildings. This, to a limited extent, can be influenced by design and construction.

Once rain is deposited on a building surface, its flow over the building surface will be determined by gravity, wind flow over the surface, and wall-surface features such as overhangs, flashings, sills, copings, and mullions. Gravity cannot be influenced by design and construction, and wind flow over building surfaces can only be influenced marginally. However, wall-surface features are completely within the control of the designer and builder. Tradition based practice has a legacy of developing architectural detailing features that have been used to direct water along particular paths or to cause it to drip free of the wall. Overhangs were developed for a reason. Flashings with rigid drip edges protruding from building faces were specified for a reason. Extended window sills were installed for a reason.

Rain penetration into and through building surfaces is governed by capillarity, momentum, surface tension, gravity, and wind (air pressure) forces. Capillary forces draw rain water into pores and tiny cracks, while the remaining forces direct rain water into larger openings.

In practice, capillarity can be controlled by capillary breaks, capillary resistant materials or by providing a receptor for capillary moisture. Momentum can be controlled by eliminating openings that go straight through the wall assembly. Rain entry by surface tension can be controlled by the use of drip edges and kerfs. Flashings and layering the wall assembly elements to drain water to the exterior (providing a "drainage plane") can be used to control rain water from entering by gravity flow, along with simultaneously satisfying the requirements for control of momentum and surface tension forces. Sufficiently overlapping the wall assembly elements or layers comprising the drainage plane can also control entry of rain water by air pressure differences. Finally, locating a pressure equalized air space immediately behind the exterior cladding can be used to control entry of rain water by air pressure differences by reducing those air pressure differences.

Coupling a pressure equalized air space with a capillary resistant drainage plane represents the state-of-the-art for Norwegian and Canadian rain control practices. This approach addresses all of the driving forces responsible for rain penetration into and through building surfaces under the severest exposures.

This understanding of the physics of rain leads to the following general approach to rain control:

- reduce the amount of rainwater deposited and flowing on building surfaces
- control rainwater deposited and flowing on building surfaces

The first part of the general approach to rain control involves locating buildings so that they are sheltered from prevailing winds, providing roof overhangs and massing features to shelter exterior walls and reduce wind flow over building surfaces, and finally, providing architectural detailing to shed rainwater from building faces.

The second part of the general approach to rain control involves dealing with capillarity, momentum, surface tension, gravity and air pressure forces acting on rainwater deposited on building surfaces.

The second part of the general approach to rain control employs two general design principles:

- Face-Sealed/Barrier Approach
  - Storage/Reservoir Systems
    - (all rain exposures)
  - Non-Storage/Non-Reservoir Systems
    - (less than 30 inches average annual precipitation)
- Water Managed Approach
  - Drain-Screen Systems
    - (less than 50 inches average annual precipitation)
  - Rain-Screen Systems
    - (less than 60 inches average annual precipitation)
  - Pressure Equalized Rain-Screen (PER) Systems
    - (all rain exposures)

Rain is permitted to enter through the cladding skin in the three water managed systems: drain-screen, rain-screen or pressure equalized rain-screen (PER) systems. "Drain the rain" is the cornerstone of water managed systems. In the three water managed systems, drainage of water is provided by a capillary resistant drainage plane or a capillary resistant drainage plane coupled with an air space behind the cladding. If the air space has sufficient venting to the exterior to equalize the pressure difference between the exterior and the cavity, the system is classified as a PER design.

In the face-sealed barrier approach, the exterior face is the only means to control rain entry. In storage/reservoir systems, some rain is permitted to enter and is stored in the mass of the wall assembly until drying occurs to either the exterior or interior. In non-storage/non-reservoir systems, no rain is permitted to enter.

The performance of a specific system is determined by frequency of rain, severity of rain, system design, selection of materials, workmanship, and maintenance. In general, water managed systems out perform face-sealed/barrier systems due to their more forgiving nature. However, face-sealed/barrier systems constructed from water resistant materials that employ significant storage have a long historical track-record of exemplary performance even in the most severe rain exposures. These "massive" wall assemblies constructed out of masonry, limestone, granite and concrete, many of which are 18 inches or more thick, were typically used in public buildings such as courthouses, libraries, schools and hospitals.

The least forgiving and least water resistant assembly is a face-sealed/barrier wall constructed from water sensitive materials that does not have storage capacity. Most external insulation finish systems (EIFS) are of this type and should be limited to climate zones which see little rain (less than 30 inches average annual precipitation).

The most forgiving and most water resistant assembly is a pressure equalized rain screen wall constructed from water resistant materials. These types of assembles perform well in the most severe rain exposures (more than 60 inches average annual precipitation).

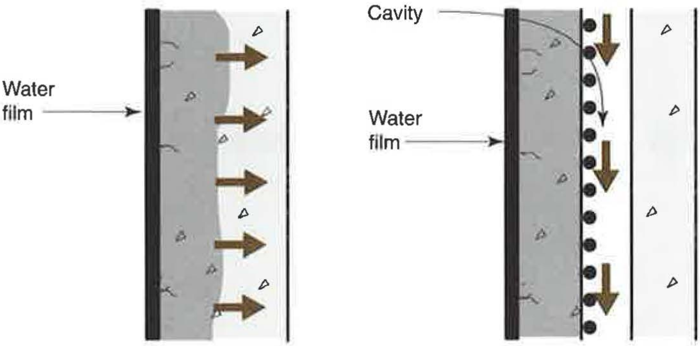
Water managed strategies should be used in climate regions where average annual rainfall exceeds 30 inches. Drain-screen systems (drainage planes without drainage spaces) should be limited to regions where average annual rainfall is less than 50 inches and rain-screen systems (drainage planes with drainage spaces) should be limited to regions where average annual rainfall is less than 60 inches. Pressure equalized rain-screen systems (drainage planes with pressure equalized drainage spaces) should be used wherever average annual rainfall is greater than 60 inches.

Face-sealed/barrier strategies should be carefully considered. Non-storage/non-reservoir systems constructed out of water sensitive materials should be limited to regions where average annual rainfall is less than 30 inches. Storage/reservoir systems constructed with water resistant materials can be built anywhere. However, their performance is design, workmanship, and materials dependent. In general, these systems should be limited to regions or to designs with high drying potentials to the exterior, interior or, better still, to both.

Drainage Plane Continuity

The most common residential approach to rain control is the use of a drainage plane. This drainage plane is typically a "tar paper" or building paper. More recently, the term "housewrap" has been introduced to describe building papers that are not asphalt impregnated felts (tar papers). Drainage planes can also be created by sealing or layering water resistant sheathings such as a rigid insulation or a foil covered structural sheathing.

In order to effectively "drain the rain," the drainage plane must provide drainage plane continuity especially at "punched openings" such as windows and doors. Other critical areas for drainage plane continuity are where roofs and decks intersect walls.



Capillary suction draws water into porous material and tiny cracks

Cavity acts as capillary break and receptor for capillary water interrupting flow

Figure I.1
Capillarity as a Driving Force for Rain Entry

- Capillary suction draws water into porous material and tiny cracks.
- Cavity acts as capillary break and receptor for capillary water interrupting flow.

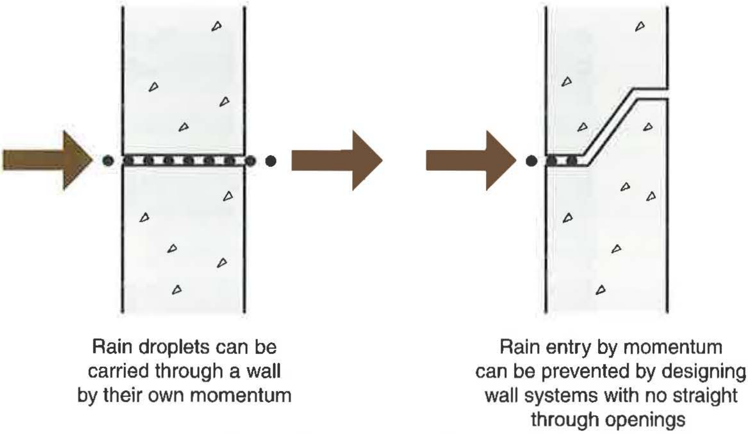


Figure I.2
Momentum as a Driving Force for Rain Entry

- Rain droplets can be carried through a wall by their own momentum.
- Rain entry by momentum can be prevented by designing wall systems with no straight through openings.

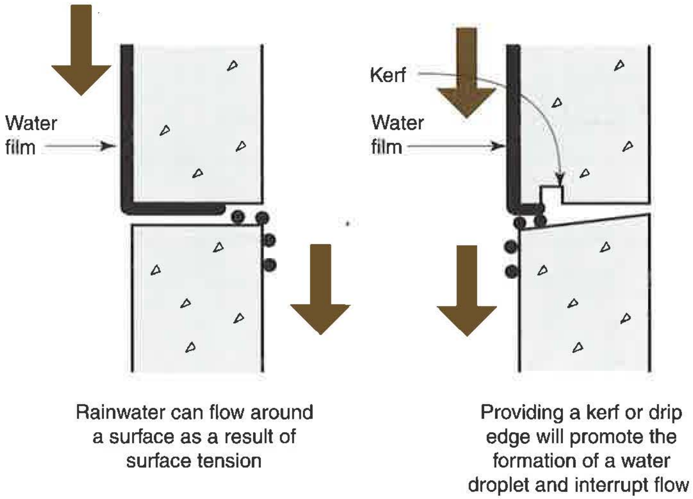


Figure I.3
Surface Tension as a Driving Force for Rain Entry

- Rainwater can flow around a surface as a result of surface tension.
- Providing a kerf or drip edge will promote the formation of a water droplet and interrupt flow.

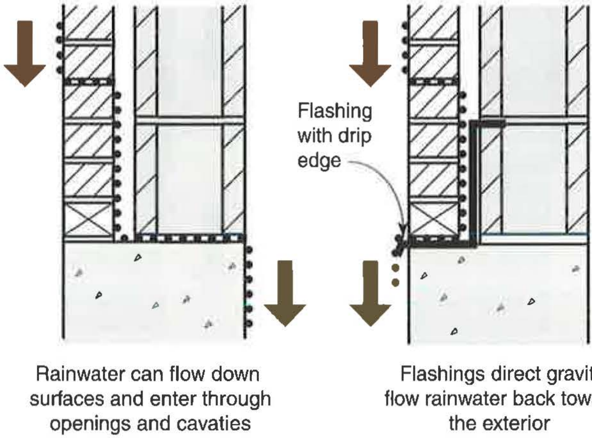


Figure I.4
Gravity as a Driving Force for Rain Entry

- Rainwater can flow down surfaces and enter through openings and cavities.
- Flashings direct gravity flow rainwater back toward the exterior.

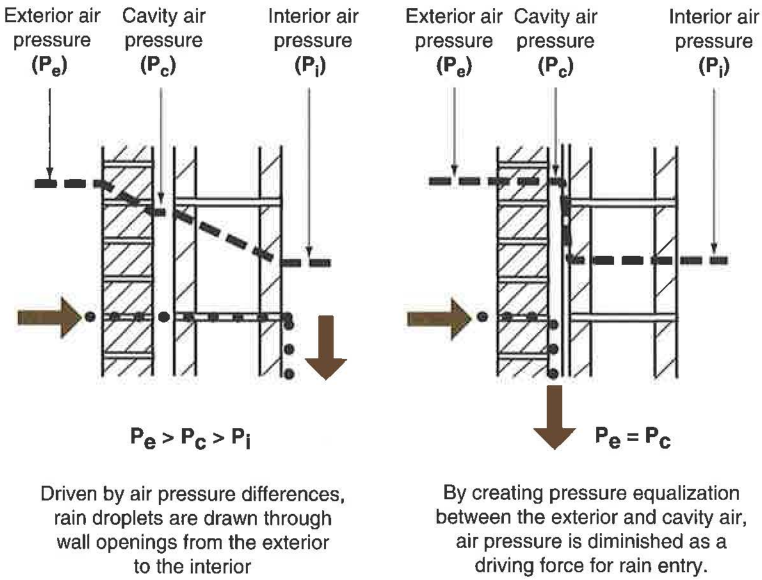


Figure I.5
Air Pressure Difference as a Driving Force for Rain Entry

- Driven by air pressure differences, rain droplets are drawn through wall openings from the exterior to the interior.
- By creating pressure equalization between the exterior and cavity air, air pressure is diminished as a driving force for rain entry.

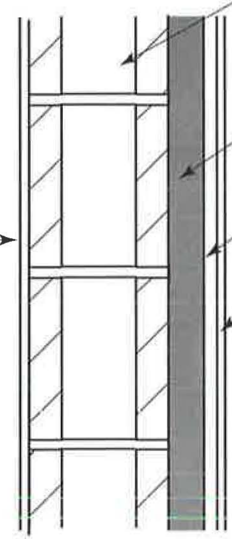


Figure I.6
Face-Sealed Barrier Wall
Storage Reservoir System

- Some rain entry past exterior face permitted.
- Penetrating rain stored in mass of wall until drying occurs to interior or exterior

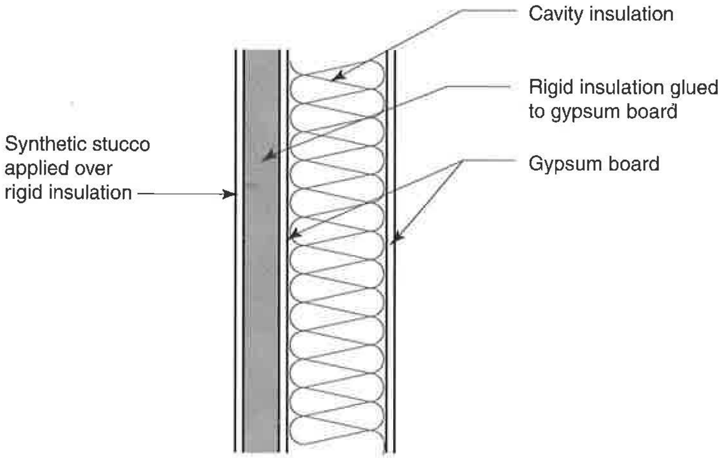


Figure I.7
Face-Sealed Barrier Wall
Non-Storage Non-Reservoir System

- No rain entry past exterior face permitted.
- Should not be used in regions where the average annual precipitation exceeds 30 inches.

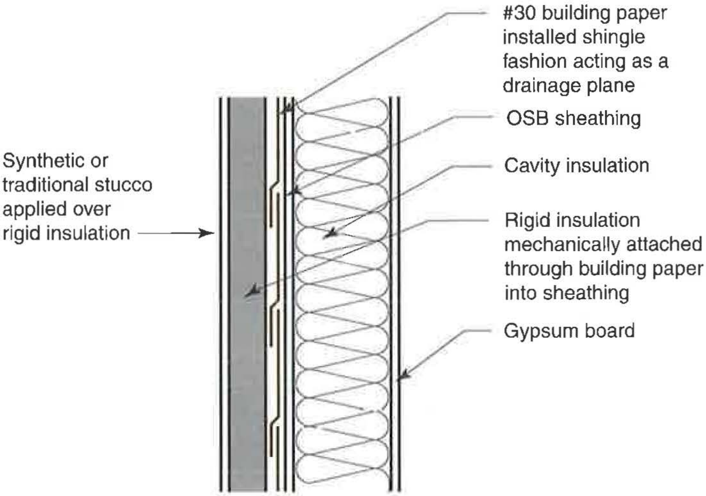


Figure I.8
Water Managed Wall
Drain-Screen System (Drainage Plane)

- Should not be used in regions where the average annual precipitation exceeds 50 inches.

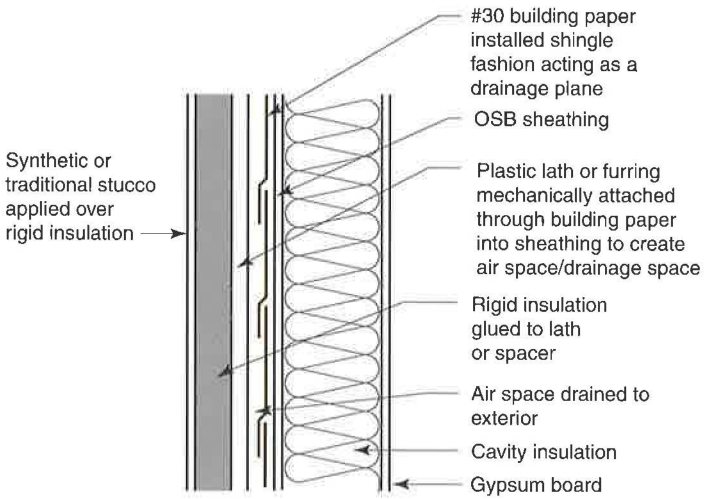


Figure I.9
Water Managed Wall
Rain-Screen System (Drainage Plane with Drainage Space)

- Should not be used in regions where the average annual precipitation exceeds 60 inches.

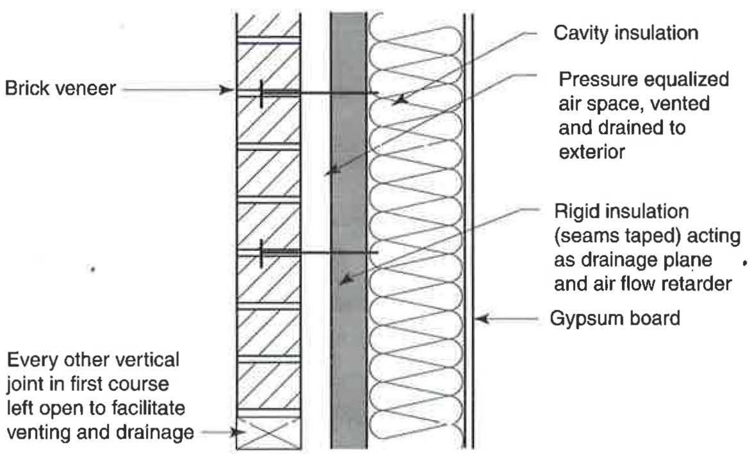


Figure I.10
Water Managed Wall
Pressure Equalized Rain-Screen System
(Drainage Plane with Pressure Equalized Drainage Space)

- Should be used in regions where the average annual precipitation exceeds 60 inches.

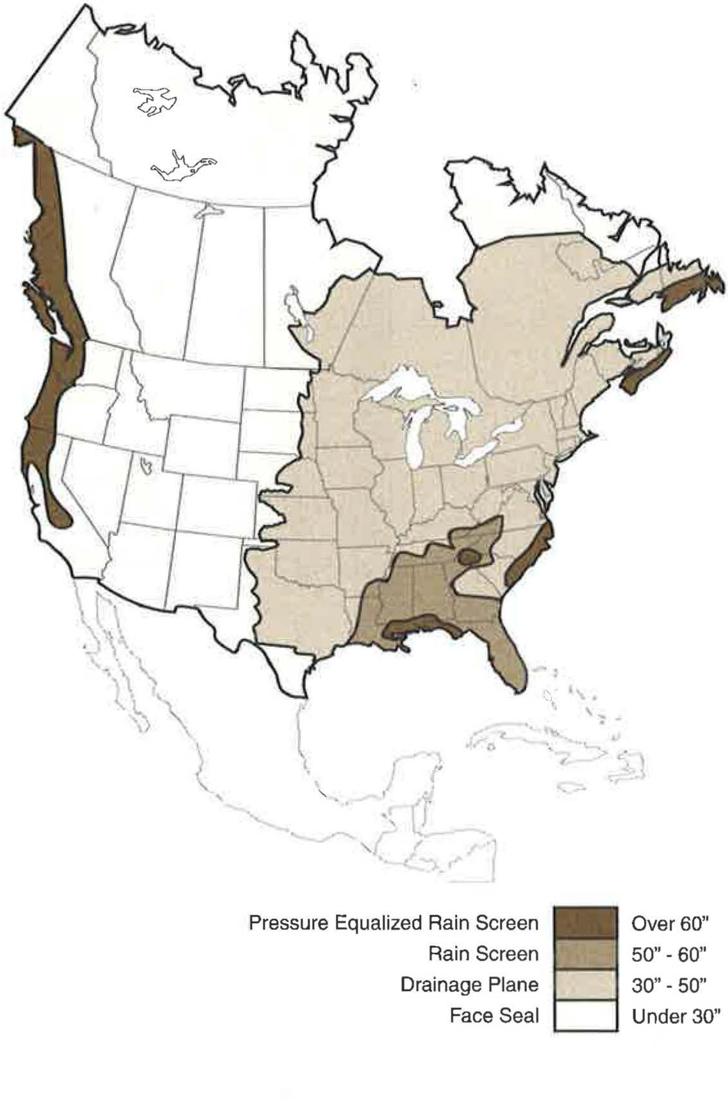


Figure I.11
Annual Rainfall Map

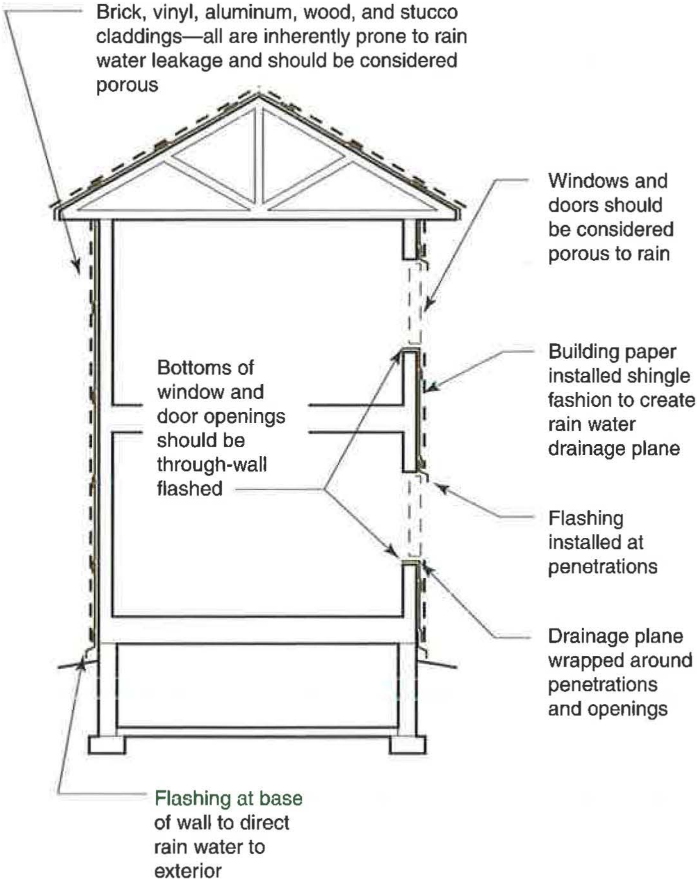


Figure I.12
Drainage Plane

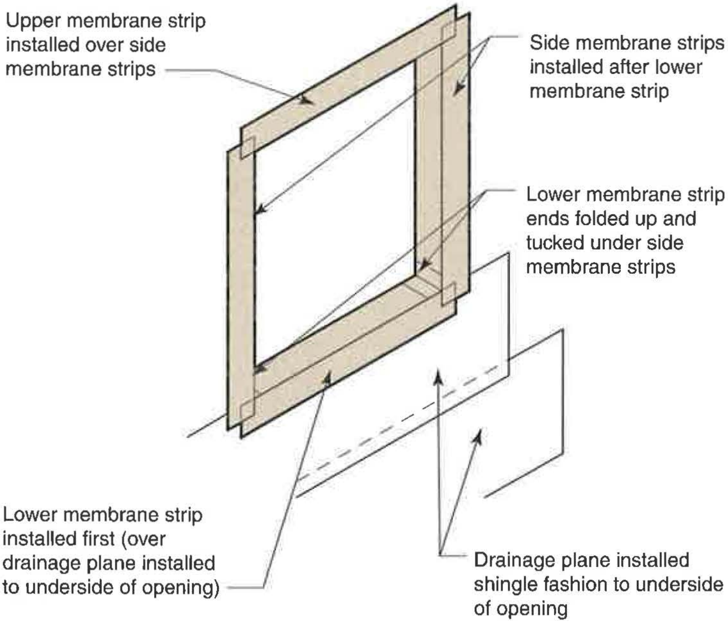


Figure I.13
Window Wrapping

- Install drainage plane shingle fashion from bottom to underside of opening
- Install lower membrane strip
- Install side membrane strips
- Install upper membrane strip
- Install head flashing
- Install drainage plane shingle fashion from underside of opening up wall
- Window installed after drainage plane installation
- Windows/doors with flanges typically installed in bed of sealant between flanges and drainage plane
- Windows/doors without flanges sealed to drainage plane with sealant

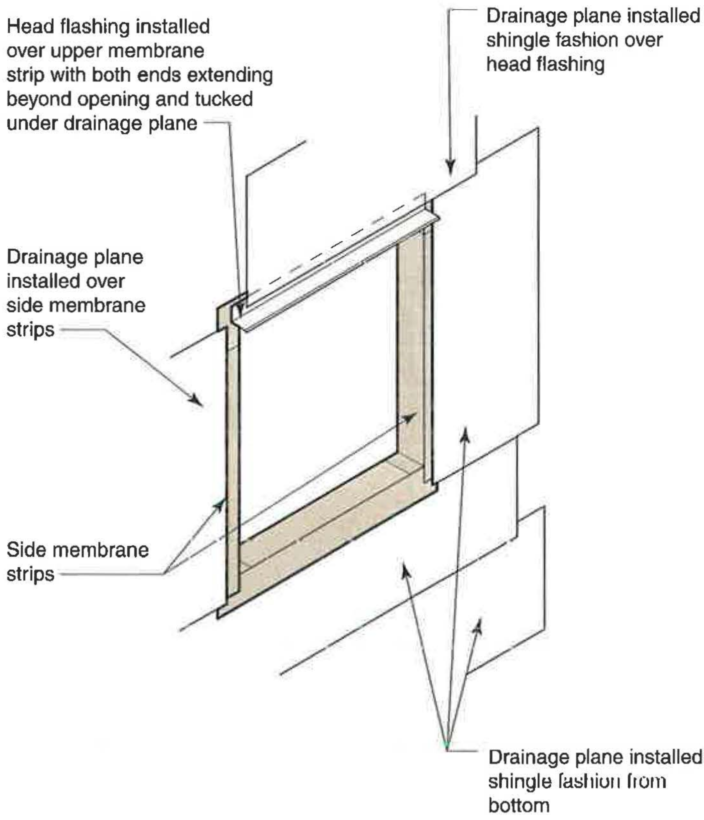


Figure I.14
Head Flashing with Building Paper

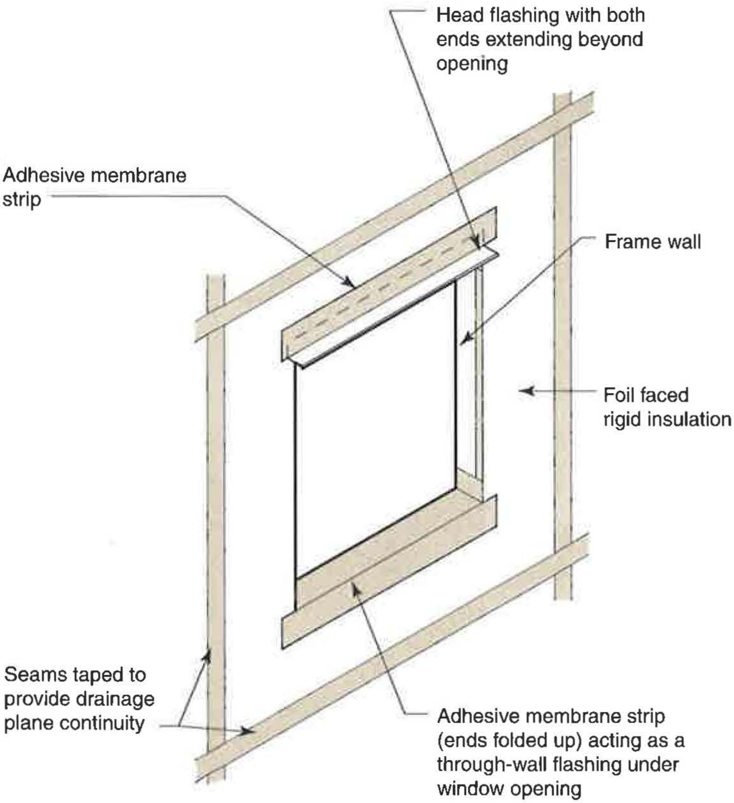


Figure I.15
Taped Rigid Insulation as Drainage Plane

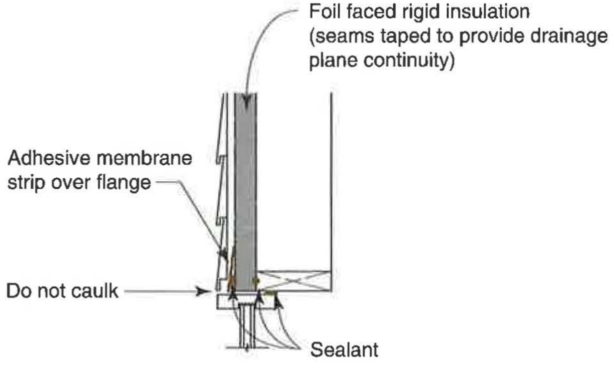


Figure I.16
Window Head

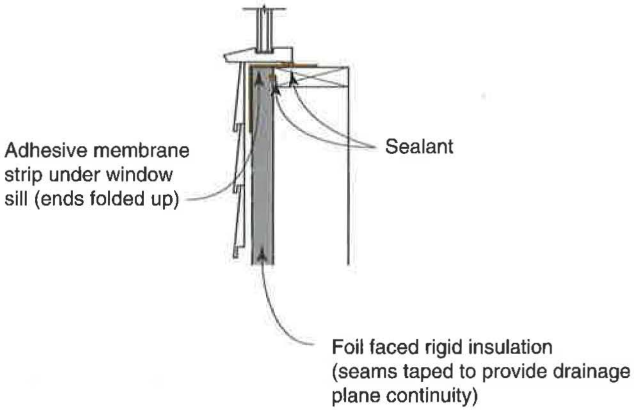


Figure I.17
Window Sill

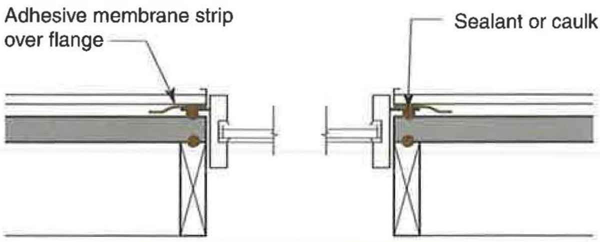


Figure I.18
Window Jamb

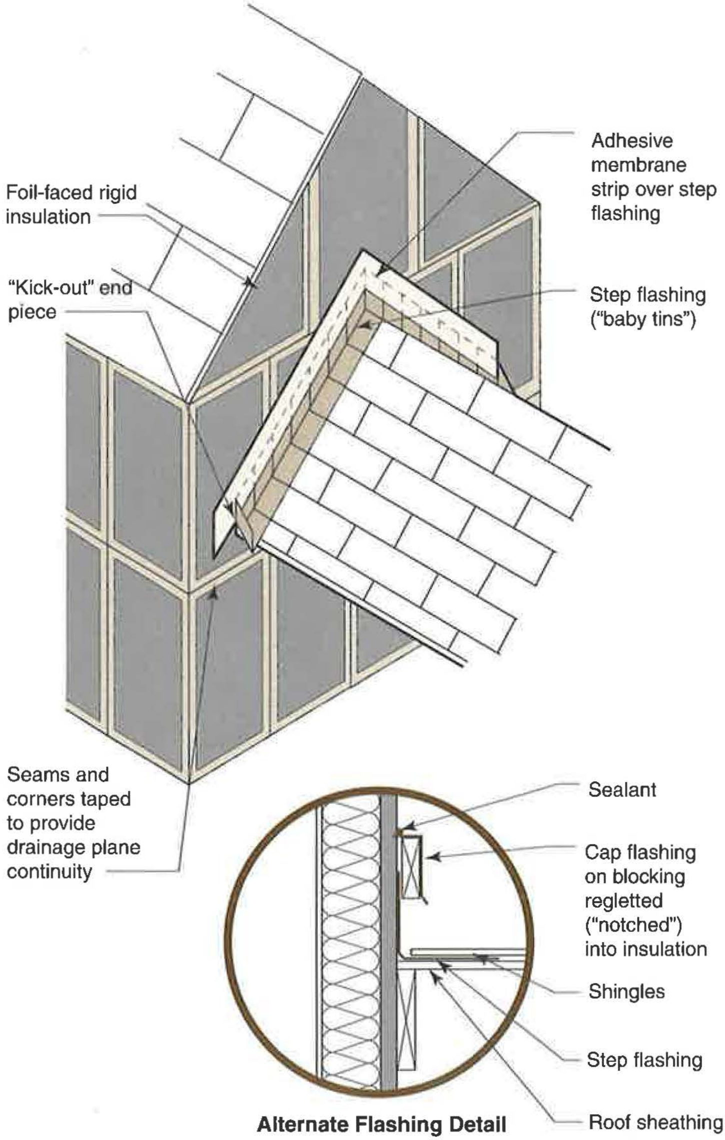


Figure I.19
Step Flashing

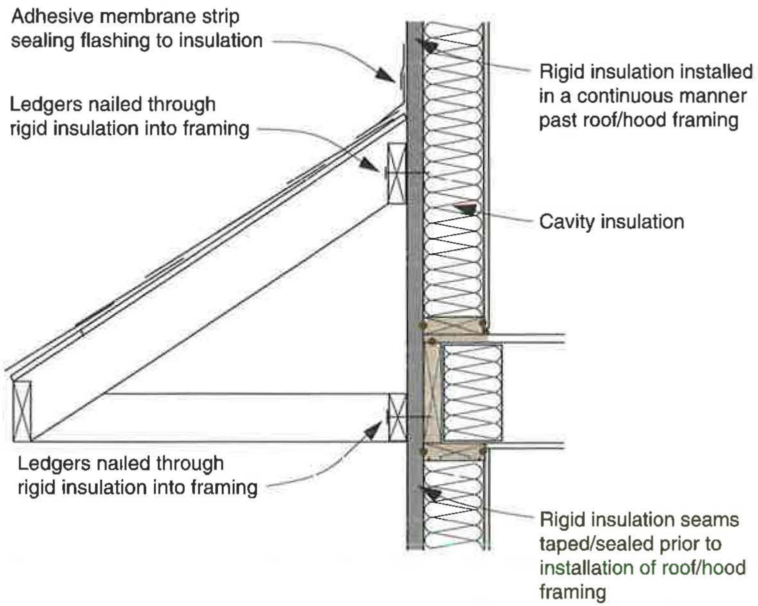


Figure I.20
Flashing Above Shed Roof

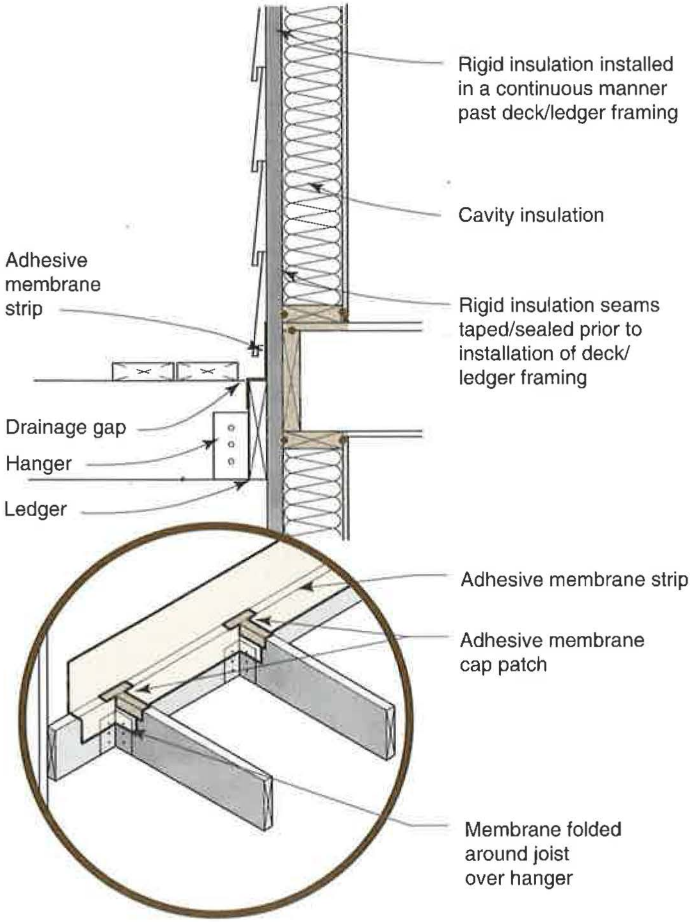


Figure I.21
Flashing Over Deck Ledger

Appendix II
Air Flow Retarders

Air flow retarders keep outside and inside air out of the building envelope. Air flow retarders can be located anywhere in the building envelope—at the exterior surface, the interior surface, or at any location in between. In practice, it is generally desirable to provide both interior and exterior air flow retarders. In heating climates, interior air flow retarders control the exfiltration of interior, often moisture-laden, air. Whereas exterior air flow retarders control the infiltration of exterior air and prevent wind-washing through insulation.

Wherever they are, air flow retarders should be:

- impermeable to air flow
- continuous over the entire building envelope
- able to withstand the forces that may act on them during and after construction
- durable over the expected lifetime of the building

Four common approaches are used to provide air flow retarders in residential buildings:

- interior air flow retarder using drywall and framing
- interior air flow retarder using polyethylene
- exterior air flow retarder using exterior sheathing
- exterior air flow retarder using building paper

Some spray applied foam insulations can be used as interstitial (cavity) air flow retarders, notably polyurethane foams. Typically applied damp spray cellulose is not an effective interstitial air flow retarder.

An advantage of interior air flow retarders over exterior systems is that they control the entry of interior moisture-laden air into assembly cavities during heating periods. The significant disadvantage of interior air flow retarders is their inability to control wind-washing through cavity insulation.

The significant advantage of exterior air flow retarders is the ease of installation and the lack of detailing issues due to intersecting partitions walls and service penetrations. However, exterior air flow retarders must deal with transitions where roof assemblies intersect exterior walls. For example, an exterior building paper ("housewrap") should be sealed to ceiling air flow retarder system across the top of the exterior perimeter walls.

An additional advantage of exterior air flow retarder systems is the control of wind-washing that an exterior air seal provides. The significant disadvantage of exterior air flow retarders is their inability to control the entry of air-transported moisture into cavities from the interior.

Installing both interior and exterior air flow retarders addresses the weakness of each.

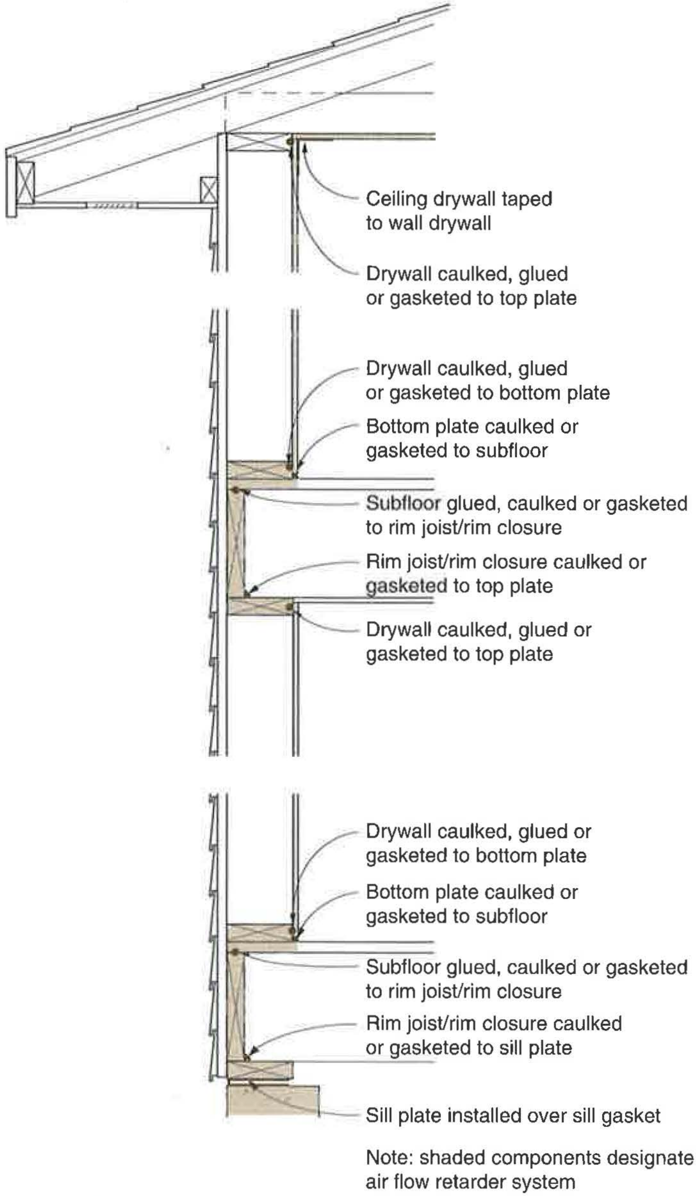


Figure II.1
Interior Air Flow Retarder Using Drywall and Framing
- Airtight Drywall Approach (ADA)

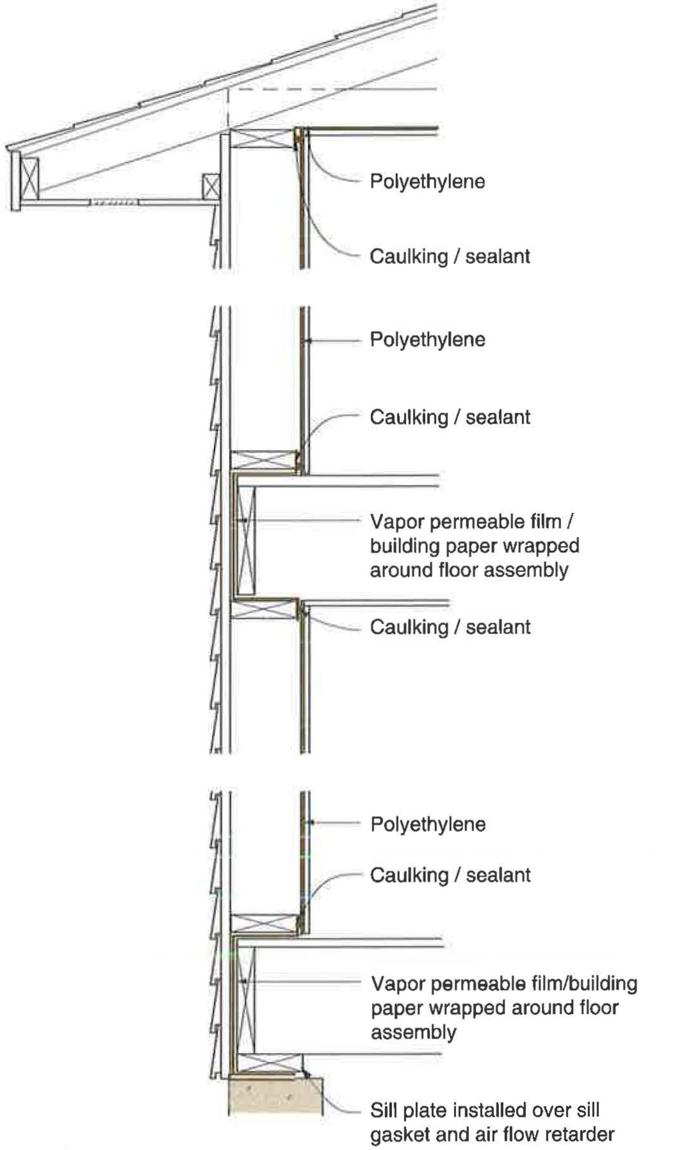


Figure II.2
Interior Air Flow Retarder Using Polyethylene

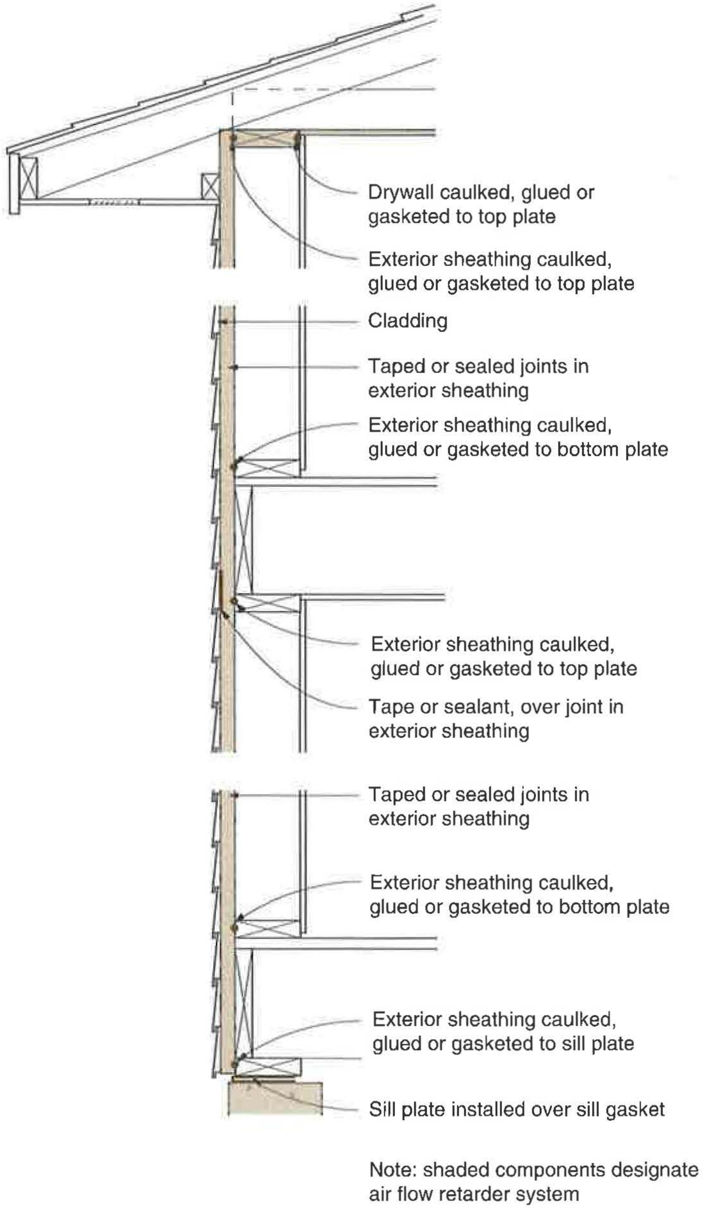
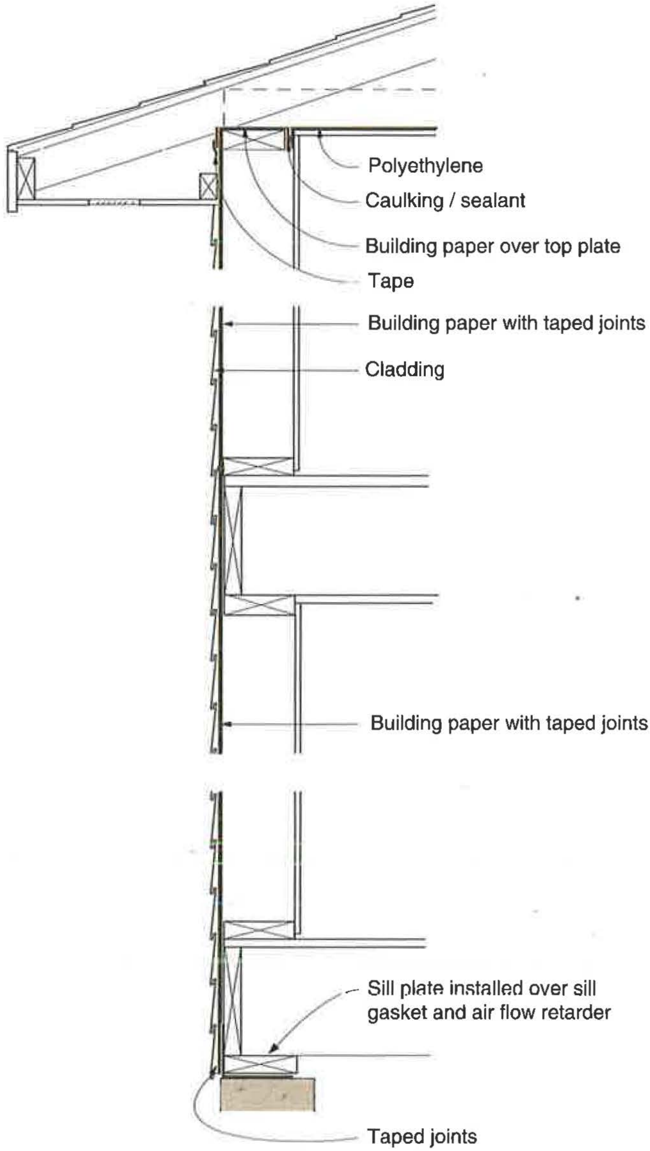


Figure II.3
Exterior Air Flow Retarder Using Exterior Sheathing



Note: shaded components designate air flow retarder system

Figure II.4
Exterior Air Flow Retarder Using Building Paper or Housewrap

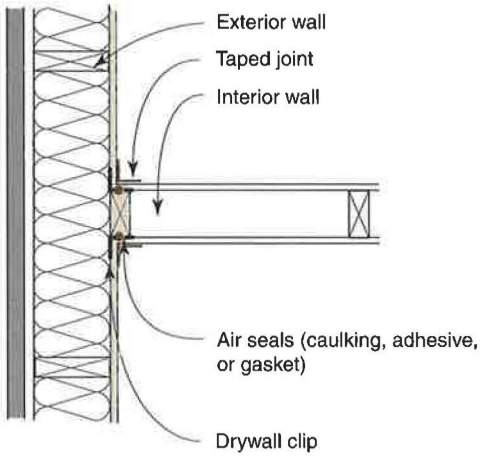


Figure II.5
Intersection Interior Partition Wall and Exterior Wall (ADA)

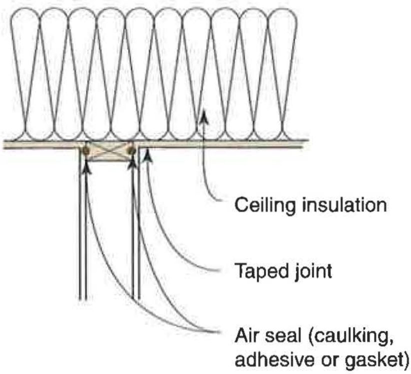


Figure II.6
Intersection Interior Partition Wall and Insulated Ceiling (ADA)

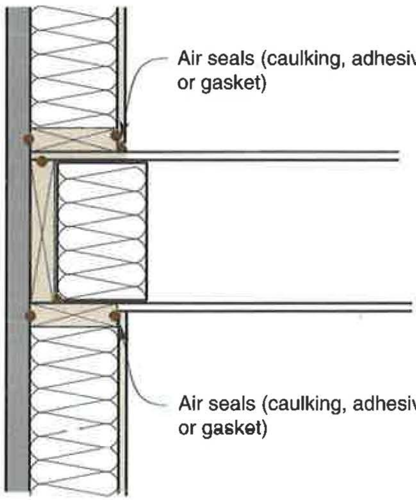


Figure II.7
Intersection of Floor Joists and Exterior Wall (ADA)

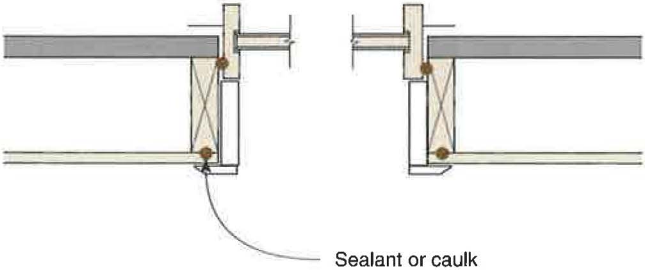


Figure II.8
Window Jamb with Wood Trim (ADA)

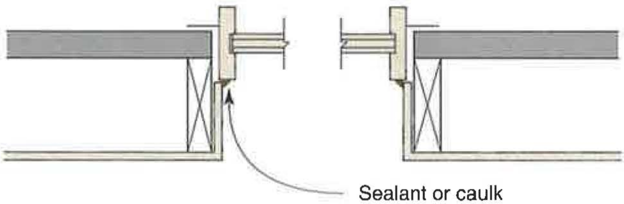


Figure II.9
Window Jamb with Drywall Returns (ADA)

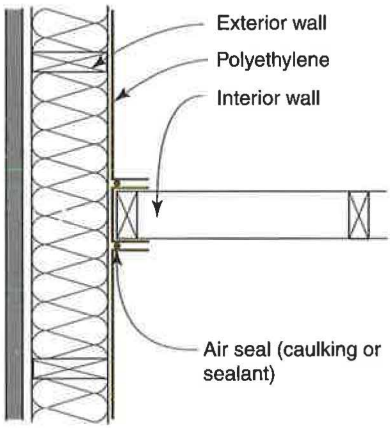


Figure II.10
Intersection of Interior Partition Wall and Exterior (Polyethylene)

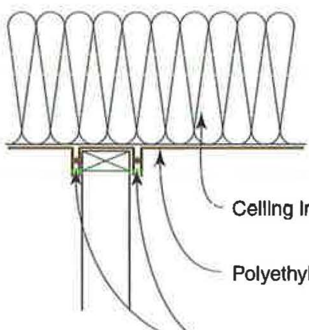


Figure II.11
Intersection of Interior Partition Wall and Insulated Ceiling (Polyethylene)

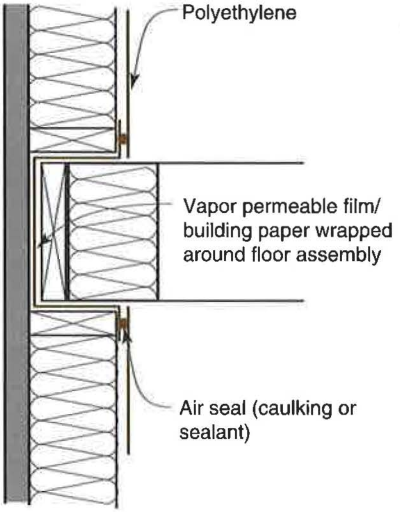


Figure II.12
Intersection of Floor Joists and Exterior Wall (Polyethylene)

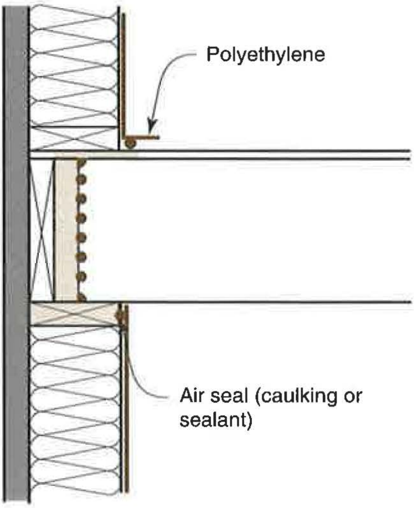


Figure II.13
Alternate Detail of Intersection of Floor Joist and Exterior Wall (Polyethylene)

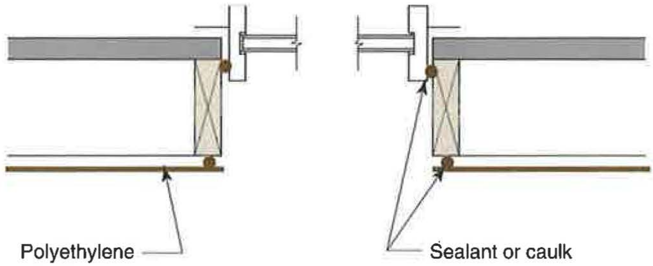


Figure II.14
Window Jamb (Polyethylene)

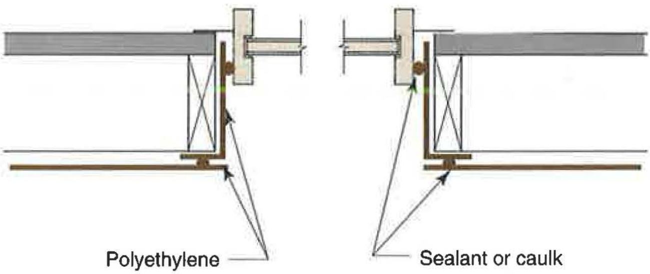


Figure II.15
Alternate Detail for Window Jamb (Polyethylene)

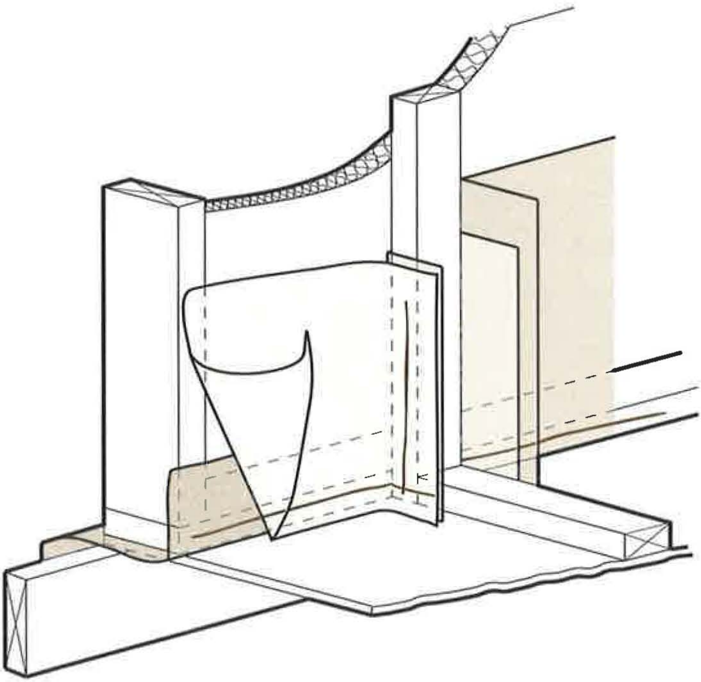


Figure II.16
Intersection Interior Partition Wall and Exterior Wall (Polyethylene)

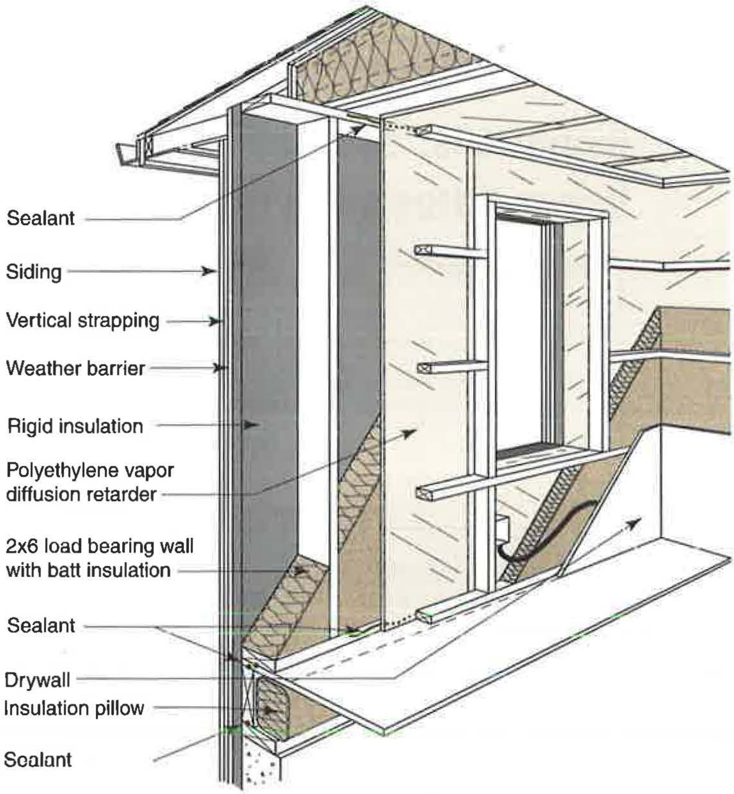


Figure II.17
Strapped Wall Construction

Appendix III

Insulations, Sheathings and Vapor Diffusion Retarders

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

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

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

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

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

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

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

Vapor Diffusion and Air Transport of Vapor

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

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

Moisture in the vapor state also moves from the warm side of an assembly to the cold side of an assembly. This type of moisture transport is called thermally driven diffusion. Moisture vapor condenses on cold surfaces. These cold surfaces act as "dehumidifiers" pulling more moisture towards them.

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

Vapor Diffusion Retarders

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

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

Water Vapor Permeability

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

The unit of measurement typically used in characterizing permeability is a "perm". Many building codes define a vapor diffusion retarder as a material which has a permeability of one perm or less.

Materials which are generally classed as impermeable to water vapor are: polyethylene film, glass, aluminum foil, sheet metal, many paints, bitumen impregnated kraft paper, almost all wall coverings and their adhesives, foil faced insulating and non insulating sheathings.

Materials which are generally classed as semi-permeable to water vapor are plywood, OSB, expanded polyestyrene (EPS), extruded polystyrene (XPS) and fiber-faced isocyanurate. Depending on the specific assembly design, construction and climate, all of these materials may or may not be considered to act as vapor diffusion retarders. Typically, these materials are considered to be more vapor permeable than vapor impermeable.

Materials which are generally classed as permeable to water vapor are: unpainted gypsum board and plaster, fiberglass insulation, cellulose insulation, dimensional lumber and board lumber, unpainted stucco, many latex based paints, masonry, brick, lightweight asphalt impregnated building papers (#15 building paper), asphalt impregnated fiberboard sheathings, and "house wraps."

Air Flow Retarders

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

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

Magnitude of Vapor Diffusion and Air Transport of Vapor

The differences in the significance and magnitude vapor diffusion and air transported moisture are typically misunderstood. Air movement as a moisture transport mechanism is far more important than vapor diffusion. The movement of water vapor through a 1 inch square hole as a result of a 10 Pascal air pressure differential is 100 times greater than the movement of water vapor as a result of vapor diffusion through a 32 square foot sheet of gypsum board under normal heating or cooling conditions (See Figure III.1).

In most climates, if the movement of moisture laden air into a wall or building assembly is eliminated, movement of moisture by vapor diffusion is not likely to be significant. Furthermore, the amount of vapor which diffuses through a building component is a direct function of area. That is, if 90 percent of the building envelope area is covered with a vapor diffusion retarder, then that vapor diffusion retarder is 90 per cent effective. In other words, continuity of the vapor diffusion retarder is not as significant as the continuity of the air flow retarder. For instance, polyethylene film which may have tears and numerous punctures present will act as an effective vapor diffusion retarder, whereas at the same time it is a poor air flow retarder. Similarly, the kraft facing on fiberglass batts installed in exterior walls acts as an effective vapor diffusion retarder, in spite of the numerous gaps and joints in the kraft facing.

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

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

Combining Approaches

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

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

Overall Strategy

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

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

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

Cold Climates

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

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

Therefore, in general, in cold climates, air flow retarders and vapor diffusion retarders are installed on the interior of building assemblies, and building assemblies are allowed to dry to the exterior by installing permeable sheathings towards the exterior. A "classic" cold climate wall assembly is presented in Figure III.4.

Hot Climates

In hot climates and during cooling periods the opposite is true. Building assemblies need to be protected from getting wet from the exterior, and allowed to dry towards the interior. Accordingly, air flow retarders and vapor diffusion retarders are installed on the exterior of building assemblies, and building assemblies are allowed to dry towards the interior by using permeable interior wall finishes, installing cavity insulations without vapor diffusion retarders (unbacked fiberglass batts) and avoiding interior wall coverings such as vinyl wallpaper. Furthermore, conditioned spaces are maintained at a slight positive air pressure with conditioned (dehumidified) air in order to limit the infiltration of exterior, warm, humid air. A "classic" hot climate wall assembly is presented in Figure III.5.

Mixed Climates

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

- Selecting either a classic cold climate assembly or classic hot climate assembly, utilizing air pressure control (typically only pressurization during cooling), utilizing interior moisture control (ventilation/air change during heating, dehumidification/air conditioning during cooling) and relying on the forgiveness of the classic approaches to dry the accumulated moisture (from opposite season exposure) to either the interior of exterior. In other words, the moisture accumulated in a cold climate wall assembly exposed to hot climate conditions is anticipated to dry towards the exterior when the cold climate assembly finally sees heating conditions, and vice versa for hot climate building assemblies;

- Adopting a "flow-through" approach by utilizing permeable building materials on both the interior and exterior surfaces of building assemblies to allow water vapor by diffusion to "flow-through" the building assembly without accumulating. Flow would be from the interior to exterior during heating periods, and from the exterior towards the interior during cooling periods. In this approach air pressure control and utilizing interior moisture control would also occur. The location of the air flow retarder could be towards the interior (sealed interior gypsum board), or towards the exterior (sealed exterior sheathing). A "classic" flow-through wall assembly is presented in Figure III.6; or

- Installing the vapor diffusion retarder roughly in the middle of the assembly from a thermal perspective. This is typically accomplished by installing impermeable insulating sheathing on the exterior of a frame cavity wall (see Figure III.6). For example, installing 1.5 inches of insulating sheathing (approximately R 10, perm rating of about 0.5 perms) on the exterior of a 2x6 frame cavity wall insulated with unfaced fiberglass batt insulation (approximately R 19). The vapor diffusion retarder is the interior face of the exterior impermeable insulating sheathing (Figure III.7). If the wall assembly total thermal resistance is R 29 (R 19 plus R 10), the location of the vapor diffusion retarder is 65 percent of the way (thermally) towards the exterior (19/29 = .65). In this approach air pressure control and utilizing interior moisture control would also occur. The location of the air flow retarder could be towards the interior or exterior.

The advantage of the wall assembly described in Figure III.7 is that an interior vapor diffusion retarder is not necessary. In fact, locating an interior vapor diffusion retarder at this location would be detrimental, as it would not allow the wall assembly to dry towards the interior during cooling periods. The wall assembly is more forgiving without the interior vapor diffusion retarder than if one were installed. If an interior vapor diffusion retarder were installed, this would result in a vapor diffusion retarder on both sides of the assembly significantly impairing durability.

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

Control of Condensing Surface Temperatures

The performance of a wall assembly in a cold climate without an interior vapor diffusion retarder (such as the wall described in Figure III.6) can be more easily understood in terms of condensation potentials and the control of condensing surface temperatures.

Figure III.8 illustrates the performance of a 2x6 wall with semi-permeable plywood sheathing (perm rating of about 0.5 perms, dry cup; 3.0 perms wet cup) located in Chicago, IL. The interior conditioned space is maintained at a relative humidity of 35 percent at 70 degrees Fahrenheit. For the purposes of this example, it is assumed that no interior vapor diffusion retarder is installed (unpainted drywall as an interior finish over unfaced fiberglass, yech!). This illustrates a case we would never want to construct in a heating climate, a wall with a vapor diffusion retarder on the exterior (semi-permeable plywood sheathing) and no vapor diffusion retarder on the interior.

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

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

Figure III.9 illustrates the performance of the wall assembly described in Figure III.7, a 2x6 wall insulated on the exterior with 1.5 inches of rigid impermeable insulating sheathing (approximately R 10, perm rating of about 0.5 perms, wet cup and dry cup), located in Chicago, IL. The wall cavity is insulated with unfaced fiberglass batt insulation (approximately R 19). Unpainted drywall is again the interior finish (no interior vapor diffusion retarder). Now this wall assembly also has a vapor diffusion retarder on the exterior, but with a huge difference. This exterior vapor diffusion retarder has a significant insulating value since it is a rigid insulation. The temperature of the first condensing surface within the wall assembly, namely the cavity insulation/rigid insulation interface (the back side of the rigid insulation), is raised above the interior dew point temperature because of the insulating value of the rigid insulation. This illustrates a case we could construct in a heating climate, a wall with a "warm" vapor diffusion retarder on the exterior and no vapor diffusion retarder on the interior.

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

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

where:

T (interface) = the temperature at the sheathing/insulation interface or the temperature of the first condensing surface

R (exterior) = the R-value of the exterior sheathing

R(total) = the total R-value of the entire wall assembly

T_{in} = the interior temperature

T_{out} = the exterior temperature

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

What happens if we move this wall to Minneapolis? Big change. Minneapolis is a miserable place in the winter. The interior relative humidity would have to be kept below 25 percent. What happens if we move the wall back to Chicago and install a modest interior vapor diffusion retarder, such as one coat of a standard interior latex paint (perm rating of about 2 perms) over the previously unpainted drywall (perm rating of 20)? If we control air leakage, interior relative humidities can be raised above 50 percent before condensation occurs.

Sheathings and Cavity Insulations

Exterior sheathings can be permeable, semi-permeable, impermeable, insulating and non-insulating. Mixing and matching sheathings, building papers and cavity insulations can be challenging. The main factors to consider are the use of wet cavity insulation and cladding system moisture storage capacities (brick, stucco and wood). Characteristics and types of exterior sheathings are tabulated in Figure III.10. The following guidelines are offered:

- Impermeable non-insulating sheathings are not recommended in cold climates (drying not possible to interior due requirement for interior vapor diffusion retarder, condensing surface temperature not controlled due to non-insulating sheathing).
- Impermeable and semi-permeable sheathings (except plywood or OSB due to their higher permeability) are not recommended for use with damp spray cellulose cavity insulations in cold climates (drying not possible to interior due to interior vapor diffusion retarder).
- Impermeable insulating sheathings should be of sufficient thermal resistance to control condensation at cavity insulation/sheathing interfaces.
- Permeable sheathings are not recommended for use with brick veneers and stuccos due to moisture flow reversal from solar radiation (sun heats wet brick driving moisture into wall assembly through permeable sheathing), unless a polyethylene interior vapor diffusion retarder is installed to protect the interior gypsum board from the exterior moisture.

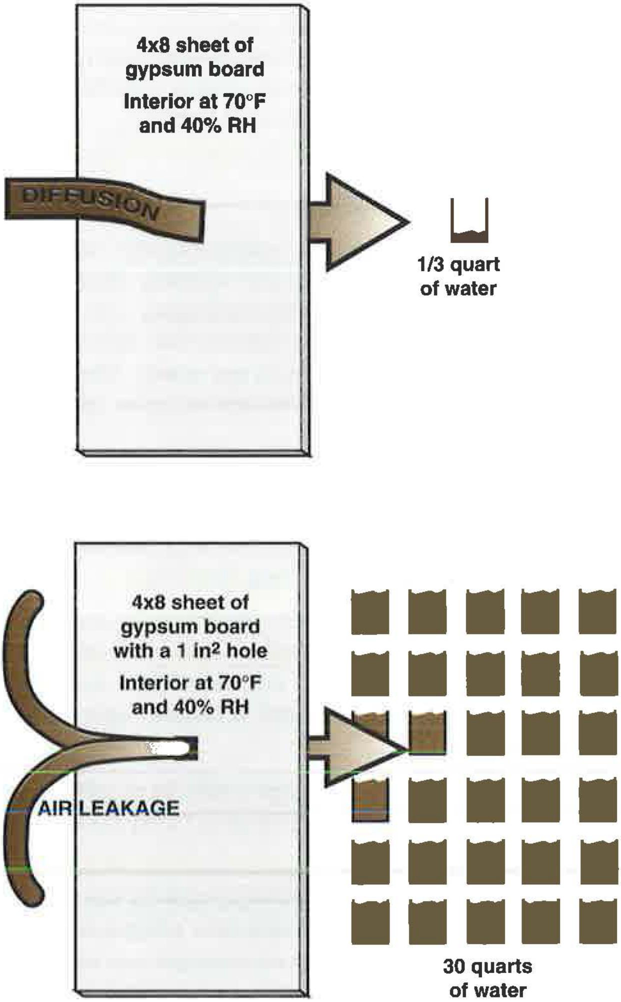


Figure III.1
Diffusion vs. Air Leakage

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

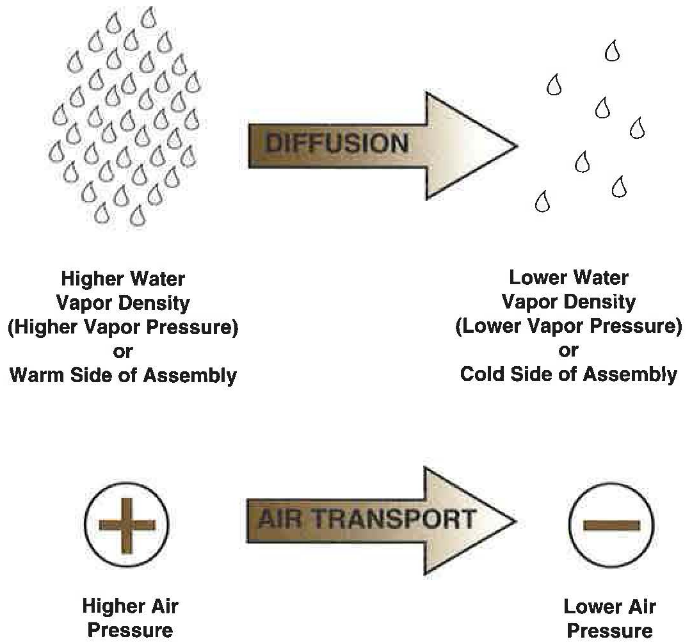


Figure III.2
Water Vapor Movement

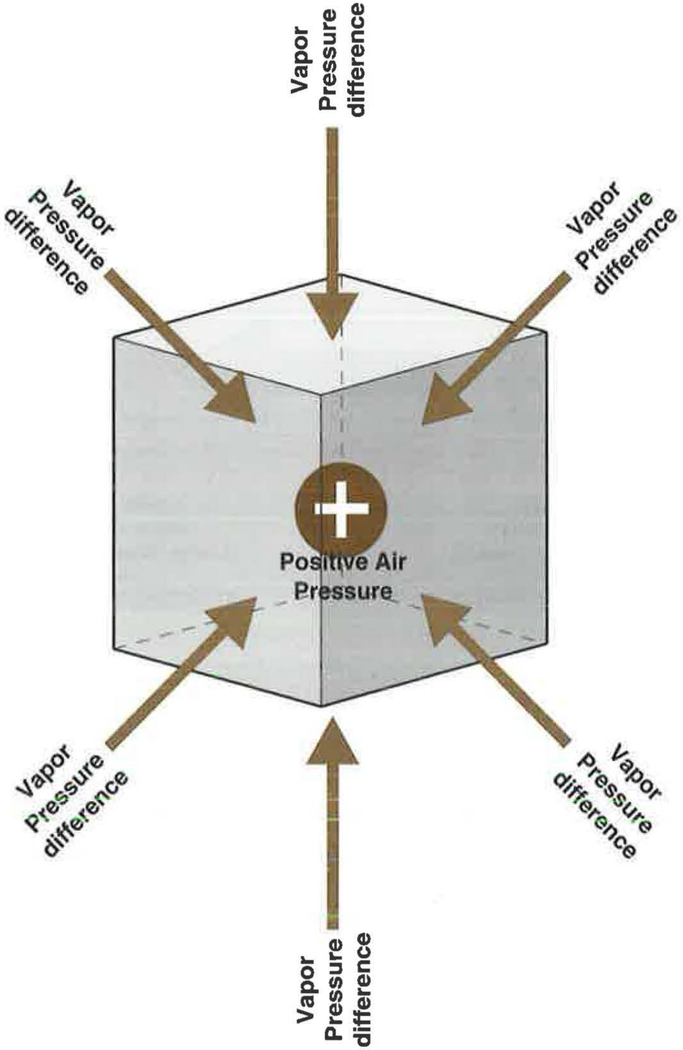


Figure III.3
Opposing Air and Vapor Pressure Differences

- Cube is under higher air pressure but lower vapor pressure relative to surroundings.
- Vapor pressure acts inward in this example.
- Air pressure acts outward in this example.

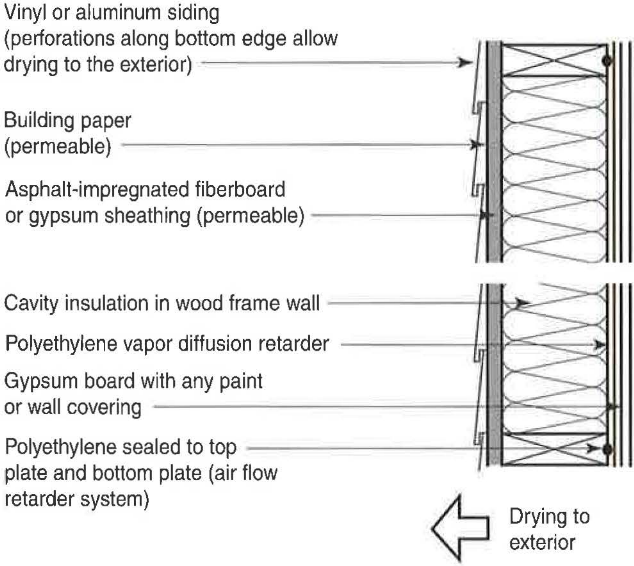


Figure III.4
Classic Cold Climate Wall Assembly

- Vapor diffusion retarder to the interior
- Air flow retarder to the interior
- Permeable exterior sheathing
- Ventilation provides air change (dilution) and also limits the interior moisture levels.

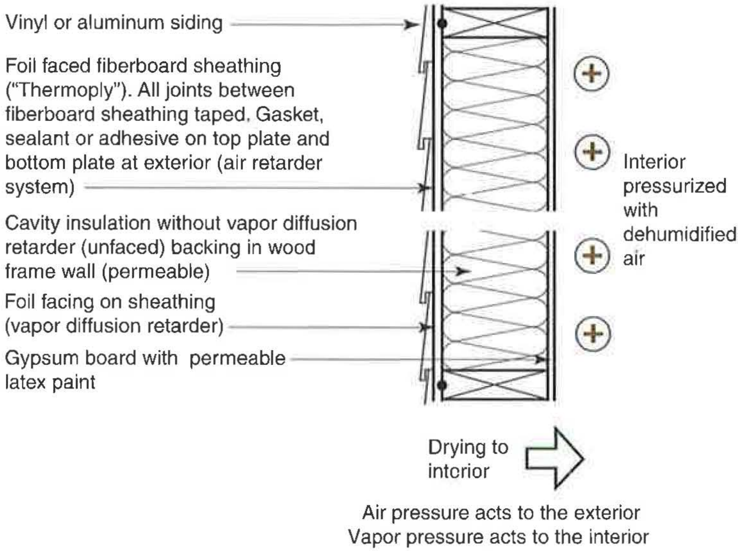


Figure III.5
Classic Hot Climate Wall Assembly

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

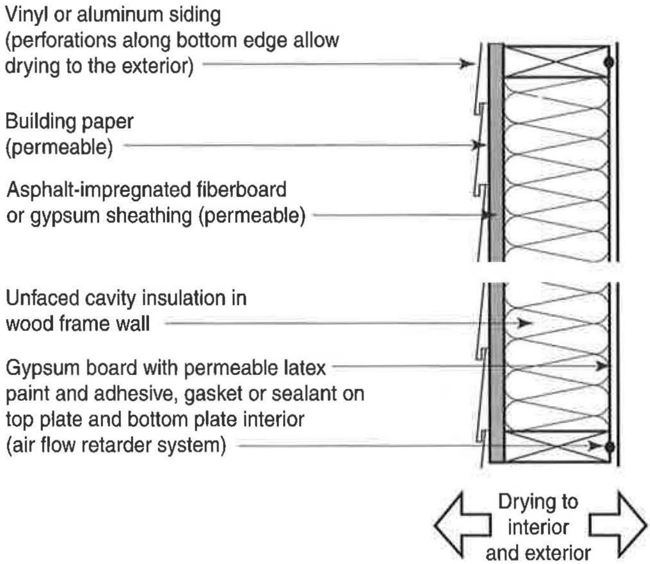


Figure III.6
Classic Flow-Through Wall Assembly

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

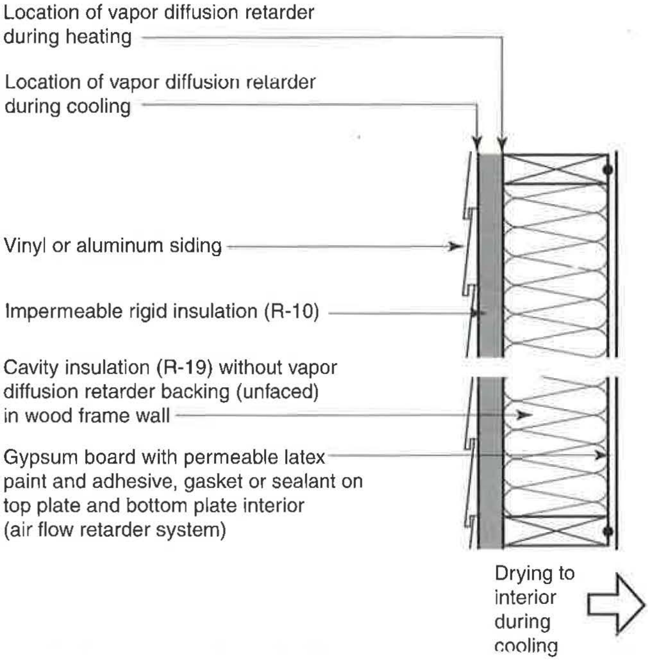
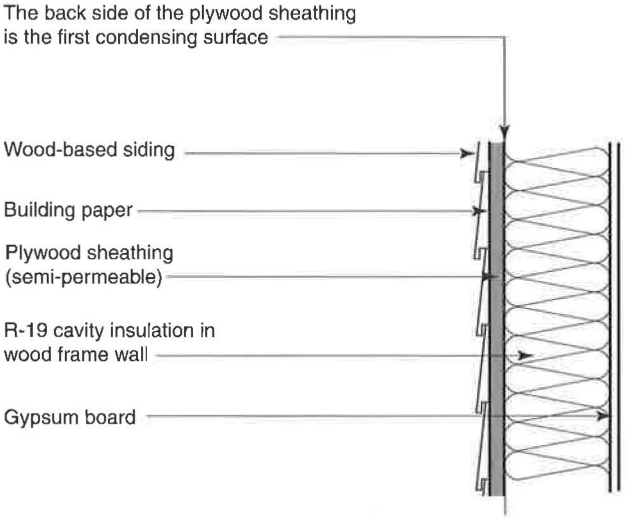


Figure III.7
Vapor Diffusion Retarder in the Middle of the Wall

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



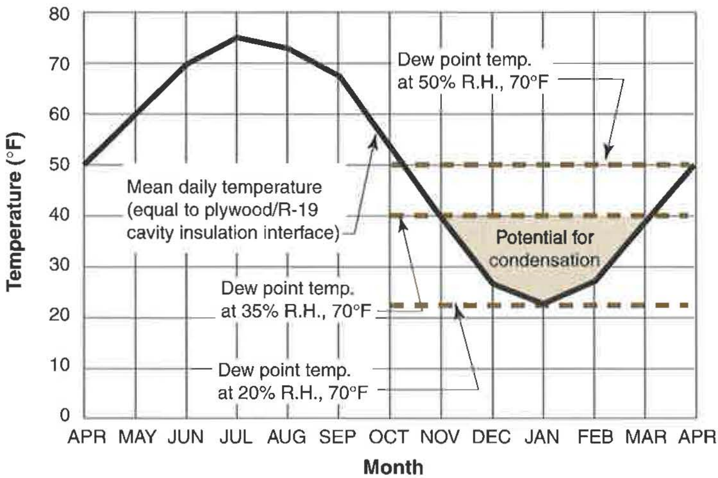
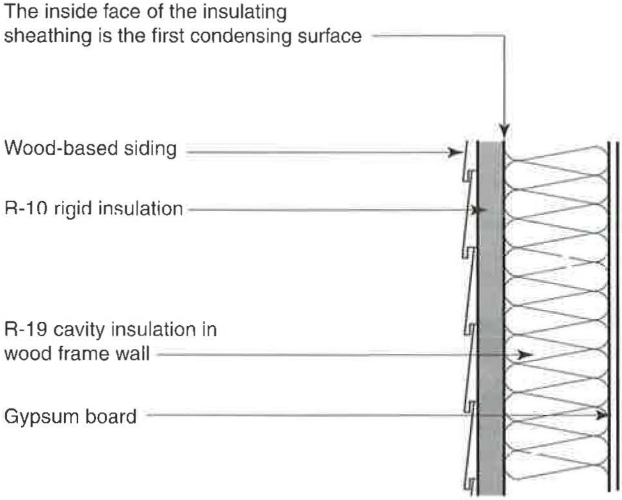


Figure III.8

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

- By reducing interior moisture levels, the potential condensation is reduced or eliminated.



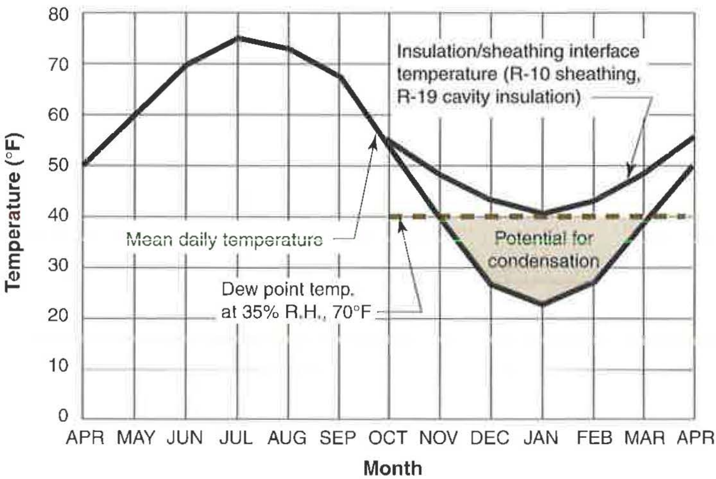


Figure III.9

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

- The R-10 insulating sheathing raises the dew point temperature at the first condensing surface so that no condensation will occur when interior moisture levels are less than 35 percent relative humidity at 70 degreees Fahrenheit.

				Compatible with:*
Permeable	Non-insulating	Asphalt Impregnated Fiberboard	Building Paper Required	Damp Spray Cellulose
		Gypsum Board	Building Paper Required	Damp Spray Cellulose
	Insulating	Rigid Fiberglass	Can Come with Building Paper Attached	Damp Spray Cellulose
Semi-Permeable	Non-Insulating	Plywood	Building Paper Required	Damp Spray Cellulose only with Airspace Between Cladding and Building Paper
		O.S.B.	Building Paper Required	Damp Spray Cellulose only with Airspace Between Cladding and Building Paper
	Insulating	Expanded Polystyrene	Building Paper Not Required	Damp Spray Cellulose Not Recommended
		Extruded Polystyrene	Building Paper Not Required	Damp Spray Cellulose Not Recommended
		Fiberfaced Isocyanurate	Building Paper Not Required	Damp Spray Cellulose Not Recommended
Impermeable	Non-Insulating	Thermoply	Building Paper Not Required	Damp Spray Cellulose Not Recommended
	Insulating	Foil Faced Isocyanurate	Building Paper Not Required	Damp Spray Cellulose Not Recommended

Figure III.10
Cold Climate Wall Assembly Characteristics

* All wall asemblies compatible with dry applied cavity insulations

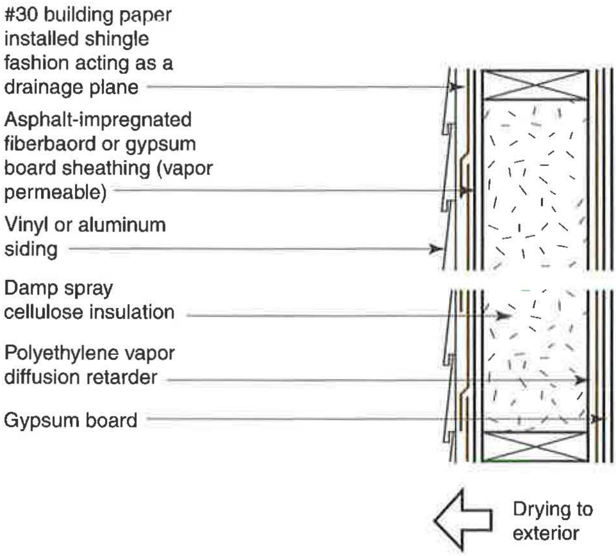


Figure III.11
Drying to Exterior

- If wood siding is used in this assembly with the damp spray cellulose, furring strips should be used to provide an airspace to promote drying and the wood siding should be back-primed to prevent wetting from the back side.
- The airspace associated with the back of vinyl or aluminum siding, due to its profile, permits drying of the wall assembly.

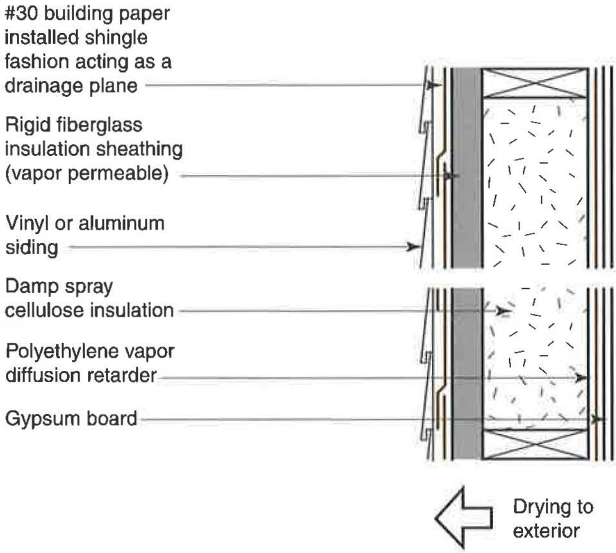


Figure III.12
Drying to Exterior

- If wood siding is used in this assembly with the damp spray cellulose, furring strips should be used to provide an airspace to promote drying and the wood siding should be back-primed to prevent wetting from the back side.
- The airspace associated with the back of vinyl or aluminum siding, due to its profile, permits drying of the wall assembly.

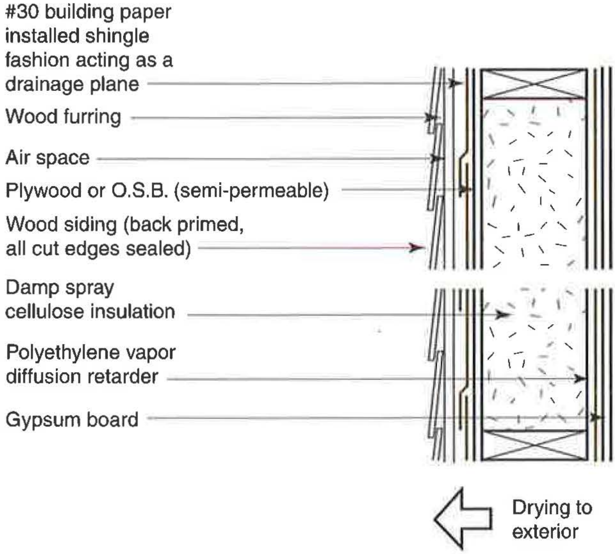


Figure III.13
Drying to Exterior

- If vinyl or aluminum siding is used in this assembly wood furring providing an airspace is not necessary.

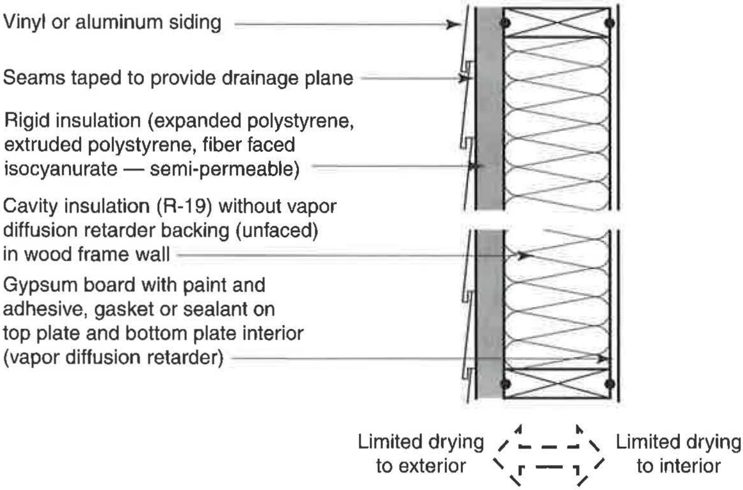


Figure III.14
Limited Drying to Exterior and Interior

- Although paint is used as an interior vapor diffusion retarder (1 to 2 perms) it is not as impermeable as a polyethylene vapor diffusion retarder (.3 to .5 perms) so that some drying to the interior is possible.
- The semi-permeable rigid insulations permit some drying to the exterior.
- If wood siding is used, it should be installed over furring strip and be back-primed, all cut edges sealed.

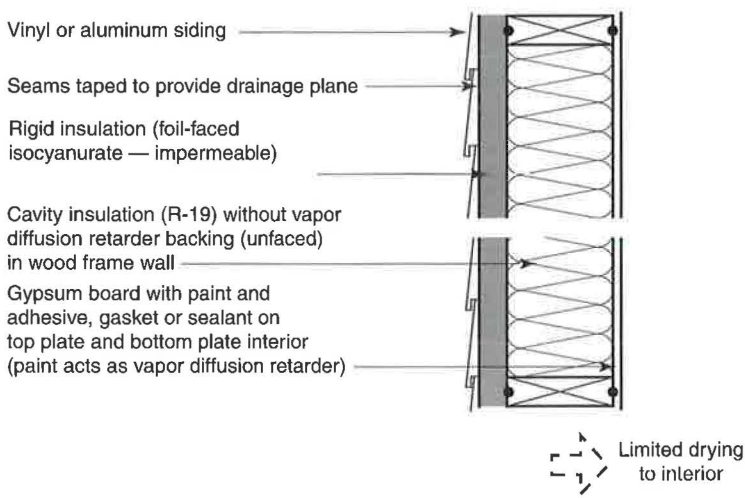


Figure III.15
Limited Drying to Interior

- Although paint is used as an interior vapor diffusion retarder (1 to 2 perms) it is not as impermeable as a polyethylene vapor diffusion retarder (.3 to .5 perms) so that some drying to the interior is possible.
- If wood siding is used, it should be installed over furring strips and be back-primed, all cut edges sealed.

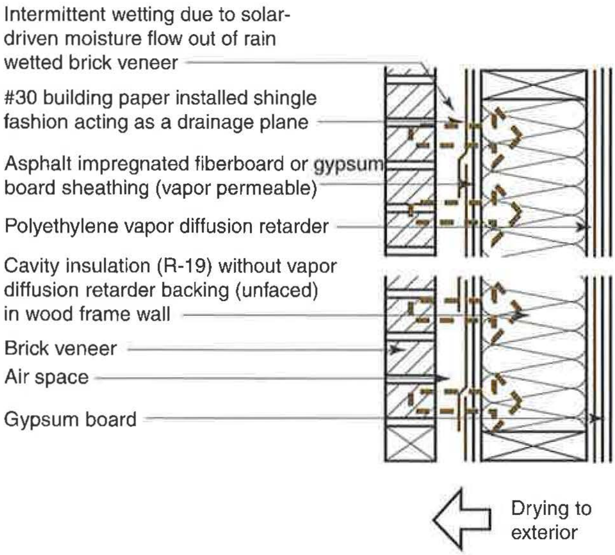


Figure III.16
Drying to Exterior

- A polyethylene vapor diffusion retarder must be installed in this assembly to protect the interior gypsum board from wetting due to solar-driven moisture.
- A rigid, impermeable or semi-permeable insulating sheathing can be used to prevent the wall cavity from getting wet due to solar-driven moisture.

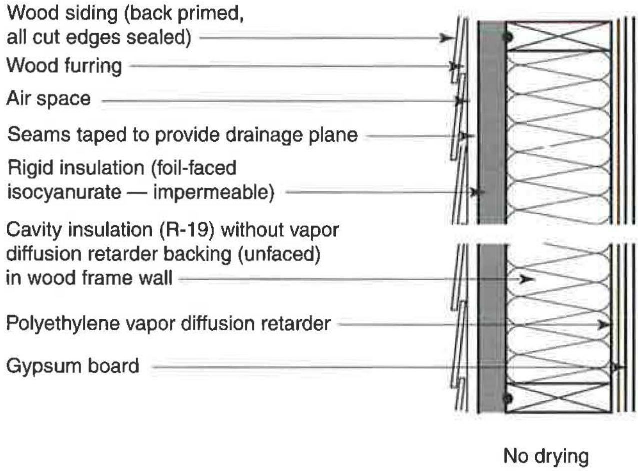


Figure III.17
No Drying

- Only dry materials should be used in the construction of this wall assembly.
- If vinyl or aluminum siding is used in this assembly wood furring providing an airspace is not necessary.
- Airspace in this assembly behind the wood siding is to permit drying of the wood siding.

Appendix IV
Windows

Introduction

Windows provide light and fresh air, and offer views that connect the interior spaces with the outdoors. However, windows have also represented a major source of unwanted heat gain in summer and significant heat loss in winter. The concern over energy and environment since 1970 has led to significant improvements in house performance based on the use of more efficient building envelopes and mechanical systems. In recent years, windows have undergone a technological revolution. They are no longer the weak link in energy-efficient home design. In fact, if windows are highly efficient, there is no significant energy penalty when total glazing area is increased. Because heat loss and gain control are now integrated into the window assembly or the glazing itself, design strategies involving shading devices, insulating window covers, or even orientation have less impact when high-efficiency windows are used.

It is now possible to have expansive views and daylight without sacrificing comfort or energy efficiency. This remarkable change has two important effects. First, any house can be made considerably more energy efficient by using high-performance windows. Second, and possibly more important, technologically advanced windows perform so much better and differently than their predecessors of just ten years ago

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The material in this appendix is drawn from the book, "Residential Windows: New Technologies and Energy Performance," by John Carmody, Stephen Selkowitz, and Lisa Heschong (W.W. Norton, 1996). This effort was supported by the U.S. Department of Energy.

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that many of the assumptions of both traditional and more recent energy-efficient design must be reexamined. Now that the window unit itself has substantial insulating value while still providing solar heat gain in winter, its net annual energy use can be better than a well-insulated wall in some cases.

Technological Improvements

Some technological innovations that are appearing in today's window products are described briefly below.

- **Glazing unit structure.** Multiple layers of glass or plastic films improve thermal resistance and reduce the heat loss attributed to convection between window layers. Additional layers also provide more surfaces for low-E or solar control coatings.

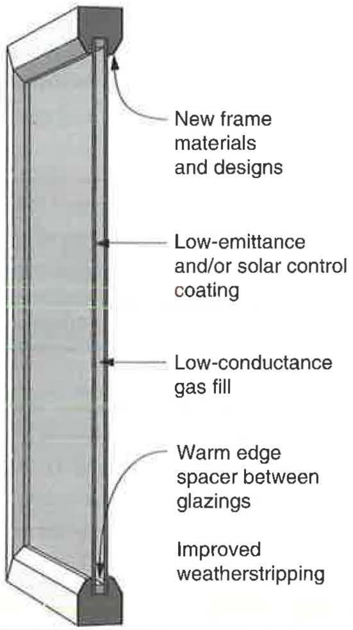


Figure IV.1
Technological Advances in Windows

- **Low-emittance coatings.** Low-emittance or low-E coatings are highly transparent and virtually invisible, but have a high reflectance (low emittance) to long-wavelength infrared radiation. This reduces long-wavelength radiative heat transfer between glazing layers by a factor of 5 to 10, thereby reducing total heat transfer between two glazing layers. Low-emittance coatings may be applied directly to glass surfaces, or to thin sheets of plastic (films) which are suspended in the air cavity between the interior and exterior glazing layers. In effect, a window with a low-E coating can transmit a significant amount of daylight as well as passive solar heat gain, while significantly reducing heat loss.

- **Low-conductance gas fills.** With the use of a low-emittance coating, heat transfer across a gap is dominated by conduction and natural convection. While air is a relatively good insulator, there are other gases (such as argon, krypton, and carbon dioxide) with lower thermal conductivities. Using one of these nontoxic gases in an insulating glass unit can reduce heat transfer between the glazing layers.

- **Solar control glazings and coatings.** To reduce cooling loads, new types of tinted glass and new coatings can be specified that reduce the impact of the sun's heat without sacrificing view. Spectrally selective glazings and coatings absorb and reflect the infrared portion of sunlight while transmitting visible daylight, thus reducing solar heat gain coefficients and the resulting cooling loads. These solar control coatings can also have low-emittance characteristics. In effect, a window with a spectrally selective coating or tint can significantly reduce solar heat gain while providing more daylight than traditional reflective or tinted glazings.

- **Warm edge spacers.** Heat transfer through the metal spacers that are used to separate glazing layers can increase heat loss and cause condensation to form at the edge of the window. "Warm edge" spacers use new materials and better design to reduce this effect.

- **Thermally improved sash and frame.** Traditional sash and frame designs contribute to heat loss and can represent a large fraction of the total loss when high-performance glass is used. New materials and improved designs can reduce this loss.

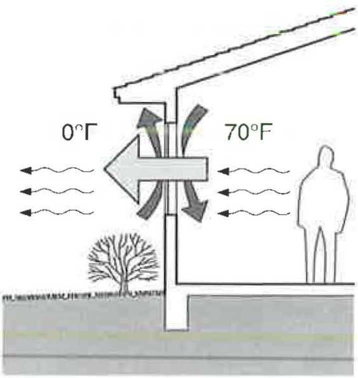
- **Improved weatherstripping.** Better weatherstrips are now available to reduce air leakage, and most are of more durable materials that will provide improved performance over a longer time period.

Energy-Related Properties of Windows

Heat flows through a window assembly in three ways: conduction, convection, and radiation. When these basic mechanisms of heat transfer are applied to the performance of windows, they interact in complex ways. Three energy performance characteristics of windows are used to portray how energy is transferred and a fourth indicates the amount of daylight transmitted. They are:

Insulating value. When there is a temperature difference between inside and outside, heat is lost or gained through the window frame and glazing by the combined effects of conduction, convection, and radiation. This is indicated in terms of the U-factor of a window assembly. It is expressed in units of Btu/hr-sq ft-°F (W/sq m-°C). The U-factor may be expressed for the glass alone or the entire window, which includes the effect of the frame and the spacer materials. The lower the U-factor, the greater a window's resistance to heat flow and the better its insulating value.

Heat gain from solar radiation. Regardless of outside temperature, heat can be gained through windows by direct or indirect solar radiation. The ability to control this heat gain through windows is indicated in terms of the solar heat gain coefficient (SHGC). The SHGC is the fraction of incident solar radiation admitted through a window, both directly transmitted, and absorbed and subsequently released inward. The solar heat gain coefficient has replaced the shading coefficient as the



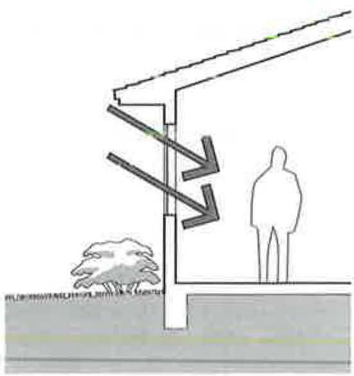


Figure IV.2
Insulating Value
- Indicated by U-factor (U-value)

Figure IV.3
Solar Heat Gain
- Indicated by solar heat gain coefficient (SHGC)

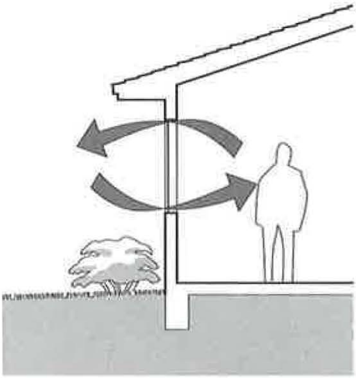


Figure IV.4
Infiltration
- Indicated by air leakage rating (AL)

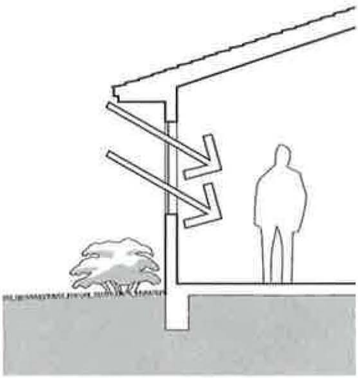


Figure IV.5
Daylight
- Indicated by visible transmittance (VT)

standard indicator of a window's shading ability. It is expressed as a number between 0 and 1. The lower a window's solar heat gain coefficient, the less solar heat it transmits, and the greater its shading ability.

Infiltration. Heat loss and gain also occur by infiltration through cracks in the window assembly. This effect is measured in terms of the amount of air (cubic feet or meters per minute) that passes through a unit area of window (square foot or meter) or window perimeter length (foot or meter) under given pressure conditions. It is indicated by an air leakage rating (AL). In reality, infiltration varies with wind-driven and temperature-driven pressure changes. Infiltration also contributes to summer cooling loads in some climates by raising the interior humidity level.

Visible transmittance. Visible transmittance (VT) is an optical property that indicates the amount of visible light transmitted through the glass. Although VT does not directly affect heating and cooling energy use, it is used in the evaluation of energy-efficient windows. For example, two windows may have similar solar heat gain control properties, however one may transmit more daylight as indicated by the visible transmittance. The visible transmittance may then be the basis for choosing one window over another. Specifically, VT is the percentage or fraction of the visible spectrum (380 to 720 nanometers) weighted by the sensitivity of the eye, that is transmitted through the glazing. The higher the VT, the more daylight is transmitted.

Condensation Potential

The figure below shows condensation potential on glazing (center of glass) at various outdoor temperature and indoor relative humidity conditions. Condensation can occur at any points that fall on or above the curves. (Note: All air spaces are 1/2 inch; all coatings are e = 0.10.)

Example 1: At 20°F (-7°C) outside temperature, condensation will form on the inner surface of double glazing any time the indoor relative humidity is 52 percent or higher. It will form at an indoor relative humidity of 70 percent or higher if a double-pane window with low-E and argon is used.

Example 2: In a cold climate where winter night temperatures drop to -10°F (-23°C), we want to maintain 65% humidity without condensation. A double-glazed window with low-E and argon will show condensation at 57% relative humidity, so the triple glazing with two low-E coatings and argon is needed to prevent condensation.

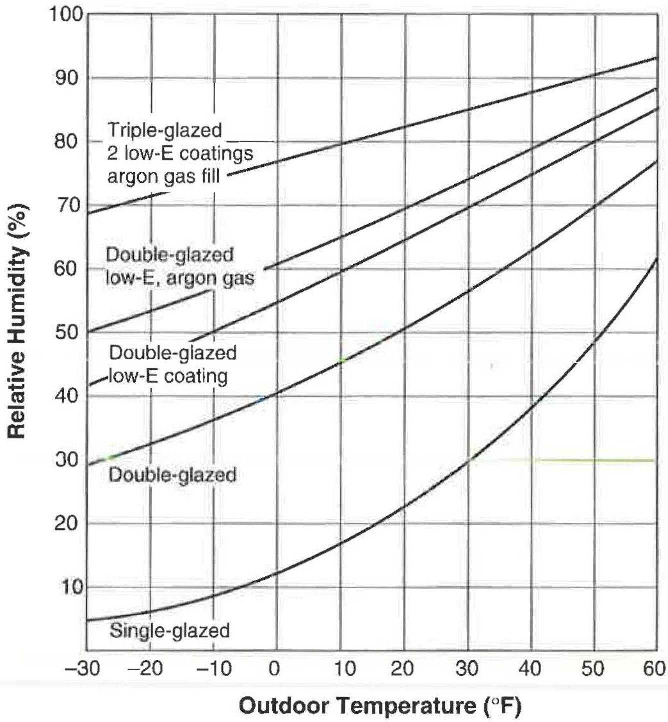


Figure IV.6
Condensation Potential

- Temperature and relative humidity conditions required for condensation to occur on different glazing assemblies

Window Rating Systems

The National Fenestration Rating Council (NFRC) has developed a window energy rating system based on whole product performance. This accurately accounts for the energy-related effects of all the products' component parts, and prevents information about a single component from being compared in a misleading way to other whole product properties. At this time, NFRC labels on window units give ratings for U-value, solar heat gain coefficient, and visible light transmittance. Soon labels will include air infiltration rates and an annual fenestration heating and cooling rating. The initial development of the NFRC rating system has focused on window units manufactured mainly for residential applications. In the future, NFRC will adapt the rating system to commercial glazing and curtain wall systems.

The National Fenestration Rating Council (NFRC) was established in 1989 to develop a fair, accurate, and credible rating system for fenestration products. This was in response to the technological advances and increasing complexity of these products, which manufacturers wanted to take credit for but which cannot be easily visually verified. NFRC procedures started to be incorporated in state energy codes in 1992. The 1992 National Energy Policy Act provided for the development of a national rating system. The U.S. Department of Energy has selected the NFRC program and certified it as the national rating system. In addition, the NFRC procedures are now referenced in and being incorporated into the Model Energy Code and ASHRAE Standards 90.1 and 90.2.

Selecting an Energy-Efficient Window

To evaluate windows with respect to annual energy performance, various types of information and tools are required. First, the basic energy-related properties of the window unit must be identified. Then, the annual heating and cooling season energy performance can be determined by using a variety of methods. In addition to quantitative issues such as the actual cost of heating fuel or electricity for cooling, energy performance characteristics are linked to other less measurable issues such as thermal comfort and condensation resistance, as noted earlier in the chapter. Choosing a better-performing window to save on fuel costs will also improve comfort and performance in other areas.

The three key energy-related properties of windows are U-factor, solar heat gain coefficient (SHGC), and air leakage rating. A fourth property, visible transmittance (VT), indicates the amount of daylight transmitted. These are defined and described elsewhere in this appendix and are the first properties to appear on NFRC window labels.

The relative impact of these properties is generally well understood:

- To improve heating season performance, select a window with a low U-factor and low air leakage rate. Generally, a high SHGC is desired if the intention is to increase passive solar heat gain.
- To improve cooling season performance, select a window with low SHGC, a moderate to low U-factor, and low air leakage.
- To provide maximum daylight, select a window with a high VT.

It is not adequate to rely on such simple guidelines, however. Balancing heating and cooling season performance must be done to establish whether a low or high SHGC is beneficial in a particular climate. Unfortunately, these basic properties do not, in themselves, give the consumer a clear indication of the actual impact on energy costs. To accurately determine annual energy performance and cost, they must be calculated based on these properties as well as other building and climate parameters.

Annual Energy Performance

A major reason to select a higher-quality window unit is the expectation of improved energy performance. A better U-factor, solar heat gain coefficient, or air leakage rating translates into less money spent on heating and cooling bills. The question is how much savings will actually result from selecting a particular window.

The impact of window selection on the annual energy performance of a building is not simple to calculate. It requires a sophisticated computer program that takes into account the properties of the windows you are comparing, and a detailed description of your house, the climate, and the way in which you will operate the house. Unfortunately, these tools are not always accessible to designers, builders, and homeowners to use in making a window purchasing decision, and even if they are, they may be too time consuming to use. While this is likely to change in the coming years as computer tools become easier to use, more widely available, and more familiar to the building community, people need guidance now.

New Tools to Determine Annual Energy Performance

To reflect the differing needs of different decision makers and to overcome the limitations of requiring detailed computer simulations for each situation, the window industry is developing a simplified annual energy rating system for windows as well as a companion computer-based approach. This rating system, currently being refined by the U.S.

	Total Window Unit			Center of Glass Only		
Window Description	U-value	SHGC	AL	U-value	SHGC	VT
Single-glazed Clear glass Aluminum frame*	1.30	0.79	0.98	1.11	0.86	0.90
Double-glazed Clear glass Aluminum frame**	0.64	0.65	0.56	0.49	0.76	0.81
Double-glazed Bronze tinted glass Aluminum frame**	0.64	0.55	0.56	0.49	0.62	0.61
Double-glazed Clear glass Wood or vinyl frame	0.49	0.58	0.56	0.49	0.76	0.81
Double-glazed Low-E (high solar gain) Argon gas fill Wood or vinyl frame	0.33	0.55	0.15	0.30	0.74	0.74
Double-glazed Low-E (medium solar gain) Argon gas fill Wood or vinyl frame	0.30	0.44	0.15	0.26	0.58	0.78
Double-glazed Spectrally selective coating (low solar gain) Argon gas fill Wood or vinyl frame	0.29	0.31	0.15	0.24	0.41	0.72
Triple-glazed Clear glass Wood or vinyl frame	0.34	0.52	0.15	0.31	0.69	0.75
Triple-glazed Two low-E coatings Krypton gas fill Wood or vinyl frame	0.15	0.37	0.08	0.11	0.49	0.68

* No thermal break in frame.
** Thermal break in frame.
All values for total windows are based on a 2-foot by 4-foot casement window.
Units for all U-values are Btu/hr-sq ft-°F.
SHGC = solar heat gain coefficient.
AL = air leakage in cubic feet per minute per square foot of unit.
VT = visible transmittance.

Figure IV.7
Properties of Some Typical Window Types

Department of Energy and window industry researchers in cooperation with the National Fenestration Rating Council, is being adopted as the official annual energy rating system of the NFRC. The intent is to give the building community and consumers a dual pathway for answers: (1) a quick and simple rating that can provide a reasonable approximation of the relative impact of window selection on annual energy performance, and (2) a more accurate technique that accounts for more specific design and operating parameters.

The simplified approach will produce comparative indicators of winter and summer energy performance (FHR and FCR) that will be incorporated directly into labels on each window. The companion computer-based tool (RESFEN) will provide more context-specific solutions for particular houses, as well as cost savings estimates.

Resources

American Architectural Manufacturers Association. *Skylight Handbook: Design Guidelines.* Palatine, IL: American Architectural Manufacturers Association, 1988.

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Appendix V

Air Leakage Testing, Pressure Balancing and Combustion Safety

Air leakage testing is a method for determining the total leakage area of a building envelope or the leakage of air distribution systems (duct work leakage in ducted forced air space conditioning systems). Air leakage testing is not a method for determining the actual air leakage or air change which occurs through the building envelope under the influence of air pressure differences created by wind, stack action (the buoyancy of heated air) and mechanical systems (duct leakage and unbalanced forced air systems).

Air leakage testing for both building envelopes and duct work is based on the fundamental properties of air flow through openings. The amount of air flow through an opening is determined by two principle factors:

- the area/size/geometry of the opening; and
- the air pressure difference across the opening.

The three parameters, air flow, area and air pressure difference can be related to each other by applying a simple mathematical relationship. Measuring two of the three parameters and applying the mathematical relationship can determine the third parameter. For example, if the air flow through an opening is measured, as well as the air pressure difference across the opening when air flow is occurring, the area of the opening can be calculated by applying the mathematical relationship. Applying this relationship to a flow rate of 1,000 cfm through an opening with an air pressure differential of 50 Pascals across the opening obtains a mathematically calculated area of approximately 1 square foot. In other words 1,000 cfm air flow occurs through a 1 square foot opening as a result of an air pressure difference of 50 Pascals.

Air Leakage Testing of Building Envelopes

Air leakage testing of building envelopes involves placing a large calibrated fan in an exterior door and creating an air flow through the fan. The calibrated fan is often referred to as a "blower door". Exhausting air depressurizes the building. Supplying air pressurizes the building. When air is exhausted from a building through a blower door, air leaks into the building through openings to replace the air exhausted. If sufficient air is exhausted to overcome any naturally occurring pressures, the quantity of air exhausted will equal the quantity of air supplied. The quantity of air exhausted through the blower door can be readily measured. This exhaust quantity can be equated to the air leaking into the building envelope through all of the openings in the building envelope. If the air pressure difference between the interior of the building envelope and the exterior is also measured, this can be used to approximate the air pressure difference across all of the openings in the building envelope.

By determining the quantity of air exhausted and the air pressure difference across the building envelope, the combined air flow through all of the openings in the building envelope as well as the air pressure difference across all of the openings is known. Applying a mathematical relationship converts the combined air flow and air pressure difference to the combined leakage area of all of the openings in the building envelope. In this manner a blower door can determine the combined area of all of the openings in a building envelope, including random cracks, flaws, openings built into the building as a result of the building process, without actually determining where the leaks and openings are.

The procedure can also be applied to building envelopes pressurized by calibrated fans. Either depressurization or pressurization can be employed. Depressurization is more common in building envelope leakage testing as a result of tradition rather than accuracy (the procedures were initially popularized in cold climates where pressurization during the heating season typically created comfort problems during testing).

Air leakage test results are expressed several ways. Test results can be presented as a flow rate at 50 Pascals air pressure difference (CFM50). In other words, the volume flow rate of air extracted out of the building envelope necessary to depressurize the building envelope 50 Pascals relative to the exterior is measured and reported. The combined or equivalent leakage area of the building (EqLA) in square inches can be determined from the CFM50 measurement by the application of the mathematical relationship.

The combined leakage area of a building envelope can also be compared to the total surface area of the building envelope using a parameter called a leakage ratio. Leakage ratios are typically expressed as square inches of leakage for every 100 square feet of building envelope area (or cm2/100m2 SI). In this manner the measured EqLA is related to the measured surface area of the building envelope.

Test results can also be expressed in the form of air changes per hour at a pressure difference of 50 Pascals (ach @ 50 Pa). In this approach, the volume flow rate extracted out of the building is related to the volume of the building envelope. For example, consider a blower door extracting air out of a building envelope at a rate of 1,000 cubic feet per minute establishing an air pressure difference of 50 Pa. This is equivalent to an air extraction rate of 60,000 cubic feet per hour. If the volume of the conditioned space is 10,000 cubic feet, this would result in 6 air changes per hour at a 50 Pascal air pressure difference (60,000/10,000 = 6). A flow rate of 1,000 cfm through an opening with a 50 Pascals air pressure difference was previously determined to require a 1 foot square opening. In other words, for this particular volume of building, 6 ach @ 50 Pa is equivalent to 1 foot square of leakage or an EqLA of 1 foot square or 144 square inches. If the surface area of the building envelope was approximately 3000 square feet, the leakage ratio would be approximately 4.8 square inches of leakage for every 100 square feet of building envelope surface area (3000/100 = 30 and 144/30 = 4.8).

The following information all describes the same building. It came from the blower door test conducted on the building described in the previous example.

CFM50 = 1000

EqLA = 144 in^2

6 ach @ 50 Pa (where building volume is 10,000 ft^3)

Leakage Ratio = 4.8 $in^2/100\ ft^2$ (where building envelope surface area is 3000 ft^2)

Not all of these values are always determined or recorded. All can be related to each other and the building envelope tested. The leakage ratio value is the most descriptive as it can be used to compare buildings of differing volumes and surface areas to each other. Since the other values are related to specific buildings with given building volumes and building surface areas, comparisons between buildings of diverse construction are less meaningful. However, where buildings are of approximately the same floor area and volume, all of the values provide reasonably comparative information.

Air leakage testing of building envelopes is typically conducted as a method of quality control to ensure that control of air flow occurs in constructed buildings. It is also used to identify leakage areas which may have been missed during construction thereby facilitating repairs and remediation.

Air Leakage Testing of Air Distribution Systems

Air leakage testing of air distribution systems is similar to air leakage testing of building envelopes in that both procedures involve using a calibrated fan to create an air pressure difference. In addition, both procedures require that air flows through the calibrated fans and pressure differentials be determined.

Air leakage testing of air distributions systems involves sealing the supply and return registers and depressurizing the system using a calibrated fan. In this approach, the duct work and the air handler is considered a closed system. The calibrated fan, sometimes referred to as a "duct blaster" is typically attached to the air handler. The quantity of air moved by the duct blaster to pressurize or depressurize the system is directly related to the leakage area of the system. By determining the quantity of air supplied by the calibrated fan and the air pressure difference between the duct work and the conditioned space, the combined air flow through all of the leakage openings in the air distribution system is determined.

Air leakage test results for air distribution systems are often presented as the flow rate through the calibrated fan required to pressurize or depressurize the duct system to a specific pressure differential. For example CFM25 values are typical. A reading of CFM25 = 60 cfm translates to: an air flow rate of 60 cfm through the calibrated fan (duct blaster) depressurized the air distribution system (duct work and air handler) to a negative of 25 Pascals (0.1" w.c.) relative to the conditioned space.

Air leakage testing of air distribution systems is typically conducted as a method of quality control to ensure control of air flow occurs in air distribution systems. It is also used to identify leakage areas thereby facilitating repairs and remediation.

Pressure Balancing

Air pressure differentials between conditioned spaces and the surroundings, as well as between rooms and between building assemblies and rooms, impact the health, safety and durability of the building envelope.

Infiltration of humid air during cooling periods is a concern as is the exfiltration of interior heated, moist air during heating periods. Infiltration of soil gas (moisture, radon, pesticides, other) below grade or from crawl spaces and slabs is a concern throughout the year. High interior negative air pressures can lead to the spillage and backdrafting of combustion appliances such as fireplaces, wood stoves, combustion water heaters and furnaces. Finally, significant depressurization can lead to flame roll out and fire in some combustion appliances such as furnaces and water heaters.

With respect to combustion appliances, installation of appliances which are not sensitive to negative air pressures as well as limiting the negative air pressures which can occur within building enclosures is an appropriate strategy for control.

With respect to the infiltration of exterior pollutants such as soil gas, pesticides, radon and below grade moisture, limiting the negative air pressure which can occur, providing positive air pressurization of building enclosures (or portions of building enclosures) as well as providing sub slab or crawl space depressurization are appropriate strategies for control.

With respect to the exfiltration of interior moisture during heating periods, constructing building assemblies which are forgiving and/or tolerant of interior moisture, as well as limiting the positive air pressure which can occur during heating periods (and/or providing negative pressures during heating periods) are appropriate strategies for control.

In all cases the maximum pressurization or depressurization relative to exterior (ambient) conditions should be limited to less than 3 Pascals.

Ducted forced air distribution systems are traditionally viewed as interior circulation systems which move air from place to place within a conditioned space, with a neutral effect on the pressure differences between the interior and exterior. However, as a result of installation practices and design/sizing faults ducted forced air distribution systems can have significant effects on air pressure relationships.

Duct leakage can result in either pressurization or depressurization of entire conditioned spaces or specific rooms. Duct leakage can significantly increase space conditioning energy requirements. Incorrect duct sizing, distribution layout or lack of adequate returns can lead to pressurization and depressurization of rooms and interstitial spaces. These effects should be limited to less than 3 Pascals positive or negative relative to the exterior or between rooms and/or interstitial (between two surfaces) cavities within building enclosures.

Exhaust fans and appliances such as whole house fans, attic ventilation fans, indoor grills, clothes dryers, kitchen exhaust range hoods can also significantly alter air pressure relationships. These effects should also be limited to less than 3 Pascals positive or negative relative to the exterior or between rooms and/or interstitial cavities within building enclosures (except in the case of whole house fans and indoor grills). Where whole house fans and/or indoor grills are operating, no other combustion appliances or heating and/or mechanical cooling systems should be in simultaneous use. Furthermore, windows and/or doors should be opened when whole house fans and/or indoor grills are operating.

Testing Pressure Differentials and Commissioning

Air pressure relationships between conditioned spaces and the exterior, as well as between rooms and between rooms and interstitial spaces should be measured under all operating conditions. Equipment should be cycled on and off at all speed settings. Interior doors should be both opened and closed during all testing. Measurements are typically taken with a digital micromanometer. Where any air pressure differential greater than 3 Pascals is measured, remediation work and/or adjustments to equipment, or the building envelope will be necessary.

Combustion Safety

If combustion appliances are selected, they should not interact aerodynamically with the building. In other words, changing interior air pressure differentials should not be able to influence the operation of combustion appliances. In order to meet this requirement only sealed combustion, power vented, induced draft or direct vented combustion appliances should be used for space conditioning and domestic hot water.

Gas cook tops and ovens should be only installed in conjunction with direct vented (to the exterior) exhaust range hoods. Recirculating range hoods should be avoided even in the absence of combustion appliances as they become breeding grounds for biological growth and a source of odors.

Fireplaces and wood stoves should only be installed with their own correctly sized air supply from the exterior. Fireplaces should also be provided with tight-fitting glass doors.

High interior negative air pressures can lead to the spillage and backdrafting of combustion appliances and significant depressurization can lead to flame roll out and fire. In all enclosures containing combustion appliances, the maximum depressurization relative to the exterior should be limited to less than 3 Pascals.

All combustion appliances (except fireplaces and wood stoves) should be tested for carbon monoxide production prior to occupancy and on a yearly basis thereafter. Carbon monoxide production of any appliance should not exceed 50 ppm. All measurements should be taken in the draft hood or vent before exhaust gases are mixed with dilution air. The installation of household carbon monoxide detectors is recommended.

Appendix VI
Goals, Objectives and Criteria for Energy and Resource Efficient Buildings

Introduction

The Energy Efficient Building Association (EEBA) has developed these goals, objectives and criteria for energy and resource efficient buildings. They provide guidance for design, construction and comprehensive rehabilitation (gut-rehab) of low-rise residential and small commercial buildings less than 20,000 square feet (1900 m^2) floor area.

Goals

Energy Efficiency

To promote building practices that result in a substantial reduction in energy use for space conditioning, water heating, lighting and appliance operation.

> *Improved energy efficiency can reduce the environmental impact of the built environment, improve economic well being and promote global stability.*

Occupant Safety

To promote building practices that result in an improvement in fire and structural safety.

> *Improved construction practices can reduce the risk from earthquakes, hurricanes, floods and fires.*

Occupant Health

To promote building practices that result in an improvement in the indoor environment.

> *Improved construction practices can reduce the risk from building related illness and sick building syndrome.*

Durability

To promote building practices that prolong the useful service life of buildings, reduce maintenance and promote serviceability.

> *Rehabilitation and replacement of damaged components and structures results in the inefficient use of resources. Improper moisture control can lead to premature failure of building components and can contribute to poor environmental conditions for occupants.*

Occupant Comfort

To promote building practices that improve thermal comfort, daylighting, lighting, humidity control, odor control, noise control and vibration control.

> *Providing comfort for building occupants is one of the fundamental requirements of shelter.*

Environmental Impact

To promote building practices that reduce the impact on the local and global environment.

> *The impacts of the built environment on the planetary environment make it necessary to make informed, environmentally responsible choices during the construction process.*

Objectives

Energy Efficiency

Energy efficient and resource efficient construction should address the following objectives for design, construction, commissioning, operation and maintenance.

A. Building Structure

Thermal transmission through heat loss and heat gains should be reduced by the specification and installation, with proper attention to detail and quality assurance, of increased levels of thermal insulation. Insulation systems should be installed such that they reduce convective, conductive and radiative heat losses and gains. Thermal anomalies such as thermal bridges should be minimized.

Moisture gain resulting in decreased thermal and structural performance should be controlled. Air flow retarder systems and vapor diffusion retarders should be used to protect the building envelope from uncontrolled air and moisture flow.

Thermal transmission through convective heat loss and gain driven by "wind washing" should be reduced by the specification and installation, with proper attention to detail and quality assurance, of an external air barrier system or external "weather barrier".

Fenestration systems should be selected according to climate, building orientation, interior comfort, daylighting, ventilation, furnishing durability and egress requirements.

B. Mechanical Systems

Indoor air quality should be facilitated by the installation of a controlled mechanical ventilation system. Heat recovery is recommended in severe heating climate zones.

Only sealed combustion or power vented direct combustion appliances should be installed in occupied spaces. Gas cook tops and gas ovens should only be installed in conjunction with exhaust fans.

Thermal and peak load reductions derived from improving levels of insulation, airtightness and fenestration performance of the building envelope should be evaluated in the sizing of equipment.

The domestic hot water system should meet high efficiency standards. Options for reducing water consumption are recommended. Solar energy for hot water heating should be considered.

Efficient illumination design and lighting systems should be used. Natural lighting of spaces should be considered prior to specifying electric illumination systems. Lighting designs and controls should consider the availability of natural light. Occupancy sensors should be considered for foyers, utility room, basements, garages and other spaces. Hard wired general area lighting should employ fluorescent fixtures. Other lighting fixtures should use compact fluorescent lamps.

Major appliances should meet high energy efficiency standards using current appliance ratings.

C. Occupant Considerations

A comprehensive operations manual should be provided to occupants which includes necessary operating, maintenance and repair information so that the performance of the building can be maximized.

Occupant Safety

In no case should the application of energy efficient or resource efficient design or construction strategies, materials, equipment or appliances violate safety codes and standards.

A. Building Structure

Recognized structural design shall be employed to resist live, static and wind loads.

B. Mechanical Systems

Mechanical systems shall be designed and constructed to facilitate occupant safety.

C. Occupant Considerations

Information relating to the safe operation of the building and me chanical systems shall be provided to occupants. Information relating to safe maintenance of installed mechanical systems shall also be provided.

Occupant Health

Energy efficient and resource efficient construction should provide a healthy living and working environment.

A. Building Structure

Selection of construction materials that have low emission rates of toxic materials; foundations designed to exclude entry of soil gas; and implementation of moisture control measures are recommended.

B. Mechanical Systems

A controlled mechanical ventilation system should be provided to facilitate occupant health.

C. Occupant Considerations

Information relating to the healthy operation of the building and its mechanical systems should be provided to the occupants.

Durability

Energy efficient and resource efficient construction should include the following moisture control measures in order to provide long term performance and durability.

A. Building Structure

The building envelope should provide mechanisms to control the migration of moisture in the liquid and vapor form.

Building materials and components should be protected from rain, snow and other moisture sources during storage on site, construction and commissioning of the building.

B. Mechanical Systems

Controlled ventilation, mechanical cooling or dehumidification systems should be provided to maintain acceptable indoor relative humidity. Such systems and their controls should maintain humidity in the range of 25 to 60 percent. Source control of moisture should be used where possible.

C. Occupant Considerations

Instructions for the proper use and maintenance of moisture control systems should be provided to occupants.

Occupant Comfort

Energy efficient and resource efficient construction should provide a comfortable living and working environment.

A. Building Structure

The building envelope should facilitate the comfort of occupants.

B. Mechanical Systems

The mechanical systems should facilitate the comfort of occupants.

C. Occupant Considerations

Information relating to the comfortable operation of the building and its mechanical systems should be provided to the occupants.

Environmental Impact

Energy efficient and resource efficient construction should minimize the impact on the environment. Design and construction strategies which account for full life-cycle energy consumption and resource utilization—including the reuse, recycling and reconfiguration of materials and practices—should be used.

A. Building Structure

The building envelope should be deployed on its site and in its local environment in an environmentally sensitive fashion.

Use of virgin materials or materials with low recycled content should be minimized.

On-site reuse of surplus construction materials should be provided. Recycling of materials should be maximized.

B. Mechanical Systems

The energy efficiency of mechanical conditioning systems should be maximized.

C. Occupant Considerations

Information relating to the resource efficient operation and performance of the building should be provided to the occupants. Measures facilitating the recycling of consumer waste should be utilized.

Criteria

The following criteria are recommended for the design and construction of energy and resource efficient buildings.

Component Criteria

A. Building Structure

Overall thermal transmission coefficients for buildings should be less than CABO Model Energy Code (most current edition); or ASHRAE 90.2-1993 (with approved addenda).

Peak load heating (total building heat loss including transmittance through building envelope and energy used for heating the outdoor air to the room temperature calculated at the design temperature difference using ACCA Manual J) will be less than 0.25 BTU/hr per degree F per square foot of conditioned floor area.

Peak load cooling (total building heat gain including skin gains and air change gains calculated at the design temperature difference using ACCA Manual J) should be less than 0.75 BTU/hr per degree F per square foot of conditioned floor area. In hot and humid climates (as defined by ASHRAE Fundamentals - 1993), peak load cooling should be less than 1.00 BTU/hr per degree F per square foot of conditioned floor area.

Air leakage of buildings (determined by pressurization testing) should be less than 2.5 square inches/100 square feet leakage ratio (CGSB, calculated at a 10 Pa pressure differential) or 0.25 cfm/square foot of building envelope surface area @ 50 Pa.

B. Mechanical Systems

Controlled mechanical ventilation at a minimum base rate of 20 cfm per master bedroom and 10 cfm for each additional bedroom will be provided when the building is occupied. A capability for intermittent base rate ventilation of 0.05 cfm per square foot of conditioned areas will also be provided. Intermittent spot ventilation of 100 cfm will be provided for each kitchen. Intermittent spot ventilation of 50 cfm or continuous ventilation of 20 cfm when the building is occupied will be provided for each washroom/bathroom. Positive indication of shut-down or improper system operation for the base rate ventilation will be provided to occupants.

Mechanical ventilation shall use less than 0.5 watt/cfm for ventilation systems without heat recovery or less than 1.0 watt/cfm for ventilation systems with heat recovery.

Mechanical ventilation system airflow should be tested during commissioning of the building.

Heat recovery on controlled mechanical ventilation is recommended in severe heating climate zones. Heat recovery rates of heat recovery ventilators should be greater than 65 percent, including effectiveness of distribution.

Ductwork leakage to the exterior for ducts distributing conditioned air should be limited to 5.0 percent of the total air handling system rated air flow at high speed determined by pressurization testing at 25 Pa.

Only sealed combustion or power vented direct combustion appliances should be installed in occupied spaces. These appliances must be rated to vent properly at largest expected negative pressure. Gas cooktops and gas ovens should only be installed in conjunction with exhaust fans.

Major appliances should meet high energy efficiency standards using current appliance ratings. Select only those appliances in the top one-third of the DOE Energy Guide rating scale.

Lighting power density should not exceed 1.0 Watts per square foot.

C. Occupant Considerations

Systems that provide control over space conditioning, hot water or lighting energy use should be clearly marked. Information relating to the operation and maintenance of such systems should be provided to occupants.

The designer and general contractor should provide comprehensive information to occupants relating to the safe, healthy, comfortable operation of the building and mechanical systems.

Indoor Environment Criteria

Energy efficient and resource efficient construction should provide comfortable indoor conditions as defined by ASHRAE Standard 55-1989.

A. Building Structure

The building and site should provide effective drainage measures to control rainfall runoff and to prevent entry into the building.

The building foundation should be designed and constructed to prevent the entry of moisture and other soil gases.

Building assemblies should be designed and constructed to permit drying of interstitial spaces.

Building assemblies should be designed and constructed to prevent airflow into insulation systems from both the interior and exterior.

Radon resistant construction practices as referenced in the ASTM Standard "Radon Resistant Design and Construction of New Low Rise Residential Buildings" should be utilized.

Materials, adhesives and finishes with tested low emission rates should be selected.

B. Mechanical Systems

Controlled mechanical ventilation systems shall be installed.

Where combustion appliances are used, only sealed direct combustion or power vented systems should be installed in habitable spaces. Gas cooktops and gas ovens should only be installed in conjunction with exhaust fans.

Forced air systems should be designed to provide balanced airflow to all conditioned spaces and zones. Interzonal air pressure differences should be limited to 3 Pa.

Filtration systems should be provided for forced air systems which provide a minimum atmospheric dust spot efficiency of 30 percent (derived from ASHRAE Standard 52-1994).

Indoor humidity should be maintained in the range of 25 to 60 percent by controlled mechanical ventilation, mechanical cooling or dehumidification.

C. Occupant Considerations

Occupants should be provided with an operators manual containing specific operating instructions on how to maintain a healthy indoor environment.

Control systems should include advisory display or indicative modes to alert occupants to "trouble" or "failure" conditions.

Environmental Impact Criteria

Energy efficient and resource efficient construction should be designed, constructed and operated to reduce overall life-cycle impact on the environment considering energy consumption, resource use and labor inputs in the fabrication, erection, modernization, operation and disassembly of the building, components and systems.

The design and construction of buildings should use recycled materials, or new materials with a high recycled content. Minimization of scrap on site and design for disassembly should be provided.

Discussion Relating to Criteria

The Criteria are for the most part self-explanatory. However, four concepts require explanation: peak load heating coefficients, peak load cooling coefficients, air leakage coefficients and ductwork leakage. The following discussion relates to these four concepts.

In selecting the approach to measure/evaluate energy use the following factors were considered:

- A "fuel blind" site energy use measurement was selected due to the inability in the foreseeable future to reach a politically correct approach in determining total energy use. Furthermore, even if a political compromise could be reached, the physics for total energy use is still beyond conventional computing. To paraphrase Churchill, the fuel blind site energy use approach is the worst possible approach to use except for the alternatives.
- The approach had to be simple to use and within the capabilities of most builders and other users. As such, a computer intensive computational tool, such as DOE2, Hot2000, etc. and hourly, monthly, or yearly simulations were rejected. Every building requires a basic heat loss, heat gain calculation to size equipment and to meet most building code requirements. The standard, basic approach used by builders and HVAC contractors is ACCA Manual J. As such using ACCA Manual J is the approach proposed. It can be done manually by hand or by hundreds of readily available computer programs.
- A single airtightness value was selected as it has become clear that it is as important to build a tight building envelope in the hot, humid south as in the cold north. Similarly, mixed, humid climates and hot, dry climates also require tight building envelopes. The importance of tight construction goes far beyond energy conservation. Health and durability are the principle concerns with respect to this issue.
- The airtightness value is based on the surface area of the building envelope not the volume. Air change per hour at 50 Pascals was rejected as a basis for measurement because it confuses the issue. We are dealing with leakage through the building envelope. Holes, holes, holes. Of course, ach @ 50 Pa is a popular, albeit misguided, criteria, the requirements have been translated for information purposes only. Based on ach @ 50 Pa, values are between 3.2 and 2.8 for 1,500 to 2,500 square foot houses with basements (not including the basements in these square footage determinations; however, basement floor areas are included in conditioned floor area determinations for peak load heating and

peak load cooling coefficients). The airtightness value is roughly double the Canadian R-2000 tightness requirement of 1.5 ach @ 50 Pa although it is roughly twice as tight as conventional construction.

Peak Load Heating - Determining the Peak Load Heating Coefficient

Calculate the design heat loss at the design temperature using ACCA Manual J. When using ACCA Manual J assume no infiltration/exfiltration losses. In other words the assumption is if a building meets the airtightness performance targets, there will be negligible infiltration/exfiltration losses. However, a heat loss associated with controlled mechanical ventilation must be added. In other words, infiltration/exfiltration losses are replaced with losses associated with controlled mechanical ventilation. The value for this controlled mechanical ventilation heat loss is determined by the ventilation requirements for each building. For example, a 3 bedroom house requires a continuous ventilation rate of 40 cfm when occupied. If heat recovery is associated with this ventilation rate, the heat loss may be reduced based on the heat recovery efficiency rating of the heat recovery device used.

For example, a 2,550 square foot house, constructed over a 1,275 square foot basement, located in Grayslake, IL has a design heat loss of 34,765 BTU/hr at an exterior design temperature of -4 degrees F and an interior design temperature of 70 degrees F. The losses associated with a controlled ventilation rate of 40 cfm of unconditioned air entering the building at -4 degrees F are included in the design heat loss.

Design Heat Loss	Design Temp	Inside Temp	Temp Difference	Conditioned Floor Area
34,765 BTU/hr	-4 deg F	70 deg F	74 F deg	3,825 ft^2

To determine the Peak Load Heating Coefficient, divide the Design Heat Loss by the Design Temperature Difference and the square footage of the Conditioned Floor Area. In determining conditioned floor areas, basement floor areas are included, even if not finished since the basement floor areas are within the thermal and pressure boundary of the building envelope.

$$\mathbf{34{,}765}\ \text{BTU/hr} \div \mathbf{74}\ \text{F} \div \mathbf{3{,}825}\ \text{ft}^2 = \mathbf{0.12}\ \text{BTU/F/ft}^2$$

Peak Load Cooling - Determining the Peak Load Cooling

Coefficient

Calculate the design heat gain at the design temperature using ACCA Manual J. When using ACCA Manual J assume no infiltration/ exfiltration losses. In other words the assumption is if a building meets the airtightness performance targets, there will be negligible infiltration/exfiltration gains. However, a heat gain associated with controlled mechanical ventilation must be added. In other words, infiltration/ exfiltration gains are replaced with gains associated with controlled mechanical ventilation. This heat gain will comprise both a sensible and latent component. The value for this controlled mechanical ventilation heat gain is determined by the ventilation requirements for each building. For example, a 3 bedroom house requires a continuous ventilation rate of 40 cfm when occupied. If heat recovery is associated with this ventilation rate, the heat gain may be reduced based on the heat recovery efficiency rating of the heat recovery device used.

For example, a 2,550 square foot house, constructed over a 1,275 square foot basement, located in Grayslake, IL has a design heat gain of 20,626 BTU/hr at an exterior design dry bulb temperature of 89 degrees F. and an interior design temperature of 78 degrees F. The gains associated with a controlled ventilation rate of 40 cfm of unconditioned air entering the building at 89 degrees F. dry bulb and a wet bulb design temperature of 78 degrees F. are included in the design heat gain.

Design Heat Gain	Design Temp	Inside Temp	Temp Difference	Conditioned Floor Area
20,626 BTU/hr	89 deg F	78 deg F	11 F deg	3,825 ft^2

To determine the Peak Load Cooling Coefficient, divide the Design Heat Gain by the Design Temperature Difference and the square footage of the Conditioned Floor Area. In determining conditioned floor areas, basement floor areas are included, even if finished since the basement floor areas are within the thermal and pressure boundary of the building envelope.

$$\mathbf{20{,}626}\ \text{BTU/hr} \div \mathbf{11}\ \text{F} \div \mathbf{3{,}824}\ \text{ft}^2 = \mathbf{0.49}\ \text{BTU/F/ft}^2$$

Air Leakage - Determining Leakage Ratios and Leakage Coefficients

Using a blower door, measure the flow rate necessary to depressurize the building 50 Pascals. This flow rate is defined as CFM50. Alternatively, determine the Equivalent Leakage Area (ELA) in square inches at 10 Pascals using the procedure outlined by CGSB. When determining these values, intentional openings (design openings) should be closed or blocked. These openings include fireplace dampers and fireplace glass doors, dryer vents, bathroom fans, exhaust fans, HRV's, wood stove flues, water heat flues, furnace flues and combustion air openings.

Calculate the leakage ratio or the leakage coefficient using the entire surface area of the building envelope. When determining the surface area of the building envelope, below grade surface areas such a basement perimeter walls and basement floor slabs are included.

For example, a 2,550 square foot house constructed in Grayslake, IL has a building envelope surface area of 6,732 square feet and a conditioned space volume of 33,750 cubic feet (including the basement). The measured Equivalent Leakage Area (EqLA) using a blower door is 128 square inches. This also corresponds to a blower door measured CFM50 value of 1,320 cfm and a blower door measured 2.3 airchanges per hour at 50 Pascals.

Surface Area	EqLA	CFM50	ach @ 50 Pa	Volume
6,723 ft^2	128in^2	1,320 cfm	2.3	33,750 ft^3

To determine the Leakage Ratio, divide the surface area of the building envelope by 100 square feet and take this interim value and divide it into the EqLA.

$$\mathbf{6{,}732}\ ft^2 \div \mathbf{100}\ ft^2 = \mathbf{67.32}$$

$$\mathbf{128}\ in^2 \div \mathbf{67.32} = \mathbf{1.9}\ in^2/100\ ft^2$$

(Leakage Ratio)

To determine the Leakage Coefficient, divide the CFM50 value by the surface area of the building envelope.

$$\mathbf{1{,}320}\ \text{CFM50} \div \mathbf{6{,}732}\ ft^2 = \mathbf{0.20}\ cfm/ft^2$$

(Leakage Coefficient)

Many airtightness measurements are recorded as air changes per hour at a pressure differential of 50 Pascals (ach @ 50 Pa). To convert ach @ 50 Pa to CFM50 multiply the volume of the building envelope (including the basement) by the ach @ 50 Pa and divide by 60 min/hour.

For example, 2.3 ach @ 50 Pa across a building envelope of volume 33,750 ft^3 is equivalent to a CFM50 value of 1,320 cfm.

$$\mathbf{33{,}750}\ ft^3 \times \mathbf{2.3}\ \text{ach @ 50 Pa} \div \mathbf{60}\ \text{min/hr} = \mathbf{1{,}320}\ \text{CFM50}$$

Ductwork Leakage

To determine the allowable limit for ductwork leakage, determine the rated air flow rate of the air handler, furnace, air conditioner, etc. at high speed from the manufacturer's literature. For example, a Carrier or Lennox or York heat pump system may have a high speed flow rate of 1,200 cfm across the blower according to literature supplied with the unit. Five percent of this value is 60 cfm. This 5 percent value becomes the ductwork leakage limit when the total air handling system is depressurized to 25 Pascals with a duct blaster.

Appendix VII

Additional Resources

Organizations

Alternative Energy Corporation
P.O. Box 12699,
Research Triangle Park, NC 27709
(919) 361-8000

Energy Efficient Building Association
2950 Metro Drive,
Suite 108,
Minneapolis, MN 55425
(612) 851-9940

Florida Solar Energy Center
A Research Institute of the University of Central Florida,
1679 Clearlake Road,
Cocoa, FL 32992
(407) 638-1000

Rocky Mountain Institute
1739 Snowmass Creek Road,
Snowmass, CO 81654-9199
(303) 927-3851

Southface Energy Institute
241 Pine Street
Atlanta, GA 30308
(404) 872-3549

Publications - Books

Building Air Quality
U.S. Environmenal Protection Agency,
Indoor Air Division,
Office of Air and Radiation,
Washington, DC 20460
(202) 233-9030

Canadian Home Builders' Association Builders Manual
Canadian Home Builders' Association,
200 Elgin Street,
Suite 702,
Ottawa, Ontario K2P 1L5
(613) 230-3060

Energy Source Directory: A Guide to Products Used in Energy Efficient Construction
Iris Communications, Inc.,
P.O. Box 5920,
Eugene, OR 97405
(541) 484-9353

Moisture Control Handbook
Lstiburek, J.W. and Carmody, J.
Van Nostrand Reinhold Company, New York, NY
(508) 589-5100

Understanding Ventilation: How to Design, Select and Install Residential Ventilation Systems
Bower, J.
The Healthy House Institute,
7471 N. Shiloh Road,
Unionville, IN 47468
(812) 332-5073

Publications - Periodicals and Catalogs

Energy Design Update
Cutter Information Corporation,
37 Broadway,
Arlington, MA 02174
(800) 964-5118

EEBA Excellence: Newsletter of the Energy Efficient Building Association
2950 Metro Drive,
Suite 108,
Minneapolis, MN 55425
(612) 851-9940

Environmental Building News
R.R. 1,
Box 161,
Brattleboro, VT 05301
(802) 257-7300

Home Energy Magazine
2124 Kittredge Street,
No. 95,
Berkeley, CA 94704
(510) 524-5405

Journal of Light Construction
R.R. 2,
Box 146,
Richmond, VT 05477
(800) 375-5981

Shelter Supply, Inc.
17725 Juniper Path
Lakeville, MN 55044
(800) 762-8399

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