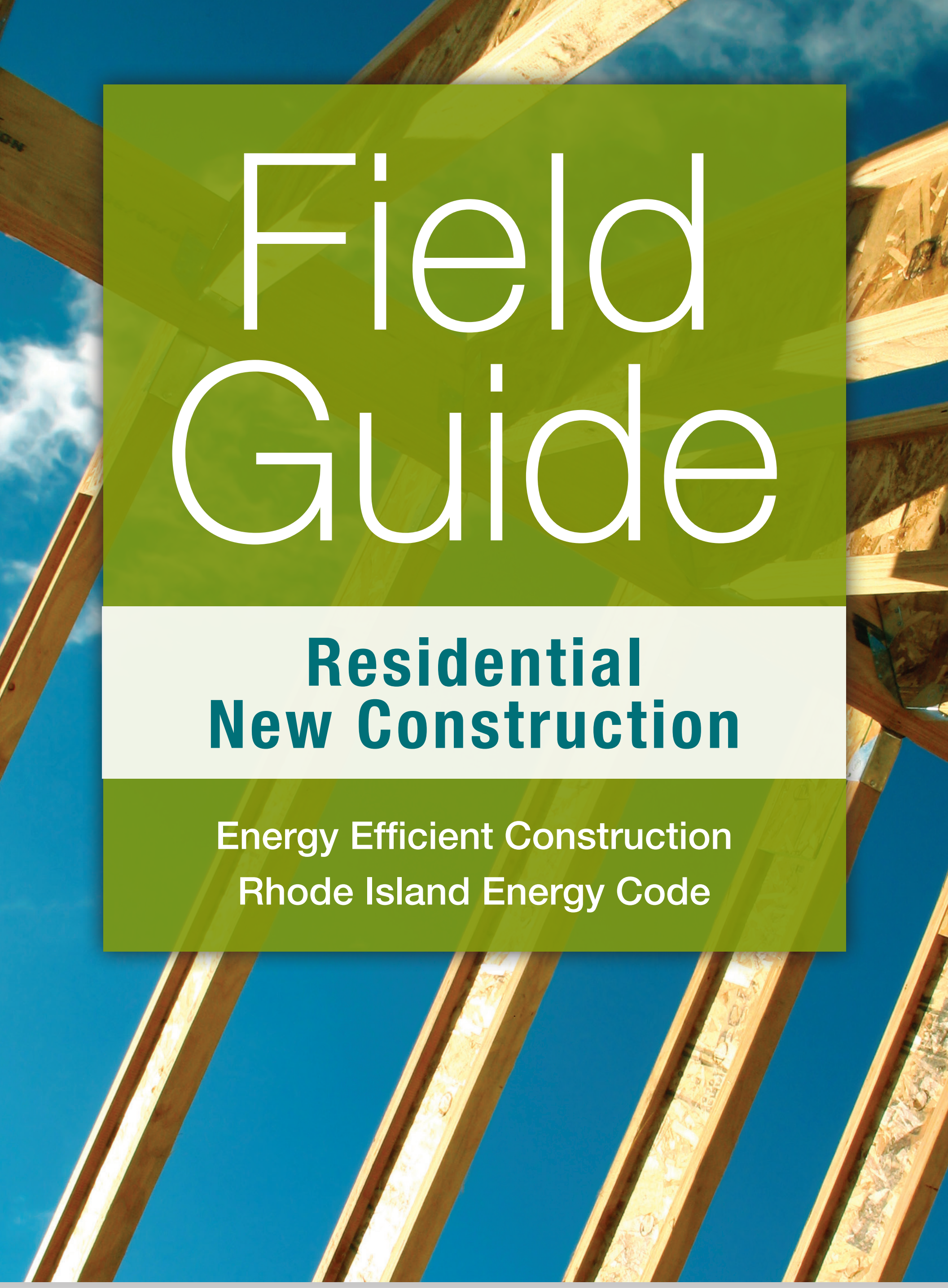

Field Guide

Residential New Construction

Energy Efficient Construction
Rhode Island Energy Code

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Energy code
technical support

Acknowledgments

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Introduction

What is "energy efficient" construction? Many people picture a space-age house, with a wall of south-facing glass. Others think about solar powered electricity or solar water heating. Still others think of superinsulation and high-tech windows. Energy efficient construction can include these features, but it does not need to.

Any home design can be energy efficient, and with careful planning additional construction costs can be minimal. Builders who use the "house as a system" concept to plan and build their homes will have happier customers, more referrals and fewer callbacks, which in the long run will more than pay for any added costs. This guide serves as a starting point to help designers and builders understand the system approach, with an emphasis on meeting the requirements of the Rhode Island SBC-8 State Energy Code.

About this guide

The purpose of this guide is to provide an overview of energy efficient residential new construction in the Northeast. The focus of the text and drawings in the guide are on two main subjects:

- Compliance with the Rhode Island State Energy Code—Rhode Island has adopted a modified version of the 2012 International Energy Conservation Code (IECC). Although there are some state-specific differences, notably in the thermal performance requirements of building enclosures.
- A systems approach to building—Understanding the way different components and materials interact in a building can reduce moisture problems, indoor air quality complaints, combustion safety problems, ice dams, and other expensive callbacks. This guide provides an overview of the key components of "house as a system" building, with a focus on energy performance.

Format

This guide is divided into sections that follow a typical construction sequence. Each section has convenient tabs marked on the edge of the page (e.g. foundation, framing, etc.). There are also special sections on the energy code and on the "house as a system" approach to building.

This guide aims to provide an overview of the important issues related to building an energy efficient new home, and also to serve as a handy field reference that designers, builders and trades people can use at every step of the construction process. Each chapter has the following features in common:

- **Energy code**—The opening section of the chapter outlines what parts of the energy code you must pay attention to during that stage in the construction process. References are made to the code document itself so you can find the actual code language that relates to your situation.

Energy code requirements are highlighted with a blue background.

Other (non-energy) code requirements that may be related to an energy concern are outlined by a blue box. Most of these requirements are drawn from the International Residential Code (IRC) for One- and Two-Family Dwellings (see Appendix B for ordering information).

- **Going further**—This guide is intended to be a concise reference; there are numerous situations which are beyond its scope. There are many references listed in Appendix B for further reading. One of these resources stands out as exemplary, thorough, and easy to understand—Building Science Corporation's *Cold Climate Builder's Guide*. The *Builder's Guide*, referenced as such throughout this book, is an ideal resource for further reading and more detail drawings. See Appendix B for ordering information.
- **Detail drawings**—Most of the drawings in this guide are found at the end of each chapter. The drawings have shaded notes that refer to code requirements. **In all drawings, the dotted line (in color) indicates the location of the primary air barrier.**

RI State Energy Conservation Code 1

This Guide Is Not the Code

The current residential energy code for Rhode Island is a modified version of the International Energy Conservation Code, 2012 edition (SBC-8). This guide attempts to portray these energy code requirements as completely and accurately as possible at the date of publication. However, building codes are subject to interpretation, as well as periodic changes. If you have any questions about the details of the code language, refer to the actual language in the current version of the code along with Rhode Island specific amendments contained in SBC-8 State Energy Conservation Code. Wherever possible, references are made to the specific section number from the code so you can look it up.

Construction Types (IECC 101.2)

The SBC-8 applies to all new homes. The focus of this guide is on low-rise (three stories high or less), residential, new construction and additions to existing buildings.

This guide does not apply to:

- buildings that are not heated or cooled
- additions to listed historical buildings
- hunting camps

How the Code Works

In practice, code compliance has four major elements, which are summarized below:

- General Requirements
- Compliance Analysis
- Documentation
- Plan Review and Field Inspections

General Requirements

The following is a summary of the general requirements. You must follow all of the requirements that are applicable to your building project.

- **Certificate (SBC-8, Section R401.3)** There must be a permanent certificate posted on the electrical box by the builder or registered design professsional listing the predominant R-values of the construction components and the results of air and duct leakage testing.
- **Basement walls must be insulated if the basement is conditioned space (SBC-8, Section R402.2.8).** The insulation must extend from the top of the wall to the top of the basement floor. Chapter 4 shows examples of basement wall insulation.
- **Slab on grade floors of conditioned space need insulation, if they are on grade, or up to 1 foot below grade (SBC-8, Section R402.2.9).** This includes the walkout portion of heated basements, or breezeways between a garage and house that share the garage slab. See Chapter 4 for more information on slabs.
- **Air Leakage (SBC-8, Section R402.4)**—Leaks must be sealed between conditioned space and outdoors, and between conditioned space and unconditioned space. The code specifies locations that must be sealed, and gives examples of ways to seal them. Air leakage rates shall be verified by pressure testing.

Many examples of acceptable air sealing are found in Chapters 5 and 11, with code requirements highlighted in blue.

- **Mechanical Systems (SBC-8, Section 403)**—This section has requirements for controls, heat loss calculations (403.6), equipment efficiency, hydronic pipe insulation, and duct sealing (see Chapter 7).
- **Service Water Heating (SBC-8, Section 403.4)**—This section addresses minimum standards for water heating equipment. Most residential equipment is covered by federal minimum standards (NAECA 1987), and meets code minimums. There are pipe insulation requirements for re-circulating hot water systems only. Some requirements for swimming pools—both heated and unheated—are also found in this section.
- **Mechanical Ventilation (SBC-8, Section 403.5)**—This section addresses the requirements for installing whole house mechanical ventilation including fan energy usage.
- **Electrical Power and Lighting (SBC-8, Section R404)**—This section addresses minimum high efficiency lighting requirements.

Compliance Analysis

Before you start building, you need to prepare a design that ensures you will comply with the code. In fact, you must do this before you can get a building permit. This is no different from any other part of the code, such as egress requirements, structural loads, etc. The Rhode Island State Building Code has three possible compliance paths listed in Section R401.2

Thermal Envelope

Before you do a compliance analysis, it is important to define the thermal envelope of the building. See page 16 for more about the thermal envelope.

Here is a summary of the compliance methods:

Prescriptive Methods (See SBC-8 State Energy Conservation Code)—These methods allow you to look up R-values and Ufactors from a table.

- The prescriptive specifications found in Chapter 4 of the IECC 2012 along with the amendments contained in SBC-8 give minimum performance specifications for building envelope components, based on the heating degree days in your location.
- Meeting the precriptive requirement of Chapter 4 of SBC-8 along with the requirements for Zone 5 in Table R402.1.1 from Chapter 4 of SBC-8.

Performance Method

- Compliance submission of RES*check* for Zone 5 & R.I. Energy Conservation Code Residential Provisions.

RES*check*—This software program is an easy-to-use compliance tool that runs on Windows. Using RES*check*:

- Allows significant flexibility for determining compliance specifications for most situations.
- Allows the designer to trade off better performance in one area, like higher R-values of insulation, to offset poorer performance in another, like higher U-factor windows. Recent versions of RES*check* **do not** allow trading off higher efficiency heating equipment to offset a less efficient building shell.
- Requires that you calculate square foot areas for all insulated components of the building such as walls, floors, ceilings, windows and doors.
- Is the most forgiving in the sense that it will be the easiest way to pass the compliance test for most houses.

The software is available for free on the internet at: www.energycodes.gov. Click on RES*check* under "Free Software Downloads". Instructions are also available with the software, and context-sensitive help menus are built in.

Some things to remember with RES*check*:

- Use gross wall areas, including all windows and doors. REScheck subtracts window and door area automatically.
- Don't forget to include band joist areas—except band joists of insulatedfloors—in the net wall area.
- Use window frame size or rough opening for window area, not the glass or sash size.

Documentation/Compliance Certification

Once you have used one of the design tools to determine the specifications of R-values, U-factors, and equipment efficiencies for your project, you must then submit construction documents with each application for a permit.

Construction documents shall:

- Be drawn or printed to scale
- Be of sufficient clarity to indicate location, nature and extent of work proposed
- Show in sufficient detail pertinent data and features of building systems and equipment contained in SBC-8

The code official shall examine the documents and determine if they meet the requirements of the code. When the documents are approved the code official issues a permit and the construction documents shall be endorsed in writing and stamped 'Reviewed for Code Compliance'. Stamped documents cannot be modified without code official approval.

Note on Additions

Additions must also comply with the energy code using the same analysis tools listed above. The thermal requirements for additions can be determined using the same analysis tools listed above. The addition can be analyzed by itself, or the entire building including the addition can be analyzed and shown to be compliant.

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Code

Building Science 2

Moisture related failures, indoor air quality problems, combustion back-drafting, sooty "ghost" stains on walls and carpets, mold and mildew in homes—callbacks of these types have increased dramatically in recent years. They are often blamed on houses that are "over-insulated" or "too tight." Although these problems were unusual in the days when houses were leaky and uninsulated, they are not *caused* by these factors alone. In fact, it is rare to find a failure of this sort which is caused by any single factor. These problems are usually the result of the different components of the house interacting, as a system, in ways that were not foreseen by the builder or designer.

Over the last century, the introduction of new materials such as plywood sheathing and housewraps has changed the way houses are built. Houses are tighter, and there are many more pollutants found inside, generated by the occupants and by the building materials themselves. As energy costs have risen, insulation has become a necessity. The advent of central heating systems with automatic controls has contributed to increased consumer demand for comfort in their homes, and heating systems have become more efficient. In addition to advances in building construction, consumer lifestyle changes have altered homeowners' expectations. People want houses that are larger and more complex, with more features than ever before. All of these things have an effect on each other, and on the operation of the house system.

It is becoming widely recognized that many of the failures and warranty callbacks in new houses are a result of mis-applying new technologies or materials—not because they were installed "wrong," but because nobody predicted the effect that a change in one area might have on some other part of the the house. Often, the complexities of a building make it difficult to find the source of a problem, even after it occurs. Consider the following example (a true story):

Building Failure Case Study

A homeowner calls in a building science specialist to help with a moisture problem during the heating season. The house has condensation and mold in the attic and living space. The specialist arrives at the property, and an interview of the client shows that this is an ongoing problem; in fact, it has gotten worse. The customer had previously consulted with several contractors and the local utility company, and was informed that the solution to the moisture in his attic was to add ventilation. When he asked how much ventilation to add, he was told, "You can't over-ventilate an attic." He was also warned that soffit vents would do him no good if they were blocked by insulation. So he installed extra soffit ventilation and pulled the insulation back from the eaves to allow free air flow. Since the hip roof did not have much ridge area, the homeowner installed two turbine vents to satisfy the need for upper ventilation.

On inspecting the house, the specialist finds the following:

- The roof sheathing is damp and spotted with mold.
- The roof has continuous soffit vents and two turbine vents.
- The fiberglass batts in the attic have been pulled away from the eaves approximately 18".
- There is black mold growing on the second floor ceilings in rectangular patterns around the house perimeter.
- The relative humidity in the living space is measured to be higher than normal for winter conditions.
- The bathroom exhaust fans are vented outdoors, but have a very low air flow rate and are rarely used.
- A blower door test confirms that the building is fairly tight, but there is still communication between the attic and the living space, by means of top plates and an open plumbing chase.
- The clothes dryer in the basement has a vent to outside, but the hose is disconnected.
- There is a piece of plywood in the basement loosely covering a sump, which leads to a small stream running underneath the building.

It is clear to the specialist what has happened. First, the turbine vents drew air not only through the soffit vents as intended, but also drew more air than ever from the house into the attic. With the high levels of humidity in the living space, combined with the fact that leaks into the attic had never been sealed, the turbines were moving moisture into the attic even more quickly than before. Second, in his effort to open up the soffit vents, the homeowner removed the insulation. This created a cold surface all around the perimeter of his upstairs ceiling for moisture to condense, and mold to grow on. No one thought to look in the basement when diagnosing the problem, but this is where the source of the moisture was lurking all the time.

The specialist wrote up a repair punch list as follows:

- Cover the sump in the basement with a gasketed cover to discourage the water from evaporating into the house.
- Re-connect the dryer hose.
- Seal leaks into the attic, to minimize the path for moisture to reach the attic.
- Replace the turbine vents with standard roof vents.
- Re-insulate the perimeter of the attic.
- Install baffles to allow free air movement through soffit vents and to direct the air over, rather than through, the insulation.
- Install a continuous running, low-level exhaust fan in one bathroom, to ensure the proper ventilation rate.

When the building was inspected the following year, the moisture was gone and the occupants were healthier and more comfortable.

Why did this building fail? The answer lies in the the fact that nobody evaluated how one aspect of the building's construction might affect another part of the building. Additionally, nobody evaluated the effects of occupant behavior on the performance of the building. When the foundation was built, it was noted that the underground water might cause flooding problems, so the decision was made to include a sump. When the framing, exterior shell, and interior finish were installed, each contractor took enough care that the building ended up with a relatively air-tight shell. But the builder did not realize that by doing these two things successfully, they had created a highway for moisture to pass through the interior wall cavities directly from basement to attic. Bathroom fans were installed and properly vented outside, but nobody predicted that the occupants wouldn't use them.

Why was the moisture problem mis-diagnosed? This is primarily because the contractors making the assessment took too narrow a view when evaluating the house. If a problem occurs in the attic, it is easy to assume that you will find the answer by looking in the attic. However, the house system is complex enough that this is often not the case.

The House as a System

When one component of the building fails, or is even out of tune, it can set off a chain reaction with unexpected results. To successfully avoid these kinds of failures, it is necessary to take a systems approach to the design and construction of buildings. Every trade may do its job properly, but if nobody is paying attention to the issues of moisture sources and ventilation, a house can end up with serious mold and mildew problems. Every aspect of a home may meet the required codes, but there can still be carbon monoxide spillage into the living space. The construction supervisor may do a fine job of managing all the subcontractors, but if no one considers the interactions of the individual parts of the building, or thinks about how the building will perform when occupied, all this hard work may be inadequate.

It is easy to look at the house as a collection of components: foundation, frame, mechanical services, drywall, trim, fixtures and finishes. But there is more to a building than this. Figure 2.1 shows a schematic of the house system with some of its interactions.

The first step to understanding the house system is to realize that the building structure itself, and the mechanical systems in it, interact with each other and with the people in the building. People turn thermostats up and down, they move switches and valves, they build walls, cut holes, and leave windows and doors open or closed. Both the building and the mechanical systems also interact with the immediate environment around the house: how cold or hot is it, which direction is the sun shining from, how much wind or rain. These environmental factors change the building directly, causing parts of it to get hot or cold, or to get wet, and to dry out; and they also affect how comfortable people are inside, causing them to act in different ways relative to the building.

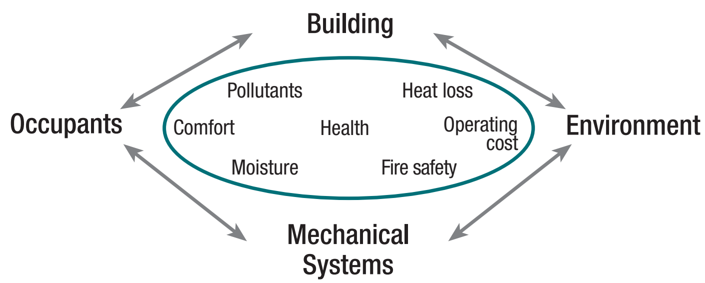
It is not necessary to make a study of every interaction that can happen in a building based on this concept. However, it is important for someone to take responsibility for the house as a whole system, and to think about common ways that the components in a house interact under everyday situations. It is imperative that house designers and general contractors learn the basics of the house as a system if they want to avoid these problems.

Fortunately, there has been much research in recent years and a growing body of field experience based on new construction, testing, weatherization and remediation work. Ice dams, indoor air quality problems, radon, nail pops in drywall, freezing pipes, combustion safety and backdrafting problems can all be reduced by understanding the basics of moisture and air movement. These effects can be understood on a level sufficient to avoid the most common problems, as long as one thinks past the individual parts and looks, instead, at the whole.

Going Further

This guide attempts to include details that are consistent with good building science as well as applicable codes. However, it is beyond the scope of this guide to address the subjects of moisture and air movement in much detail. Many of the sources listed in Appendix B contain excellent information on building science and house system interactions. The *Builder's Guide* has more detailed information on building failures, along with their causes and solutions.

FIGURE 2.1
The House as a System



Planning 3

This chapter gives designers, general contractors, and builders guidance on what energy-related issues are best resolved before breaking ground. In addition, guidelines for ensuring that the house complies with the energy code right from the beginning are provided. Whether the house is designed by an architect with help from engineers, by an owner, or by a design-builder, good planning pays off with systems that work well together.

Energy Code Requirements

The designer or builder of a new home is responsible for designing a home that will meet the energy code. To determine minimum insulation R-values, maximum window U-factors, and the efficiency of the heating system, choose and complete one of the compliance methods described on pages 5-6. Performing the compliance analysis early in the planning process has several benefits:

- The thermal performance of various components can affect the detailing; the R-value of walls and cathedral ceilings, for example, can have an impact on the thickness of those assemblies.
- It is much easier to make adjustments to the design based on energy code constraints before the design has been finalized.
- As the designer, it may be faster for you to calculate the square foot areas of the various components to show code compliance.

As you develop specifications for subcontracted work, specify the energy performance standard (where applicable) indicated by the Energy Code compliance analysis. It is also a good idea to build some "cushion" into the specifications (i.e., create a margin of safety in complying). That way, if the client decides to make a change that will impact the analysis (like adding a window during the construction process), the house is more likely to remain compliant.

Other energy code-related considerations are highlighted within the text of the remaining portion of this chapter.

The Thermal Enclosure

The thermal envelope is the collection of insulated and sealed floors, walls, and ceilings in the building that separate conditioned spaces from both unconditioned spaces and the outside (see Figures 3.1 and 3.2). A well-detailed envelope is one of the most critical aspects of a high performance home, affecting not only its energy efficiency, but also its durability and occupant comfort. Unfortunately, decisions relating to the placement and detailing of the thermal envelope are often made on the fly.

Frequently (and regrettably) the concept of a thermal envelope is not even considered as part of the design and construction of a home; insulation is installed where the insulation subcontractor thinks it should be installed and there is little, if any, conscious effort devoted to air sealing.

A thermal envelope should be integrated with the design of all homes.

Deliberate decisions about its placement and the materials that will be used to create the envelope are an important part of this process. There are two primary components to the thermal envelope: (1) the thermal boundary (insulation) and (2) the pressure boundary (air barrier). Provisions should be made to ensure that these two components are aligned with one another and installed continuously around the entire volume of conditioned space. In a set of drawings, one or more sections can be used to effectively convey this information.

Unfortunately, there is sometimes a disconnect between what is laid out in a set of plans and what is actually constructed in the field. For the thermal envelope, this disconnect can be remedied by complementing plans/specifications with the following practices:

- Make sure the general contractor and all subcontractors understand the design associated with the thermal envelope, and the importance of seeing the design through to completion.
- Facilitate implementation by having the necessary materials on site before they are required. Air barrier material and insulation, for example, may be required before a shower-tub assembly is installed (see Figure 12.8).
- Require all subcontractors to seal any penetrations they make through the thermal envelope. Provide them with the materials they may need, or alternatively:
- Assign someone (typically on the builder's crew) the responsibility of making sure that the integrity of thermal envelope is maintained through every stage in construction.
- Perform a final air sealing check before insulation is installed.

Design Elements

The following is a rough outline of the construction process, paralleling the sequence of upcoming chapters. In each section, considerations that are unique to the planning phase are addressed. Some of the considerations relate to energy code compliance.

Foundation

The treatment of a foundation wall depends on whether or not it encloses a conditioned space.

- If the foundation encloses a conditioned space, the foundation walls must be insulated. There is a right way (see Figures 4.4-4.6, 4.11) and a wrong way (see Figure 4.3) to insulate foundation walls; this portion of the home should be designed accordingly.
- If the foundation does not enclose a conditioned space, the insulation must run across the floor above the basement or crawlspace instead (see Figure 4.7).

There is a growing consensus among many in the energy efficient building industry that it is preferable to condition basements and crawlspaces. Planning for a conditioned basement or crawlspace offers the following advantages:

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Planning

- It is easier to install continuous, uninterrupted air and insulation barriers along foundation walls than it is to install them as part of the floor assembly (which is obstructed by framing, pipes, wires, ducts, etc.)
- The foundation wall is often the better air barrier to begin with.
- It is easier to control the temperature, humidity, and comfort levels in a space that is enclosed by insulation and an air barrier.
- Mechanical and distribution systems are often installed in the basement or crawlspace, and they perform better in conditioned spaces.
- Many homeowners will eventually finish and use the basement space. If they install insulation poorly or are not informed about potential moisture issues, they are much more likely to create moisture and mold problems for themselves later on.

On the other hand, a conditioned basement or crawlspace may:

- Cost more to build. Even without factoring in slab insulation, the area of foundation walls is often greater than the area of the floor they enclose. Insulation that is exposed to the living space also needs to be protected from fire (by installing a code-approved barrier such as 1⁄2" gypsum board).
- Create a hidden pathway for insect entry (see page 35) and require protection of above-grade surfaces (if the insulation is installed on the exterior surface of the foundation, see Figures 4.6 and 4.10).
- Increase the need to focus on moisture control. It is especially important to build elements of moisture control into the design of a building that will include a conditioned basement (see pages 29 & 30 and Figures 4.1-4.2).

Framing

In enclosed building cavities (e.g., walls and cathedral ceilings), the amount of insulation that can be added is limited by the framing depth. If the framing depth is not sufficient to accommodate the minimum amount of insulation required by energy code, the following options should be considered:

- Specify an insulation product that has a higher R-value per inch (see Table 3.3). High density fiberglass batts, for example, can be used to increase R-values where space is limited; they are also much easier to work with and install correctly. Some rigid board and spray foams can provide R-values as high as 6 per inch!
- Plan for a continuous layer of (rigid foam) insulation that is applied over the framing. Using continuous insulation is the best way to improve the effective R-value of an insulated assembly (see Figure 12.2). A 2x4 wall with 2" of rigid insulation, for example, will outperform a 2x6 wall with cavity insulation without affecting the depth of window and door openings.
- Use deeper framing. This is usually the least cost-effective option.
- Use a different compliance method and/or compensate for R-value limitation by improving performance in other areas (e.g. higher heating system efficiency, lower window U-factor, etc.)

Energy savings associated with framing can also be achieved by using details that (1) require less wood and leave more room for insulation (see page 43 and Figures 5.9-5.10), and (2) include provisions for air sealing (see Figures 5.1, 5.2, 5.8 and 5.11-5.17).

Windows

Window type, quantity, orientation, and shading all play a significant role in determining the energy use of a home. Energy use can be minimized by orienting a home in such a way that most of the windows face south.

South-facing windows capture heat from the winter sun but do not contribute as significantly (and undesirably) to heat gain in the summer when the sun is much higher in the sky. By contrast, east- and west-facing windows account for more heat gain in the summer than winter. It is preferable, therefore, to orient the long axis of a building east-west if possible.

On the south side of the home, overhangs can be provided to allow for solar gain in the winter and to provide shade in the summer. On the east and west sides of the home, mature trees can provide shade. Regardless of orientation, high performance windows with low U-factors should be specified (see page 55 and Figure 6.1). In Rhode Island, the need for heating and air conditioning can be reduced significantly by making smart choices with respect to window type, orientation, and shading.

Despite recent advances in window technologies, windows should still be viewed as weak spots in the thermal envelope (i.e., they allow for rapid transmission of heat from one side of the wall to the other). Compliance with energy code is quite sensitive to the size and number of windows in a house. The more window area, the more difficult it will be to demonstrate compliance. This often results in having to push the efficiency of other building components (insulation R-values) to higher levels.

Mechanical Systems

Placement is one of the most important considerations with respect to designing a mechanical system. A designer usually has little control of the quality of mechanical installations, but they can influence their placement.

Heating and cooling equipment, including the distribution system (ductwork or hot water pipes), should be located within the thermal envelope.

Duct leaks that occur outside the thermal envelope can cause thermal, comfort, moisture, and backdrafting problems. Resist the temptation to use the wide open space of an unconditioned attic to "house" mechanical and distribution systems. Interior 2x6 walls, soffits, and floor trusses can all be used to facilitate the installation of mechanical systems within conditioned spaces. Consider planning for the space requirements for the mechanical systems and specifying them on the plans.

Heating and cooling systems tend to be substantially oversized, even in conventionally built houses. If the HVAC installer uses the same rules of thumb to size equipment for an efficient house, they will be even more oversized. Oversized equipment may cost more to install and may also lead to comfort problems. You can save money on a project by sizing the heating and cooling systems properly (both equipment and distribution systems), and this savings can help pay for the upgrades to the building shell.

To promote efficiency and to eliminate the risk for backdrafting, sealed combustion heating systems and hot water heaters should be specified (see page 64). There are additional cost savings if a chimney can be eliminated as a result. Note that combustion flue gas venting options vary according to fuel type. (See Table 3.1 on page 24.)

A distribution system must also be determined during the planning phase. Again, there are numerous options and related considerations. (See Table 3.2 on page 25.)

Ventilation

Nearly all new homes include some form of mechanical ventilation. A system that is intended to promote good indoor air quality, however, is rarely part of the design. An energy efficient home is an airtight home; an airtight home needs adequate, controlled ventilation. This line of thought is often expressed as "Build tight; ventilate right" (see pages 70-71).

Ventilating "right" may lead you to adopt different strategies in different homes. Use the answers to the following questions to help you decide what will work best for the project you are working on:

- How big is the house? Large houses, especially those with high ceilings, have a greater volume of air to dilute pollutants. Small houses, especially those with several bedrooms, often require the most aggressive ventilation strategies.
- How many people will live in the house? More people will require more fresh air.
- What is the layout of the house? Relatively open, compact houses can be ventilated more effectively from a single point. Sprawling houses and two-story homes benefit more from distributed ventilation.
- How important is fresh air to the owners? Everyone needs fresh air, but some people value it more highly than others. If the owners need or expect very good indoor air quality, you should obviously plan for a system that will provide the desired result.

Plumbing and Electrical

Pipes and wires that run through the thermal enclosure create leakage pathways and insulation voids that compromise thermal performance. Just as with mechanical systems, plumbing and electrical components should be installed within conditioned space, and associated penetrations through the thermal envelope should be minimized and sealed. Consider planning for the space requirements of these building elements and specifying them on the plans. Additional energy (and water) savings can be achieved by laying out the plumbing components in a sensible manner (e.g., installing a hot water tank in close proximity to the kitchen/bathrooms). See Chapter 9 for an overview of related recommendations.

Air Sealing

Air sealing is one of the most important aspects of energy efficient construction. Homes that are not consciously air sealed at key stages during construction rarely perform well. Adopt a proactive approach to air sealing. Important guidelines for adopting such an approach are outlined in the "Thermal Envelope" section of this chapter (see page 16). In general, simple shapes are the easiest to seal. Many new homes are expansive and have designs that feature complex geometries. In these homes, pay extra attention to identifying and treating attic bypasses, framing transitions, and other potentially significant sources of air leakage (see Chapter 11). Also consider locating the building envelope where there is the greatest likelihood of achieving a continuously air sealed barrier (e.g., the roof instead of the ceiling; see Figures 5.15-5.17).

Insulation

Specify insulation products that are easy to install correctly, and that are appropriate for the unique characteristics of the assembly to be insulated (see Table 3.3). Rigid or spray foam, for example, are better choices for insulating foundation walls than fiberglass or cellulose (see Figures 4.3-4.6). Spray foams may be more appropriate for complex cathedral ceilings. Loose fill or blown-in insulation is more appropriate in flat attics. Some types of insulation, such as densepacked or damp-spray cellulose, or spray foams, fill cavities completely, help to reduce air leakage, and add more R-value in the same sized framing cavity. Rigid foam applied to the exterior walls or ceiling not only adds R-value, but also reduces the thermal "bridge" of the framing, can form a good air barrier if the seams are sealed, and provides condensation resistance. Think about specifying some of these materials to improve the performance of the building.

Plan for Success

Good planning is important for good buildings, but good planning does not guarantee good buildings. Many building plans are drawn with exemplary construction details, and those details are ignored, botched, replaced, or omitted by "value engineering," before or during the construction process. Subcontractors often complete their jobs without consulting plans and without giving any consideration to how their work might affect other subcontractors. Similarly, general contractors who are not committed to the "house as a system" approach to building may not see the project through in a seamless, integrated fashion. No matter how it is defined, success will be unlikely in these cases.

Careful planning must be complemented by effective communication, teamwork, and verification. The designers on the front end of a project (architects, engineers) must work with the builder and subcontractors at the back end, and vice versa. A home energy rater or other energy consultant, acting as an independent third party, can also help to verify home performance (by performing visual inspections and testing) and can offer guidance from the design phase through to project completion.

3
Planning

Table 3.1 Heating fuel characteristics

Fuel Type	Venting Options	Other Considerations
Home Heating Oil	• Best vented through a chimney • Direct vent available, but requires careful design and installation • Combustion air kits available for some equipment	• Expensive fuel; high heat content • Low-output equipment not as common; hard to find right-sized equipment for low-energy homes • Fuel must be kept warm • Flue gases should not be allowed to condense in heat exchanger or vent • Equipment must be cleaned periodically
Liquid Propane	• Can be chimney or direct vented • Sealed combustion appliances common	• Usually the most expensive fuel; lower heat content per gallon than oil • Modulating burners can vary heat output • Higher efficiencies and reduced maintenance (most natural gas equipment is available in an LP version) • Suitable for small, tight, energy efficient buildings
Natural Gas	• Can be chimney or direct vented • Sealed combustion appliances common	• Wide range of equipment available; suitable for most homes. • Modulating burners can vary heat output
Wood/Biomass	• Best vented through a chimney • Direct vent available in electric pellet stoves • Combustion air kits available for some new stoves	• Cord wood less expensive than oil; pellets cost about the same as oil • Relatively low efficiency • Relatively high particulate output. Can also produce significant pollutant.

Table 3.2 Distribution system options

Distribution Type	Considerations
Ducts (forced air)	• Usually the least expensive option, but the most prone to installation defects (poor sealing and/or insulation) which can dramatically reduce system efficiency • Most commonly paired with a furnace and/or air conditioning system. Boiler can also be used as heat source by installing hydro-air handler • Long duct runs and/or poorly installed (undersized, improperly balanced) ducts can seriously reduce heat delivery and occupant comfort levels • Ducts can be used to facilitate distribution of fresh air (by integrating a mechanical ventilation system) • Air handler can account for significant amount of electrical energy use; choose ECM motor to save electricity (see page 90)
Hot water baseboard	• Can only be paired with boiler or hot water heater • Must be sized according to the heat/cool loads, water temperature, and rated output. • Easier to divide distribution system into several zones
Hot water radiator	• Same consideration as for hot water baseboard above • Saves space compared to baseboards or ducts
Radiant floor	• Most expensive distribution system, but typically associated with highest comfort levels • Should be paired with condensing boiler for maximum efficiency • Radiant tubes can be embedded in concrete slabs (including thin, lightweight concrete slabs that can be applied to framed, wood floors) or can be secured to the floor from below. • Typically a poor match for a passive-solar heated slab floor; may not be a good investment in a very energy-efficient home
No distribution (space heater or ductless heat pumps)	• Can adequately heat small, energy efficient homes that have a relatively open floor plan.

Table 3.3 Insulation Properties[1]

Form	Method of Installation	Where Applicable	Advantages	Notes
Product(s) — (R-value per inch)[2]				
Blankets: Batts or Rolls **Fiberglass** — (3.1-3.7, depending on density) **Rock Wool** — (3.3-4.2, depending on density)	Fitted between studs, joists and rafters	All wall, floor, and ceiling cavities prior to hanging drywall	Inexpensive and readily available	• Only suited for standard stud and joist cavities that are relatively free from obstructions. • Prone to installation defects which can dramatically reduce effectiveness of insulation (see Figure 13.2). • High-density fiberglass batts (e.g., R-21 batts for 2x6 walls) provide a higher R-value per inch and are easier to install properly (see page 126). • Must be protected from "wind washing" (see page 126).
Loose-fill (blown-in) **Rock Wool** — (3.0) **Fiberglass** — (2.0-4.2, depending on density and product) Cellulose — (3.5 - 3.7, depending on density)	Blown into place using specialized equipment (hopper, blower and hoses)	Enclosed building cavities and unfinished (open) flat attics	Fills gaps and voids typically found in irregularly shaped spaces and around obstructions. "Dense pack" fibrous insulation can help to reduce, but not completely stop, air movement	• To avoid settling, insulation should be installed according to manufacturer's instructions. • R-value depends on density (number of bags per square foot), not thickness. • Dense pack cellulose has a slightly reduced R-value per inch. • Must be protected from "wind washing" (see page 126).

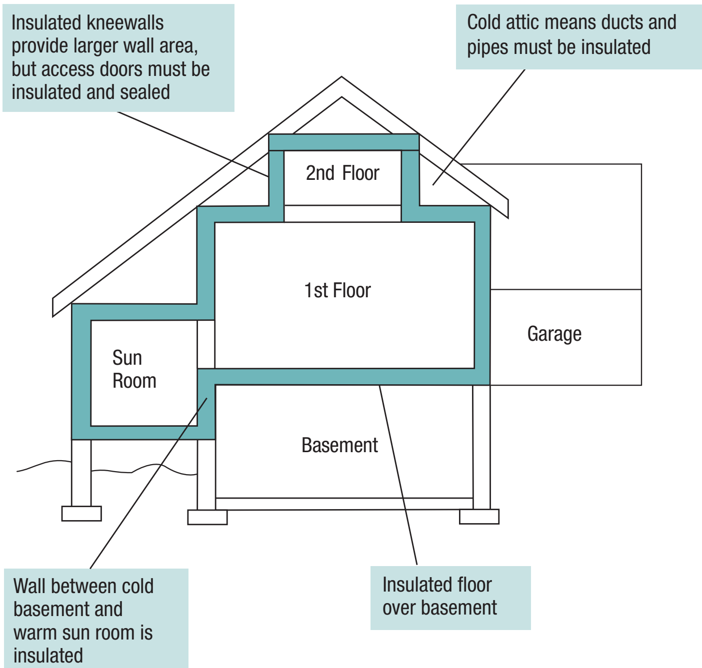
Table 3.3 Insulation Properties[1]

Form	Method of Installation	Where Applicable	Advantages	Notes
Product(s) — (R-value per inch)[2]				
Spray Applied **Cellulose** — "damp" - (3.5)	Same as above. A fine mist of water is applied simultaneously to make cellulose "stick"	Open wall cavities prior to drywall	Same as above	• Cost effective alternative to fiberglass batts. • Requires some drying time before interior wall sheathing is installed.
Spray Applied **Polyurethane Foam** — (3.4 - 6.0, depending on density)	Chemical components stored in separate containers; mixed in nozzle at end of hoses	All wall, floor, and ceiling cavities prior to hanging drywall	Can provide excellent fit and air barrier performance	• Vapor permeance and price vary according to density and foam cell structure. High density, closed-cell foam has a perm rating of less than 1 perm-inch and is more expensive; low density, open cell foam has a permeance rating of about 10-15 (at 5" thick) and needs an added vapor retarder in many situations. • Significant waste can be generated when excess foam is "shaved."
Rigid Insulation - Foam **Extruded polystyrene** (XPS) — (5.0) **Expanded polystyrene** (EPS or bead board) — (4.0) **Polyisocyanurate**— (6.0)	Installed as insulating sheathing. Sometimes cut to fit into building cavities and used as wind blocking. Some rigid insulation can also be applied directly to concrete (interior or exterior, see Figures 5.4 -5.10)	Slab floors, foundation walls, above grade walls, ceilings, and roofs	High R-value per inch. Significantly improves thermal performance when used as continuous, uninterrupted layer of insulation	• For fire safety, interior applications typically must be covered with 1/2-inch gypsum board or other building code-approved material • Exterior applications must be covered if exposed to sunlight. EPS and Polyisocyanurate should not be used in ground-contact or wet applicaitons.

1 Table adapted from Department of Energy, DOE/CE-0180/with Addendum 1, October 2002

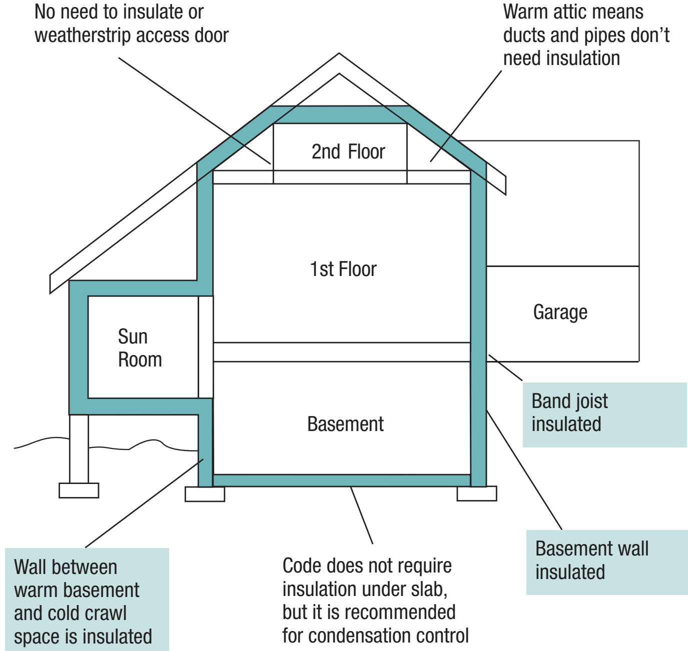
2 Conservative estimates provided for use in absence of better documentation. In order to achieve listed R-values, insulation must be installed (1) according to manufacturer's instructions and (2) without any voids, gaps, or compression. Common installation practices vary by product and installation defects can significantly reduce the effective R-value.

FIGURE 3.1
Typical cape with unconditioned basement



This is a schematic of a cape style house with an unconditioned basement and unheated kneewall areas.

FIGURE 3.2
Cape with conditioned basement and insulated rafters



This schematic shows the same cape style house with a heated basement and kneewall areas. Note that the two choices are independent of each other, it is possible to have heated kneewall attics with an unheated basement, or the reverse.

Foundation 4

Foundation Moisture

Aside from structural concerns, the most important consideration for foundation design is moisture. No client wants a wet basement. No client wants a damp basement. No client wants mold in their basement. If a dry basement is your objective, the first priority should be protecting it from bulk water by directing water down and away from the entire house at every possible point of entry (see Figure 4.1). Top-down foundation drainage should be complemented by the following (see Figure 4.2):

- A continuous capillary break that separates the basement slab and foundation walls from the ground.
- A continuous air and insulation barrier (to reduce the risk for condensation). Insulation used to the interior of a foundation wall must be airtight, relatively vapor impermeable, and able to withstand exposure to moisture or damp conditions. Fibrous insulation should not be used to insulate the interior of foundation walls unless it is installed to the interior of air-impermeable rigid or spray-foam insulation. While it may be possible to retrofit insulation later, the least-cost and lowest risk opportunity is when the foundation is constructed.
- The IRC does not require a vapor retarder to the interior side of foundation walls or below-grade walls. In fact, significant vapor retarders

should be avoided at the interior side of insulated foundation wall assemblies.

- Particularly moisture-sensitive materials should never be used in basement assemblies. Only non-paper-faced gypsum should be used where gypsum wall board is used in a basement or crawlspace.

Energy Code Requirements

All basement spaces must be defined as "conditioned" or "unconditioned." See pages 28 and 29 and Figures 3.1-3.2.

Conditioned Basements

In a conditioned basement, you must:

- Insulate the foundation walls on the inside or the outside of the wall. The required R-value depends on the results of your compliance analysis or prescriptive requirements if that is the option chosen for compliance.
- Insulation must extend from the top of the wall to the basement floor (SBC-8, Section R402.2.8).
- Insulate the band joist of the floor framing above the basement.
- Seal air leaks in the foundation walls and slab floor, as well as the sill / band joist area.
- If the foundation is insulated with rigid foam on the exterior, the insulation must be protected with a rigid, opaque and weather-resistant barrier that extends at least 6" below grade (SBC-8, Section 303.2.1).

Important note: When you are doing compliance analysis on a conditioned basement, you must look at each basement wall separately and determine, wall by wall, whether the wall is more than 50% above grade or more than 50% below grade. Walls that are 50% or more above grade, must be added in with above grade walls in your calculations, and insulated to the same R-value. Walls that are more than 50% below grade are treated as "basement walls."

Unconditioned Basements

In an unconditioned basement, you must:

- Seal air leaks in the floor system between the basement and the first floor, such as wiring and plumbing penetrations, and weatherstripping on the basement door. Include the basement door in your calculations.
- Insulate the floor above the basement. The required R-value depends on the results of your compliance analysis.
- Insulate the stairwell between the basement and conditioned first floor.

Slab-on-grade

Slab perimeter (edge) insulation must be installed where the slab is part of the conditioned space of the house and is within 12" of grade (see Figure 4.8). This includes a slab-on-grade house or addition, the walk-out portion of a heated basement, or conditioned space that shares a slab with an unconditioned breezeway or garage.

The R-value to use depends on the results of your compliance analysis. If the slab edge insulation is on the exterior, the insulation must be protected with a rigid, opaque and weather-resistant barrier that extends at least 6" below grade (SBC-8, Section R303.2.1).

Slab perimeter insulation must run all the way to the top of the slab. It may extend straight down horizontally, or down and across, as long as it extends a total of 24". See Figures 4.9-4.10 for examples.

Crawlspace

Building science has shown that ventilating crawlspaces often does more harm than good, and codes are starting to catch up with the more sensible approach of building a tight crawlspace with good drainage and vapor control. In fact, national energy codes are beginning to include exceptions that allow for unvented crawlspaces that are either mechanically exhaust- vented to the exterior, or directly conditioned (IRC 2012, Section R408.3).

Ideally, a crawlspace should be constructed like a short basement, including:

- Adequate footing drainage
- Thorough, durable and continuous vapor barrier
- A continuous air and insulation barrier

If the crawlspace has a dirt, gravel or otherwise exposed earth floor, it should be covered with a vapor barrier at least 6 mil thick, and all seams should be overlapped by 6" and sealed with a good quality tape (e.g., 3M contractor's tape or Tyvek tape) [SBC-8, Section R402.2.10]) or compatible sealant. It should be mechanically fastened to the exterior walls, and all penetrations (including piers) should be sealed. If a concrete slab is installed, rigid foam can be used in place of polyethylene.

An unvented crawlspace should be detailed like a conditioned basement and the walls must be insulated according to the R-value shown in the compliance analysis for "crawlspace walls." As with any basement, it's important to keep inside air away from the foundation wall to prevent condensation (Figure 4.11).

The thermal envelope must follow the floor of the house if the crawlspace is ventilated. Treat the floor over a vented crawlspace as you would a floor over an unconditioned basement: air seal and insulate to the level indicated by the compliance analysis or in the case where the Prescriptive compliance path is chosen, according to SBC-8, Table 402.1.1.

Other Recommendations

- Install at least 4" of uniform sized, washed stone underneath the slab floor. This acts as a capillary break to help prevent absorption of ground moisture. It also makes it easy to add a sub-slab ventilation system for radon mitigation, if radon is found after construction (see page 107).
- Insulate basement slabs, even in unheated basements. Rigid polystyrene foam under the slab will keep it warmer in summer and reduce the chance of condensation which can wet the slab and lead to mold and mildew. This will also improve comfort and reduce moisture problems if the basement is finished off later.
- Do not install carpeting on below-grade slab floors unless the slab is insulated under its entire area, and the foundation is well drained. Moisture from condensation on an uninsulated slab, or drawn up by capillary action can lead to hidden mold and mildew problems in carpets.
- Always insulate under the entire surface of radiant heated slabs, even though the code does not require it. Most radiant equipment manufacturers specify insulation under the slab; if you are heating the slab, the insulation will reduce heat loss and improve comfort. Because of the high temperature of radiant heated slabs, a minimum of R-15 rigid insulation is suggested even though manufacturers may recommend less. For slab on grade homes, code requires R-15 at slab edge and R-5 under entire slab (SBC-8, Table R402.1.1)

Conditioned or Unconditioned?

The choice of whether to insulate the basement is yours, unless you have an intentional heat supply. There are several reasons for and against constructing a conditioned basement space:

- People often want to use basements. Even if they are not finished space, people often use basements for laundry, projects, storage or other uses. They really don't want the basement to be a very cold space in winter. If they do finish off the space later, it will be easier if the basement is already insulated.
- It's easier to air seal the foundation walls. Floors and the enclosures around basement access stairs are usually far leakier than foundation walls, and are also harder to seal.
- In some cases, pipe insulation may be eliminated in conditioned spaces There's no need to insulate HVAC ducts or pipes in a conditioned basement, which can save money.
- Warm basements are less likely to have condensation and related mold and mildew problems than cold basements.
- Insulating foundation walls has potential pitfalls. Exterior insulation may provide pathways for insects, must be protected, and tied in somehow with the wall above. Interior insulation cools foundation walls, and if drainage and insulation details are not implemented properly there is substantial risk of condensation and mold growth.
- Insulating walls often costs more than insulating the floor over a basement.

Going Further

Other issues to think carefully about when planning foundation details include:

- Concrete movement and cracking can result in callbacks, air leaks and water entry in foundations. The *Builder's Guide* includes a discussion of

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Foundation

concrete movement and control joints—which can reduce or eliminate these problems—as well as other foundation issues.

- Moisture, drainage and capillary breaks—Foundations are built in the ground. Depending on where you build, the ground is either sometimes wet or always wet. All foundations should be built with good drainage and moisture protection.
- Insect entry—Termites and carpenter ants can tunnel through rigid foam insulation. If the foam insulation is between the ground and the wood frame of the house, they can use it as a way to get to the wood without being seen. For this reason some model codes have prohibited the use of foam insulation above grade in termite-prone areas.

While the Northeastern and mid-Atlantic states are not generally considered to be termite-prone, termite protection still warrants consideration. Termites don't eat foam board, but they will eat wood, causing structural damage. Carpenter ants don't eat either one, but they will nest in both and over long periods can cause structural damage.

There may be ways to effectively block insect entry from foam board to adjoining wood framing (or above grade foam sheathing); however, the details for such a system must be implemented very carefully. The energy code (and common sense) requires insulation in heated basements to the top of the foundation wall; after all, most heat loss occurs where the foundation wall is exposed above grade. You can't cut exterior foam board off at grade and still have effective insulation, so it may be better to insulate conditioned basements on the inside of foundation walls than to attempt an insect barrier between exterior foam and the wood framing.

- Alternative foundation systems—such as insulated concrete forms (ICFs) or precast concrete walls can speed up the construction process (especially in the winter) and provide a pre-insulated, airtight assembly. They can be very cost-effective, when compared to a poured concrete wall with a built-up insulated stud wall.

FIGURE 4.1
Top-down foundation drainage

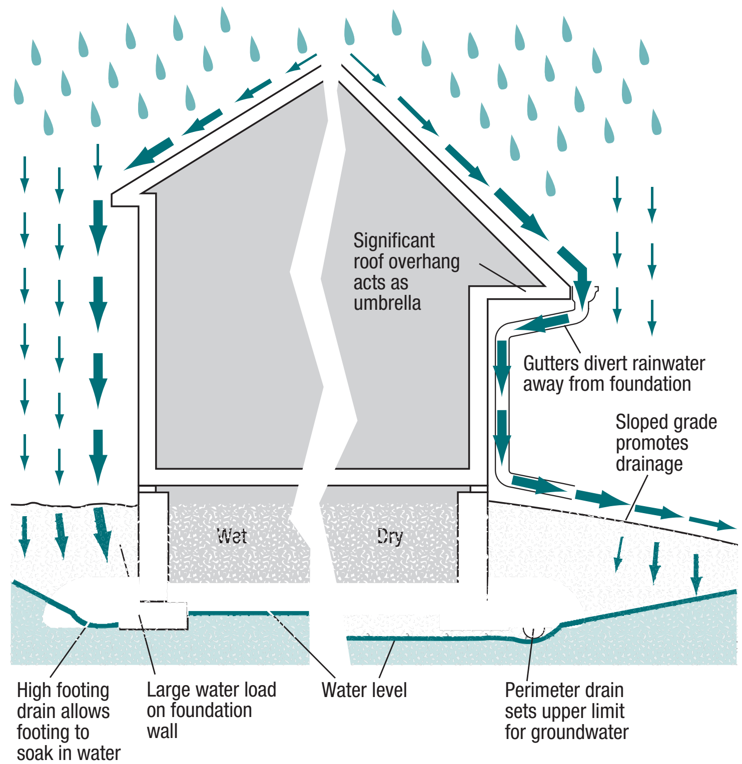
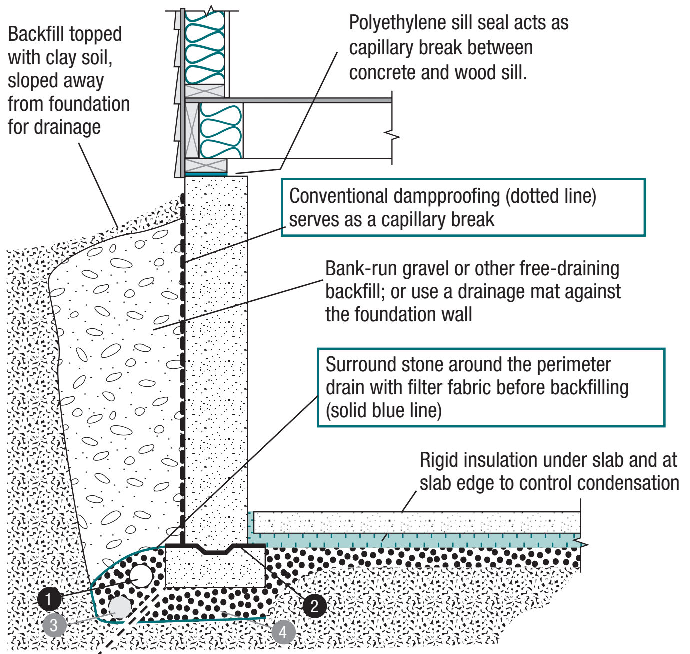


FIGURE 4.2

Foundation moisture control



1. Perforated drain pipe at footing level, drains downhill to daylight or to sump pit inside basement
2. Dampproofing or cement-based waterproofing applied to top of footing as capillary break between footing and wall (dark line)

Alternate Strategy—#3 and 4—more effective, where allowed by local codes.
Note: the footing drain can only be installed below the footing level if the footing is completely supported by uniform sized washed stone, which is noncompressible.
When in doubt about the bearing capacity of the underlying soil, consult a soils engineer.

3. Drain pipe installed below footing level (and beyond load bearing range of stone, as indicated by dotted line) to carry water away from footing
4. 4-6" washed, uniform sized stone (1/2" – 1 1/2") under footing provides capillary break and drainage.

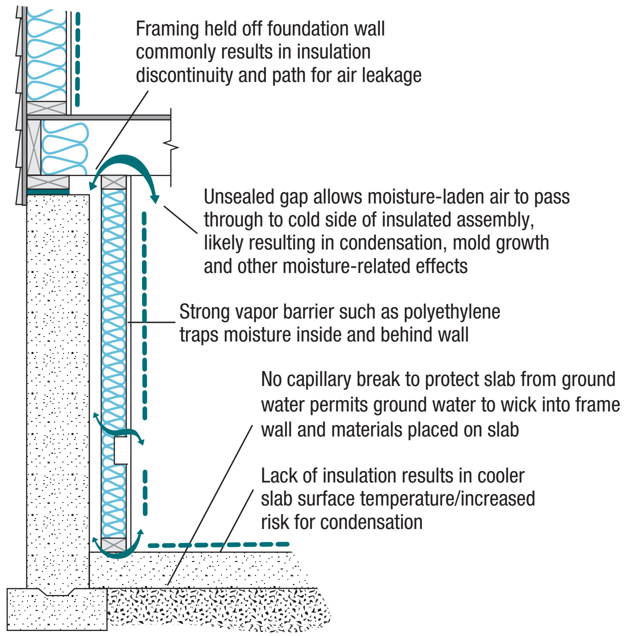
CAUTION:

The stone surrounding the perimeter drain, under the slab and/or under footing must be uniform in size and washed (with no fine grains), to prevent settling or undermining.

TIP: One inch of rigid foam insulation under the slab will reduce the potential for condensation in the summer. Even if the foundation walls do not enclose conditioned space, condensation on the slab can contribute to moisture problems in the home.

FIGURE 4.3

Foundation insulation pitfalls

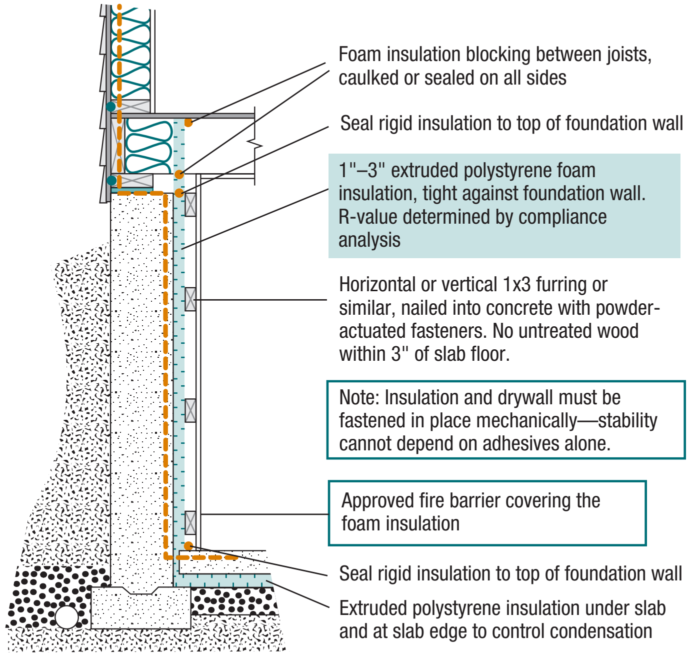


CAUTION:

While this option is allowed by code, it is not recommended because even with careful detailing, a cavity-insulated frame wall is more prone to failure than the other options shown. All or most of the insulation should be continuous and sealed directly to the foundation (see Figures 4.4-4.6).

FIGURE 4.4

Conditioned basement with interior rigid foam



CAUTION:

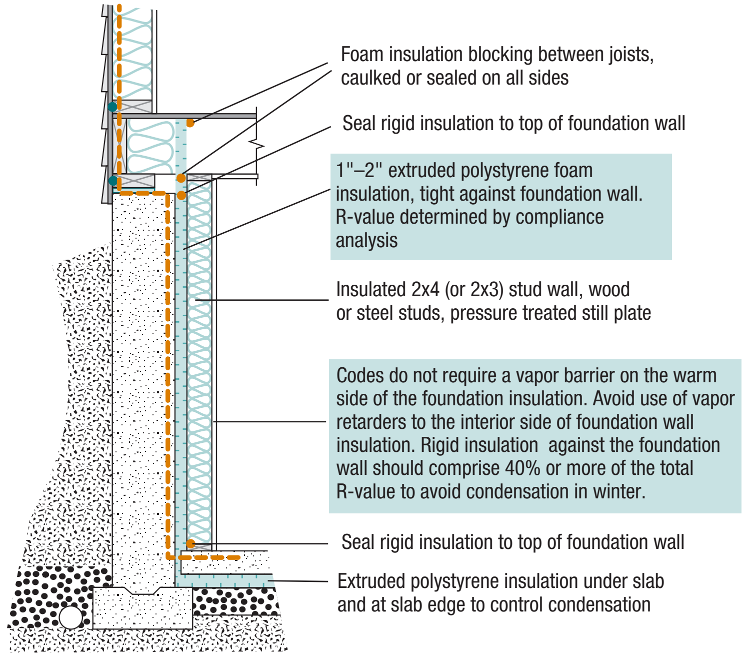
All vertical and horizontal joints in the insulation as well as the perimeter of the insulation must be carefully sealed to prevent humid air from reaching the cool foundation wall, where it can condense.

TIP: Glass-faced gypsum board or cement “tile-backer” board is much less vulnerable to moisture than paper-faced drywall. It can be finished with veneer (skim-coat) plaster. Use vinyl or fiber-cement components for baseboard trim.

Foundation drainage and capillary break details not shown for clarity—refer to Figure 4.2.

FIGURE 4.5

Conditioned basement with interior stud wall



CAUTION:

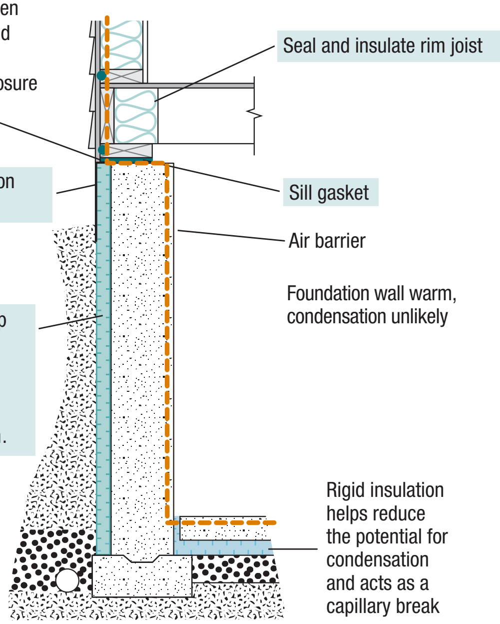
All vertical and horizontal joints in the rigid insulation as well as the perimeter of the insulation must be carefully sealed to prevent humid air from reaching the cool foundation wall, where it can condense.

TIP: Glass-faced gypsum board or cement “tile-backer” board is much less vulnerable to moisture than paper-faced drywall. It can be finished with veneer (skim-coat) plaster. Use vinyl or fiber-cement components for baseboard trim.

Foundation drainage and capillary break details not shown for clarity—refer to Figure 4.2.

FIGURE 4.6

Basement with exterior rigid foam



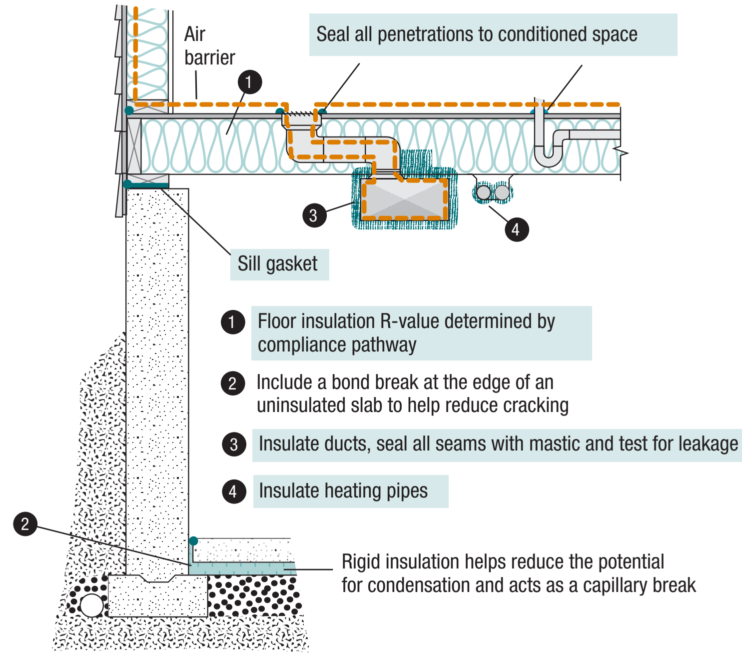
CAUTION:

Exterior foam insulation may provide a pathway for termites and carpenter ants to reach framing. See page 39.

Foundation drainage and capillary break details not shown for clarity—refer to Figure 4.2.

FIGURE 4.7

Unconditioned basement



TIP: One inch of rigid foam insulation under the slab helps to reduce the potential for condensation in the summer. Even if the foundation walls do not enclose conditioned space, condensation on the slab can contribute to moisture problems in the home.

If conditioned space is adjacent to an unconditioned space (e.g., in a partially finished basement), then the wall between these two spaces must be insulated according to results of the compliance analysis.

Foundation drainage and capillary break details not shown for clarity—refer to Figure 4.2.

FIGURE 4.8

Slab edge insulation, walkout basement

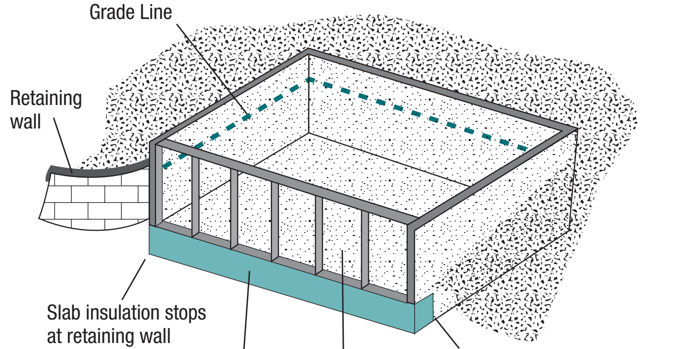
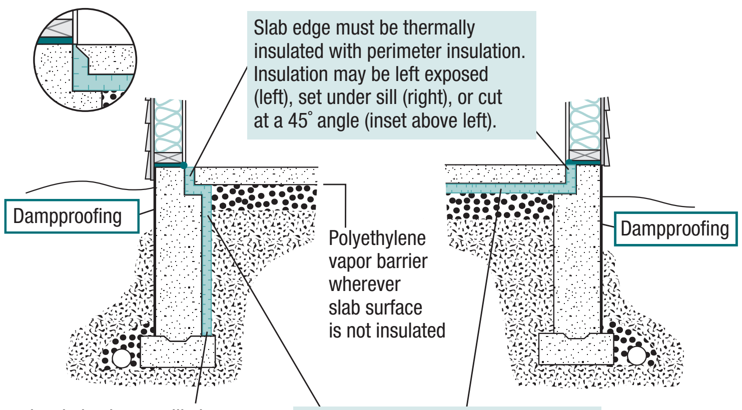


FIGURE 4.9

Slab on grade with interior insulation

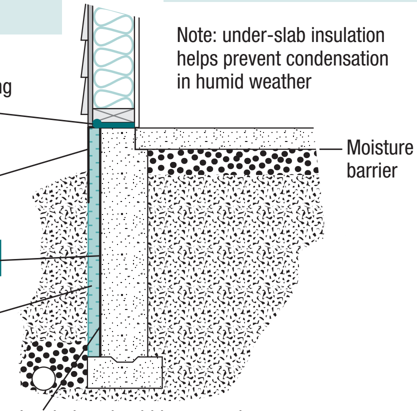


Most of the foundation moisture control strategies shown in Figure 4.2 apply to slab on grade construction as well. Drainage details not shown for clarity.

Note: under-slab insulation helps prevent condensation in humid weather.

FIGURE 4.10

Slab on grade with exterior insulation

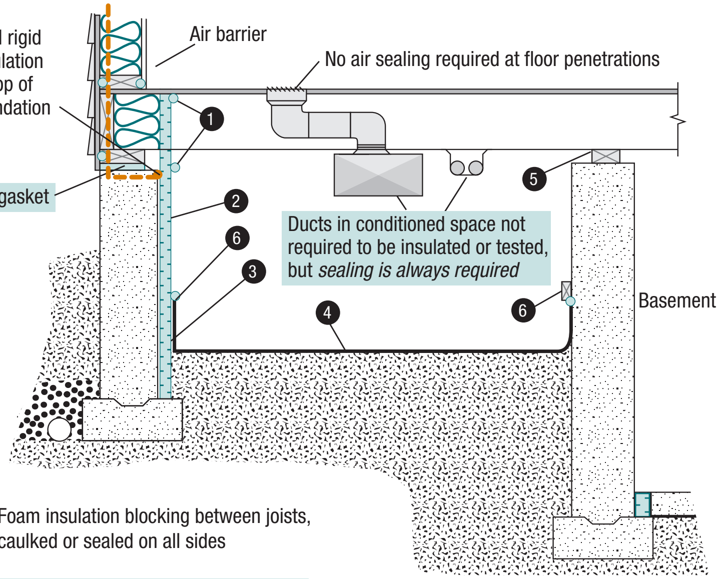


CAUTION: Exterior foam insulation may provide a pathway for termites and carpenter ants to reach framing.

Most of the foundation moisture control strategies shown in Figure 4.2 apply to slab on grade construction as well. Drainage details not shown for clarity.

FIGURE 4.11

Conditioned, unvented crawl space with interior insulation



1. Foam insulation blocking between joists, caulked or sealed on all sides
2. Insulation should be in substantial contact with wall, with all seams sealed. The insulation should be sealed to the top of the foundation wall.
3. If the crawlspace floor is 12" or more below the outside grade, the insulation should extend at least to the crawlspace floor. If the crawlspace floor is less than 12" below outside grade, the insulation should extend to the top of the footing.
4. A minimum 4-mil thick polyethylene vapor retarder is required by most codes. It is highly recommended to install 6-mil or laminated poly, lapped 6" and taped at all seams, and mechanically fastened and sealed to all walls, piers, columns, and service penetrations. Note: Rigid insulation beneath the vapor retarder can help prevent condensation in humid weather
5. No air sealing or insulation needed next to conditioned spaces
6. Extend vapor retarder 6" up walls and columns, and attach with nailer and adhesive

CAUTION: All vertical and horizontal joints in the insulation as well as the perimeter of the insulation must be carefully sealed to prevent humid air from reaching the cool foundation wall, where it can condense.

Foundation drainage and capillary break details not shown for clarity—refer to Figure 4.2.

Framing 5

Energy Code Requirements

- R-values of insulation—The R-values determined from your compliance analysis can affect the dimensions of framing lumber you use. For example, an R-20 wall would often be built with 2x6 wall studs. However, SBC-8 allows a 2 x 4 wall with R-13 in the cavity, plus R-5 continuous in lieu of a 2 x 6 wall with R-20.
- Air sealing details—Most air sealing details can be carried out at any point up until the insulation and drywall are installed. However, many are much easier to implement during framing. Some of these critical details include band joist/sill areas, housewrap details (if housewrap is used as an air barrier), taping sheathing joints (if the sheathing is to be used as part of the air control system), dropped soffit areas, draftstop blocking between wall and roof or wall and floor assemblies, etc. Detail drawings showing appropriate air sealing of these areas are shown in Figures 5.1, 5.2, 5.8, and 5.11-5.18.
- Raised truss construction or equivalent roof framing—This type of construction gives you some credit in the code compliance analysis, and also performs better. Examples of raised truss equivalents are shown in Figures 12.5-12.8.
- Use details that need less wood and leave more room for insulation, at

exterior wall corners, partition wall intersections, headers, and the like. For example, structural headers and jack studs can usually be omitted in non-bearing walls. See Figures 5.4-5.7. The *Builder's Guide* has a section on framing with detail drawings showing additional options.

- Housewraps have been marketed for years as air barriers, but their primary purpose and benefit is as a drainage layer behind the exterior cladding. No siding and flashing system is completely waterproof, so a dependable drainage plane under sidings is needed as a secondary line of defense. Appropriate counter-flashing details are critical, and a back-drained and back-vented cladding can provide the best performance for keeping water out of the building. Housewrap, properly installed and sealed with tape, can contribute slightly to the air tightness of a building, but does nothing to slow down air leakage in most large leaks, which are located in basements and attics or other locations where a housewrap is not typically installed. In addition, some plastic housewraps may be incompatible with unprimed cedar and redwood, and with cement stucco materials. Perforated plastic housewraps have been shown to leak water much more rapidly than unperforated plastics or felt paper. Felt paper or building paper is still an alternative but today's builders have many more options to achieve the desired balance of tear resistance, ease of installation, vapor permeability, air control performance, water hold-out, exposure limits, etc. for a particular building project. Any weather barrier system, regardless of material, will perform better if there is a gap between the weather resistive barrier and the cladding/trim to allow drainage. The *Builder's Guide* has in-depth discussions about rain drainage planes and air flow retarder systems.
- Try to discuss HVAC layouts with mechanical subcontractors before framing. If you can adjust framing to allow space for ducts and pipes, layouts can be more efficient and less costly, and less damage will be done to the frame during installation. For example, if a long center wall in a two-story house is framed with 2x6 studs, duct risers can be more easily installed for registers in the upper story. Be sure to align floor framing with wall studs. At the very least, be sure that adequate mechanical chases exist. This type of approach can save on duct installation costs. The *Builder's Guide* section on design has more ideas related to HVAC integration.
- It is recommended to seal against air leaks in the exterior of the walls as well as the interior. Two air barriers are better than one air barrier. Exterior air barriers help prevent wind-washing of the cavity insulation, and they also tend to be easier to install in a continuous fashion (see the *Builder's Guide* section on air barriers).

Going Further

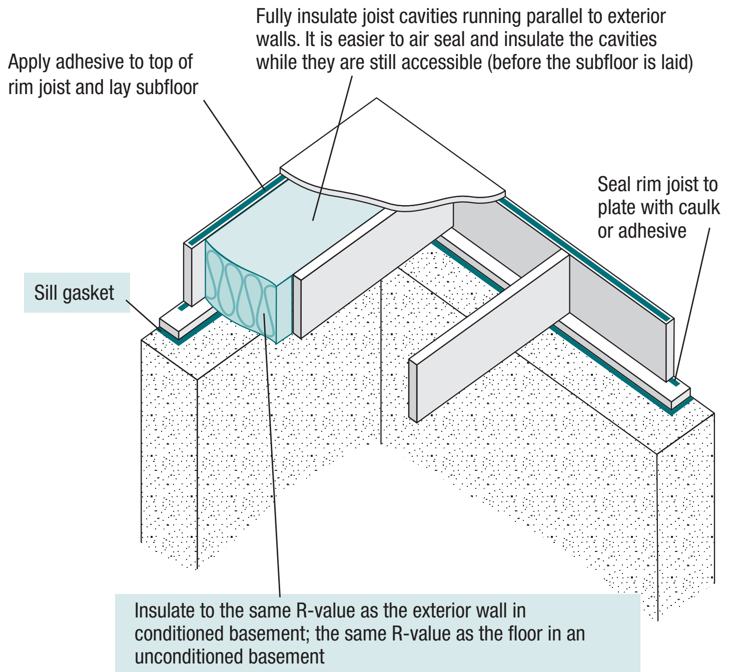
Use advanced framing techniques that allow you to use less wood in the frame of the building, leaving more room for insulation and more room in the budget (see Figures 5.9-5.10). You can choose to use some of these techniques and not others; but you do have to think about how to apply these details. For example, don't use single top plates unless you "stack" roof, wall and floor framing. Don't use a single stud at the rough opening unless you hold the header up with hangers rated for the load. When they are applied properly, these techniques meet codes and work well. For more detail on advanced framing (sometimes called "Optimum Value Engineering") see *Cost Effective Home Building: A Design and Construction Handbook* by NAHB (contact information in Appendix B).

Think about the ways in which framing affects the installation of an effective rain control system (roofing, siding, trim, flashing, etc.), and an effective water vapor control system (vapor retarders, roof ventilation, etc.). For example, roof framing has a direct impact on the effectiveness of various roof ventilation strategies. See the *Builder's Guide* for more on rain control, framing details for moisture control, insulation, sheathings and vapor diffusion retarders.

5 Framing

FIGURE 5.1

Sealing and insulating band joists during framing

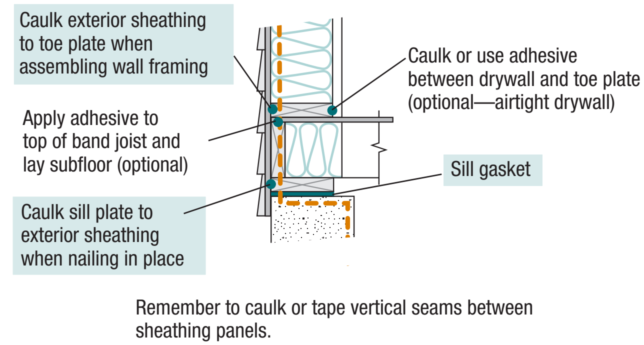


TIP: If you use a blown-in or sprayed insulation such as foam, blown-in cellulose or fiberglass, or a similar system, this area can usually be insulated with the rest of the house.

Insulating the band joist after the floor sheathing is installed can be very difficult, depending on the joist layout. Care must be taken to keep insulation dry when installed during framing.

FIGURE 5.2

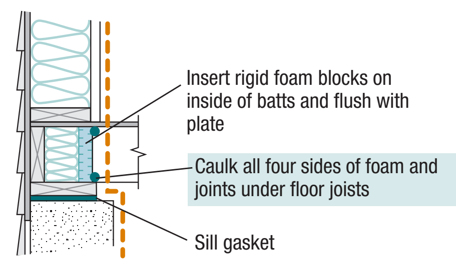
Sealing band joists during framing



TIP: For better results, also use construction adhesive when setting the band joist on the sill.

FIGURE 5.3

Sealing band joists after framing (alternate method)

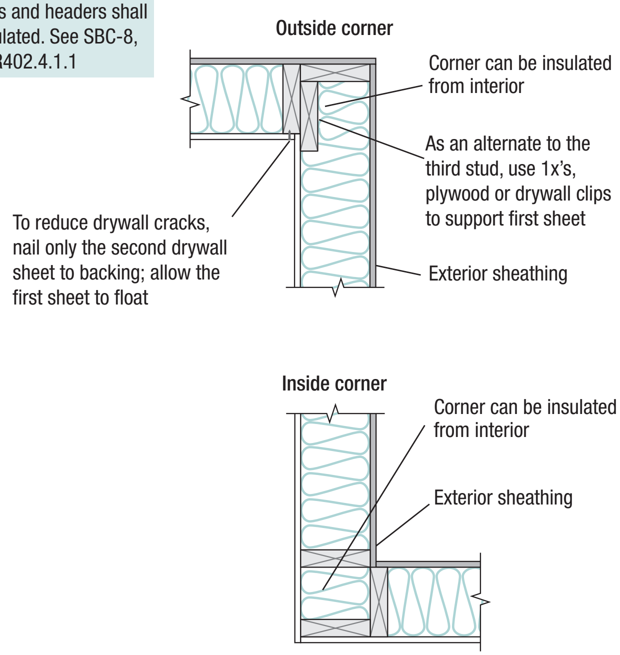


Sealing the band joist is easiest to do during framing, but if it is missed at that time, this technique works well also.

FIGURE 5.4

Insulated three-stud corners

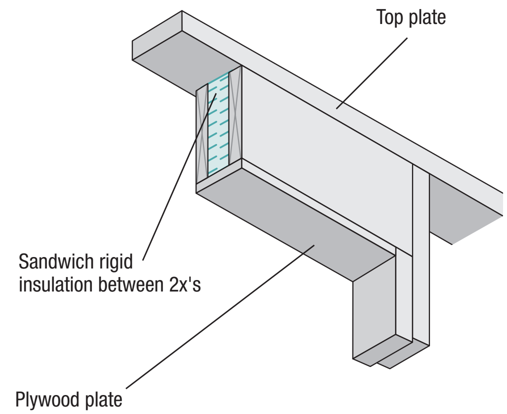
Corners and headers shall be insulated. See SBC-8, Table R402.4.1.1



Conventionally framed corners are difficult to insulate and use more wood than insulated three-stud corners. For more savings and reduced drywall cracking, use clips for drywall backing at outside corners instead of the third stud.

FIGURE 5.5

Insulated header in a 2x6 wall

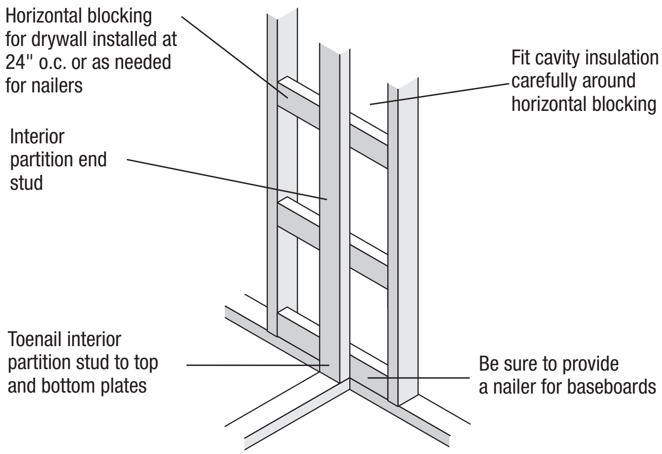


TIP: Use a few standard header sizes that will work in several locations. There is no need to size all headers equally.

As an alternative, insulated headers pre-manufactured from engineered wood I-beams and rigid foam may be used. Follow manufacturer's instructions regarding acceptable loading, span and support.

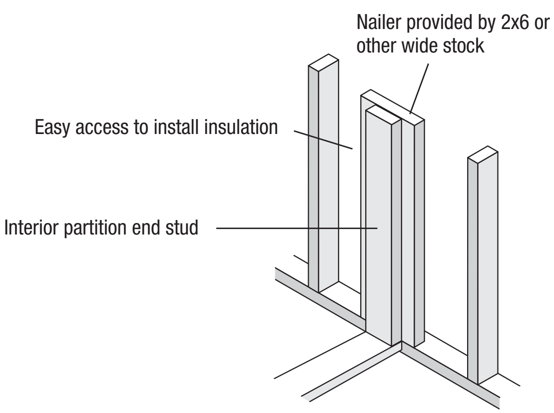
5 Framing

FIGURE 5.6
Ladder blocking for interior partition walls



Conventional box channels for partition walls are difficult to insulate. Ladder blocking (or vertical backing, Figure 6.7) use less wood, are easier to insulate, and are easier for electricians as well. See Figure 12.3 for air sealing details.

FIGURE 5.7
Drywall backing for interior partition walls



Vertical nailing stock can also be replaced by drywall clips to support drywall.

FIGURE 5.8
Cavity sealing example: chase on exterior wall

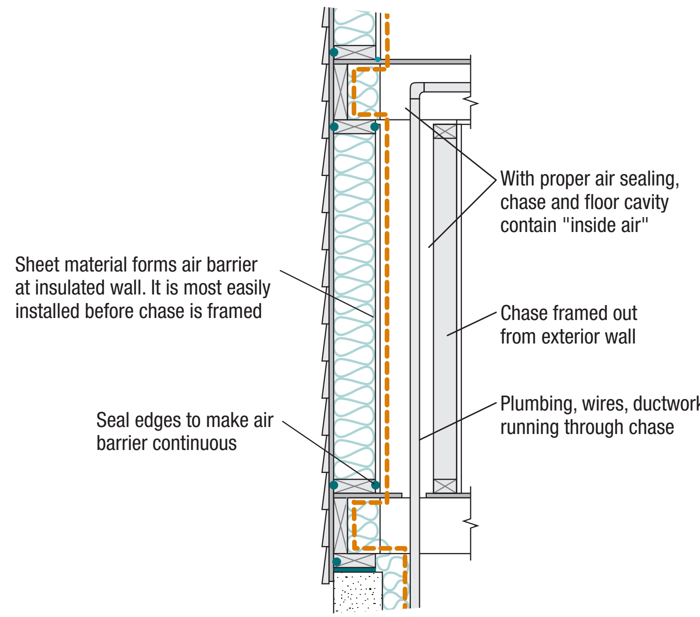
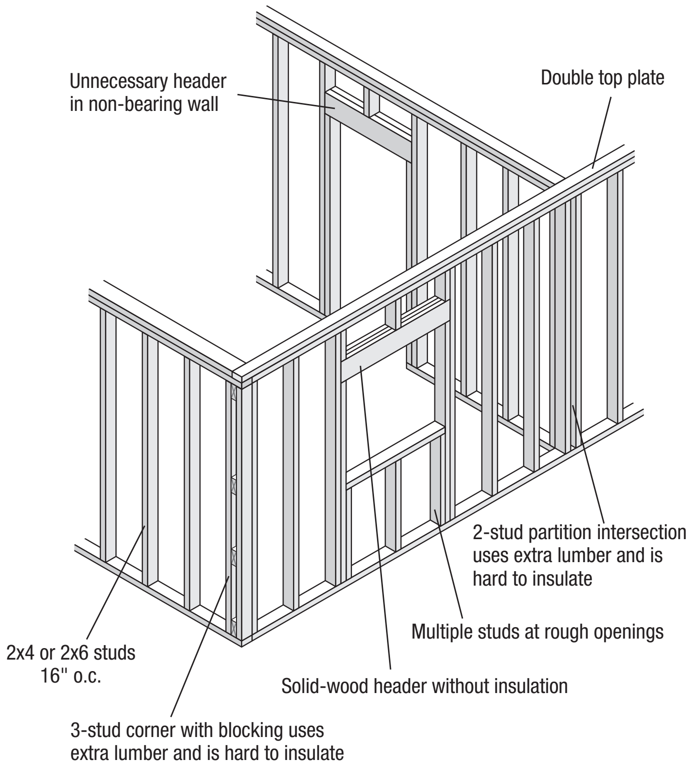
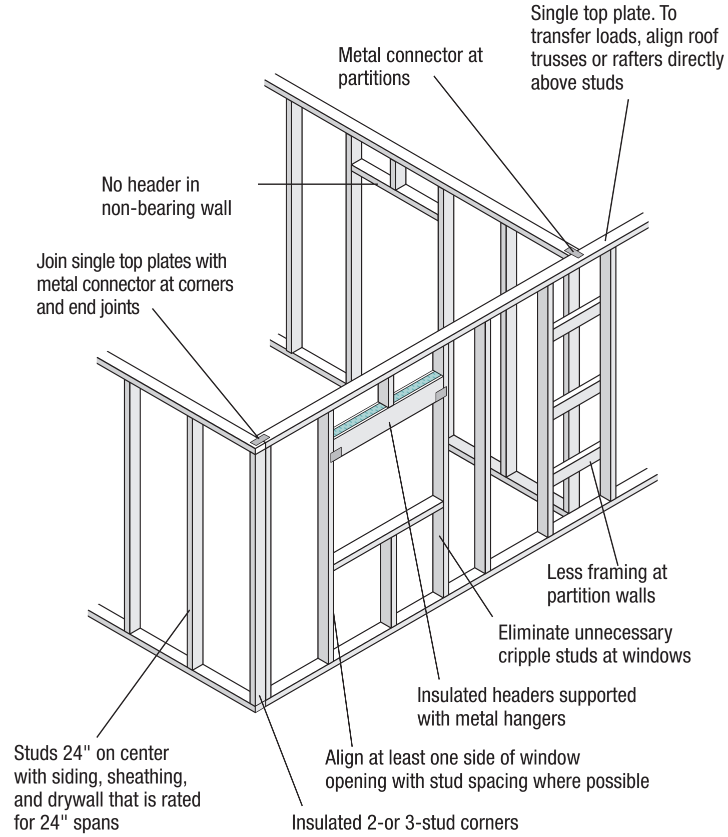


FIGURE 5.9
Conventional framing



Standard framing techniques use unnecessary wood and leave less room for insulation. Advanced framing techniques are tested and proven by the National Association of Home Builders, and meet structural codes. For more detail on advanced framing (sometimes called "Optimum Value Engineering") see *Cost Effective Home Building: A Design and Construction Handbook* by NAHB (contact information in Appendix B).

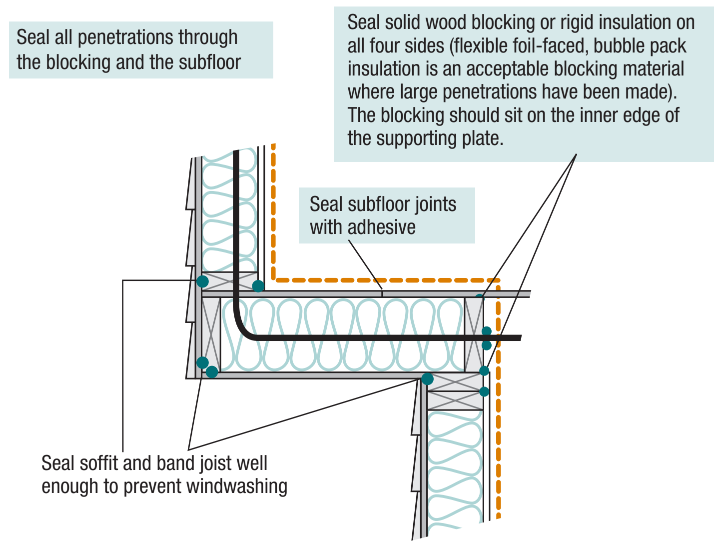
FIGURE 5.10
Advanced framing



Advanced framing uses up to 25% less wood, increases overall insulation R-values by 5 to 10%, and costs less to build. Most of these techniques can be used even when framing at 16" on center.

CAUTION: Code requires stack framing (structural support members are all aligned vertically) and metal splice plates to be used with single top plates.

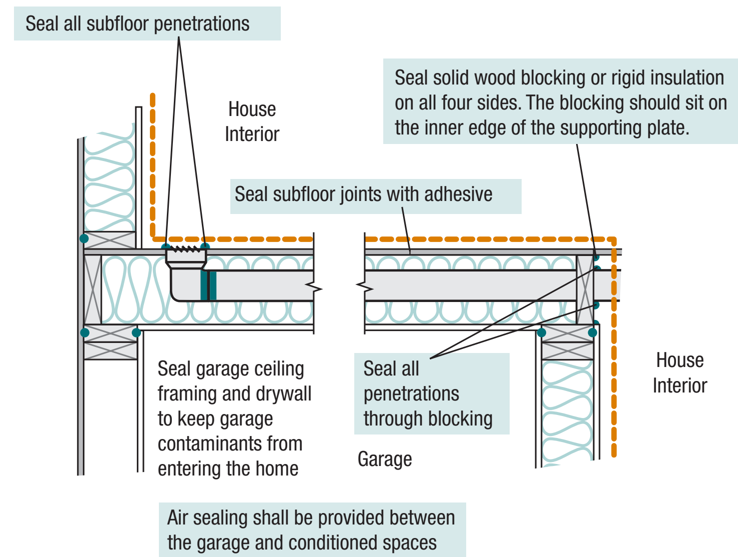
FIGURE 5.11
Exterior cantilever floor with interior air sealing



CAUTION: Blocking is often pushed out by subcontractors. Encourage subs to make slightly oversized holes in blocking which are easier to seal later, rather than removing the entire piece.

Note: In a typical sequence where the subfloor is installed before the soffit, exterior cantilevered floors must be insulated from the exterior. Avoid locating plumbing in cantilevered floors if possible.

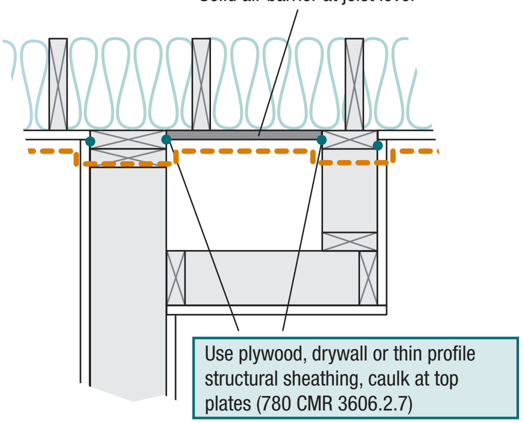
FIGURE 5.12
Tuck-under garage



Tuck-under garages and attached garages are especially important to seal and isolate from the rest of the house, not only because of heat loss but also for health and safety reasons. Air leakage paths from a garage into the house can bring car exhaust, fumes from stored gasoline or other dangerous chemicals, or fire from the garage into the house. The floor over a garage is also a common area for freezing pipes and poor heat distribution. Provide both an interior and exterior air barrier to thoroughly isolate the floor system and reduce these potential problems. It is also recommended to avoid locating plumbing and ducts in the floor assembly over the garage.

FIGURE 5.13

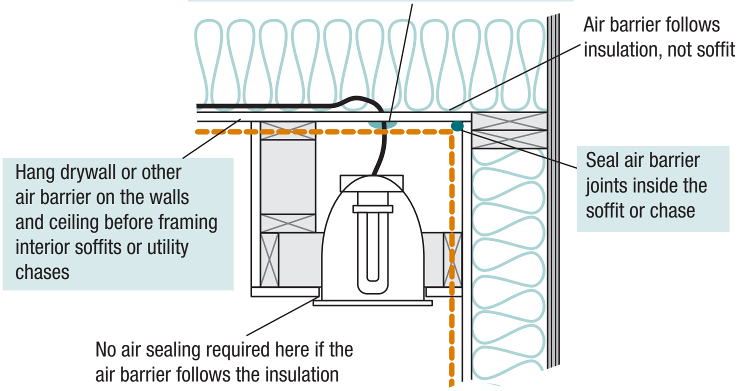
Dropped soffit on interior wall



Note: Dropped soffits at exterior walls require a similar treatment. See also, Figure 5.8.

FIGURE 5.14

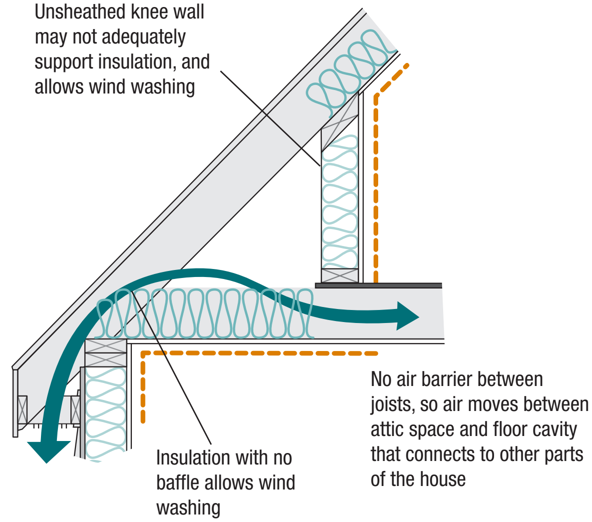
Interior soffit on exterior wall



Dropped soffits are commonly built with direct air paths from inside interior walls into attics. When recessed lights are installed, heat from the lights drives air leakage even faster. Installing air barriers before framing the soffit requires coordination of framing crews and materials.

FIGURE 5.15

Typical 1½-story knee wall



Typical knee wall details that are found in cape style homes, bonus rooms over garages, and the like are one of the largest and most common air leakage problems. This figure shows the air movement that allows outdoor air into all the joist bays, between floors. This problem can be eliminated by careful blocking of the floor framing under the knee wall, or by insulating the rafters and providing an air barrier, as shown in Figures 5.16-5.17.

FIGURE 5.16
1½-story knee wall outside the air barrier

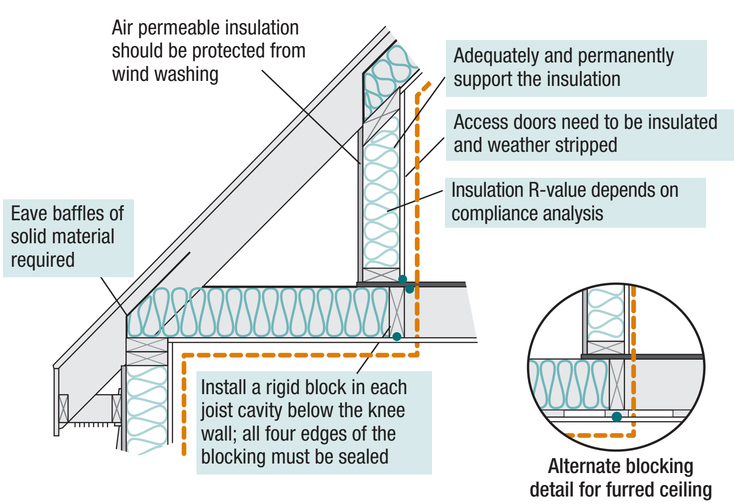


FIGURE 5.17
1½-story knee wall inside the air barrier

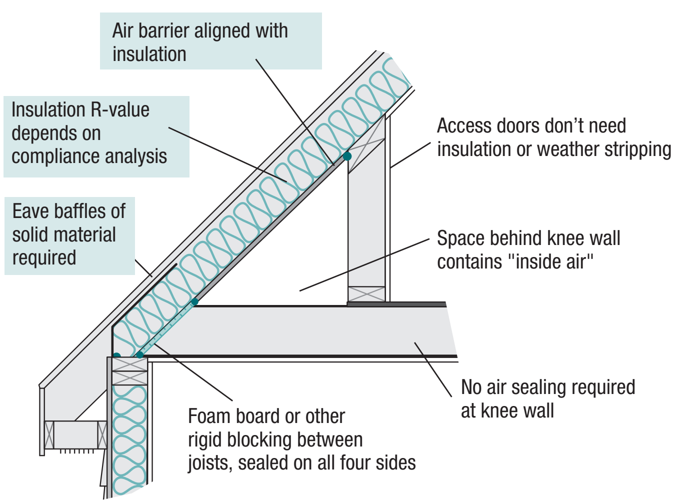
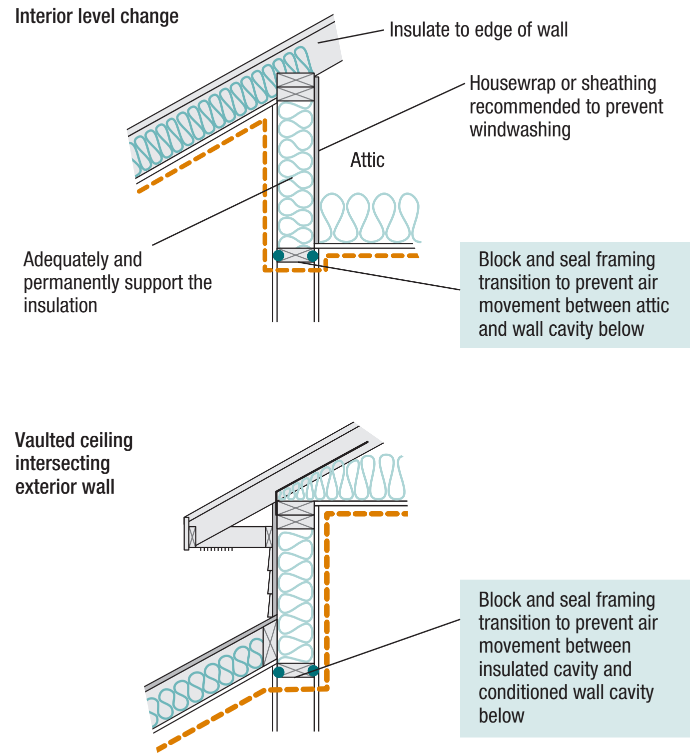


FIGURE 5.18
Sealing split levels



The lack of draftstop blocking in typical split-level details is another large leak. Be especially careful around stairways framed near these areas in "Tri-level" homes.

Windows and Doors 6

Energy Code Requirements

The primary window requirement in the energy code is for the *U-factor* of installed windows (which includes skylights and glass doors). Note that the U-factor is 1/R, which means smaller U-factors have better thermal performance. This U-factor requirement will vary depending on the results of your compliance analysis. There are only two ways that the code lets you determine the U-factors for a given window:

- **NFRC rating (SBC-8, Section R303.1.3)**—In order to take credit for a manufacturer's rated "U-factor," the product must be listed by the National Fenestration Rating Council (NFRC). The rating is based on simulations that are verified by a laboratory test, and its purpose is to provide a "level playing field" for all manufacturers to compare their products. The rating information should be available in product catalogs. Additionally, an NFRC sticker attached to every window unit displays the U-factor, along with other performance ratings that also impact the comfort and energy use of the home. (see Figure 6.1). Be sure you don't remove the stickers until your building inspector has verified the installed product's U-factors!
- **Default tables**—For products that do not have an NFRC rating, you can use SBC-8, Table R303.1.3(1). This table contains default U-fac-

tors for windows, glass doors, and skylights of various types. There are categories for single pane and double pane glass, and for various frame materials and sash types. Doors, with and without storm doors are listed in Table R303.1.3(2). The main reason for the table is to provide U-factors for the occasional non-rated side lite, transom window, decorative glazing unit, or door. You can use the default values for every window in a house, as long as the house passes the compliance analysis. However, the default U-factors are conservative, and don't allow credit for low-e coatings, gas fills, or any other feature that can't be verified in the field.

- **Remember** that when you calculate window (or skylight or door) area for the purposes of code compliance, you must use the *whole* unit area (frame dimensions or rough opening). Don't use glass or sash sizes.

Prescriptive Compliance

If you use the prescriptive tables from SBC-8, Chapter 4, you will have a "Maximum" U-factor to use for all windows in the house. If you have windows (or skylights) with different U-factors, you can do an average U-factor calculation for the whole group. A worksheet for that purpose is included in this guide (see Appendix A).

Windows

Although people commonly refer to double glazing as "insulating glass," it's important to realize that windows are not "insulated." Windows typically represent three to ten times greater heat loss (per square foot) than wall assemblies. The "best" commonly available, mainstream windows (double, low-e, argon, without special heat mirror films or other premium features) have an R-value of approximately 5—that's more than three and one half times the heat loss of the worst wall that most people would ever build today (R-18).

Glazings have improved steadily over recent years. Fifty years ago, the vast majority of windows were single glazed. Double glazing became the norm for homes in all cold climates in the country. Double glazed windows have, in turn, been supplanted by double glazed windows with low-e coatings and gas fills. Earlier versions of double-glazed windows used metal spacers between the layers of glass resulting in significant conduction around the perimeter of the window. The advent of double glazing with low-e coatings and gas fills also made the conduction through the window frame a relatively significant factor in window thermal performance.

Today, windows with "warm edge" spacers and thermally broken or low conductivity frames are ready available.

More recently, high performance windows that employ 3 or more layers of glazing have become increasingly competitive. The best (highest performance) windows currently available combine multiple glazings with gas fills and coatings tuned to exposure and climate. These high performance windows also typically have frames that are made of foam-filled rigid fiberglass, foam-filled vinyl, wood or a combination of wood and fiberglass (see Figure 6.2).

Foam-filled fiberglass frames conduct less heat than the typical wood or vinyl frames, and they are generally very durable and dimensionally stable.

6
Windows and Doors

The ENERGY STAR designation can be used as a baseline for window performance.

To get a complete picture of the factors that affect the impact of window type on the energy performance of the building, you must also consider the following:

- **U-factors**—There are many different performance numbers associated with a given window type (see Figure 6.1). The only number that is used for energy code compliance in Rhode Island is the *whole-unit* U-factor (as determined by the National Fenestration Rating Council [NFRC]). The lower the U-factor, the better it performs relative to controlling heat loss.
- **Orientation**—South facing glass can reduce heating loads and adds little to cooling loads as compared to east or west facing glass. South facing glass is good. If you have south facing glass area (not including frame area) that's more than 7% of the floor area of the building, you should think about controlling solar gains through the use of shading (e.g. overhangs), windows with lower solar heat gain coefficient (SHGC), or adding extra thermal mass to avoid overheating. East and west facing glass does not reduce heating loads in winter, but is the primary source of summer cooling loads. Limit east and west glass if you can; if you need large areas of glazing in these directions, consider using

"southern" low-e products (which often cost the same if you order in advance) with low solar heat gain coefficients (SHGC).

- **Shading** is another way to reduce unwanted heat gain from east and west facing glass. Trees, overhangs, decks, or awnings can all be used to reduce the time that the sun shines in these windows. On the south side, properly designed shading can admit the sun in winter when it is low in the sky and block it out in summer when the sun is high.

Window installation is another factor that can affect not only the energy efficiency of a house, but also its durability. Regardless of the window type selected, care should always be taken to ensure that any water that gets behind the siding or through the window frame is drained back, out and over the sheathing wrap or building paper. Use a properly lapped sill flashing that is integrated with the building drainage plane. An excellent resource for this and related flashing details is the *Water Management Guide* published by Building Science Press (see Appendix B). Outdoor air should also be prevented from entering the house by sealing the window frame and/or casing to the rough opening in the framing (see Figures 6.2 and 6.4).

By carefully selecting windows, you can trade off upgrade costs immediately with dollars saved elsewhere. High performance glazings, when coupled with air sealing, can reduce peak heating and cooling loads, and may allow savings on mechanical equipment and distribution costs. For example, upgrading from minimally code-compliant windows to windows with low SHGC on the west and east sides, can reduce cooling loads by 1/2 to 1 ton in a typical house. Also, the better surface temperature of high performance windows and reduced convection drafts may allow HVAC contractors to put supply registers or baseboards near inside walls, saving significant installation costs.

Doors

Doors can generally be divided into two categories—those that are insulated and those that are not. Insulated doors typically have R-values between 2.5 and 7. Metal doors perform much better if they have *thermal breaks*—interruptions in the conductive metal components—built into the door and frame. Insulated fiberglass doors can achieve high R-values without special thermal breaks. Uninsulated doors (e.g. all wood doors) have R-values closer to 1. Most new doors that have any amount of glazing are also NFRC-rated (by U-factor), which makes it easier to compare one door to the next. Usually, aesthetics and price drive consumers to select one door over another, which is fine; doors take up a small enough area of the thermal envelope that the conduction through the door has a small impact on the overall performance. Of course, all other things being equal, it's still a good idea to choose the most efficient one available.

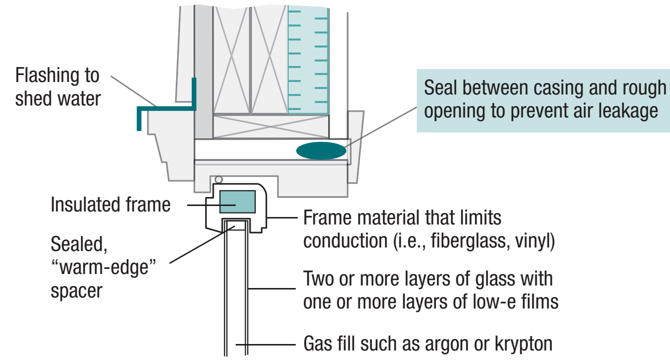
6
Windows and Doors

FIGURE 6.1
NFRC Sticker

TIP:

The National Fenestration Rating Council (NFRC) rating is the only way allowed by code to verify the manufacturer's rated thermal performance of windows, skylights and glass doors. A sticker similar to the one shown above is attached to each window. In addition to the performance ratings expressed above, condensation resistance (measured on a scale from 0 to 100; the higher the number the better) may also appear on the label. The ratings associated with condensation resistance and air leakage (measured in CFM/square foot) are optional; the manufacturer decides whether or not to include them. Performance ratings can also be found in the NFRC Certified Products Directory (see Appendix A), or can be obtained directly from the manufacturer.

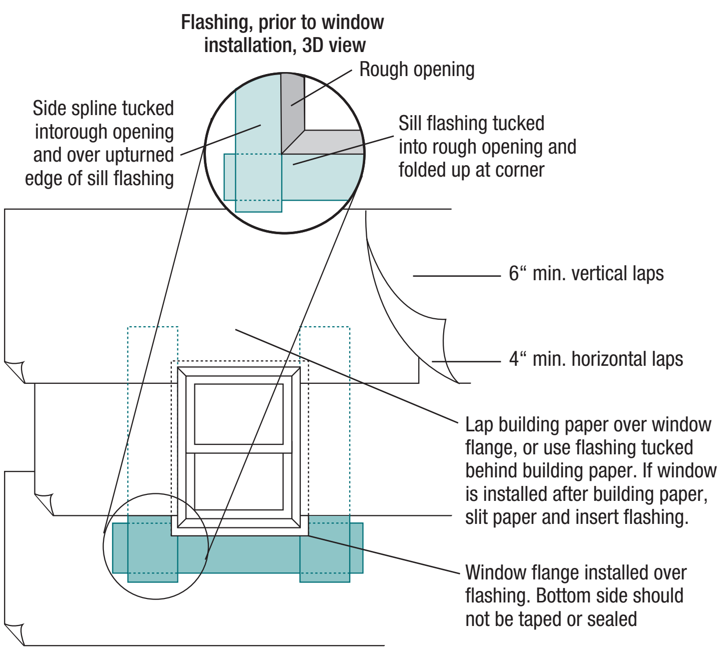
FIGURE 6.2
Features of a high performance window



TIP: Most high performance windows are ENERGY STAR-rated. For northern climates, ENERGY STAR windows (and doors) have a whole-unit U-factor of 0.30 or less. A U-factor of 0.35 or less is required to comply with SBC-8.

NOTE: Window flashing should be integrated with building drainage plane; details not shown for clarity—refer to Figure 6.3.

FIGURE 6.3
Window flashing



Note: Traditionally, the rough sill was prepared with felt or building paper; best practice today is to flash the rough sill with a more robust flashing membrane. A beveled or sloped sill or back dam to divert water to the exterior is also extremely important.

CAUTION: It is difficult to convey the steps required to effectively flash a window opening in a single drawing. Furthermore, there are many combinations of window type and wall assemblies, so one procedure cannot be portrayed to work in every situation. Construction scheduling also affects the detailing: the process is different if you install the windows before, or after, the sheathing wrap.

There are many ways to do this right, but there are even more ways to do it wrong. This figure is only meant to convey an overall strategy. For step-by-step guidance and better specifics, please refer to the *Water Management Guide* (see Appendix B, page 141 for ordering information).

Mechanical Systems 7

Energy Code Requirements

The energy requirements of the building code that apply to HVAC installations (SBC-8, Section R403) are in addition to any plumbing, mechanical, and fuel gas codes that apply to these systems. Although it is generally the HVAC installer's responsibility to follow these requirements, the builder may also have to know what they are and to communicate them to the subs for a given project because they are in the building code. Here's a summary of the HVAC requirements. Remember that these requirements generally apply to all residential buildings, but more complex mechanical systems typically found in multifamily residences may have to meet additional requirements—see SBC-8, Section R403 for more detail.

- Heat loss calculations and system sizing (SBC-8, Section R403.6)—Systems serving multiple dwelling units shall comply with Sections C403 and C404, SBC Commercial Provisions. Heating and cooling load calculations must be done according to a specified process. Air Conditioning Contractors of America (ACCA) Manual J (see Appendix B for ordering information) is required by the IECC 2012, Section R403.6. The design parameters used for these calculations are given in SBC-8, Section R301.1, Table R301.1.
- HVAC system efficiencies—The current minimum efficiency requirements for HVAC systems are listed below. Note that code minimums

for efficiency follow federal minimum efficiency standards. See following table and the next bullet for more information.

Equipment	Rating	Current Federal Minimum *
Hot Water Boilers (oil and gas)	Annual Fuel Utilization Efficiency	84 oil, 82 gas
Furnaces (oil and gas)	Annual Fuel Utilization Efficiency	83 oil, 78 gas
Heat Pumps (air source)	Heating Seasonal Performance Factor	7.7
Central Air Conditioning	Seasonal Energy Efficiency Ratio	13

*Federal minimum efficiency standards for gas furnaces, central air conditioners and heat pumps are scheduled to increase in 2015.

- Heating system trade-offs—Many boilers and furnaces are more efficient than the code minimums. You can take credit in the performance compliance methods for systems with higher than minimum efficiency. Get the equipment efficiency ratings from your HVAC installer (or subcontractors you have worked with) *before* you do the compliance analysis. As a designer or builder you can specify high levels of efficiency, which makes it easier to meet the code. However, be careful to know in advance what your requirements are, and how much the upgrade costs.
- HVAC controls (SBC-8, Section R403.1)—Temperature controls for forced-air heating and cooling systems must include the capacity to be set to 55 degrees (for heating) and/or 85 degrees (for cooling). Although not required by code thermostats used to control heating and cooling simultaneously should have a temperature range (of at least 5 degrees) within which calls for heating and cooling are either suspended or reduced. Similarly, humidistats should have the capacity to prevent energy consumption (suspend operation) between 30 and 60% relative humidity. Heat pumps that include auxiliary electric resistance heaters must have controls that, except during defrost cycles, lock out the auxiliary heaters when the heat pump compressor can meet the heating load.
- Mechanical ventilation systems (SBC-8, Section R403.5)—Must meet the requirements of the *International Residential Code* or *International Mechanical Code* as applicable. The system must have automatic or gravity-driven dampers at the points of intake and exhaust that close when the system is not operating. Whole house mechanical ventilation fans must meet the efficiency requirements of Table 403.5.1. If a whole house ventilation system is integrated with an existing HVAC system the system fan must be an electronically commutated motor.
- Duct and pipe insulation is required for all HVAC ductwork and pipes in unconditioned spaces, as indicated in SBC-8, Sections R403.2.1 and R403.3. For most single family work, the insulation must meet the levels shown in the following table. Note that flex duct must have R-value labels on the outside jacket (SBC-8 Section R303.1.2).

Table 9.1 Common Duct and Pipe Insulation Levels

Ducts in unconditioned space		Hydronic pipes in any unconditioned space
Supply ducts in attic	All other ducts	up to 2" pipe diameter
R-8	R-6	R-3

- Duct sealing is required on all low-pressure ductwork (SBC-8, Section R403.2.2). All portions of stud bays or joist cavities used as return ducts must also be sealed. Materials used to seal flexible ducts or flexible air connectors must comply with UL181 B. Look for the UL181 B-FX mark for pressure-sensitive tape and the UL181 B-M mark for mastic. Products and systems used to seal metal ductwork must be installed in accordance with the manufacturer's instructions. SBC-8 provides that duct tightness shall be verified by performance testing except where the forced-air distribution (ducts and air handler) is located entirely within conditioned space. (see Figure 7.1). Only two types of tapes are permitted for use in duct sealing, and their applications are specific to the type of duct being installed. Respectively, tapes meeting UL 181A and 181B may only be used for rigid fiber ducts (A) and for flex ducts (B). Duct tape is not allowed for duct sealing.
- Service Water Heating (SBC-8, Section R403.4)—All pipes in recirculating hot water pipe loops must be insulated to R-3. Circulation pumps must be equipped with readily accessible manual shutoffs.

General Recommendations

- Bring ducts and pipes inside—Ducts and pipes in unconditioned attics, garages, basements and crawlspaces lead to higher heat loss and can contribute to problems such as discomfort and ice dams. *Whenever*

7 Mechanical Systems

possible, bring the mechanicals inside the insulated envelope of the house. Builders and designers can help make sure that framers leave room to run the heating and cooling distribution system inside the thermal envelope.

- Avoid ducts in outside walls—If you must put a heating duct in an outside wall cavity, install at least R-14 rigid insulation between the duct and the exterior sheathing or use continuous insulating sheathing to provide adequate insulation to the exterior side of the duct.
- Use direct vent/sealed combustion equipment to avoid backdrafting and carbon monoxide in the home. Figure 7.2 shows one typical back-drafting scenario; any large exhaust fan can backdraft atmospheric vented combustion appliances. Installation of sealed combustion boilers, furnaces, and water heaters may avoid the expense of building a chimney; many of them can vent through the side wall (see Figure 7.3).
- Use high efficiency equipment which will save the buyer money, and is one of the easiest ways to gain credit toward energy code and higher performance ENERGY STAR. The following table can be used as a guideline for purchasing high efficiency equipment.

Equipment	Rating	Target Efficiencies
Oil-fired Boilers and Furnaces	Annual Fuel Utilization Efficiency	≥86
Gas-fired Boilers and Furnaces	Annual Fuel Utilization Efficiency	≥92
Heat Pumps (air source)	Heating Seasonal Performance Factor	≥9.0
Central Air Conditioning	Seasonal Energy Efficiency Ratio	≥13

- Maximize the overall efficiency of the mechanical systems—Integrated heating/hot water systems can save energy where the water heating approach would otherwise be a standard efficiency direct-fired water heater. An indirect-fired water heating configuration (a boiler and an indirect fired water storage tank) that uses a high efficiency condensing boiler provides hot water more efficiently than a typical stand-alone tank, uses only one burner to do both jobs, and needs only one venting system. Some high efficiency direct vent/sealed combustion water heating equipment can provide the service of a water heater and boiler in one appliance. If forced air is desired, a high efficiency water heater or boiler can provide heat through a "hydro-air" fan coil. Avoid using a "tankless coil" in the boiler (not the same as an instantaneous "tankless" water heater) for water heating; they have the lowest efficiency of all hot water heating methods.
- Be aware of the impact of fuel choice—Electric resistance heating and water heating tends to be the cheapest to install and the highest cost to operate. Electric resistance heating and water heating is almost always the least efficient in terms of primary energy (energy used at the power plant). Modern heat pump technology, on the other hand, can meet heating and cooling loads very efficiently. Products that allow heat pump technology to provide water heating are maturing although efficiencies may not be better than condensing gas-fired technology. Propane can allow the use of fully-condensing direct vent combustion equipment at a site that does not have access to natural gas, but propane also tends to be a relatively expensive fuel. Natural gas supports the use of direct-vent fully-condensing combustion appliances at a relatively low fuel cost. However, the connection and service charges associated with maintaining connection to natural gas distribution can outweigh energy cost savings.
- Sizing for air conditioning systems is especially important because the ability to dehumidify is an important part of their function. When an air conditioner is oversized, it is not as effective at removing water from the air. The air gets chilled enough to satisfy the thermostat, but ends up "cold and clammy." A properly sized air conditioning system not only saves money on installation, but actually provides a higher comfort level.
- Consider setback thermostats to give homeowners a convenient way to manage indoor temperatures. Although these thermostats will only provide a benefit if the occupants choose to use the setback feature, most people will use it. Interestingly, the benefit of a setback thermostat tends to be less as the thermal performance of the building enclosure gets better.

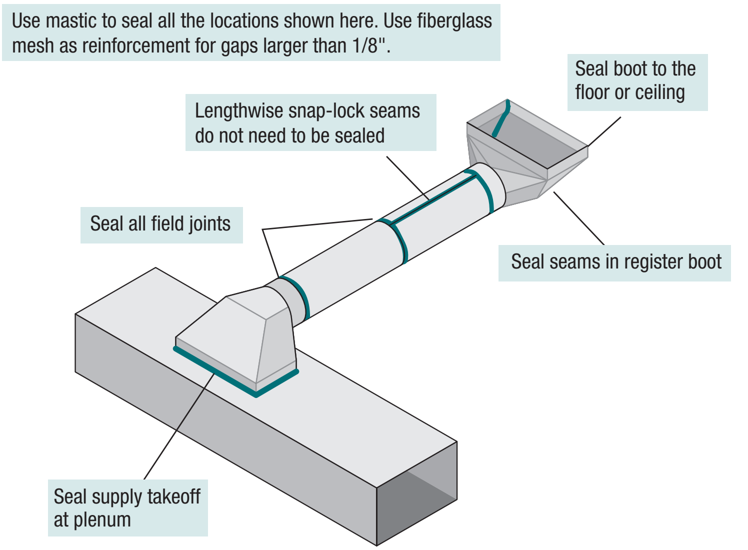
Going Further

There are a number of references listed in Appendix B specifically related to indoor air quality, ventilation, and HVAC systems.

7
Mechanical Systems

FIGURE 7.1

Sealing duct runs within unconditioned spaces



Leaky ductwork in unconditioned basements and attics is a major source of heating and cooling losses. Run ducts inside the conditioned envelope wherever possible; duct sealing is not required in conditioned spaces.

To apply mastic, use protective gloves and smear it in place by hand or brush. Pay close attention to:

- folded corners on end caps, boots and takeoffs;
- plenum connections;
- filter racks;
- swivel elbows; and
- finger-jointed collars

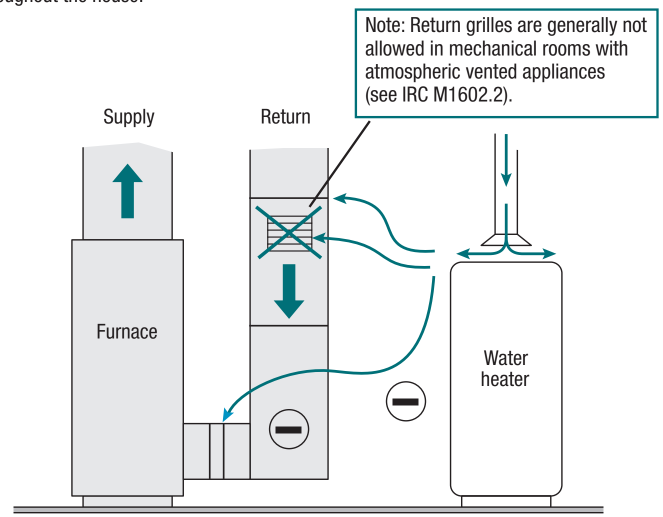
Joints and seams shall comply with IMC or IRC UL ratings for sealants

TIPS: Mastic is much faster to install and more reliable than the more common aluminum tapes.

FIGURE 7.2

Depressurization and backdrafting

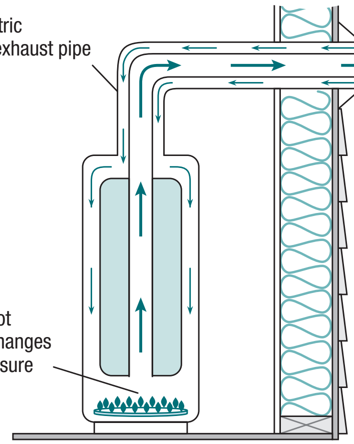
This figure shows a typical scenario. Leaks in return ducts depressurize the basement. Depressurization can backdraft the water heater vent or the furnace burner. Backdrafted combustion products, which may include deadly carbon monoxide, are then circulated throughout the house.



Depressurization that causes backdrafting can be created by any exhaust appliance. The large ones that are most likely to create depressurization include range vents, whole house fans, dryers, central vacuum, and fireplaces without outdoor air supply. Leaks in return ducts and/or the presence of return air registers in the vicinity of a combustion appliance can also cause backdrafting (as shown in the diagram above). **Mechanical code requirements for passive combustion air inlets or volume of air space do not guarantee against backdrafting, yet they add to building heat loss.**

FIGURE 7.3

Direct vent water heater

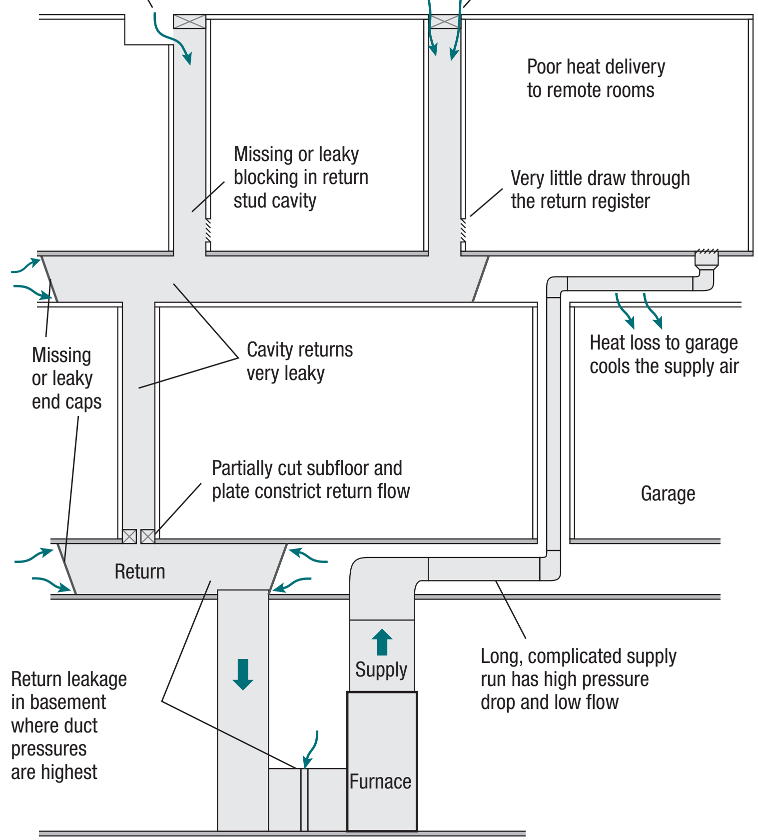


TIP: The placement of a direct vent appliance is limited by the allowable length of the intake/exhaust pipe. Plan carefully for locating these appliances.

The direct vent water heater is completely sealed from indoor air, so backdrafting into the living space cannot occur. Similar arrangements are available for furnaces, boilers, and gas or wood fireplaces and stoves.

FIGURE 7.4

Problems with framing cavity ductwork and other typical duct problems to avoid



7
Mechanical
Systems

Ventilation 8

Energy Code Requirements

The SBC-8 requires that all new homes be constructed with a mechanical ventilation system that includes automatic controls.

The venting requirements are listed in Table M1507.3 and Table 403.3 of the 2012 IRC. Note that the required ventilation rates in these tables are less than the values listed in ASHRAE 62.2-2013, Table 4.1a. Also see Chapter 13 for an in-depth discussion regarding indoor air quality and health and safety.

A home that includes a mechanical ventilation system provides the following benefits:

- **Healthier indoor air**—ASHRAE recommends that residential buildings be maintained at 30 to 60% relative humidity for optimum health. Why? Some biological contaminants thrive in low or high humidity, but most are minimized in the recommended range. How do you control the humidity? In any climate and in any season, the first step is to control the air exchange rate. In the winter, dryness is caused by excess air leakage; when dry outdoor air is heated, the relative humidity drops. High humidity, on the other hand, is often caused by underventilation and poor source exhaust for moisture-producing activities such as cooking and bathing. Control the dryness by limiting air leakage, and control the moisture by ventilating the house. In the summer, the only way to control humidity is with mechanical dehumidification or properly sized air conditioning systems (see pages 108-109).

In the past a typical home has compromised air quality due to its materials and contents. Just as mechanical ventilation provides the ability to control humidity, it also allows occupants to dilute indoor pollutants like volatile organic compounds, fumes from solvents and cleaning agents, carbon monoxide, and other compounds people shouldn't be breathing. Note that the most effective way to ensure indoor air quality is to avoid bringing contaminants into the home in the first place.

- **More reliable and consistent supply of fresh air.** Leaving ventilation to random air leaks doesn't work. Even leaky buildings tend to be underventilated in the spring and fall, when there's little driving force for air movement. They are also overventilated in the winter when the driving forces are large, and when it costs more money to heat up the leaking air. Leaving ventilation to operable windows and doors doesn't work. Build the house tight enough to limit the air leakage, and then give the occupants control over background ventilation rates.
- **Reduced moisture**—As well as supporting healthier indoor air, controlled ventilation helps to limit moisture problems in the building. Water is by far the biggest threat to building durability. Exhausting water vapor as it is produced and keeping the indoor humidity reasonable is important in keeping the whole building free of moisture problems. Humid indoor air tends to find its way into building cavities and unconditioned spaces and to deposit water there. And once the building does get wet, high humidity will slow down the rate at which drying will occur. Kitchen range hoods should be exhausted to outdoors, especially if there is a gas range. Don't use dryer hose, use rigid duct. Keep duct runs as short as possible. Of course, ventilation will not be enough to avoid problems if moisture is getting into the house because of improper foundation drainage, roofing, or siding details.
- **Improved comfort**—Sealing air leaks in the building limits overventilation and drafts. Ventilation contributes to improved comfort in several ways. Controlling background ventilation rates reduces cooking odors, damp musty smells, "stale air," and elevated levels of carbon dioxide. By controlling indoor humidity, air sealing and ventilation work together to improve comfort.
- **Fewer callbacks**—A newly built house has a lot of moisture in it. Foundations, frames, drywall, plaster and paint all bring water into a new home. Depending on the weather and other conditions, there may be a lot of water. The most likely time to get a moisture-related callback is in the first winter of occupancy. When a new homeowner calls you to say "Our windows are sweating and there's mildew in the bathroom," what will you tell them? "Open a window?" How about, "Set your ventilation system to run more often (or at a higher speed)."

When people are more comfortable in the home they are less likely to complain and more likely to provide referrals.

How much ventilation?

The ventilation rate requirement for whole-house ventilation systems is set by the 2012 IRC Table M1507.3.

Types of ventilation systems

- **Bath fan system**—The easiest type of ventilation system to install is a simple exhaust fan system. Choose one bath fan to upgrade with a quiet fan (less than 1.5 sone, preferably). People won't use a fan that sounds like an airplane. Choose a model that is rated for continuous operation (typically 30,000 to 50,000 hours). This is to make sure it doesn't break after a year or two. The fan must be ducted to outdoors. This type of system is relatively inexpensive: most importantly, the source of make-up air is uncontrolled. With the exhaust-only approach, makeup air comes in through small leaks that exist even in a very tight building. It is not as effective at providing fresh air to upstairs rooms as a fully ducted supply air system, such as an energy recovery system (see below).
- **Central exhaust**—This is a middle-of-the road type of system. You can run ducts from the bathrooms and kitchen to a central exhaust fan, which has a 24-hour timer or variable speed control. Be careful to size the ducts for adequate airflow, to balance the system properly, and to get adequate airflow from each bathroom for moisture removal.

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Ventilation

Most exhaust fans are not rated for range hood duty, so don't place the kitchen exhaust register right over the stove! This system also gets its makeup air through leaks in the building shell. Although central exhaust fans are often installed in the attic, putting the fan in the basement and exhausting out the band joist eliminates the need to insulate the ducts and places the fan in a location that stays warm, isn't dusty, and is much easier to get to for service. It also eliminates a void in the attic insulation.

- **Return makeup air**—These systems pull fresh air into the home through the return duct of a forced-air distribution system (see Figure 9.1). A very important aspect of these systems is that they allow one to control where the make-up air is coming from. They are better than exhaust type systems at distributing fresh air into all the rooms in a house. These systems also provide the benefit of mixing are within the home. In order for this approach to be effective and economical, a few issues need to be covered. The fan needs some sort of control that will run it even if there is no need for heating and cooling, or the house won't be ventilated during those times. The system will also need a motorized damper and controller on the fresh air duct. When the heating or cooling needs are greatest, the air handler fan will be running a lot, and the house will be overventilated unless the rate is controlled. Also, using a forced air system for ventilation means that the fan will run more, so electrical cost becomes a concern because typical furnace or air conditioner fans use a lot more power than typical ventilation fans. Fortunately, simple and low-cost controls are available that allow the ventilation operation to "piggy back" with heating and cooling as much as possible in order to minimize the additional ventilation-only fan run time. The 2012 IECC, Section R403.5.1 requires that a system of this type be powered by an electronically commutated motor (ECM).
- **Heat recovery ventilation (HRV) or energy recovery ventilation (ERV)** systems allow for control of the make-up air location and also use a heat exchanger (HRV) or enthalpy exchanger (ERV) to exchange a portion of the heat (HRV) or heat and moisture (ERV) in the exhaust air to the fresh air stream. Typically, these systems are provided with distribution in one of two configurations. Independently ducted systems use dedicated ductwork to supply ventilation air to certain parts of the home and exhaust stale air from other parts of the home. Integrated HRV/ERV systems use central heating/cooling system ductwork to distribute ventilation air. When an HRV/ERV system is integrated or partially-integrated (e.g. just exhaust drawn from the central system ductwork or just ventilation supply connected to the central system ductwork) with a central heating/cooling system, it should be separated from the heating/cooling ductwork with motorized dampers to prevent uncontrolled ventilation. Also an integrated HRV/ERV system should have an interlocking control to ensure that the central heating/cooling fan operates to distribute the ventilation air. As with a return makeup air system, an integrated or partially-integrated HRV/ERV system will rely upon the air conditioner or furnace fan for distribution. Look for controls that "piggy back" ventilation on heating and cooling operation and use central air handlers with ECM motors to minimize the additional fan energy use.

Ducts and Controls

All exhaust fans must be ducted all the way outdoors (not into attics or other spaces). Any exhaust ducts running through unconditioned spaces must be insulated to minimize condensation. The commonly-used vinyl flex duct is not recommended. Much better air flow can be obtained with smoothwalled rigid ducts of aluminum or steel. PVC or polypropylene duct pipe also works well.

Minimize sharp turns. Use mechanical fastenings (screws, clamps) rather than tape. Seal the ducts airtight. Noise can be minimized by using flexible mountings for fans and by attaching the ducting to the fans with short lengths of flex duct.

Controls are not only important; they are required by the state energy code. Fans on switches don't run for a long enough time. The best strategy, and the only one that meets Rhode Islands energy code, is to provide some minimum ventilation automatically even if occupants don't interact with the system. You can have the fan run all the time or put it on an automatic timer. Simple 24-hour pin type timers work well, or you can install more sophisticated controls that offer more options. Dehumidistats, which turn on and off based on humidity the way a thermostat does based on temperature, may seem to be a good option, but the setting

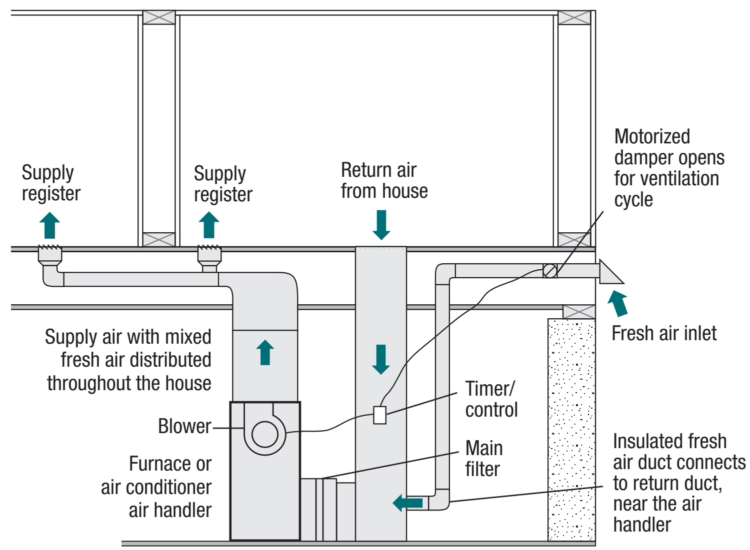
8 Ventilation

needs to be changed according to the season. Most occupants won't do that consistently.

New homes tend to have a lot of moisture stored in the building materials, and they also typically have chemical compounds in the air from carpets, paint, cabinetry, etc. It may be a good idea to ventilate the building at a somewhat increased rate for some time, including the first winter, when many houses experience their greatest levels of window condensation.

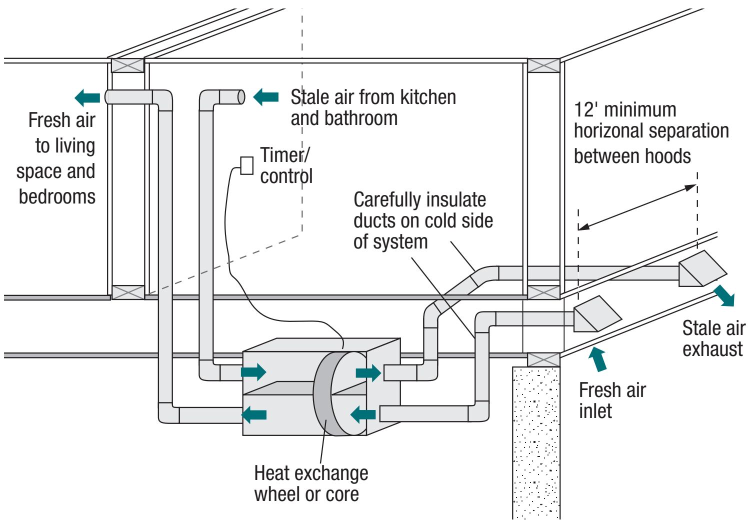
FIGURE 8.1

Return duct fresh air



8 Ventilation

FIGURE 8.2
Energy (or heat) recovery ventilation



Plumbing and Electrical 9

Energy Code Requirements

Sealing penetrations

Plumbing and electrical penetrations are major sources of air leakage in buildings. All penetrations through the insulated envelope of the building must be Air-sealed (see Chapter 11). This can be done by individual sub-contractors, but is more likely to be done by the builder. Electricians and plumbers can help by cutting holes slightly oversized to allow room for spray foam (see Figure 11.4), and by minimizing unnecessary penetrations.

Recessed lights

Recessed lights in insulated ceilings must be rated for Insulation Contact ("IC" rated), and must be airtight. See page 119 for further details.

Tub/shower units on exterior walls

Be sure there is an adequate air barrier in place before installing the unit. Also, where a vapor retarder is needed to the interior side of the wall assembly, this should be installed before the tub or shower enclosure. See Figure 11.8.

Installing Insulation

In addition, pipes and wires in exterior walls can make it difficult to install insulation properly. Keep plumbing out of exterior walls whenever possible (especially if the walls are being insulated with fiberglass batts). Try to run electrical wires low across walls, so it is easier to split batts on either side. If the walls are insulated with a blown- or sprayed-in insulation, there is less concern about interference. It's still a good idea to run plumbing in interior walls, or stay as close as possible to the interior in a 2x6 or larger wall, to avoid problems with freezing pipes.

Going Further

Water Conservation

Energy savings associated with service water heating can be achieved by opting for high efficiency mechanical systems (see Chapter 7) and also by reducing the amount of hot water that is actually consumed. Here are some ways to save water and the energy used to heat it.

- **Low flow fixtures**—Showerheads with a 2.0 gallon/minute (GPM) capacity conserve water but still have enough flow for a comfortable shower. Kitchen faucet aerators should be rated at 1.5 GPM, bathrooms at 1.0 GPM.
- **Water saving appliances**—Front-load washing machines use an average of 10 gallons per wash less water than similarly sized top-load washing machines. Such machines save electricity, detergent, and the energy used to heat wash water. They spin the clothes more thoroughly dry than conventional machines, saving even more.
- **House design**—Plan for centralized plumbing by locating the kitchen, bathrooms, the laundry room and the water heater in a common vertical space. By grouping and stacking in this manner, hot water can be readily delivered to the locations where it is required, resulting in less water use and a reduction in heat loss through the hot water pipes.
- Hot water distribution effectiveness—reduce water and energy waste by structuring the plumbing system to minimize the wait for hot water at fixtures. A good rule of thumb is to aim for less than 1 1/2 cups of water between the fixture and the source of hot water.
- **Distribution**—If long runs from the water heater to the plumbing fixtures cannot be avoided, consider installing a parallel pipe (or homerun) system to reduce pipe losses as a result of the direct connection between the hot water source and the fixture (see Figure 9.1).

Hot Water Circulation

In large houses, recirculating hot water pipe loops are sometimes used to keep hot water close to every fixture. As an alternative, a demand recirculation system can be used to reduce "standby" losses. These systems rapidly replace water in the pipe with hot water before the tap is opened and the energy savings compared to the continuously circulating loop is significant.

Heat Recovery

Most of the hot water used in a home goes down the drain with plenty of heat still left in it. A drain water heat recovery device (see Figure 9.2) can capture some of that heat and send it back to the water heater using no electricity and with no moving parts. These systems work best when there is a prolonged usage of hot water (i.e., when the hot water is draining at the same time that the water tank is filling). A drain water heat recovery system is typically installed in the drain line below the most commonly used shower, or on the main drain just before it exits the house. Cold water bound for the water heater is preheated as it circulates around the drain line, picking up heat from the drain water.

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FIGURE 9.1
Home run plumbing

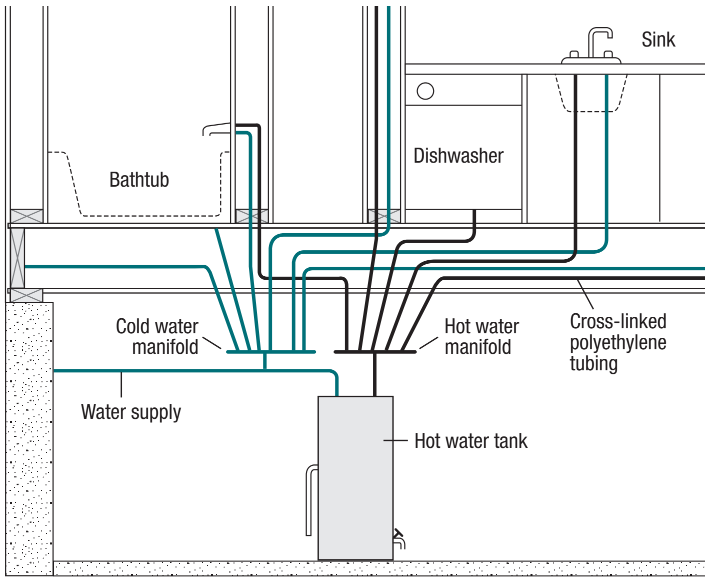
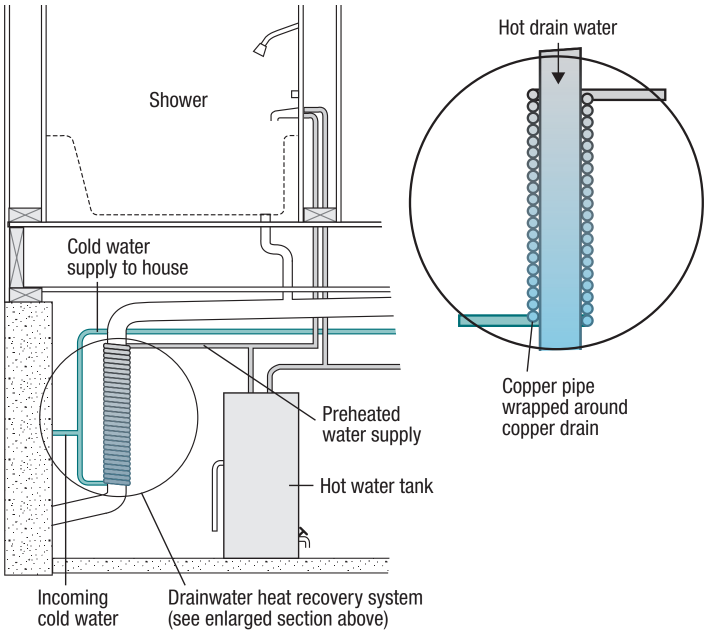


FIGURE 9.2
Drainwater heat recovery system



Piping arrangement shown for illustrative purposes only. Please consult manufacturer's recommendations and local codes for details of piping requirements.

9 Plumbing and Electrical

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Plumbing and Electrical

Lighting and Appliances 10

Energy Code Requirements

Lighting equipment (Mandatory)

A minimum of 75% of the lamps in permanently installed lighting fixtures shall be high-efficacy lamps. SBC-8, R404.1

Recessed lights

Recessed lights in insulated ceilings must be rated for Insulation Contact ("IC" rated), and must be airtight as outlined in the SBC-8, Section R402.4.4. Don't forget to include gaskets on the trim ring or other components that may be specified for the system to be rated for airtightness. The airtightness standard of 2.0 CFM when tested at 1.57 psf (75 Pa) (ASTM E 283) is required.

Tip: Do not install recessed cans in the thermal boundary.

LEDs

LEDs (light-emitting diodes) are now incorporated into bulbs and fixtures for general lighting applications. LEDs are small and provide unique design opportunities. Some LED solutions may even look like traditional light bulbs. LEDs that have earned the ENERGY STAR certification are subject to specific requirements designed to replicate the lighting of an A-type bulb. (Refer to Lighting Design: Kitchen for further detail.)

ENERGY STAR Qualified Residential Lighting Fixtures

ENERGY STAR qualified light fixtures are laboratory verified to meet strict efficiency, performance, and durability specifications set by the EPA.

All fixtures that have earned the ENERGY STAR mark meet strict criteria for efficacy, color rendition, and color temperature. In addition all qualified fixtures must also be flicker-free, emit no hum or buzz, and come with a minimum two-year manufacturer warranty. For more information on ENERGY STAR qualified fixtures, visit www.energystar.gov.

Lighting Design

There are many considerations associated with creating an effective, efficient lighting design. This section highlights a number of these considerations on a room-by-room basis. Frequent references are made to general, accent and task lighting, which for the purpose of this discussion, can be defined as follows:

- General lighting—indirect light from a central location
- Accent lighting—light that emphasizes a particular part of the room
- Task lighting—bright, focused light that illuminates a work surface

Kitchen

Today's kitchen is much more than a place to cook. The kitchen can be a gathering place for a crowd or a quiet place to prepare and eat an intimate meal. Kitchen lighting, therefore, needs to be inviting and functional. Use a range of lighting strategies to create the ambience you want, to properly display the natural colors of foods, and to provide sufficient work light. While the color temperature and color rendering index (CRI) are important criteria in most spaces, these performance parameters are particularly important in a kitchen.

- **Under-cabinet lighting** provides direct illumination of kitchen work surfaces (see Figure 10.1). Under-cabinet fixtures are out of sight and positioned to minimize shadowing on countertops. Under-cabinet lighting can provide both accent and task lighting. ENERGY STAR certified LED under-cabinet fixtures are now available and provide "directional" light source. This means LEDs emit light in a specific direction, unlike incandescent and compact fluorescent bulbs which emit light—and heat—in all directions. For this reason, LED lighting is able to use light and energy more efficiently in many applications" (source: ENERGY STAR). ENERGY STAR introduced LEDs in its lighting specifications in 2008.
- **Traditional ceiling domes and close-to-ceiling fixtures** provide general, indirect lighting from a central location. Complement these light sources with task lighting that targets high-use areas like countertops or sinks. The kitchen light is often the most used light in the house and an ideal location for an ENERGY STAR fixture.
- **Recessed ceiling fixtures** provide both accent and task lighting. Recessed fixtures carrying the ENERGY STAR designation are available; some models include special provisions to protect the ballast from heat, and some are available as dimmable fixtures. Recessed lights in the thermal envelope reduce insulation coverage and allow house air to escape into the attic, therefore, it is not recommended to avoid installing recessed ceiling fixtures in thermal enclosure assemblies. The energy code requires recessed lights in the thermal envelope to be air-tight, "IC" rated, and sealed or gasketed to the finish. Fixtures that are rated to be sufficiently air tight (2.0 cfm at 75 Pa) according to ASTM E283 meet these requirements. For recessed fixtures, ENERGY STAR certified fixtures using LED lighting elements are recommended as these typically last up to five times longer than CFL lamps.
- **Pendant fixtures** can be used over high-use areas like a table or breakfast nook. To control glare, hang a lamp above either side of a high-use area. To minimize shadows, avoid locating hanging fixtures near cabinets or in areas that will cast light on the back of a person working in the kitchen. ENERGY STAR qualified LEDs are generally completely enclosed to conceal the bulb.
- **Light fixtures that are integrated into the interior architecture** can provide both accent and general lighting (see Figure 11.1). Linear fixtures can be built into spaces above cabinets, into crown molding

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Lighting and Appliances

or behind decorative valances. Because architectural lighting is built on-site, you won't find an ENERGY STAR label. Ask for linear LED or fluorescent fixtures with high lumen output and a robust warranty.

Living Room

In living rooms, where comfort and ambience are key considerations, emphasize accent and task lighting, with a minimum of general lighting. Start with accent lighting over bookshelves, special artwork, a fireplace or entertainment system. Add table, floor or recessed lights for reading areas. Complete the room with a close-to-ceiling fixture for general lighting, or an ENERGY STAR ceiling fan/light for air circulation and general lighting.

Dining Room

When designing lighting for the dining room, consider how the space will be used. If this is a very formal area, indirect lighting may be just right. A single ceiling fixture over the table, recessed lights, and/or ambient light installed behind a soffit or valance will provide formal dining rooms with soft, diffused illumination. On the other hand, if the dining room is a central location that is used frequently for a variety of activities, supplement general lighting with task lighting, like a hanging pendant fixture and/or downward directed lights. A larger table may be better served by more than one fixture.

Bedrooms

In the bedroom, the importance of general lighting is secondary to warmly illuminated small areas and accurately lit task areas. Reading light can be provided by a table lamp on a nightstand or a fixture mounted on a wall behind the headboard. Desks, closets, and vanities require their own task lights. Architectural lighting, wall sconces, or a torchiere will provide sufficient lighting for the rest of the room.

The ENERGY STAR label can be found on a wide variety of portable fixtures. ENERGY STAR labeled table and floor lamps use much less electricity, and run much cooler and safer than conventional incandescent and halogen lamps.

Hall/Stairway

The main concern when lighting halls or stairways is to provide sufficient

illumination for safety. Wall sconces are popular for these areas, as are ceiling fixtures and sometimes architectural lighting.

Bathrooms

Bright, uniform, high-quality light is necessary in the bathroom. ENERGY STAR labeled bathroom fixtures will accurately show the colors of skin, clothes, and cosmetics. Place bath bar fixtures on either side of the mirror, or a single, wide fixture directly above it to avoiding casting shadows on faces. A ceiling fixture or soffit lighting works nicely for general room illumination.

Outdoor Lighting

ENERGY STAR qualified outdoor lighting fixtures also incorporate automatic daylight shut-off (photo-cell) and reduced energy use at night through use of an energy-efficient LED or CFL with motion sensor. Outdoor fixtures that are on for many hours each night can consume a great deal of electricity. Place wall-mounted fixtures on either side of your doors or ceiling fixtures in porch or entry overhangs. Illuminate walkways and driveways with lights on posts, on landscaping walls and in planting beds.

Light Quality

To be sure the homeowner will be happy with the efficient fixtures you choose, consider these elements of light quality:

- **Light output** (measured in lumens). LEDs that are bright enough to replace incandescents for household use (i.e. producing the same number of lumens as standard 40- or 60-watt bulbs) typically only use 9 to 12 watts. The U.S. Department of Energy advises that consumers who want to replace a 60-watt incandescent bulb should look for an LED that produces close to 800 lumens; for a 40-watt bulb, look for 450 lumens. All modern lighting packaging shows the number of lumens the bulb produces.
- **Color temperature** (measured in degrees Kelvin). The color of the light lies on a scale from warm (lower numbers on the scale) to cool (higher numbers on the scale). ENERGY STAR lighting has color temperatures suitable for residential use. Warm (2700° to 3000° Kelvin) light is common in living rooms and bedrooms. Cool (3500° to 5000° Kelvin) gives a crisp, clean look to kitchens and bathrooms. LEDs come in

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Lighting and Appliances

many color temperatures. Be cautious about mixing color temperatures of lighting within a space. Consistent color temperature within a space is generally more pleasing.

- **Color rendering** (measured on a scale of 1-100). Good color rendering (high index numbers) accurately displays colors, with 100 being a perfect score (e.g. sunlight). ENERGY STAR lighting has a color rendering index (CRI) suitable for residential use. Look for an LED with a CRI of 82 or higher; some LEDs are available with a CRI of 92.

For more information about energy-efficient lighting, visit www.energystar.gov, click on "New Homes," and go to Products in the top navigation bar.

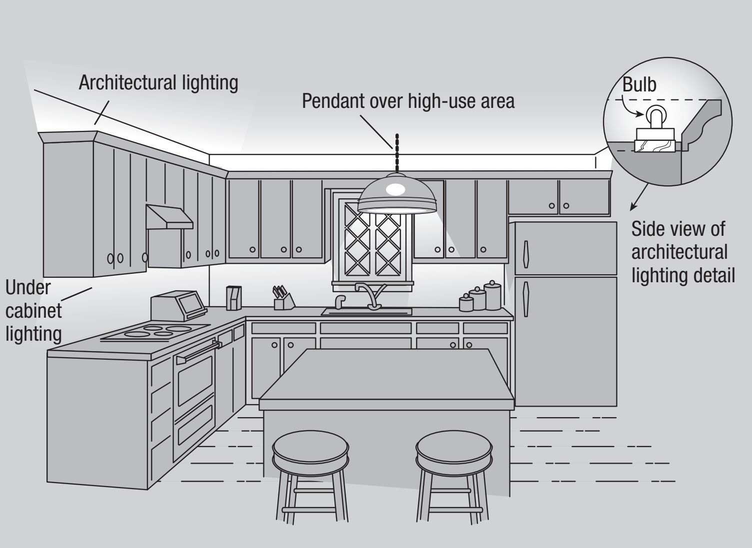
Appliances

By law, many major household appliances must display the Energy Guide label (see Figure 10.2). Use this information to compare the operating costs of different models.

The ENERGY STAR label (found on the Energy Guide or on the appliance itself) indicates an appliance that is significantly more efficient than the average appliance in its class. ENERGY STAR heating and cooling equipment can help earn the ENERGY STAR label for the homes you build. Also look for ENERGY STAR refrigerators, dishwashers, and washing machines.

The real cost of any appliance includes the purchase price, as well as maintenance and operating costs. Help your homeowners minimize operating costs by purchasing energy-efficient appliances.

FIGURE 10.1
Kitchen lighting design



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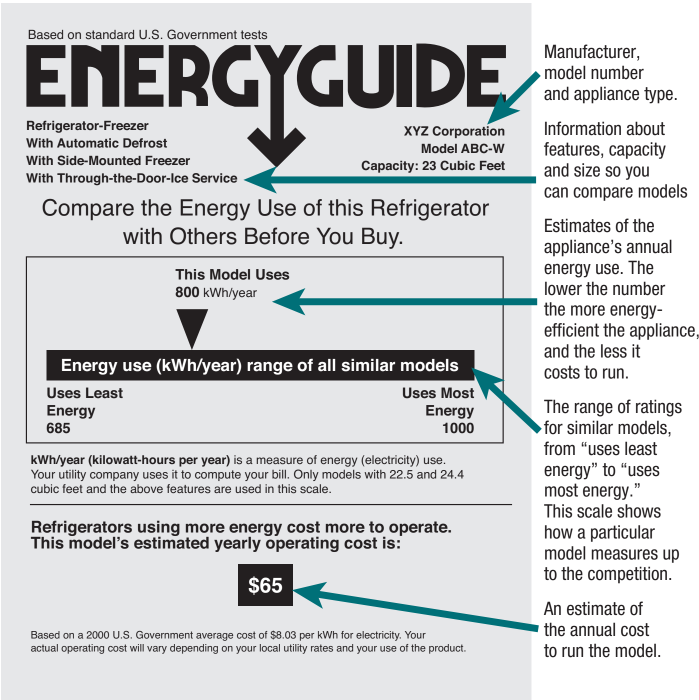
Lighting and Appliances

FIGURE 10.2

Energy Guide label



Air Sealing 11

Energy Code Requirements

The code has a list of areas that must be sealed (SBC-8, Table 402.4.1.1). The locations to be sealed include leaks between conditioned and unconditioned space, and leaks between conditioned space and outdoors. Note that fiberglass batts do not stop air and cannot be used as a sealing material.

It is interesting to note the extent to which code requirements for air sealing and fireblocking overlap: "Fireblocking shall be provided to cut off all concealed draft openings (both vertical and horizontal)…" (2012 IRC Section R302.11). Fire is much the same physically as heat loss, except it's much faster and more destructive. Specific fireblocking requirements parallel the requirements for air sealing that are outlined in the IECC, calling for draft stops that address the following:

- Hidden leaks in walls that intersect with attics and/or basements, including the openings around and associated with chimneys, ducts, vents, furred ceiling spaces, and the like (chaseways and cavities).
- Leaks that result from a change in ceiling height (e.g. soffits, drop ceilings).
- Leakage pathways associated with stair stringers.

In general, wherever draftstopping makes sense from an energy perspective, it is probably also required by fire code. Fire code however, may call for draft stops in places that do not align with the thermal envelope (such as between two heated floors). With respect to energy efficiency, these stops are less of a concern.

Fireblocking and air sealing requirements not only overlap, but are also complementary. With fireblocking, the emphasis is placed on selecting an appropriate material to serve as a draft stop (acceptable materials include 2" of lumber, 3/4" nominal plywood or particle board, 1/2" drywall or 1/4" cement board). Energy code complements this requirement by calling for the perimeters of these stops (or baffles) to be sealed to the surrounding surfaces. Both steps are required to achieve a complete and effective air barrier.

It is important to note that there is also one way in which these two sections of the code are *not* complementary. In addition to the items listed above, mineral and glass fiber materials are also allowed for use as fire stops. Fibrous materials however, are ineffective at stopping air. Consequently, they should not be used where air sealing is required.

The SBC-8 goes on to require sealed draft stops anywhere there are openings between conditioned and unconditioned space. The following is a list of some of the most important locations:

- Between wall and roof or ceiling; wall and floor; between wall panels. These are often some of the largest leaks in a house. They typically occur in places where cavities between studs or joists connect a conditioned space to an attic or basement area. "Draftstop" blocking is the simplest way to deal with these leaks. Typical examples are shown in Figures 5.11-5.18.
- Penetrations of utility services through walls, floors, ceiling/roofs, wall plates. Plumbing, electrical, duct and chimney chases are examples of these leaks. See Figures 4.7, 5.8, 5.11-5.12, 5.14, and 11.1- 11.7.
- Door and window frames—Rough openings should be sealed to frames with low expansion foam, caulking, or backer rod and caulk. Be careful, even with low expansion foam; if you fill large spaces it can still push out the jambs. To control this, don't worry about filling the entire space; just bridge the gap between the rough opening and the jamb.
- At foundation/sill—The numerous framing members between the top of a foundation wall and the toe plate of the wall above allow significant leakage. The weight of a house is not enough to force these pieces together. Foam "sill seal" between the foundation and sill is commonly used. In addition, seal the band joist area according to Figure 5.2 or 5.3. Note: vertical "steps" in the foundation height (where the grade changes) need special attention to avoid air leakage. Sill sealer will not generally stop air leakage in these locations.
- Around/behind tubs and showers—These leaks cause heat loss, and are common causes of comfort complaints and freezing pipes. Bathrooms over garages are especially prone to such problems. See Figures 11.7-11.8.
- At attic and crawlspace panels—Attic scuttles, pull-down stairs, access doors through knee walls into unheated attic spaces, add weather-stripping as well as insulation. See Figure 11.10.
- At recessed lights—The requirements for recessed lights are given on page 99, and Figure 11.9.

Durable caulking, gaskets, tapes, housewraps or air barrier systems should be used to seal these areas. The code also says to "allow for differential expansion and contraction of the construction materials," for example where wood, metal, concrete and/or plastic join each other. If you use housewrap for an air barrier, it should be installed according to manufacturer's instructions. These instructions generally call for careful detailing and taping of all seams, including—but not limited to—the edges around window and door openings, at the sill area, and where exterior walls meet roof lines. Also note that housewrap generally does not address many of the most significant leakage pathways in a house (which are typically found in attics and basements). See the *Water Management Guide* for more information about bulk water control.

Air sealing is an important part of energy efficient construction, but does not neatly fit into any one category of subcontractor. Some air sealing is done most easily by framers as they put the pieces together. Some can be done by drywall crews. Some insulation contractors specialize in air sealing.

But it is the builder who is ultimately responsible to see that adequate air sealing is done by the right people at the right times. If planned thoughtfully and done at the right stages of construction, most air sealing can be done with very little added expense.

The concept of air sealing is to provide a continuous air barrier all the way around the house. It does not mean hermetically sealing the building—there will always be leaks and cracks where air can get in and out. It does mean thinking about what material is going to stop indoor air from mixing with outdoor air (see Table 11.1, page 112). Note that in all drawings, the dotted line (in color) represents the primary air barrier.

Here are some hints to help with air sealing:

- **Get the biggest leaks first.** This may seem obvious but in the field, it's easy to overlook the biggest leaks. There's little point in caulking the small cracks or sealing electrical boxes if you have a plumbing chase or floor system that leaves a hole of ten, or twenty, or forty square feet, straight into an attic. A simple rule of thumb is, first seal up the ones you can crawl through. Then seal up the ones a cat can crawl through. Then go after the details.
- **Get the least expensive ones next.** Think about ways that you can build air sealing into tasks you are doing anyway, with materials that are on hand. Some examples: specify drywall adhesive or acoustical sealant on top plates and end studs of partition walls. Specify construction adhesive on all layers of floor framing instead of just the subfloor. Use leftover scraps of rigid insulation to block off chases or floor cavities. Then, before drywall is hung, have one person go around with a foam gun and seal up all the small wiring and plumbing penetrations in top plates or end studs, as well as the window and door frames. If you do whatever you can in two or three hours, it will make a big difference in most houses.
- **Once the drywall is up, all the leaks become invisible.** They don't go away—they just disappear so you can't see them. Walk through the house before the drywall crew shows up, imagine that only the ceiling sheetrock has been applied and ask yourself, "Can I stick my hand past the sheetrock, through the insulation and into an attic space from here?" Then imagine the sheetrock has been applied only to the walls and ask yourself a similar question: "Can I stick my hand through the insulation to the outside or to an unconditioned space (e.g., a garage) from here?" If the answer to either question is "Yes," then draft stops or blocking should be added before the drywall is hung. It will never happen later. (Of course if you are using "airtight drywall approach" then the drywall itself may be a substantial component of your air barrier. See Airtight Drywall Approach section (page 109) and Figures 11.1-11.3 for more information.)
- **Insulating and air sealing are separate issues.** Though some insulation materials resist the flow of air more than others, the choice of insulation material alone does not ensure air tightness. Proper detailing is important. Many air leaks occur in locations other than where the insulation is typically installed (for example, under a bottom wall plate, or around a window). No insulation will adequately seal large chases. Even when using a material like spray foam, care should always be taken to identify and address remaining leakage pathways.
- **Interior wood finishes should be backed by a separate, continuous air barrier.** Wood planking, tongue and groove wood products, etc. allow significant quantities of air to pass through their assemblies. These assemblies should never be left open to insulated building cavities that are part of the thermal envelope. Back these finishes with a continuous air barrier, such as drywall or rigid insulation that is sealed at the seams.

Other techniques

Much of the focus on building very tight buildings has historically concentrated on interior air barriers, particularly sealing and detailing of polyethylene vapor retarders as the primary air barrier. This should not be done in any house that has air conditioning. Instead use a material that's already there, such as the drywall or exterior sheathing, as the primary air barrier.

The use of "airtight drywall," for example, can significantly enhance the air tightness of a home at little extra cost. Another alternative worth considering is "smart membranes", typically used in Passive House construction.

Airtight drywall approach

If you use adhesive or acoustical sealant to attach drywall to top plates and end studs of partition walls, where they meet insulated walls and ceilings, this helps keep the air in the wall from getting "out." Add adhesive around window and door rough openings, caulk around electrical boxes, to complete a reasonable air barrier. At a minimum, specify adhesive on all top plates of walls that intersect insulated ceilings. If your drywall crew

11 Air Sealing

doesn't want to do that, you can squeeze a thick bead of acoustical sealant in these areas, and you have an instant gasket. See Figures 11.1-11.3 for more about "airtight drywall approach."

What if I build the house too tight?

There is no way to build a house "too tight." Tight is good. You can build an underventilated house, but not if you put in a ventilation system. Tight houses save the customer money and reduce callbacks, but you must install ventilation. Mechanical ventilation is required for all new homes. And the ventilation air will cost less to heat than random infiltration in a leaky house, every time.

Going Further

In addition to energy savings, you get other important advantages by building a tighter house. Tight construction can help reduce:

- **Ice dams**—Most discussion of ice dam prevention concentrates on passive ventilation of the roof sheathing, such as continuous soffit and ridge vents. Ice dams are caused by heat in the attic melting snow from the bottom. Although ventilation does dilute heat that gets into the attic, reducing the flow of heat in the first place is more important. Sealing up air leaks into the attic is the most important factor in reducing ice dams, followed by keeping HVAC out of the attic, and proper insulation.
- **Moisture in building frame**—Most of the focus on preventing water vapor from getting to cold surfaces (wall sheathing, attic structures, etc.) has traditionally centered on vapor retarders. Vapor retarders are important; but it has been shown that over 100 times more water vapor is carried into these spaces by leaking warm, moist air, than by diffusion. Seal up the air leaks (and install mechanical ventilation) to reduce moisture that causes structural damage and health risks. See the *Builder's Guide* for more on the relationship between vapor diffusion retarders and air flow retarders, and the mechanisms of vapor diffusion.
- **Freezing pipe problems**—Most pipe freeze-ups are a result of moving cold air, not just cold temperatures. Of course it is important to keep pipes on the warm side of insulated assemblies. However, it is also critical to define a good air barrier and keep the pipes on the "inside." Many pipe freezes occur in areas such as garage ceilings, kneewall floors, and other places where the air barrier is typically not well defined.
- **Insects and rodents**—Of course air sealing alone won't keep vermin outside the building, but it will greatly reduce their access to the living space. Be careful about exterior rigid insulation on foundations, which can provide invisible insect access into the house.

A wide variety of materials can be used to air seal a building. Material compatibility, the size and location of the leak, ultraviolet and/or high heat exposure, etc. should all be considered when selecting the products to be used. Important material-specific considerations are outlined in the following table.

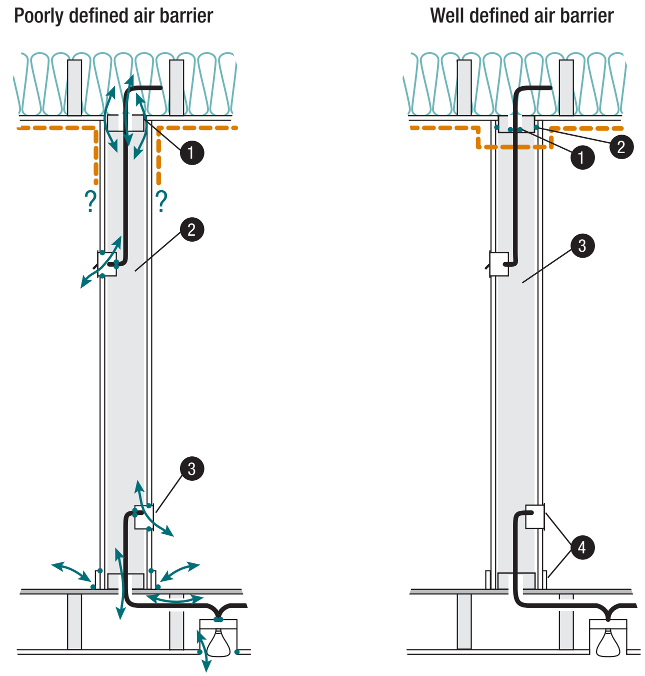
11 Air Sealing

Table 11.1 Air Sealing Materials

Material (Products)	**Notes**
Gaskets (backer rod, sill seal, EPDM gaskets, Trelleborg, Willseal 600)	• Gaskets are commonly used around windows and doors and between the foundation and mud sill, but can also work well in most other areas where a seal is required • More tolerant of differential movement of building assemblies than foam or caulk • Pre-formed EPDM gaskets are expensive, but can be very effective for sealing sill plates, drywall-to-plate connections, and other areas
Low Expansion Foam (Pur Fil, Great Stuff)	• Ideal for sealing gaps that are between 1/4” and 1/2” (e.g., around windows and doors, wiring holes, drywall cutouts, etc.) • Not rated for use in high temperature locations • Difficult to clean up; not for use on finish materials • Cans that are equipped with a reusable gun are the easiest to use and the best value • Protect from UV exposure
High Expansion Foam (Zero Draft, Froth Pak)	• Ideal for sealing locations with multiple leakage pathways, such as a band joist, top plates in an attic (after the drywall has been installed), a chase that is obstructed by ducts, pipes and/or wires, and other hard-to-reach areas • Do not use around windows and doors • Protect from UV exposure
Acoustical Sealant (Quiet Seal, Tremco)	• Durable caulk that stays flexible and accommodates differential movement of building assemblies • Can be used to seal drywall to framing (“air tight drywall approach”) • Only sealant that permanently adheres to polyethylene • For indoor use only
100% Silicone Caulk, Urethane Caulk	• Durable caulk for indoor or outdoor use • Use to seal gaps that are up to 3/8” (see manufacturer’s instructions) • Not paintable • Caulking should never be used on the building exterior as a barrier to rainwater entry; it’s not dependable for that application
Siliconized Acrylic Caulk	• Use to seal gaps that are up to 3/16” • Less flexible and durable than 100% silicone, but paintable • Use only where painting is required
Fire-rated Sealants (firerated caulking, furnace cement, high heat mortar)	• Non-combustible • Use to seal gaps around chimney/fluepipes • Wide variety of products, available in tubes or tubs
Rigid and Semi-Rigid Blocking (cardboard, foil-faced bubble pack or foam board insulation, wood, sheetrock, etc.)	• Blocking is needed to seal bypasses/chases that are too big to seal using any of the materials listed above • Perimeter of blocking should sealed to surrounding materials with foam or caulk • Metal flashing, sheet metal and/or foil-faced rigid fiberglass can be used to seal large leaks around chimneys or fluepipes • Wood, sheetrock, cement board or sheet metal must be used to seal bypasses/chases that are part of a fire-rated assembly (between dwelling units or between a dwelling unit and an attached structure that is categorized as a different type of occupancy)

FIGURE 11.1

Strategic sealing: interior partition wall intersection with attic



A lot of material and effort may be needed with no guarantee that leakage will be stopped.

Sealing the top plate, before the drywall is hung, requires little effort and completes the air barrier at the insulated ceiling.

Poorly defined air barrier:

1. Air barrier is broken at attic/wall intersection. Top plate shrinks away from drywall when wood dries
2. Wall cavity serves as duct linking unconditioned attic to rest of house
3. Many potential air leakage paths. Sealing one may simply shift leakage to another.

Well defined air barrier:

1. Seal top plate penetrations
2. Seal drywall to framing–“air tight drywall approach”
3. “Inside air”
4. No need to seal drywall penetrations in interior wall

FIGURE 11.2
Sealing intersections at the ceiling

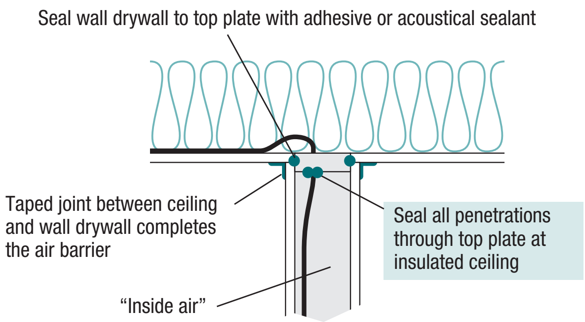
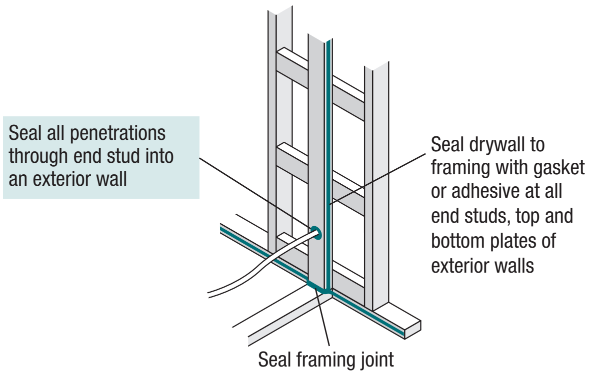
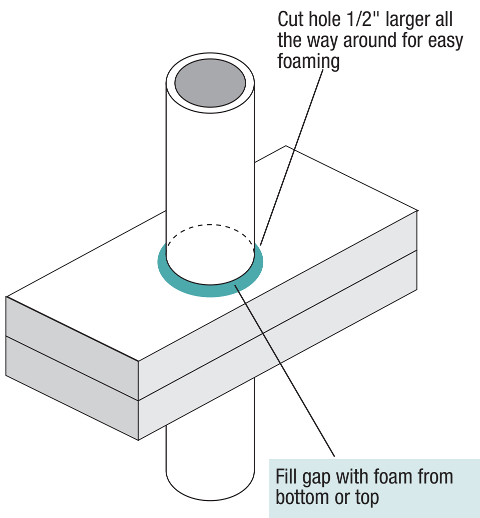


FIGURE 11.3
Sealing intersections at exterior walls



The sealing techniques shown in Figures 11.1 to 11.3 are the fundamental components of "airtight drywall approach" (which includes airtight or sealed electrical boxes, and carefully sealed band joists as well). Even if you are not using a complete "airtight drywall" system, specifying adhesives at top plates and end studs will significantly reduce air leakage. Be especially careful at the intersections where multiple partition walls meet each other at insulated ceilings.

FIGURE 11.4
Sealing plumbing vent pipes

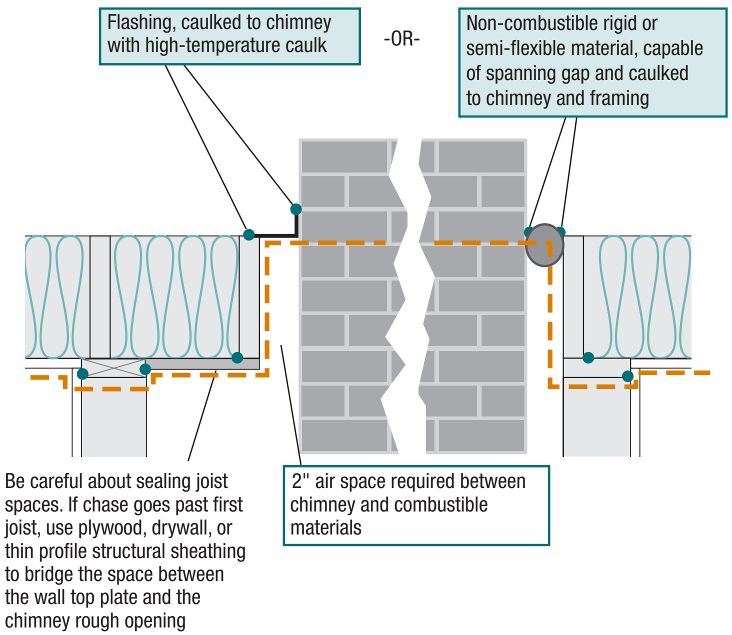


Plumbing vent pipes can be sealed with foam from above or below. Long, straight pipe runs may be sealed using a rubber boot or roof boot to address the movement of pipes relative to the framing. This requires coordination with the plumber, to install it as the pipe goes in.

11
Air Sealing

FIGURE 11.5

Chimney Chases

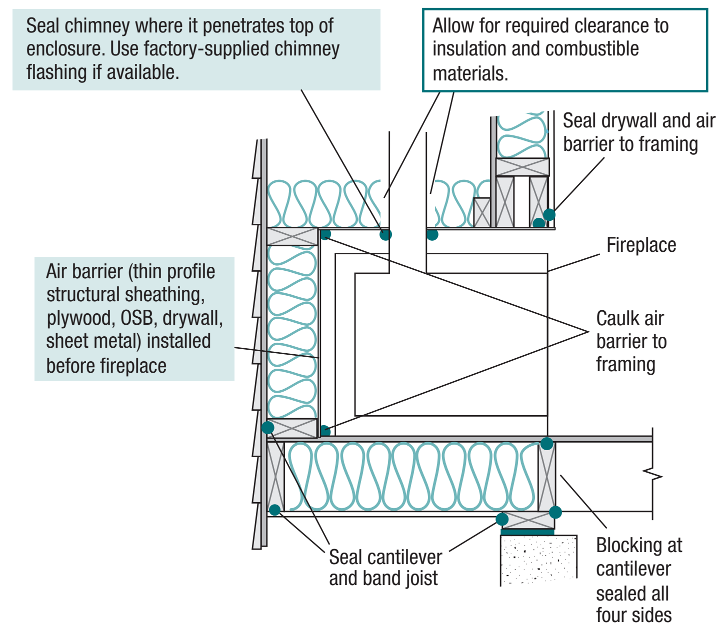


NOTE: Duct chases can be just as large a leak, but ducts can be sealed directly to framing with spray foam.

Unsealed chimney chases are often one of the largest leaks in a house. Be careful to keep combustible materials at least 2” from the chimney, and use high-temperature silicone caulking or firestop caulk. Many prefabricated chimneys have draft blocking and/or insulation guard kits available to fit them; follow the manufacturer’s instructions.

FIGURE 11.6

Air sealing fireplace enclosures



TIP: In some instances with complex framing, such as a home entertainment center recessed above the fireplace cavity, it may be simpler to use the exterior sheathing as the air barrier. However, it is still necessary to seal the top of the chase as shown in Figure 11.5.

Insulate, install the air barriers and do the sealing before the fireplace is set in place.

FIGURE 11.7

Boxed-in tub in insulated floor

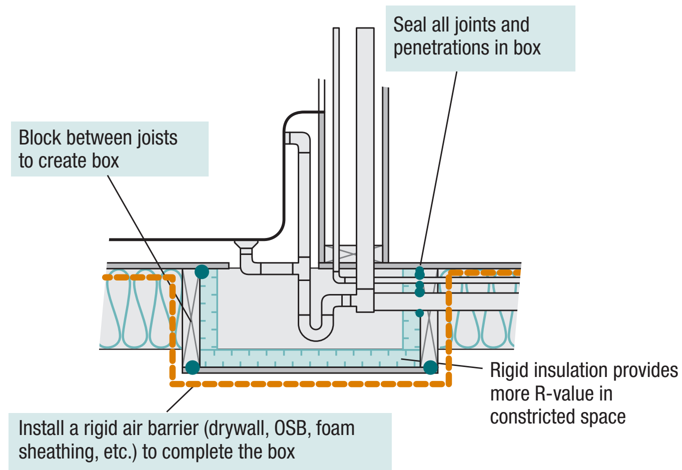
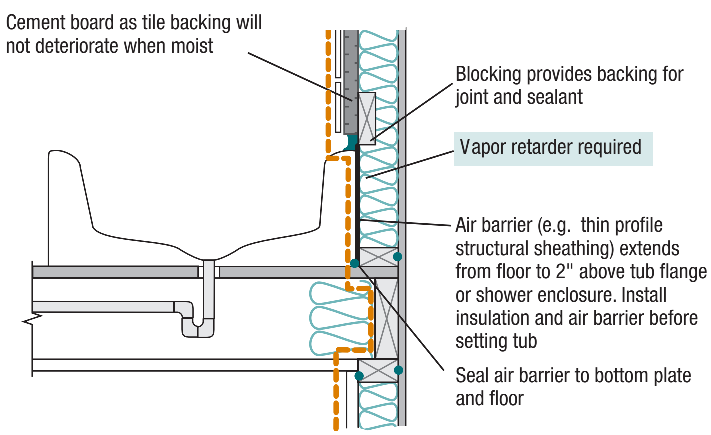


FIGURE 11.8

Sealing tub and shower enclosures



CAUTION: Do not use standard or moisture resistant drywall as a tile backing material in this application. They deteriorate when they get wet.

FIGURE 11.9

Recessed lights

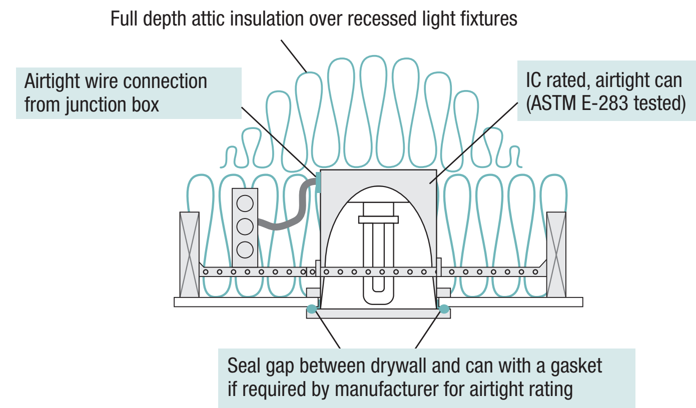


FIGURE 11.10

Attic hatch

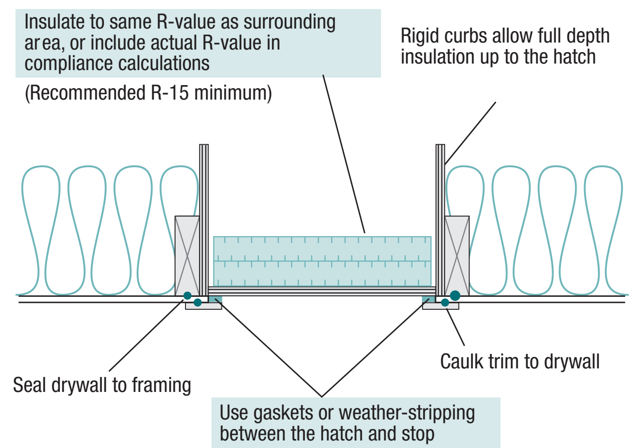
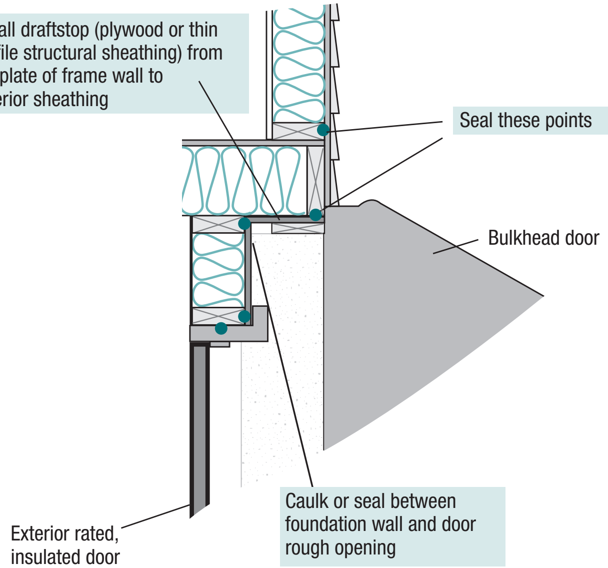


FIGURE 11.11
Bulkhead door detail



NOTE: This area may contribute to air leakage even in an uninsulated basement.

CAUTION: This area may contribute to air leakage even in an uninsulated basement.

NOTE: Bulkhead flashing should be integrated with building drainage plane; details not shown for clarity.

Insulation 12

Energy Code Requirements

Insulation R-values

The R-values of insulation in any part of the thermal envelope are defined by your compliance analysis. Whether it is a prescriptive table, a RES*check* printout or any other approach, the minimum R-value for each component is specified and documented with the building permit application (SBC-8, Section R103.2). If, during construction, you want to substitute a lower than specified R-value for a particular component (wall, ceiling, etc.), you must redo the compliance analysis to see if that will pass the code, and re-submit the paperwork with the new specifications. You may have to substitute higher R-values somewhere else in the building to compensate, or choose a different compliance package.

Proper installation

All R-values are based on proper installation. For fiberglass batts, this means:

- **Full loft**—Insulation should be fluffed to its full thickness, not compressed, and not rounded or scalloped at the edges.
- **Fill the cavity**—Insulation should be in snug contact with all wall studs, plates, sheathing and drywall. In ceilings and floors, it should be

in contact with the drywall or subfloor, and extend all the way to joists on both sides without gaps (see Figure 12.2).

- **Cut around obstacles**—Insulation should be split around wires and small pipes; cut out around electrical boxes, larger pipes and other obstacles; and split over cross bridging in floors. Never stuff insulation in to get it to fit (see Figure 12.1).

Refer to industry standards such as *Fiber Glass Building Insulation: Recommendations for Installation in Residential and other Light-Frame Construction* (North American Insulation Manufacturers Association), *Standard Practice for Installing Cellulose Building Insulation and Standard Practice for the Installation of Sprayed Cellulosic Wall Cavity Insulation* (Cellulose Insulation Manufacturers Association), or the SPFA Technical Documents and SPFA Tech Tips available from the Spray Polyurethane Foam Alliance. These resources are listed in Appendix B.

Documentation of R-values (SBC-8, Sections R301.1.1-4)

Many common insulation products have R-value markings right on them. Faced and unfaced fiberglass batts, and rigid foam insulation must be installed so the markings are visible to the building inspector. If you are using blown- or sprayed-in insulation such as cellulose, spray foam, or blown fiberglass, the installer should provide a certificate showing installed thickness, settled thickness, the square feet of coverage, the number of bags (or amount of material) used, and the net installed R-value.

For blown-in attic insulation, "tell-tale" inch markers are also acceptable, provided they show installed thickness and settled thickness (one marker minimum per 300 square feet of attic.)

Credit for "raised truss" construction (SBC-8R, 402.2.1)

Insulation in flat or cathedral ceilings is assumed to be compressed over the exterior walls, as is typical (Figure 12.4). If you can install the insulation in such a way as to get the full R-value of insulation all the way to the outside of the exterior wall, then you can take credit for "raised truss" in the RES*check* software ceiling input box. In the prescriptive method a raised truss or its equivalent allows you to substitute R-30 for R-38. This does not mean you have to use a raised heel truss to get this credit; examples of alternative methods are shown in Figures 12.5-12.7, 12.9.

Depending on the roof geometry and the care of installation, you may not even need to modify the framing.

For example, a high-pitched roof truss with a large overhang may not need any special treatment to achieve the full R-value at the eaves.

Access Openings (SBC-8, Section R402.2.4)

Attic hatches, scuttles, pulldown stairs, etc. must be insulated to the same R-value as the surrounding area, or the actual R-value must be accounted for in your calculations (see Appendix A).

Steel Framing

Steel is an excellent conductor of heat. Consequently, the effective performance of insulation in steel framed building assemblies is reduced dramatically. Cold interior surfaces near the steel studs bring an increased potential for condensation and mold growth. Code accounts for the thermal "bridging" that results from the use of steel framing by making insulation requirements more stringent. The easiest way to meet these requirements is to add a layer of continuous, rigid insulation that covers all the framing and acts as a thermal "break" (see IECC 2012, Table R402.2.6) for insulated steel and wood wall equivalencies).

Insulation Grading

The national Home Energy Rating System (HERS) industry has developed guidelines for assessing insulation installation quality. These guidelines (summarized below) are an integral part of the HERS industry. The installation grade must be factored into the HERS analysis that is used to determine performance- based compliance.

- **Grade I**—Near perfect installation quality (full height, full width, full depth, no voids, no gaps, cut to fit neatly around any intrusions, etc.). Grade I is also used to describe insulation that is generally installed according to manufacturer's instructions and/or industry standards. There are other location-specific requirements for Grade I for walls, ceilings and floors.
- **Grade II**—Average installation quality with a minimum of voids and compression. Insulation may have occasional defects such as gaps around wiring, electrical outlets, plumbing and other intrusions. There

are other location-specific requirements for Grade II for walls, ceilings and floors.

- **Grade III**—Poor installation quality, which may include gaps, voids, compression, rounded edges or "shoulders," incomplete fill, etc.

Here are some additional guidelines:

- **Faced batt insulation** may be installed by stapling the flanges to either the sides or face of the framing that runs along the edges of the batt (see Figure 12.3). When side stapling, be sure to staple the tabs neatly (no buckling), and to compress the batt only at the edge of each cavity and only to the depth of the tab itself. Face stapling is generally considered to be preferable to side stapling from an energy perspective, but the performance difference is likely to be small. Face stapling is often disliked by drywall installers. To lessen the potential impact, be sure to set staples firmly into the studs, avoid pulling fiberglass fibers over the face of the studs, and mark the stud locations on the floor.
- **High density fiberglass batts** such as R-13, R-15, and R-21 get a higher R-value in the same cavity. They also tend to be stiffer, and fluff up so it is easier to get a good fit without compression. It is a good idea to use high density batts if you are using fiberglass. You can get credit for the added R-value in the code analysis.
- **Air barriers and eave baffles to prevent wind washing** (Grade I requirement)— No matter how well you install insulation, cold air washing through it will not only severely compromise its effectiveness, but also increase condensation potential by cooling the interior finish. Eave baffles made of solid material are essential and a code requirement (SBC-8, Section R402.2.3) (see Figures 12.5, 12.6 and 12.8); if the baffle extends above the top of the insulation, no vent chute or "propavent" is required. Also vulnerable are exposed insulated walls, such as attic knee walls (Figures 5.15, 5.16 and 5.18). Cover the exposed fiberglass on the attic side with a vapor permeable air barrier such as housewrap, polystyrene foam, drywall, or similar material. Floor insulation over piers, cantilevers and the like should also be sealed to prevent outside air from circulating into the insulation (Figures 5.11 and 5.12). Flat or sloped attic insulation need not be covered, but baffles should be provided near eaves (see Figures 5.16, 5.17, and 12.5, 12.8, and 12.9).

- **Cavity fill types that improve air tightness**—Some insulation materials can help. See page 22.
- **Avoid strapped ceilings**—1x3 furring strips running perpendicular to the joists provide a cavity for free air circulation, which often compromises the insulation performance, especially near eaves and in cathedral ceilings. Once nailed in place, they also make it very difficult to install insulation properly. This is another area where money can be saved while thermal performance is improved.
- **Higher R-values in sloped ceilings** can be achieved with smaller framing by adding sister joists with plywood gussets (see Figure 12.9) or by adding a continuous layer of rigid insulation on the underside of the roof rafters.

FIGURE 12.1

Insulating around plumbing, wiring, and other obstacles

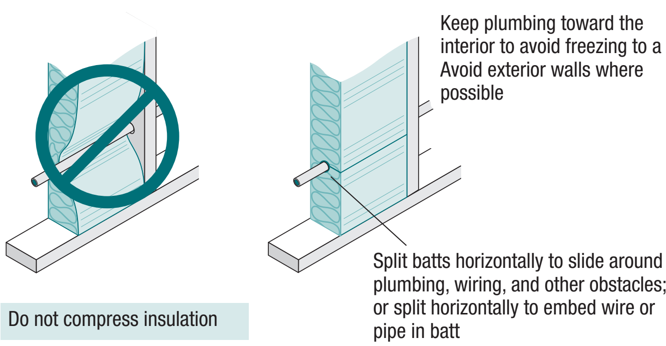


FIGURE 12.2

Effective R-value of insulation

This schematic shows the effect of insulation installation quality and technique on effective (or installed) R-values. Note that the same depth of insulation (12", nominally R-38) is used in all three cases.

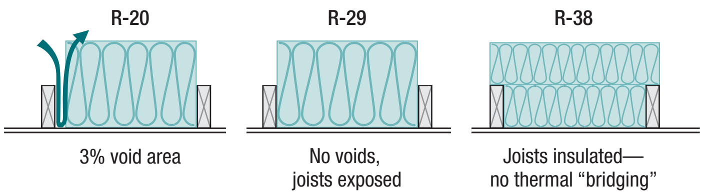


FIGURE 12.3

Face-stapling versus inset stapling kraft-faced batts

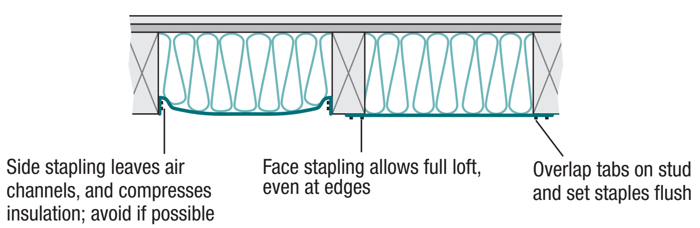


FIGURE 12.4

Conventional truss

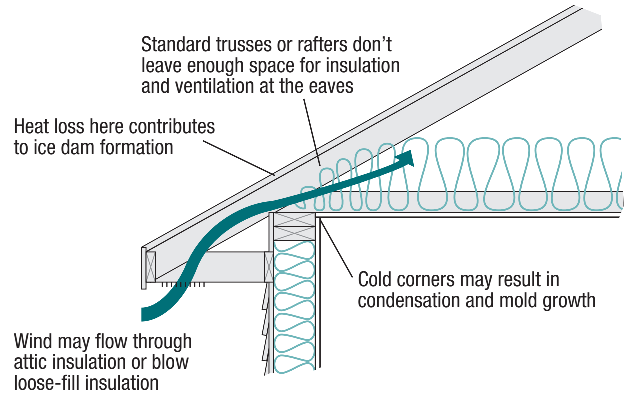
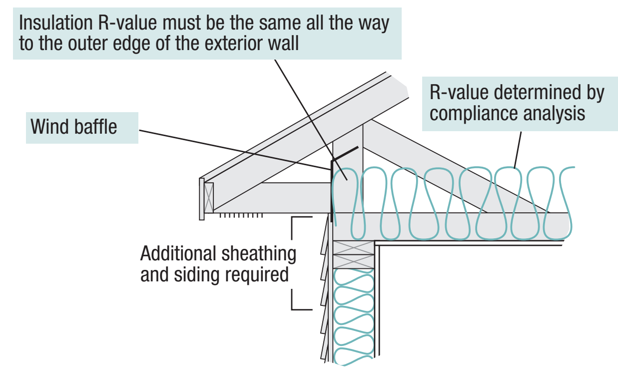


FIGURE 12.5

Conventional truss

Raised heel trusses can be ordered for any eave height.



Credit is given in the code compliance analysis for better performance. See Figures 12.6 and 12.7 for other options.

CAUTION: Trusses must be sized carefully so that the truss heel lines up with the edge of the wall below.

FIGURE 12.6

Conventional truss or rafter with insulated eaves

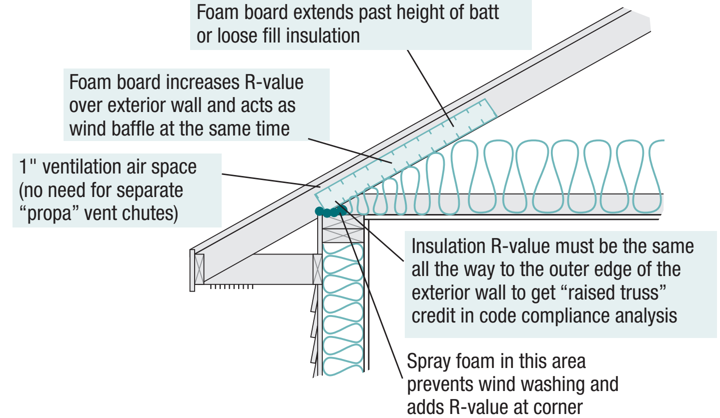


FIGURE 12.7

Conventional rafter with raised plate

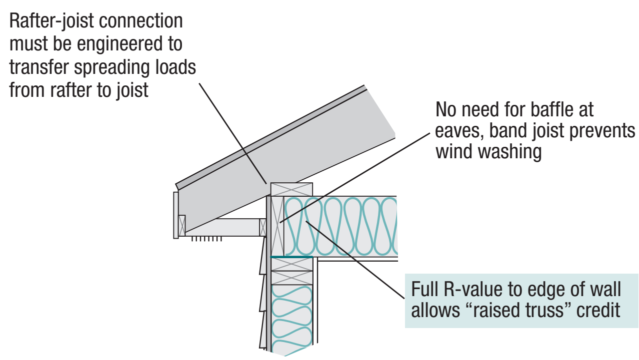


FIGURE 12.8

Vented cathedral ceiling

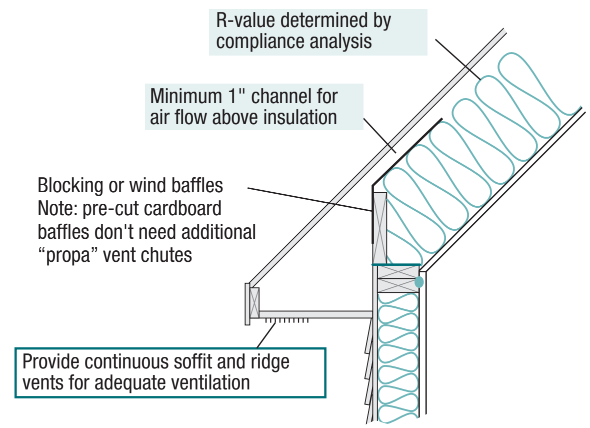
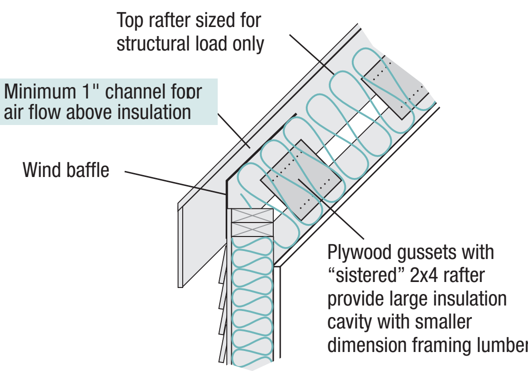


FIGURE 12.9

Cathedral ceiling with built-up rafters



12
Insulation

12
Insulation

Health and Safety 13

Indoor air quality, moisture, and mold continue to be growing areas of awareness and concern for both new-construction builders and homeowners. Home health and safety derives from the performance of the "house as a system" and is impacted by all components of a home. Unfortunately, incomplete or watered down information in popular media can confuse the issue, often portraying moisture problems as a result of one aspect in isolation, such as "tight" construction. (In reality, most of the mold and moisture problems in buildings result from poor exterior water management, followed by thermal- and air-barrier defects.)

Additionally, building materials contain more "mold-loving nutrients" than existed even 10-15 years ago. For example, codes and building practices have emphasize highly vapor permeable exterior sheathings and highly impermeable interior vapor barriers—resulting in cases of dramatic building failures caused from inward-driven moisture in air-conditioned buildings.

A builder or designer who wishes to set him- or herself apart from the competition can easily learn the fundamentals of healthy construction, indoor air quality, and especially mold and water management. While you must be careful not to promise a "mold-free" environment, you—as a builder or designer knowledgeable about health and safety—can promise new construction with "reduced risk" for mold and other air quality concerns.

In many cases, health and safety may attract more attention among buyers than energy efficiency. In truth, if you design and build a building to be mold-resistant, comfortable, and healthy, you also design a building that is energy efficient.

Overview

There are many health and safety issues in residential buildings. Structural integrity and loading of beams, seismic, wind and snow loads, fire protection and egress, basic sanitation, and electrical safety are all covered in building codes and associated mechanical, fire, plumbing, and electrical codes.

The majority of code requirements are related to life safety issues: prevent the building from falling on occupants, evacuate occupants quickly in case of a fire, prevent electrocution and fire hazards from wiring, and provide for clean, reliable potable water and waste removal. These are the immediate, obvious health and safety issues which codes properly govern to ensure a basic level of security for homebuyers, and a level playing field for builders.

Codes that address other health-related concerns, such as fresh air ventilation standards, are often not as clearly understood. And there are less obvious—but equally important—issues that arise in residential building construction.

The purpose of this section is to provide a brief overview of the health and safety aspects of the "house system." This summary is only a brief introduction to "healthy construction" concepts; more resources are provided in Appendix B.

Are cars safer than homes?

Not really, but you can think about these health and safety issues in the context of shopping for an automobile. Whether you buy a luxury model, a compact economy car, an SUV, or a sports car, you expect a certain level of safety. Even though these cars may perform very differently and fulfill different needs, they all have seat belts, headlights, and air bags. Similarly, even though houses are designed to meet many different needs, they should all have a basic set of protections for health and safety beyond those that are found in building codes.

Air sealing and water vapor control is as critical as a seat belt in a car. A mechanical ventilation system is as essential as an air bag. Sealed combustion equipment and a carbon monoxide detector can be compared to headlights and taillights, and a good exterior water management system is the equivalent of windshield wipers. You wouldn't buy a car without these safety features, and every home should have health and safety as a priority as well.

Priorities

New-construction homeowners, and the industry as a whole, increasingly prioritize mitigation of health hazards resulting from indoor mold exposure, dust mites, volatile organic compounds, and other airborne contaminants. We've learned that incidence rate of asthma has nearly doubled in the last 30 years, in turn impacting childhood health, well-being and school performance (source: EPA). Scientists identify changes in the indoor environment as the primary cause.

Researchers have also found that indoor air quality is more polluted—sometimes as much as 100 times more—than outdoor air, and contributes to allergies, nausea, sinusitis, fatigue, and even extreme chemical sensitivities. Because Americans spend up to 90 percent of their time indoors, it is of highest importance that we, as new construction professionals, commit to health and safety best practices.

To build a safe, healthy home, we abide by **six principles** which serve to control the indoor environment. These principles are expressed as control of air flows, water vapor flows, bulk water flows, energy flows, particulate flows, and pollution sources and flows. The following paragraphs outline the basic approaches to help control the indoor environment:

- **Air flows**—Unintended air flows can be unhealthy for many reasons. These air flows can result from the stack effect (uncontrolled infiltration), duct leaks in basements and attics, unbalanced supply and return duct flows, exhaust fans, or combustion appliance makeup air, all of which create air pressures.

  Low pressures in basements can increase concentrations of radon, sub-soil pesticide treatments, or other soil gases in the home, as well as increased energy loads. High pressures can result in warm, moisture-laden air being pushed into exterior walls or into attics and roof systems, where water vapor can condense and cause mold, mildew, and decay. Air flows caused by induced pressures or by the stack effect can draw deadly car exhaust or fumes from stored chemicals from a garage into the house, or can backdraft combustion appliances. For all these reasons, it is important to reduce or eliminate unintended air flows. The most important methods to control air flows are as follows:

—Create a substantially airtight building envelope by sealing air leaks

—Design duct systems properly for balanced air flows

—Seal ducts tightly

—Install only sealed combustion appliances

—Design and install makeup air for large exhaust appliances, if necessary

- **Moisture flows**—Either too much or too little moisture can be unhealthy. High humidity can lead to increased concentrations of biological contaminants, such as mold and mold spores, dust mites, mildew, bacteria, and viruses. Low humidity can result in increased incidence of respiratory infections, rhinitis (chronic runny nose), and discomfort. It is generally recommended to keep indoor moisture levels between 30 and 60 percent relative humidity (some experts say 35 to 50 percent—also see page 85). To control indoor moisture levels year-round, you must:

—Build an airtight envelope to reduce the air exchange that dries air in the heating season and draws humid air in the summer. This includes sealing ducts that may be outside the insulated envelope.

—Provide spot ventilation for bathrooms and kitchens, and any other special sources of moisture loading (e.g. pool, hot tub, fish tanks).

—Provide dehumidification or air conditioning in the summer. Note that oversized air conditioning will not provide the level of dehumidification needed to keep humidity levels under control; it is actually better to have a slightly undersized air conditioning system for optimum health throughout the summer. (With a slightly undersized air conditioner, the indoor air temperature may drift up by a degree or two for a few hours during the hottest days of the year.) Indoor air quality, by contrast, will be improved for the vast majority of the humid cooling season.

- **Bulk water** leaking into a home (or from plumbing) can also be a source of high humidity or wet building materials, resulting in many of the same biological contaminants. The following steps are also critical to control moisture:

—Foundation water-management systems, such as damp-proofing, capillary breaks, site and foundation drainage, rainwater drainage, grading, and proper basement/crawl space insulation and conditioning.

—Exterior water-management systems, such as a continuous drainage plane, flashing, siding, and roofing details. Best practice for exterior walls is to use a vented rain screen, with an air space between the siding and the drainage plane. Be especially careful of flashing details where roofs and decks meet vertical walls. (See the *Builder Guide* and *Water Management Guide*.)

- **Energy flows**—Energy use in a building is related to health, although less directly than the other listed approaches. In addition to increased energy loads that result from large air flows through the building envelope, cold, poorly insulated surfaces may lead to condensation, mold, and mildew. It is possible that people living in a comfortable home also tend to be healthier.

—Select windows that have, at a minimum, low-e glazing and argon gas fills. Higher performance glazings, heat mirror films, "warm edge" spacers, and insulated frames raise surface temperatures and reduce the chance of condensation and fungal growth on the glass and sash.

—Higher levels of insulation and framing that avoid thermal "bridging" of framing from inside to outside surfaces will also reduce condensation problems and increase comfort.

—Insulate basement walls and slab floors to prevent condensation in the summer, even if they are not in the finished living space.

—Duct insulation and vapor jackets on the exterior of insulated ductwork are critical. Heating, air conditioning, or exhaust air ducts traveling through unconditioned spaces should be well insulated; the vapor jacket on the exterior of insulated ductwork should be uninterrupted. Cold-air ducts in conditioned and unconditioned spaces should also be insulated carefully with an exterior vapor jacket. (If ductwork exists in unconditioned space, it should be sealed and insulated.)

- **Particulate flows**—Most homes lack the equipment to filter indoor air. Filters that come with furnaces, central air conditioners or heat pumps are only designed to protect the equipment from damage. Better air filters can reduce many of the particles that can cause health problems. High Efficiency Particulate Attenuation (HEPA) filters are the best grade of filter, and may be ideal for people with existing respiratory ailments. It's also a good idea to design a whole-house ventilation system or air distribution system with the capability of adding a HEPA filter, if needed. Avoid electrostatic filters, ionizers, and any air treatment devices that produce ozone. Also note that any filter must be carefully designed into the air handling system, to account for any pressure resistance created by the filter.

  —One advantage of balanced supply and exhaust ventilation (such as an Energy Recovery Ventilator) is that the fresh air supply can be filtered, unlike exhaust-only systems.

  —The air-handler fan of a furnace or air conditioner can provide whole-house air circulation with filtration. Use a low-speed setting on the blower with constant or intermittent circulation. Look for controls that keep track of blower run-time to ensure minimum ventilation rates.

  Because cooking is a significant source of particulates, it is essential that cooking appliances be paired with an adequate range hood that exhausts to the exterior. Ideally, the range hood exhaust would be automatic or interlocked with operation of the cooking appliance.

- **Contaminant sources and flows**—Contaminants are indirectly related to energy, but as new construction professionals, health and safety—and thus contaminants—is our top priority. Sources of contaminants are many: volatile organic compounds (VOCs) are found in paints, paint strippers, solvents, wood preservatives, and carpeting, as well as stored fuels and automotive products; formaldehydes are found in manufactured-wood products such as interior grade plywood, medium density fiberboard (MDF), carpets, and furniture; stored household chemicals such as cleaning products, aerosol sprays, and moth repellents are often toxic; and pesticide and herbicide treatments may be present immediately around or stored in the home. Radon gas can be drawn into the house from below the ground, if present. Many contaminant sources can be controlled by the builder or designer:

  —Source reduction is the most effective way to reduce exposure. Use of low-VOC paints, glues and finishes, hard surface flooring (wood or tile) instead of carpeting, wood cabinets or sealed MDF, and non-toxic wood preservative treatments all can help improve the health of the occupants.

  —Reduce exposure by separating sources from the living space. Garages, combustion appliances, and the earth around foundation typically contribute contaminants; thus controlling air flows between conditioned and unconditioned space will help mitigate contaminants.

  —Proper fresh-air ventilation dilutes contaminants and helps ensure that existing contaminants (or contaminants that may be introduced after the house is finished) can be reduced to safe levels. Building codes now require a whole-house ventilation system in every home or living unit.

  —Radon pre-mitigation is a form of controlling contaminant flows. Every basement or on-grade slab should have at least 4" of uniform, washed stone underneath, 1/2" to 1-1/2" diameter, with no fine particles. Put it under the insulation if you are insulating the slab. Radon levels should be tested after occupancy by an EPA-certified lab. If high levels are found, the stone will allow for effective sub-slab depressurization with a fan to be added later. At a minimum, install a short stub of 4" PVC pipe vertically through the slab, left 4-6" above and capped off. The bottom end should be in the stone layer. Even better, run the pipe right up through the roof, and if a fan needs to be added later it can be easily installed in the attic with minimal disruption.

TIP: For in-depth steps to help ensure indoor health and safety, visit epa.gov/indoorairplus/pdfs/construction_specifications.pdf

13 Health and Safety

Appendix A

R-Value/U-Value Average Worksheet

COMPONENT DESCRIPTION	R-VALUE	U-VALUE (1÷R-VALUE)	AREA	UA (U-VALUE x AREA)
			TOTAL AREA=	TOTAL UA=

______ ÷ ______ = ______
TOTAL AREA ÷ TOTAL UA = WEIGHTED AVERAGE R-VALUE

______ ÷ ______ = ______
TOTAL UA ÷ TOTAL AREA = WEIGHTED AVERAGE U-VALUE

If you wish, make extra copies of this page. A similar worksheet can be found in the RES*check* support materials from www.energycodes.gov (see Appendix B).

This worksheet can help you calculate the overall R-value or U-factor of groups of components that have different thermal performance. You can use it to calculate the average R-value of two ceiling, wall or floor areas that have different insulation levels; or to get the average U-factor of two different types of windows or doors.

You may find this especially useful if you are using a prescriptive compliance method for a house or an addition. This is the only way that you can get an insulation level "trade off" using the prescriptive method.

The examples on the following page show how to calculate an overall Rvalue for a ceiling with an uninsulated attic hatch; and the overall U-factor for a group of windows of U-0.36 and a patio door of U-0.42.

R-Value/U-Value Average Worksheet

COMPONENT DESCRIPTION	R-VALUE	U-VALUE (1÷R-VALUE)	AREA	UA (U-VALUE x AREA)
attic flat	38	0.026	932	24.5
hatch	1	1	4	4
			TOTAL AREA= 936	TOTAL UA= 28.5

This example shows the effect of a single uninsulated attic hatch on the R-value of a well-insulated ceiling. R-38 is degraded to R-33!

TOTAL AREA	÷	TOTAL UA	=	WEIGHTED AVERAGE R-VALUE
936	÷	28.5	=	32.8

TOTAL UA	÷	TOTAL AREA	=	WEIGHTED AVERAGE U-VALUE
	÷		=	

COMPONENT DESCRIPTION	R-VALUE	U-VALUE (1÷R-VALUE)	AREA	UA (U-VALUE x AREA)
windows	—	0.36	239	86
patio door	—	0.42	40	16.8
			TOTAL AREA= 279	TOTAL UA= 102.8

In this example, the patio door has a small effect on the overall window U-value.

TOTAL AREA	÷	TOTAL UA	=	WEIGHTED AVERAGE R-VALUE
	÷		=	

TOTAL UA	÷	TOTAL AREA	=	WEIGHTED AVERAGE U-VALUE
102.8	÷	279	=	.37

Appendix B

Resources

Codes

Energy Code Assistance Center
Rhode Island Energy Code Technical Support
855-343-0105
https://www1.nationalgridus.com/EnergyCodeTechSupport

The International Energy Conservation Code (IECC) and the International Residential Code (IRC) for One- and Two-Family Dwellings are all available from:
International Code Council, Inc.
www.iccsafe.org

The RES*check* software and user's guide available as free downloads from:
www.energycodes.gov/rescheck

General Building Science

Builder's Guide to Cold Climates
2011, reprinted 2014
Building Science Corporation
www.buildingscience.com

Here are some helpful links and resources on the Rhode Island energy code and better building practices.

SBC-8 RI State energy conservation code
http://sos.ri.gov/documents/archives/regdocs/released/pdf/BCSC/7284.pdf

Rhode Island state building code
http://sos.ri.gov/library/buildingcodes/

Database of state incentives for energy efficiency and renewable energy
http://www.dsireusa.org/

DOE Building Energy Codes Program
A variety of resources, including: compliance tools, training materials, cost savings analysis, and technical assistance options.

Building America Solution Center
https://basc.pnnl.gov/
Access to expert information on hundreds of high-performance construction topics, including air sealing and insulation, HVAC components, windows, indoor air quality, and much more.

www.bestofbuildingscience.com
Short videos specifically designed for builders, sub-contractors, and design professionals in the residential construction business.

www.buildingscience.com
Great resource with lots of valuable building science information and design details.

www.buildinggreen.com
Website for Environmental Building News, a great technical periodical.

www.greenbuildingadvisor.com
Valuable technical resources and discussions boards. If you like podcasts, The Green Architect's Lounge is a great resource.

Local conferences

BuildingEnergy:
Annual conference in Boston, MA in March

JLC Live:
Annual conference in Providence, RI in March

Better Building by Design:
Annual conference in Burlington, VT in February

Affordable Comfort:
roving regional conferences

Publications—Periodicals and Catalogs

Environmental Building News
Brattleboro, VT
(802) 257-7300
(800) 861-0954
www.buildinggreen.com

Fine Home Building
The Taunton Press
Newtown, CT
(203) 426-8171
(800) 477-8727
www.taunton.com/finehomebuilding

Home Energy Magazine
Berkeley, CA
(510) 524-5405
www.homeenergy.org

Journal of Light Construction
Williston, VT
(800) 375-5981
www.jlconline.com

Product Distributors

The Energy Conservatory
Minneapolis, MN
(612) 827-1117
www.energyconservatory.com

Energy Federation, Inc.
Westboro, MA
(800) 876-0660
www.efi.org

Positive Energy Conservation Products
Boulder, CO
(303) 444-4340
(800) 488-4340
www.positive-energy.com

Shelter Supply, Inc.
www.sheltersupply.com

Manufacturer Associations and Standard-Setting Organizations

North American Insulation Manufacturers Association (NAIMA)
http://www.naima.org/index.php

Cellulose Insulation Manufacturers Association (CIMA)
http://www.cellulose.org/

Spray Polyurethane Foam Alliance (SPFA)
http://www.sprayfoam.org/