MAINE GUIDE to ENERGY EFFICIENT RESIDENTIAL CONSTRUCTION

A MANUAL OF ACCEPTED PRACTICES

Second Edition

State of Maine
Energy Conservation Division
Department of Economic and Community Development
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The Maine Guide to Energy Efficient Residential Construction: A Manual of Accepted Practices

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The details presented in this book are schematic design ideas and are not meant to be working construction drawings. The Department advises you to consult an architect, engineer, designer or builder for complete construction details. The Energy Division of the Office of Community Development and its contractor, R.J. Karg Associates, make no statement, representation, claim or warranty with respect to the methods described or illustrations contained in this publication. For questions on this publication, or other energy related information, write to the Energy Programs Division, Office of Economic & Community Development, State House Station 59, Augusta, ME 04333.

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Dedication

Andrew P. Wynn
1941 - 1997

This edition of the *Maine Guide to Energy Efficient Residential Construction: A Manual of Accepted Practices* is dedicated to Andrew P. Wynn, energy specialist, colleague and friend, who died unexpectedly in January, 1997. Andy coordinated the writing of the previous edition of this manual; he truly "owned" the information herein. He possessed an ecological stewardship that challenged those of us who knew him to see our work not so much as a career, but as a calling. It is with such a spirit that this manual is made available to you.

Acknowledgments

The Energy Division of the Office of Community Development gratefully acknowledges the substantial contributions made by those who participated in the publication of this *Maine Guide to Energy-Efficient Residential Construction: A Manual of Accepted Practices.*

Among those whose efforts made this publication possible are:

Alexander T. Wilson, President of West River Communications, Inc., who reviewed the OER's old *Manual of Accepted Practices* and revised, expanded, and improved its contents;

Donald McCollester, of General Art, who provided the technical illustrations under contract to West River Communications, Inc.;

Andrew P. Wynn, of the Energy Division, who coordinated the revision, and provided technical assistance. This second edition is dedicated to Andy;

John Merrill, of the Energy Division, who provided editorial and proof reading;

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Rick Karg, of R.J. Karg Associates, who shaped the first edition into the second edition; and

The Members of the Advisory Council on Energy Efficiency Building Performance Standards, whose broad range of professional experience and knowledge helped in evaluating and expanding the information contained in this Guide.

The Advisory Council
on
Energy Efficiency Building Standards

Introduction

This guide has been developed to acquaint builders with Maine's residential energy standards and to present to them techniques that they can use to achieve the required efficiency levels. It goes beyond simply presenting Maine's energy standards. It is designed to serve as a construction reference for builders by addressing a wide range of issues, materials and techniques relevant to the construction of energy-efficient buildings. Maine, because of its location, has varied climatic conditions—i.e., dampness on the coast, dryness in the mountains, high winds, seasonal temperature variations of up to 130°F and daily temperature variations of as much as 50°F—which present a challenging environment for the building of dependable energy-efficient houses.

Although written for builders, this guide is not intended to be a how-to manual of construction practices for the first-time builder. It is intended to complement existing skills and knowledge and is written with the presumption that the user is fully familiar with conventional construction practices, building materials, and job-site safety. For those who are not skilled builders, it is highly recommended that this guide be used as a companion to introductory and other more comprehensive construction publications. Terms that may not be familiar to builders or homeowners appear in **boldface** when they first appear. These are defined in the Glossary (see page 79).

The details and techniques in this manual should serve as examples only. Wherever practicable, more than one way is suggested for meeting the efficiency levels required by Maine's standards. The construction details and techniques set forth in this guide are not to be thought of as the only options available to a builder. It is recommended instead that they be thought of as a basis for the development of still better building techniques and to augment existing practices.

Building design and construction are ongoing processes which evolve to meet changing economic, practical and aesthetic requirements. It is hoped that builders, through the use of this guide, will incorporate into their building practices the latest and best energy-efficient methods.

This *Maine Guide to Energy Efficient Residential Construction* was developed with the help of builders, architects and engineers. It represents a consensus of opinion on energy-efficient construction practices at the time of its writing. Because advances in the field of energy-efficient construction and the development of new products are continuous, it is to be expected that this guide will need to be revised periodically. Suggestions on how it could be made more useful or instructive will be welcomed by the Energy Division of the Office of Community Development, State House Station #59, Augusta, ME 04333, Telephone: 287-2656.

Part 1. Summary of Maine's Residential Energy Standards

The Energy Efficiency Standards for residential buildings became effective January 1, 1989. The prescriptive method of compliance is summarized in **Figure 1** and **Table 1** below. These prescriptive standards are designed to be simple and easy to follow.

The Energy Efficiency Standards also allow compliance by means of an alternate performance-based method. Please see **Appendix F** for details of this alternate means of compliance.

The required efficiency levels were developed to be cost effective for Maine's climate to achieve energy-use levels in accordance with national goals.

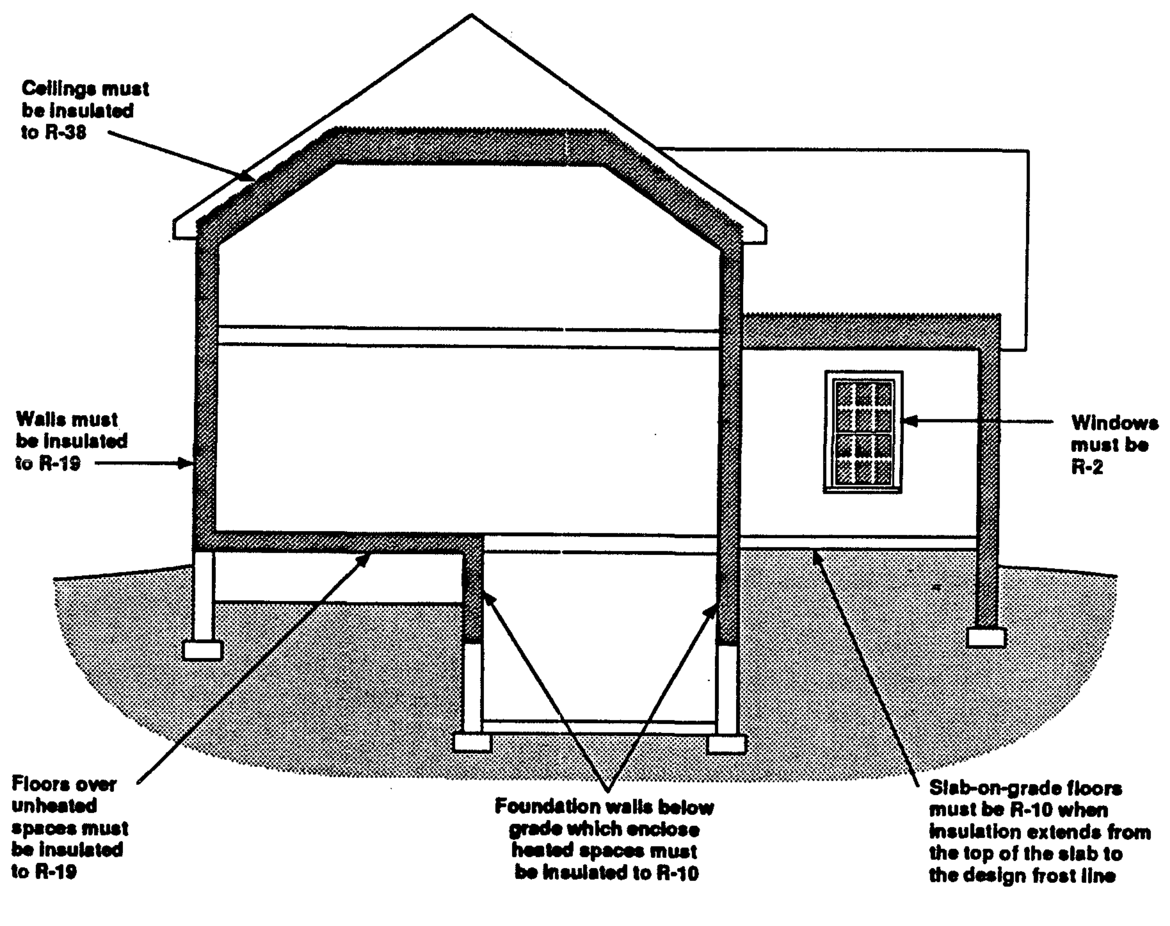


Figure 1. Maine's energy standards are simple and easy to follow. And they make good economic sense. An energy efficient building means lower heating bills. It means higher resale value, too. The extra costs involved in meeting the standards are small and are usually paid back very quickly through energy savings. Energy efficient construction makes sense for the builder, the homeowner and the State of Maine. Required insulation levels for different building components are shown.

TABLE 1.

Minimum Insulation Levels Required by Maine Energy Standards

Building Component	***Description***	***R-Value****
Ceilings	All ceilings that face outdoors or unheated spaces, including cathedral or sloped ceilings. See special definitions and conditions for ceiling insulation below (**Tables 2** and **3**).	R-38
Walls	All walls which face outdoors or unheated spaces, including insulated knee walls in heated attics. Band joists at wall perimeters must be insulated to the same level.	R-19
Windows	All windows, including glass patio and terrace doors. The unit R-value is an area-weighted average of the R-values of the frame material, the edge of the glass, and the center of the glass.	R-2
Floors over unheated spaces	Floors over crawl spaces, floors over unheated basements, overhanging floors, garages.	R-19
Slab-on-grade floors	There are two options for insulating slabs in slab-on-grade construction: either a) around the perimeter from the top of the slab to the design frost line; or b) around the perimeter of the slab itself and horizontally or diagonally beneath or away from the slab for a distance equivalent to the design frost line. See zone map of Maine on page 4 and the design frost depths that apply in **Table 4**.	R-10
Foundation walls that enclose below-grade heated space	The insulation must extend from the top of the foundation to the design frost line.	R-10

* The specified R-value refers to the rated R-value of the insulation only, not taking into account reductions in the system R-value due to framing members, and not including the added system R-value for other building components (sheathing, siding, drywall, etc.) and air films.

Performance-Based Compliance Alternative - an alternative method of complying is available, see **Appendix F** for details.

1. Special Definitions and Conditions for Ceiling Insulation:

For determining compliance with the residential Maine Energy Standards, ceiling insulation shall be considered to total R-38 in the following situations:

Sloped ceilings: In sloped ceilings, fibrous insulation is considered to have its rated R-value when installed in a rafter space of the same nominal depth as named in standard lumber dimensions, even when roof ventilation channels are present. In other words, 12-inch, R-38 insulation meets the standard even when compressed to fit into 2x12 rafters with an air space at the top. Extra insulation must be added for rafters with less than 12 inch nominal depth (see **Tables 2** and **3**).

TABLE 2.

Batt Insulation Requirements for Sloped Ceilings

Nominal rafter depth in inches	*Batt insulation thickness permitted, plus additional required R-value to be placed at the underside face of the rafter*
12 inches (2x12 rafter)	12-inch batt (R-38 typical)
10 inches (2x10 rafter)	9-1/2-inch batt (R-30 typical), plus additional R-8
8 inches (2x8 rafter)	8-inch batt (R-25 typical), plus additional R-13
6 inches (2x6 rafter)	6-1/4-inch batt (R-19 typical), plus additional R-19
4 inches (2x4 rafter)	3-1/2-inch batt (R-11 typical), plus additional R-27; or 3-5/8-inch batt (R-13 typical), plus additional R-25

TABLE 3.

Blown Fibrous Insulation Requirements for Sloped Ceilings

Nominal rafter depth in inches	*Rafter cavity to be filled, plus additional R-value to be placed on the underside of rafters*
12 inches (2x12 rafter)	Fill available space
10 inches (2x10 rafter)	Fill available space, plus additional R-8
8 inches (2x8 rafter)	Fill available space, plus additional R-13
6 inches (2x6 rafter)	Fill available space, plus additional R-19
4 inches (2x4 rafter)	Fill available space, plus additional R-27

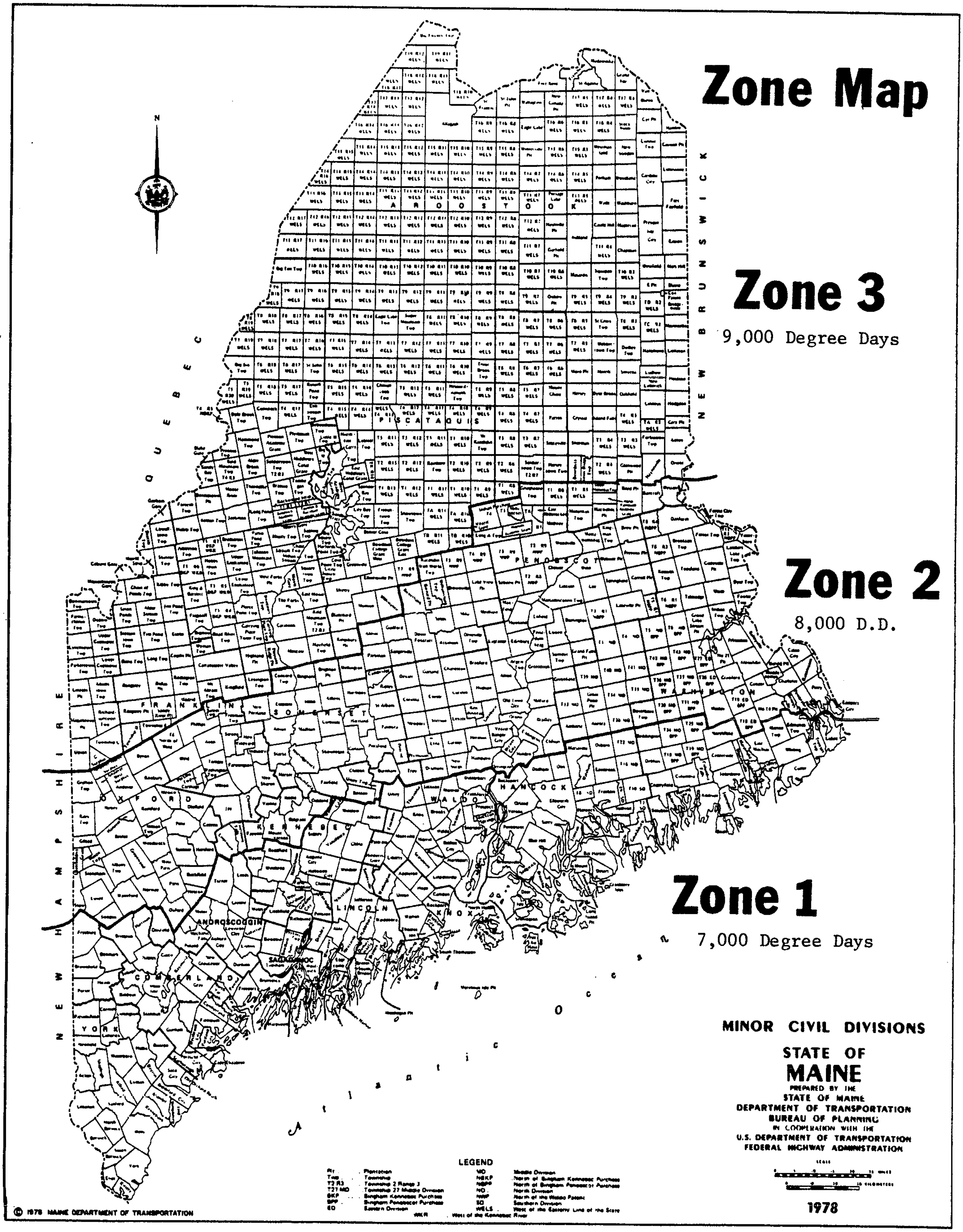


Figure 2. Zone map for determining required depth for foundation insulation.

Horizontal ceilings: At the eaves of horizontal ceilings, when rafters or roof trusses limit the depth of the insulation, the minimum thickness of compressed fibrous insulation shall be 7 inches, measured at the outside edge of the exterior wall framing. The insulation shall increase in depth as rapidly as possible until it reaches the depth at which it is fully rated at R-38. In other words, the insulation level is acceptable even if it is compressed to as little as 7 inches at the eaves. Problems can be avoided by cantilevering a standard truss one foot out over the eave-side walls.

2. Buildings that must comply:

Except as stated below, any single-family and multifamily residential structure designed for year-round or winter seasonal use must comply with the prescriptive or performance standards.

The following construction is exempted from the standards:

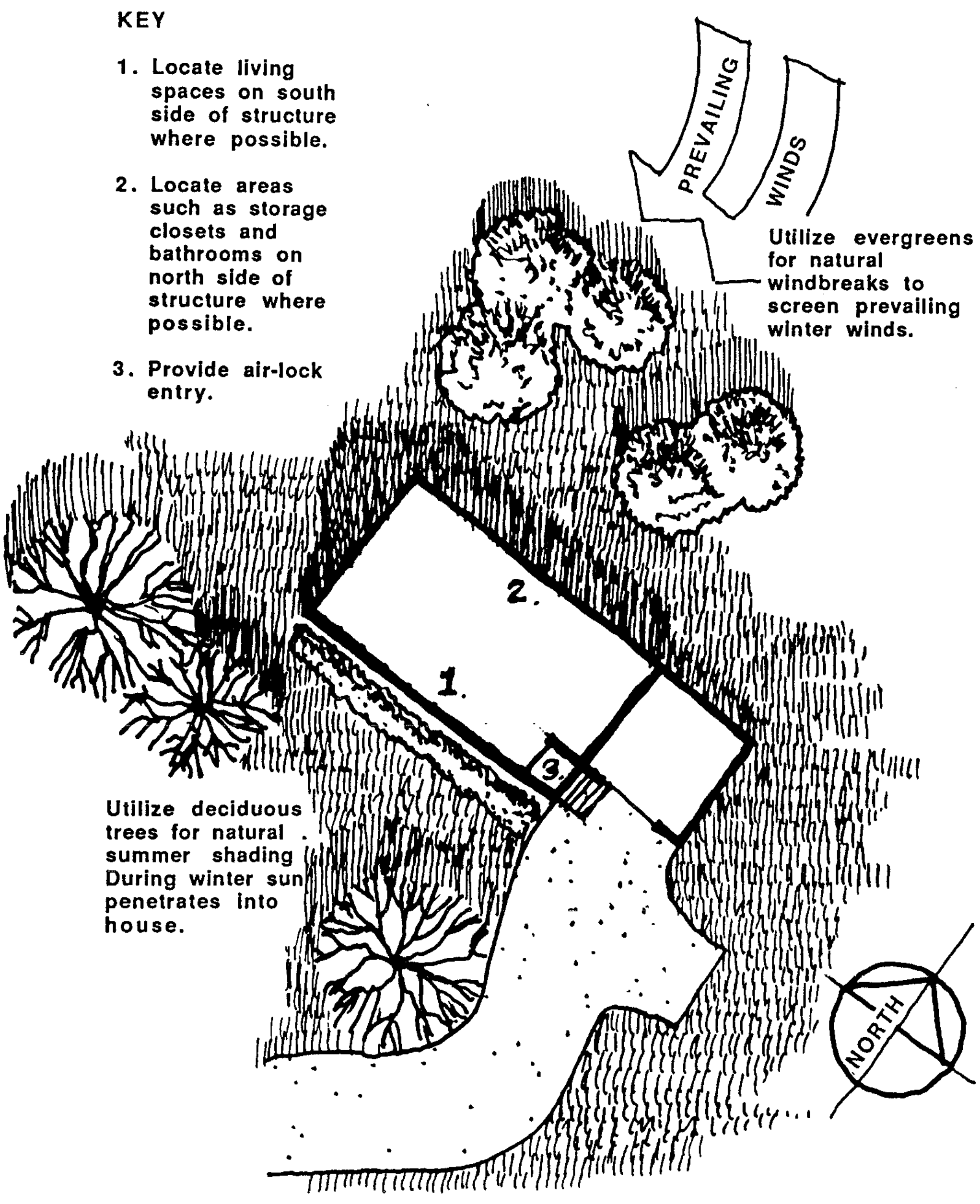
- Single-family residences built by an individual to be his or her own personal residence.
- Single-family residences built by a contractor who is hired by an individual to build that individual's personal residence.
- Log homes.
- Summer camps.

Despite the above exemptions, homeowners should realize that building to the residential energy standards almost always makes sense. If you are a builder or designer, you should encourage your clients to follow these standards even though they may not be required to by law. If you are an owner-builder, following the standards—or prudently exceeding them—will save you thousands of dollars over the life of your home compared with more typical insulation practices.

As you will see throughout this guide, many recommendations are made that are not strictly a part of the energy standards. These are recommended, rather than required, practices. Some of these recommended practices do not directly involve energy, addressing such issues as moisture, indoor air quality, radon and drainage. Such information is included to make the guide as useful as possible. In situations where specific insulation levels or practices are required, they will be identified as such in the guide.

TABLE 4.
Design Frost Levels for Determining Foundation Insulation Requirements

Zone (see map, Figure 2)	*Design frost line in feet below grade*
Zone 1	4 feet
Zone 2	5 feet
Zone 3	6 feet


KEY
1. Locate living spaces on south side of structure where possible.
2. Locate areas such as storage closets and bathrooms on north side of structure where possible.
3. Provide air-lock entry.
PREVAILING
WINDS
Utilize evergreens for natural windbreaks to screen prevailing winter winds.
2.
1.
3.
Utilize deciduous trees for natural summer shading During winter sun penetrates into house.
NORTH

Part 2. Siting and Initial Design Considerations

There is a lot more to building an energy efficient house than insulation, air-leakage control, and a heating system. Planning should start with a careful evaluation of the building site and how it will influence your design and the performance of the structure. You should consider solar exposure for passive solar heating, prevailing weather conditions, landscaping possibilities to provide natural wind protection and summertime shading, water drainage and building lot development considerations.

1. Solar Orientation

Suntempering and **passive solar** heating can reduce heating costs while boosting comfort and making a living space more exciting. With either approach (described below), the house must be oriented to allow maximum use of south-facing glass. Ideally, a long wall of the house should face true south, but variation of up to 30° east or west will not significantly affect solar heating performance (see **Figure 3**).

To determine the solar orientation of a building site, use a compass and be sure to correct for the **magnetic declination** for your location. The declination is the difference between true direction and where the compass points. In Maine, magnetic declination varies from 16° to 22° west, meaning that true south is actually west of magnetic south. Magnetic declination is shown on any USGS topographic map. The Energy Division publishes a guide for determining the solar potential of a building site. Call and ask for the *Maine Solar Primer*.

For purposes of determining whether nearby trees, mountains or buildings will block the solar exposure of a new house, you will need to determine **sun angles** at various times of the day and year. As shown in **Figure 4**, the sun moves across the sky, rising in the east and setting in the west. In the summer it rises much higher in the sky—has a greater altitude—than during the winter. With passive solar design, it

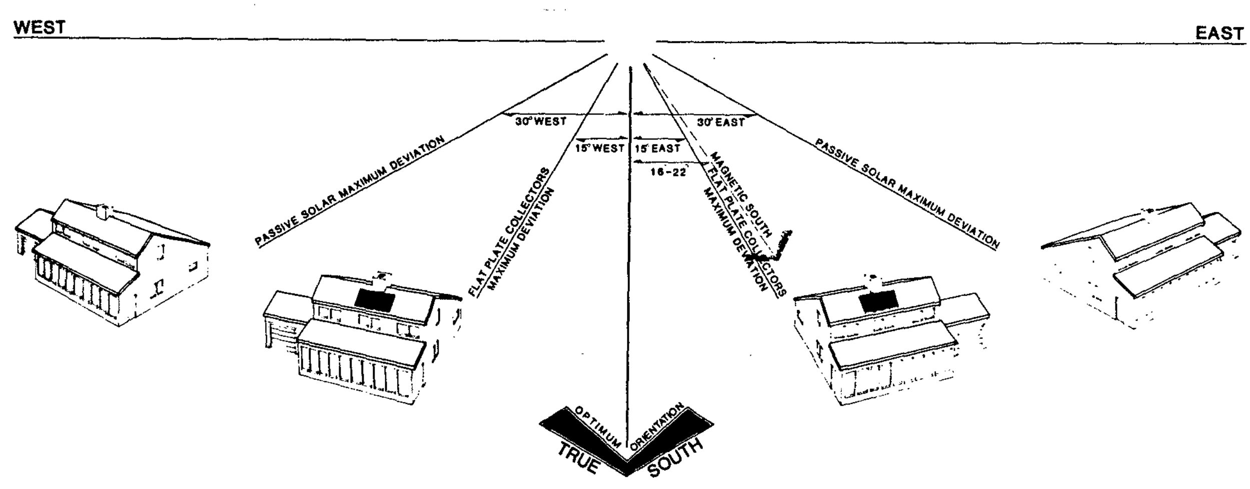


Figure 3. For proper functioning of a passive solar or suntempered heating system, it should face no more than 30° east or west of true south. Note that in Maine, true south varies from magnetic south by 16°-22° west.

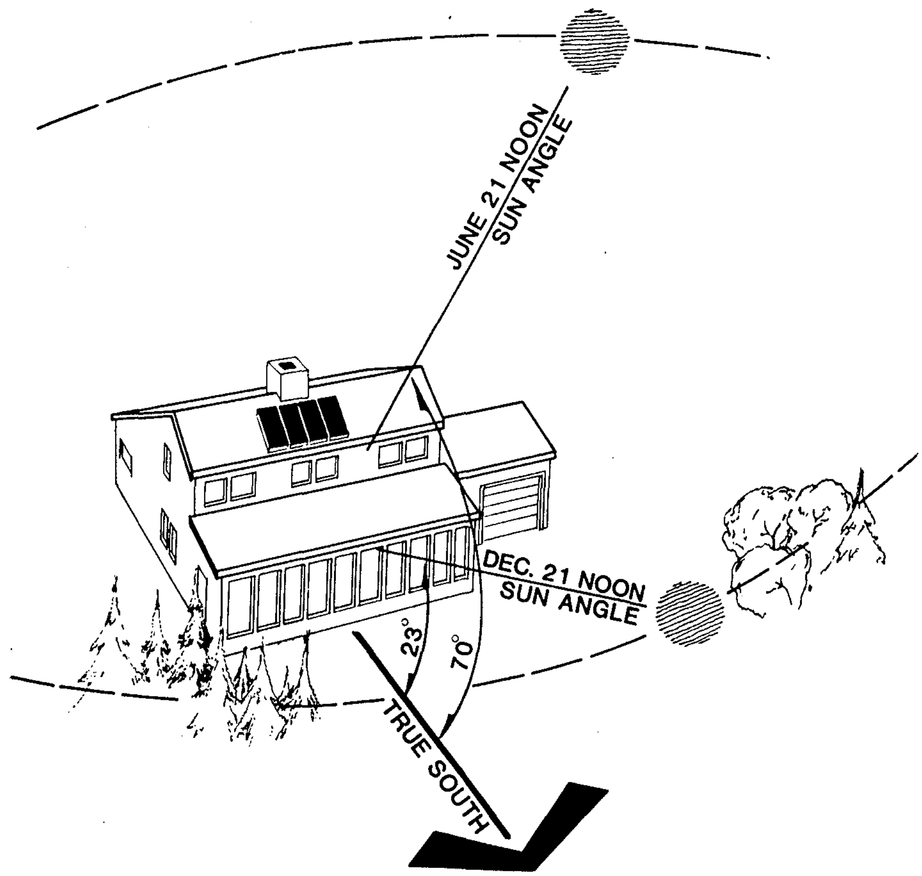


Figure 4. To determine if south-facing glass will be shaded, you will need to determine the sun's path across the sky during the winter.

is necessary for the south-facing glass to be exposed to the sun during as much of the day as possible during the winter months when the sun is low in the sky. Simple tools and kits are available for determining the precise path the sun follows across the sky at different latitudes (see references).

2. Prevailing Weather Conditions and Landscaping Considerations

At some building sites, it makes sense to determine what the local weather patterns are, particularly on coastal and mountain locations where high winds can significantly affect comfort and heating costs. In most of Maine, the prevailing winter winds are from the north and west, but this is not always the case, especially along the coast. Check with a local weather station or nearby airfield for information on prevailing winds in your area, or visit the site and ask neighbors about wind conditions.

If the winter winds are primarily from one direction, it makes sense either to locate the house on a portion of the building site where it will be protected from those winds, or to plan on planting a windbreak (see **Figure 5**). Conifers (pine, spruce, fir, hemlock) are best for a windbreak, because they do not lose their leaves in the winter. Local topography can also be used in protecting the house from winter winds. By setting the house into a south-facing hillside, for example, winds from the north will tend to rise up over it.

To provide solar exposure on the south, most trees should be removed. A few tall deciduous trees (these usually lose their leaves in the fall) close to the house will be all right,

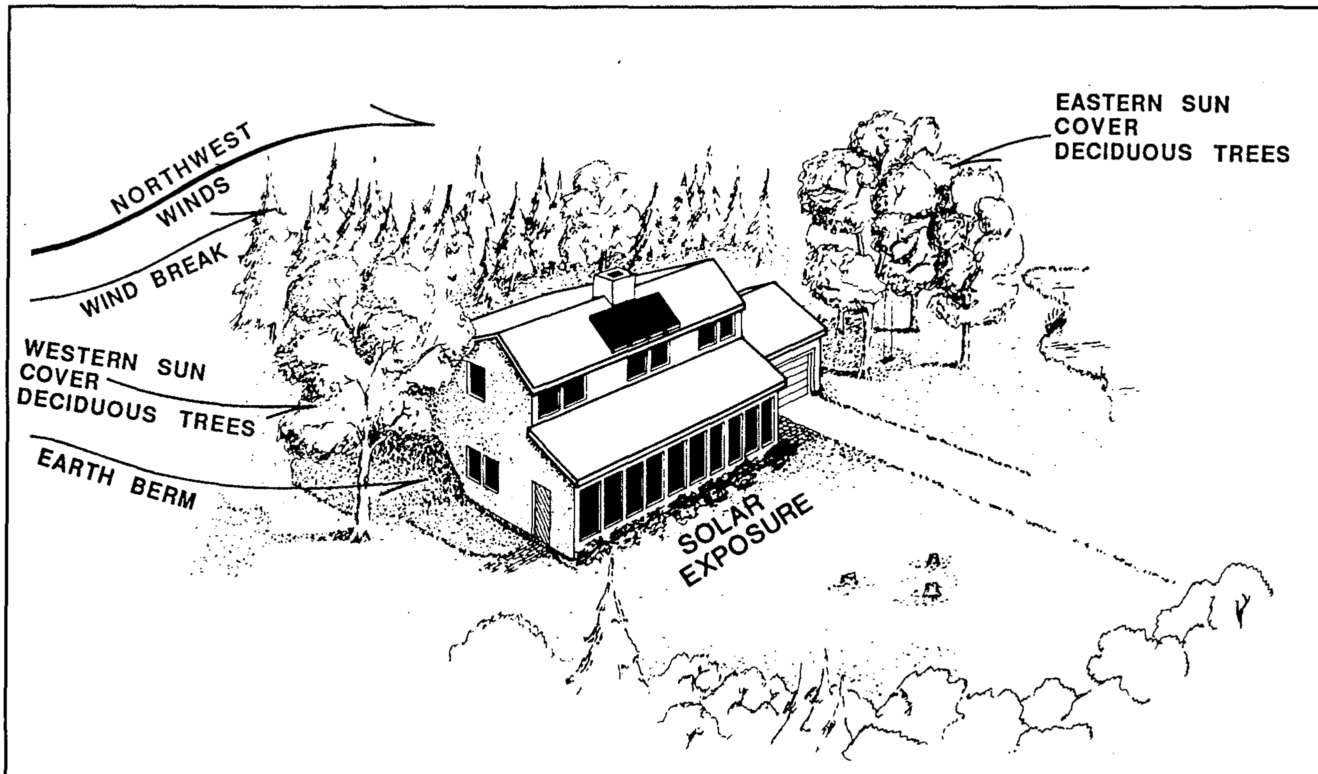


Figure 5. A windbreak on the north or west can help protect a house from cold winter winds. On the south side of the house, it is better to remove trees and allow warm winter sunlight to penetrate.

especially if the lower branches are removed to allow the winter sun to penetrate. When leafed out in summer, these tall trees will help block the hot summer sun, reducing the possibility of unwanted heat gain. On the east and west sides of the building, it often makes sense to leave some deciduous trees to block the summer sun. This is particularly important on the west, where afternoon sun can be quite hot and uncomfortable in the summer. If trees are not already present on the west, it makes sense to plant some, both to provide afternoon shading and to protect the house from cold winter winds (**Figure 5**).

Of course, all landscaping plans should take into account the potential views from the house. If the house overlooks a lake on the north, the importance of the view may well outweigh the energy benefits of planting a windbreak or the energy penalty of incorporating a large area of glass.

3. Suntempering and Passive Solar Design

Suntempering and passive solar design are strategies to collect and use the sun's energy, without specialized mechanical means of distributing or storing it. In general, **suntempering** refers to the simple addition of south-facing glass (within 30° of true south) *without* incorporating materials to store the collected heat. To prevent daytime overheating on sunny winter days, the south glass area in suntempered houses is usually limited to 7 percent or less of the *floor* area. Suntempered houses can be designed and built by builders and architects who have no specialized knowledge of solar design.

Passive solar systems, on the other hand, incorporate more sophisticated designs to provide for thermal storage and a larger south-facing glass area. Using passive solar heat generally requires specialized knowledge of passive solar design.

There are a number of different types of passive solar heating systems, the two most

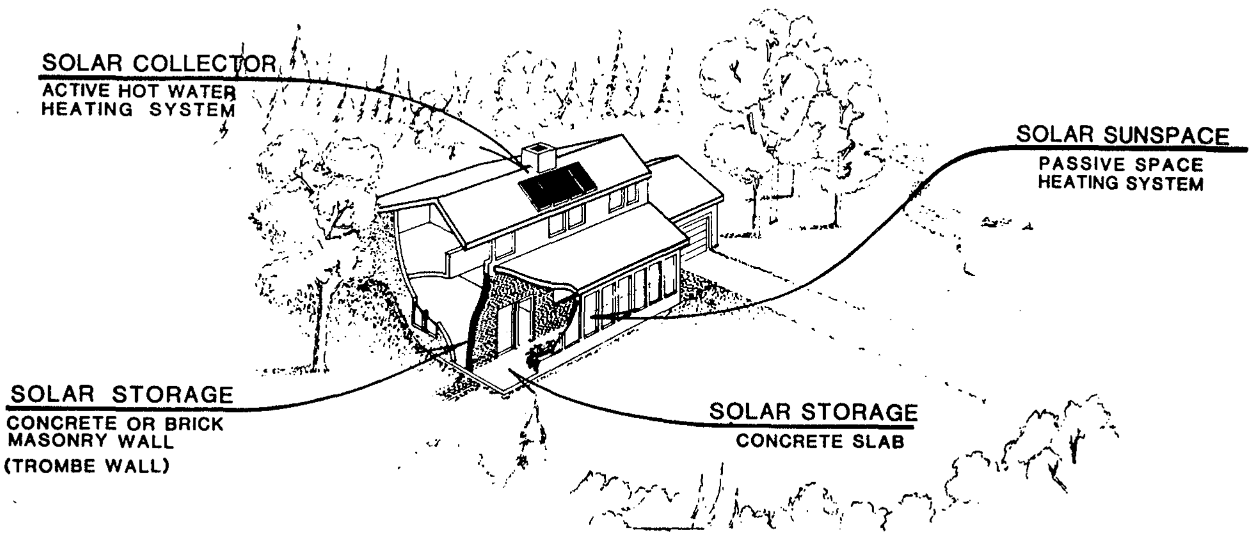


Figure 6. Passive solar heating can save a great deal on heating costs, but such systems require careful design by someone with passive solar design experience.

common being direct gain and solar sunspaces with thermal storage (**Figure 6**).

Direct gain is simply more elaborate suntempering. High-density materials are incorporated into the design to absorb and store the solar energy transmitted through south-facing glass. Common heat storage materials include masonry fireplaces, brick walls, tile floors and specially designed containers of water. To effectively absorb solar energy, dark surfaces are recommended. Wood and drywall can also provide heat storage, but larger areas are required because they cannot absorb and store as much heat. To be most effective, high-density heat storage materials should be exposed to direct sunlight for at least part of each day during the heating season.

Properly designing a passive solar heating system involves careful calculations and understanding of sun path diagrams. Faulty design can result in overheating during the day and cool indoor conditions at night. If you have not had experience with passive solar design, it may make sense to hire the services of a designer with such experience.

A solar sunspace is an extension out from the house with a means of storing heat and for transferring heat from the sunspace into the house. To prevent the sunspace from robbing heat from the house at night, there should be a way to seal it off from the house—closable connecting doors.

When looking at solar energy possibilities, consider the potential installation of solar collector panels in the future. For example, while solar water heating panels may not be installed during the initial construction, you may want to install them later. Is there a south-facing roof that could be used in the future for solar panels? Is there access to the utility room (where a storage tank would probably be located) from an appropriate roof?

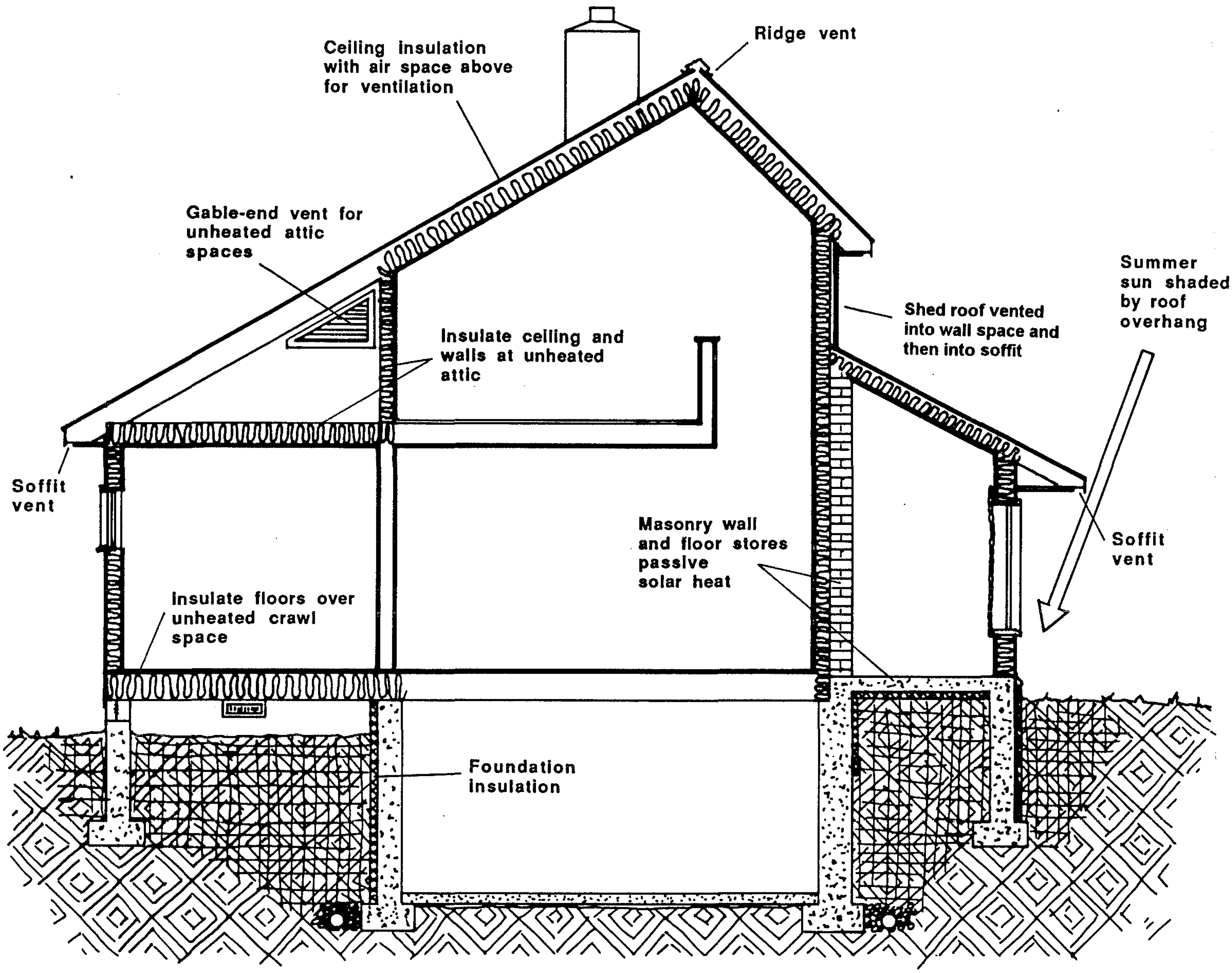
4. House Layout

Room layout can have a significant effect on energy use in the home. Again, many factors are involved in determining which living spaces should be located where, but when possible, it makes sense to locate the spaces used during the daytime toward the south where natural daylight (and passive solar heat) can be utilized. Bedrooms usually don't need as much daytime

light, so locations on the east, west, or north side of the house make sense. Many people prefer east-facing bedrooms because they like awakening to the rising sun. Try to keep storage areas, utility rooms, closets and other spaces that don't need windows toward the north, so that north-facing windows, which admit no significant solar heat, can be kept to a minimum.

During the initial planning, try to provide for an air-lock entry for the most often used entrance to the house. This will cut down on air leakage while providing a place to take off boots and hang coats. The air-lock entry should have tight-fitting doors both to the outside and to the living space. The actual space can be within the heated envelope of the house or outside of it, but if it is inside the primary building envelope, it is not necessary to heat it. For best performance, the air-lock entry should be insulated both on its exterior walls/ceiling and on its common walls with the house. Try to locate entry doors in sheltered locations—sheltered either by the house itself, or by natural features of the site, such as vegetation.

When any living space is located over a garage (a practice many building scientists discouraged because of indoor air pollution concerns), think about the use of this space. If the garage ceiling is properly insulated (R-19 minimum) and sealed with an air barrier and vapor barrier, as it should be, the space above the garage will be no less comfortable than other parts of the house. But if there is concern about the quality of insulating or sealing, consider locating less important space above a garage, such as a storage area or guest room.


Ceiling insulation
with air space above
for ventilation
Ridge vent
Gable-end vent for
unheated attic
spaces
Summer
sun shaded
by roof
overhang
Shed roof vented
into wall space and
then into soffit
Insulate ceiling and
walls at unheated
attic
Soffit
vent
Masonry wall
and floor stores
passive
solar heat
Soffit
vent
Insulate floors over
unheated crawl
space
Foundation
insulation

Part 3. Important Considerations for the Design Phase

During the past twenty-five years, interest in energy efficiency has dramatically changed the way houses are built. New materials and advanced construction techniques have reduced energy consumption as much as fourfold, but these changes have also greatly increased the complexity of houses.

Today's designer and builder needs to know about everything from heat flow and insulation materials to moisture migration, radon, and have knowledge of many new products and technologies. He or she needs to know how the different components of a house interact, enhancing comfort and reducing operating costs on the positive side, but potentially causing moisture problems and callbacks on the negative side. In today's tighter, more energy-efficient houses, moisture problems and indoor air pollution, for example, should be a concern to both the designer and builder.

In this section, a wide range of important issues relating to new home construction are addressed. Full understanding of these topics will assure proper implementation of the construction details presented later in this guide.

1. Insulation

Heat always flows from warmer areas to colder areas. During the winter months, all the heat that is used to keep a house warm is eventually lost through the building envelope. How quickly that heat escapes depends on two factors: the difference in temperature between the inside and outside of the building, and how effectively the building envelope retards the flow of heat. Installing insulation is the primary strategy used to slow down the transmission of heat through walls, ceilings and floors. The resistance to heat flow of insulating materials is measured by the **R-value**. Insulation R-values are based on very specific testing requirements of the Federal Trade Commission and must be listed on all commercially sold insulation materials.

Insulation levels required for walls, ceilings, floors and foundations under the Energy Efficiency Standards are presented in **Part 2** of this manual, along with special definitions that apply. Specific construction details to satisfy those requirements are described in **Part 4** (Recommended Construction Practices).

Common insulation materials and their properties are listed in **Table 5**. Insulation materials may be divided into two categories: cavity-fill and rigid board. Included among cavity-insulation materials are fiberglass (batts or loose-fill), mineral fiber (batts or loose-fill), cellulose (loose-fill or wet-spray), vermiculite (loose granule), perlite (loose granule), and several specialized installed-in-place products. Rigid board insulation materials include extruded polystyrene (such as Dow Styrofoam®), expanded polystyrene (beadboard), polyisocyanurate, polyurethane and phenolic foam.

For wall, ceiling and floor applications, fiberglass batt insulation is the most common product. Batts are available in a wide range of thicknesses and widths to meet different framing and thermal requirements. In flat ceilings and closed wall cavities, loose-fill cellulose is very common and usually less expensive than fiberglass. In walls, **wet-spray cellulose**, though still relatively uncommon, is gaining popularity.

When high insulation levels are required and/or a thinner wall or cathedral ceiling is desired, rigid board insulation is typically

TABLE 5.

Common Insulation Materials

TYPE OF INSULATION	R-value per inch (range)	Where used	How Installed	Resistance to*: Water Abs.	Moisture Damage	Direct Sun	Fire	Max. Temp.	Available in:
BATTS, ROLLS									
Fiberglass	3.17 (3.0-3.8)	wall, floor & ceiling cavities	Fitted between studs, joists or rafters	2	1	1	2	180°F	Batts and rolls Widths - 11" to 48"; Thicknesses 1"-13" Available unfaced, with kraft paper facing or aluminized paper facing.
Rock Wool	3.17 (3.0-3.7)	Wall, floor & ceiling cavities	Fitted between studs, joists or rafters	2	1	1	1	>500°	Batts and rolls Widths - 11" to 24"; Thicknesses - 3" to 8"
LOOSE, POURED OR BLOWN									
Fiberglass	2.2 (2.2-4.0)	Ceiling cavities	Poured and fluffed, or blown by machine	2	1	1	2	180°	Bags: 15-30 lb.
Rock wool	3.1 (2.8-3.7)	Ceiling cavities	Poured and fluffed or blown by machine	2	1	2	2	>500°	Bags: 25-35 lb.
Cellulose	3.2 (2.8-3.7)	Ceiling cavities	Blown by machine	4	4	2	3	180°	Bags: 15-30 lb.
Perlite	2.7 (2.5-4.0)	Hollow concrete block	Poured	3	2	1	2	200°	Bags
RIGID BOARD									
Expanded Polystyrene (Beadboard)	4.0 (3.6-4.4)	Wall, ceiling, roof	Glued, nailed	4	2	4	4	165°	Boards: 2'x8', 4'x8', other sizes Thicknesses: 1/4" to 10" Special facings, T&G edges available
Extruded Polystyrene (Styrofoam®) (Foamular®)	5.0	Foundation, roof	Glued, nailed sub-slab, wall, ceiling, roof	1	1	4	4	165°	Boards: 2'x8', 4'x8' Thicknesses: 3/4"-2" Special facings, coatings, T&G edges available
Isocyanurate (Thermax®) (Hi-R®)	6.0 (5.6-7.7)	Wall, ceiling, roof	Glued, nailed	2	1	4	4	200°	Boards: 4'x8' Thicknesses: 1/2"-4"
Phenolic Foam (Koppers)	8.3	Wall, ceiling, roof	Glued, nailed	3	1	1	1	300°	Boards: 4'x8' Thicknesses: 1/2"-3"
Rigid Fiberglass	4.4 (3.8-4.8)	Wall, ceiling, roof, foundation wall	Glued, nailed	2	1	1	2	180°	Boards: 4'x8' Thicknesses: 1"-3" Available with various facings
INSTALLED IN PLACE									
Wet-Spray Cellulose	3.5 (3.0-3.7)	Wall cavities	Sprayed in open cavities	4	3	2	3	165°	K-13 formulation Installed by contractor only
Polyurethane	6.2 (5.8-6.8)	Wall & ceiling cavities, roofs	Foamed in open cavities	1	1	4	4	165°	Different formulations available Generally Installed by contractor Cannisters and cans available for small sealing applications
Magnesium Silicate (Air Krete®)	3.9	Wall cavities	Foamed in open cavities	3	2	1	1	>500°	Foamed in place by licensed contractor

* 1 = EXCELLENT 2 = GOOD 3 = FAIR 4 = POOR

Source: *Insulation Facts*, Energy Division of the Maine Office of Business Development.

used—often in conjunction with batt or loose-fill insulation. Foil-faced polyisocyanurate, polyurethane and phenolic foam provide the highest R-values per inch—from R-6 to R-8 per inch, although these R-values may drop somewhat after "aging." These materials use chlorofluorocarbons (CFCs) in their production and the CFC gas is retained in the material to provide the high R-value. (Lower R-value insulation materials, including fiberglass, cellulose and expanded polystyrene, rely on trapped pockets of air to provide the resistance to heat flow.) Because CFCs have been linked to ozone depletion, some homeowners prefer not to use insulation materials containing them, and the reduced availability of CFCs is driving up the cost. Until alternative foaming agents for rigid foam insulation are found, we are likely to see reduced use of these materials.

Extruded polystyrene is also produced with CFCs, but some manufacturers have already begun switching to an environmentally safer foaming agent. Expanded polystyrene and rigid fiberglass do not require the use of CFCs in their production.

For below-grade exterior foundation insulation applications, extruded polystyrene or rigid fiberglass are generally recommended. The other rigid insulation materials will absorb moisture and lose effectiveness.

There are a number of foam-in-place cavity-fill insulation materials for use in wall and ceiling cavities. This methods are usually more expensive than conventional methods, but in certain applications, they may be a better alternative.

For more information on insulation materials, refer to the booklet *Insulation Facts,* published by the Energy Division.

2. Air Leakage

Air leakage heat loss is the uncontrolled movement of air into and out of buildings. It both brings cold air into the house and allows warm air to escape. It is the second major heat loss type, the first being **surface or transmission heat loss** which takes place when thermal energy transmits through building materials. Air leakage typically accounts for 30 to 50 percent of the total heat loss. By careful planning in the design phase and careful attention to details during construction, air leakage can be greatly reduced. In fact, with proper attention to air barriers, vapor barriers, tight-fitting windows and doors and careful sealing at sills and around all building envelope penetrations, air leakage will often be low enough to require mechanical ventilation for adequate fresh air inside a house (see discussion below).

Potential air leakage locations in new construction are shown in **Figure 7.** To keep leakage to a minimum, follow the guidelines listed below, most of which are keyed to the illustration:

1. Build in a vestibule or air-lock entry at the most often used entry door. This allows the exterior door to be closed before the door to the house is opened to reduce air leakage through the open door.

2. Minimize the placement of electrical outlets on exterior walls (within electrical code guidelines), and carefully seal those receptacles to the air barrier. Special airtight boxes for receptacles are available that can be easily sealed to the air barrier. Install gaskets under the plates on electric outlets and switches located on exterior walls.

3. Install only high-quality, pre-hung, factory-weatherstripped windows. Choose casement, awning or fixed windows rather than double-hung or slider windows (see discussion on windows below). Look for windows that have rated air leakage levels below 0.1 cfm/ft (ratings should be listed in product literature and are based on standard industry tests in a 25 m.p.h. wind).

4. Install only high-quality, pre-hung, factory-weatherstripped metal or wood entry doors. Metal doors are much less likely than wood doors to warp and become air leakage sources. Look for doors with integral magnetic, high-quality foam, or interlocking weatherstripping and adjustable thresholds.

5. During window and door installation, carefully seal around jambs with foam backer rod, caulk, or expanding foam sealant. Expanding foam sealant provides the tightest seal. Apply a heavy bead of *low-expanding* foam sealant to continuously "weld" the window jamb to the rough opening. Be careful not to apply too much foam sealant,

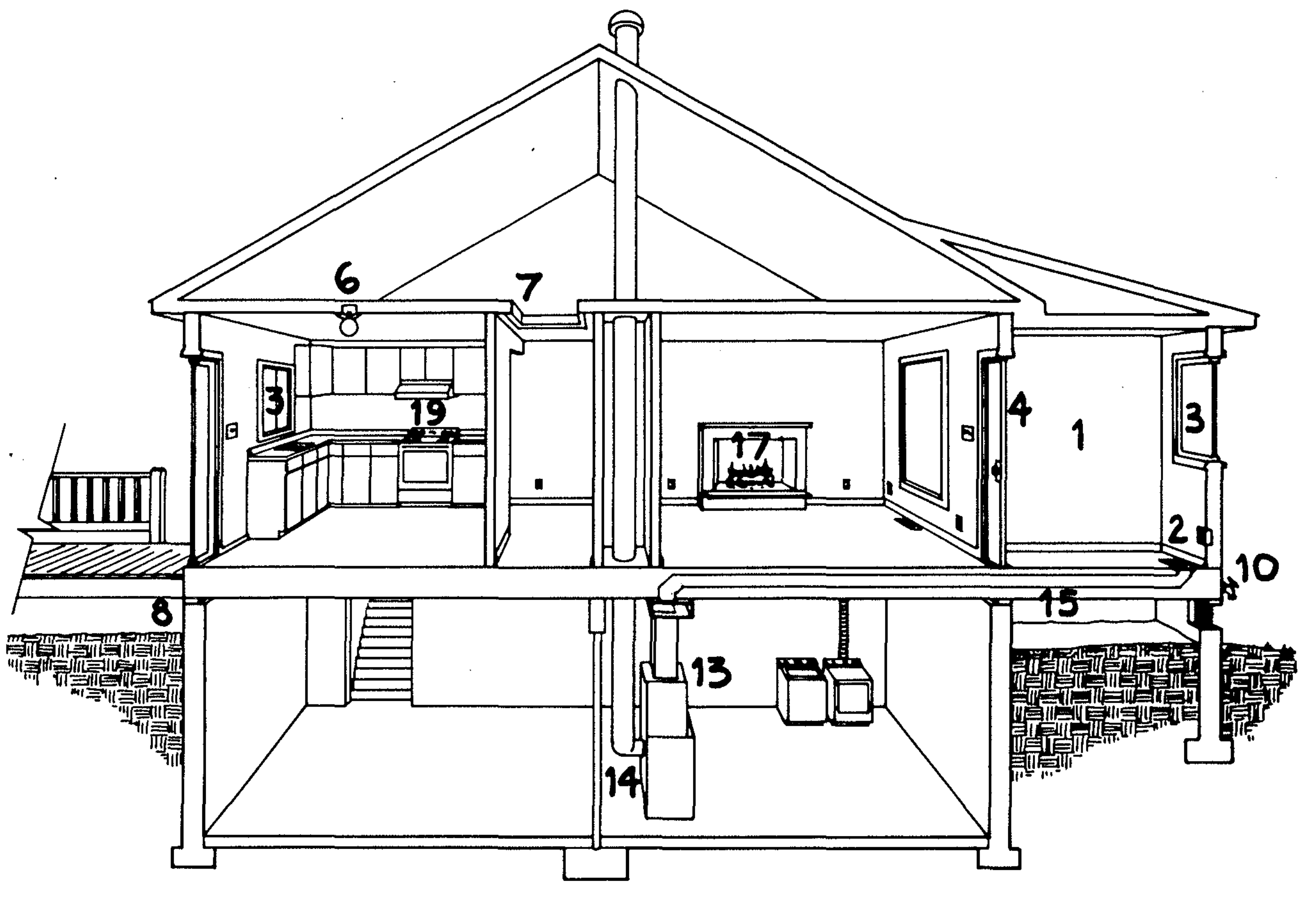


Figure 7. Common air leakage locations in the home.

especially if it is a high-expanding type, as it could make window operation difficult. The suggested practice is to fill only one-half to two-thirds of the cavity depth. During framing, be sure to allow a large enough rough opening to allow proper sealing (3/8"- 1/2" on all sides). See discussion of foam sealants below.

6. Do not install recessed lights below unheated attic spaces or in other spaces that are connected to cold outdoor air.

7. For access to an unheated attic (if necessary), install a tight-fitting, well-insulated attic hatch. If properly weatherstripped and insulated units are not available, you may have to add weatherstripping and insulation yourself. With pull-down stairs, install an insulated box cover that can be lifted off when climbing the stairs. Consider adding an attic access door through exterior gable-end wall rather than one through the ceiling.

8. Install a sill sealer and/or caulk between the sill and foundation. An open-cell foam sill sealer allows both very tight compression and excellent air blockage at larger gaps.

9. Install a continuous **air barrier** toward the inside of all exterior walls and insulated ceilings. Edges and overlaps should be taped or caulked. If using polyethylene sheeting as an air barrier, this can also serve as the **vapor barrier**. Be especially careful with air barrier installation at problem construction areas such as drop ceilings over bathtubs, over kitchen cabinets and at heated attic knee walls. If the bathtub is to be installed along an exterior wall before drywall is installed, be sure that the air barrier is not punctured and seal the edges of the tub carefully.

10. Seal cracks around all pipes, vent stacks, wires and conduits penetrating the exterior walls and ceilings. Also seal penetrations into plumbing or wiring chases that extend between floors. Use high-quality caulk or foam sealant (see discussion below). This helps create a continuous air barrier.

11. During framing, caulk the plates to the subfloor as wall sections are tilted into place. After the drywall is installed, caulk the joint between the bottom edge of drywall and the floor on all walls

before installing baseboard molding.

12. Install an **house wrap** underneath exterior siding. This house wrap will offer good temporary protection from the weather and help make the building slightly more airtight. The house wrap should be as continuous as possible. Tape it to the sheathing at the top and bottom and at all overlapping joints. Also tape it to the framing at all window and door openings. Use a high-quality contractor's tape. If using plywood sheathing, a house wrap is not as important but it will help block air flow at plywood joints and is still recommended by many experts.

13. If possible, install only **direct vent** (sometimes referred to as **sealed combustion**) space heating and water heating equipment. These use direct ducted outside air for combustion rather than air from the house and, therefore, pose no risk of **back-drafting** harmful combustion gases into the house.

14. Install a code-approved fireproof seal around any flues penetrating walls or floors.

15. If ducting for the heating system passes through unheated space, fully insulate the ducts and seal the joints between duct sections with approved **duct mastic** (do not rely on duct tape for sealing ducts, it breaks down in a short time).

16. Do not use ducts partially formed by joist or wall cavities because such ducts cannot be tightly sealed. Cold air may be pulled in from unheated spaces through the framing, or warm air passing through the ducts may be lost to unheated spaces.

17. Fireplaces are generally *not recommended* in energy-efficient houses because of their inherent inefficiency and the heat loss associated with them. However, if a fireplace is to be installed, do the following:

    a. Install a tight-fitting damper at the top of masonry fireplace flue.

    b. Install high-quality, tight-closing glass doors on the front of the fireplace.

    c. Install a combustion air inlet duct(s) with tight-fitting damper directly to the fireplace.

    d. With masonry fireplaces that extend through exterior walls, construct a thermal break at the wall penetration.

    e. Seal chimney and flue penetrations through insulated ceilings and roofs in accordance with local fire codes. An air space is generally required next to the masonry; this should be sealed at the top and bottom of the penetration with 26-gauge (minimum) galvanized steel and a noncombustible, high-temperature sealant.

18. If installing a wood stove, seal stack penetrations through insulated floors, walls and ceilings (use insulated flue pipe as required by code for these penetrations). If possible, select a wood stove with an outside-air supply connection.

19. Install kitchen and bathroom exhaust fans with tight-fitting backdraft dampers. In place of standard bathroom exhaust fans, you can use heat recovery ventilators (see section on indoor air quality below), which are better from an energy standpoint. These devices should not be used for ventilating kitchen ranges. Timers can be used on fans to control operation time. Carefully seal duct penetrations through insulated walls and ceilings with caulk and/or foam sealant.

20. Provide tight-fitting insulating covers for through-the-wall air conditioners and air conditioning sleeves.

The air leakage rates for houses are measured in **air changes per hour (ACH).** To accurately estimate air leakage rates, the house must be tested with either a tracer gas or a blower door. With a tracer gas test, a known quantity of an inert gas is released into the house, air samples are collected over time, and the gas concentrations measured. In this way, the rate of air replacement (air changes) in the house can be calculated.

A blower door test involves setting up a specialized fan in an exterior door opening of the house, closing all other exterior doors and windows, and then using the fan to depressurize the house. The rate of air flow through the blower door required to maintain a specific negative pressure in the house (usually 50 pascals) is converted to air changes per hour. A simple chart allows the technician to convert the ACH rate at elevated pressure to the ACH rate at normal atmospheric pressure.

With both tracer gas and blower door testing, a specialized energy audit technician is generally brought in to perform the analysis.

By following the construction practices recommended in this guide, the air leakage rate should end up no more than about 0.4 ACH. With very careful attention to the measures described above, the air leakage rate can be kept as low as 0.1 ACH.

In houses with air exchange rates lower than 0.35 ACH, some type of mechanical ventilation is strongly recommended to ensure an adequate supply of fresh air for the occupants. These issues are addressed in the **Indoor Air Quality** section, pages 20-24.

An advantage of blower door testing is that the technique can be used to find air leakage spots. With the blower door operating, you or an energy audit specialist can look for leaks with a smoke generator. Walk around each room holding the smoke candle close to the wall and watch for strong air currents, which identify leakage areas. Because the house is under fairly high negative pressure, any leaks will be greatly exaggerated and very noticeable.

A Word About Materials Used for Reducing Air Leakage

Building a tight house that will remain tight necessitates using high-quality materials that are installed properly. Select caulks, gasketing

TABLE 6.
Common Caulking Materials

Generic Product	*Cost*	*Useful Life*	*Joint Movement*	*Comments*
Oil-based	Low	3-5 years	Very poor - 1%	Poor adhesion to wet surfaces. Considerable shrinkage. Generally not recommended.
Butyl Rubber	Low to Medium	3-10 yrs.	Fair - 5-10%	Good adhesion to masonry and metal; poor to wet surfaces. May be stringy during application. Long curing time before paintable.
Acrylic Latex	Low to Medium	3-10 yrs.	Poor - 2%	Use only for interior applications on joints between similar materials. Easy to use; cleans up with water; paintable.
Siliconized Acrylic Latex	Medium	10-20 yrs.	Fair - up to 10%	Silicone greatly improves product over standard acrylic latex. Easy clean-up and painting; minimal shrinkage. Considerable variation between brands relative to percent silicone.
Silicone	High	20-50+ yrs.	Highest - 50%	Excellent flexibility. Good adhesion to most materials. Effective over very wide temp. range. Easy application. Most are not paintable. May not bond well to all woods.
Polyurethane	High	20-30 yrs.	Good - 25%	Excellent adhesion to most surfaces. Very good performance. Paintable. Clean-up may be difficult. Used by professionals for years; only recently has it become widely available.
Ethylene Copolymer	Medium	> 20 yrs.	Good - 25%	Good adhesion to most materials; good flexibility; paintable. Good general-purpose caulk.

materials, air barriers, vapor barriers and other materials that are rated for a long life—twenty to fifty years.

To function properly in sealing between two surfaces, a caulk must be able to expand and contract with the seasonal movement of the materials (wood, for example, expands in the summer months and shrinks in the winter). Some products maintain much greater flexibility over time than others. High-quality silicone, siliconized latex, and polyurethane caulks, for example, will maintain excellent flexibility for more than twenty years, while oil-based caulks will dry out and lose all flexibility after just a few years.

Properties of common caulking materials are shown in **Table 6**. When you are comparing caulks at a building supply center, it may be difficult to distinguish one type of caulk from another by their labels. If you cannot determine what type of caulk it is, read the label and look for properties you want, such as a long lifetime, a guarantee of quality, paintability, and ability to bond to the substrates you will be using. Price is often a good indicator of quality—the better, longer-lasting caulks cost more.

When you apply caulk, remember that proper bonding of any caulk depends on the surface to which it is being applied. Surfaces should be structurally sound and free of dust, grease, mold, mildew, and moisture.

Expanding foam sealants have simplified the sealing around window and door frames, at wiring penetrations, and at other large gaps. These sealants are available in cans or larger canisters. Specialized application guns are available from some manufacturers for use with the larger cans. Both low-expanding and high-expanding foam sealants are available. In general, the low-expanding types are preferable for all but the largest holes. Using low-expanding foam sealant around windows and doors is especially important, because the high-expanding sealants can push and warp the jambs, making window and door operation difficult.

High-expanding foam sealants are more common than low-expanding types, and the high-expanding foam may be the only type available at local building supply stores. Examine the literature on the foam sealant carefully. If unavailable as a stock item at building supply stores, low-expanding foams can generally be ordered by the store or purchased directly from the manufacturer. All foam sealants are polyurethane. While some contain CFCs, there are several new foam sealants available that do not.

In addition to caulks and foam sealants, **foam gaskets** and **backer rod** can also be used to reduce air leakage. High-quality closed-cell or polymer-saturated open-cell foam gaskets should be used under sill plates. Foam backer rods (round in cross-section) can be used for sealing deep or wide cracks or for providing a backing for caulk in deep cracks. Open-cell foam gaskets can be used for sealing between exterior wall sections, plates and subfloor.

Air barriers are also important defenses against air leakage. This barrier—generally a four- to six-mil layer of polyethylene—should always be installed on the *interior* (warm) side of wall and ceiling insulation. The air barrier blocks air flow into the wall and ceiling cavities, where cooler temperatures could cause condensation of the water vapor that is carried by air. *To be effective, all air barrier joints and tears should be sealed with tape or non-hardening caulk* (see discussion of moisture migration and air and vapor barriers below).

The **vapor barrier** or retarder has a different function than an air barrier. Whereas the air barrier is meant to stop the flow of air and its contained water vapor through walls and ceilings, a vapor barrier is meant to retard the *diffusion* of moisture through walls, ceilings, and floors. Often the air barrier and the vapor barrier are the same material, such as 6-mil polyethylene.

Other builders use taped and gasketed drywall and the air barrier and vapor-barrier paint primer on the inside of the drywall as a vapor barrier. Please see the discussion of **Moisture Control** below for more information.

3. Indoor Air Quality

With all houses, but especially with tight ones, you need to keep indoor air quality in mind. It is possible to have too little fresh air coming into the house via air leakage, so that indoor air pollutants might build up, causing high concentrations of harmful pollutants or odors. Indoor air pollution comes from building materials, furnishings, activities of the home-owners (such as smoking, cooking, cleaning and breathing), combustion appliances, high humidity, and even from the ground around and under the house. The Energy Division distributes a comprehensive guide to indoor air quality—*The Inside Story*—which is available by calling 287-2656. Some of the more common indoor air pollutants and their sources are listed in **Table 7**.

TABLE 7.
Common Indoor Air Pollutants

Pollutant	***Sources in the Home***
Formaldehyde	Plywood (particularly interior grade), particleboard, paneling, other laminated wood products Carpeting, drapes, clothing and other synthetic products Indoor combustion sources
Volatile organic compounds	Cleaning products, pesticides, fabric softeners, deodorizers Synthetic materials used in interior construction and decorating
Poisons	Pesticides, rodent poisons, roach sprays, flea powder Sawing and sanding dust from pressure-treated wood Dust from older materials with lead paint (e.g., recycled doors)
Asbestos	Usually no longer used in new products Commonly found in older homes where it was used as an insulation on heating pipes and as a siding material In new construction, only found in a few recycled building materials
Combustion gases (carbon monoxide, carbon dioxide, sulfur dioxide, nitrogen dioxide)	Unvented kerosene heaters Improperly vented combustion appliances Gas ranges that are improperly adjusted Cigarette smoke Wood stoves and fireplaces leaking smoke into living space
Airborne biological agents (bacteria, mold, viruses, dust mites, fungi)	Illness in the house High humidity (above 50% relative humidity), damp basements Improperly installed heating systems ductwork
Radon	Gas that seeps into homes from the surrounding soil or bedrock Well water can also be a source of airborne radon
Water vapor	Household activities (showering, bathing, cooking) Exterior water sources (improper drainage, roof leaks) Breathing Combustion appliances

While many of the potential health effects of indoor air pollutants are long-term and difficult to attribute to a particular pollutant, some individuals are allergic to certain chemicals or suffer from acute chemical sensitivity, which makes them reactive to a wide range of common household pollutants. Some experts claim that acute chemical sensitivity is becoming more common.

It is important for builders to have a general understanding of indoor air quality issues, how to protect against problems, and what to do if problems are identified by homeowners. There are four levels of action that can be taken to deal with indoor air pollution problems.

First and most importantly, potential pollution sources should be kept out of the house. This might include installing only direct vent or sealed combustion appliances; avoiding products containing formaldehyde, such as medium density particleboard (commonly used in kitchen cabinets); and designing the foundation to keep radon out.

Second, if materials that emit pollutants are used to construct the house, you may be able to seal in these material surfaces with the result of lowering pollutant emissions effectively. For example, kitchen cabinets can be sealed with a high-quality finish to effectively lock the formaldehyde in and keep it out of the household air.

Third, it is often advisable to spot-ventilate close to pollution sources. Fans should be installed in kitchens to exhaust cooking odors and fumes from a gas and electric ranges. Bathroom fans should be installed to ventilate odors and water vapor. A window in a bathroom is not an adequate substitute for an operating exhaust fan. If a room is planned as a hobby room or darkroom, design in a ventilation system.

Fourth, and finally, general ventilation is recommended in very tight houses to insure an adequate supply of fresh, outdoor air. If the expected or measured air exchange rate is below 0.35 air changes per hour, the American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) recommends that mechanical ventilation be used to bring the ventilation rate up to 0.35 ACH, or at least 15 cubic feet of fresh air per person per minute (15 cfm/person). If you follow the recommended practices discussed earlier to minimize air leakage, the air leakage rate could be as low as 0.1 ACH.

Some indoor air pollution sources are primarily a concern only for the first month or two after construction is completed (paint, varnish and adhesive fumes and high water vapor release from drying concrete and wood, for example). Dealing with these pollutants may require higher-than-normal ventilation for a period of several weeks or months following construction. This can be accomplished by opening windows or operating **heat recovery ventilators** or exhaust fans at higher settings than would otherwise be required.

Mechanical Ventilation

Mechanical ventilation can be provided either with exhaust-only fans or with heat recovery ventilators, sometimes called air-to-air heat exchangers.

Exhaust-only fans, including kitchen and bathroom fans, are the most common means of providing mechanical ventilation. Make-up air is provided by air infiltrating through cracks around windows, doors, and other leakage areas. One problem with this ventilation strategy for very tight houses is that there are few leakage sources, so the house ends up operating under negative pressure while the exhaust fans are operating.

While slight negative pressure is not a big problem itself, it can create hazardous conditions within the house. If there are any non-direct-vent combustion appliances, the negative pressure can cause **backdrafting**—pulling potentially dangerous flue gases into the house instead of allowing them go up the chimney. Each year people die from carbon monoxide poisoning resulting from backdrafting, and many more suffer from less severe poisoning. Negative pressure in the house can also pull radon gas into the basement from the ground (see discussion below).

Many homeowners complain of noisy exhaust fans. If occupants feel that the fans are annoying, they are less likely to turn them on or leave them on long enough to do much good. If you plan to rely on exhaust-only ventilation, it is recommended that you install quiet (low sone), low voltage, high-quality fans. As an alternate option, consider installing a central exhaust ventilation system, ducted to various points in the house, including, but not limited to, the kitchen and bathrooms.

To avoid the negative pressure problem in tight houses with exhaust-only ventilation, **air inlet vents**—essentially intentional holes—can be installed in the exterior walls of the house. This may sound contradictory to good sense, but is not. After making an effort to make the house tight, who would want to actually put holes in the house? Why not just build a looser house? But the idea has merit as a simple make-up air strategy for exhaust-only ventilation systems. For one thing, you can control where the inlet vents will be and install them in locations where a slight draft will not be noticeable. In addition, you can control the total area of vents precisely and install exactly as many as required to balance the exhaust ventilation system being installed (manufacturers of quality ventilation systems will be able to help you size the inlets).

The other alternative for mechanical ventilation is heat recovery ventilation. Heat recovery ventilators exhaust stale air from the house and, at the same time, bring in an equal amount of fresh outdoor air. In addition, they preheat the incoming fresh air to some extent by transferring thermal energy from the warm exhaust air to the cold, fresh, incoming outdoor air. The house does not experience negative pressure, and the make-up air does not have to be heated as much as it does with the other ventilation strategies. A high-quality heat recovery ventilator will recover 60 to 85 percent of the heat that would otherwise have been lost by exhaust-only mechanical ventilation.

The most significant problem with heat recovery ventilation systems is that both tradespeople and homeowners are often unfamiliar with the equipment. Heating and air conditioning contractors have little experience with it, and they are reluctant to risk their reputations on an unfamiliar technology.

Perhaps because homeowners cannot see what a heat recovery ventilator is doing and the problems associated with *not* using one are not immediately obvious, homeowners tend to turn them off. Until the heat recovery ventilator industry grows to the point where it can afford a broad educational campaign to convince homeowner of their value, these problems will probably persist.

There are two types of heat recovery ventilators: 1) single through-the-wall units and 2) whole-house units with air inlets and outlets ducted to various parts of the house.

Whole-house units are far preferable to through-the-wall units—they are quieter, less obtrusive in the house (the central unit is usually located in the attic or basement), generally more efficient, and have better controls. As might be expected, whole-house air-to-air heat exchangers are also more expensive than through-the-wall units.

Radon

Radon is a colorless, odorless, radioactive gas present in bedrock throughout much of the country. High radon levels have been found in many parts of Maine. The gas can seep into a house through the basement and increase risk of lung cancer among the occupants, particularly if they are smokers.

In recent years, concern over radon and its adverse health effects have generated considerable public concern and a recommendation by the U.S. Environmental Protection Agency (EPA) that every house be tested for the gas. If levels over 4.0 picoCuries per liter (pCi/l) are found, EPA suggests remedial action to bring the levels down below this level.

Houses can be tested for radon levels quite easily using one of several types of low-cost monitors. Unfortunately, there is no good way to test a building *site* for a potential radon

problem; the house must be fully completed before a valid radon test can be done. For this reason, all houses should be designed with radon control and mitigation in mind. Fortunately, many of the methods for controlling radon are the same strategies that should be used for building energy-efficient houses. Specialized measures are quite simple and relatively inexpensive.

Designing buildings to avoid radon problems involves a three-part strategy: minimizing radon entry pathways, avoiding negative pressure in buildings (which will pull air into the house through the basement walls and floor, as discussed above), and incorporating strategies to facilitate future radon mitigation if it proves necessary. These strategies are shown in **Figure 8.**

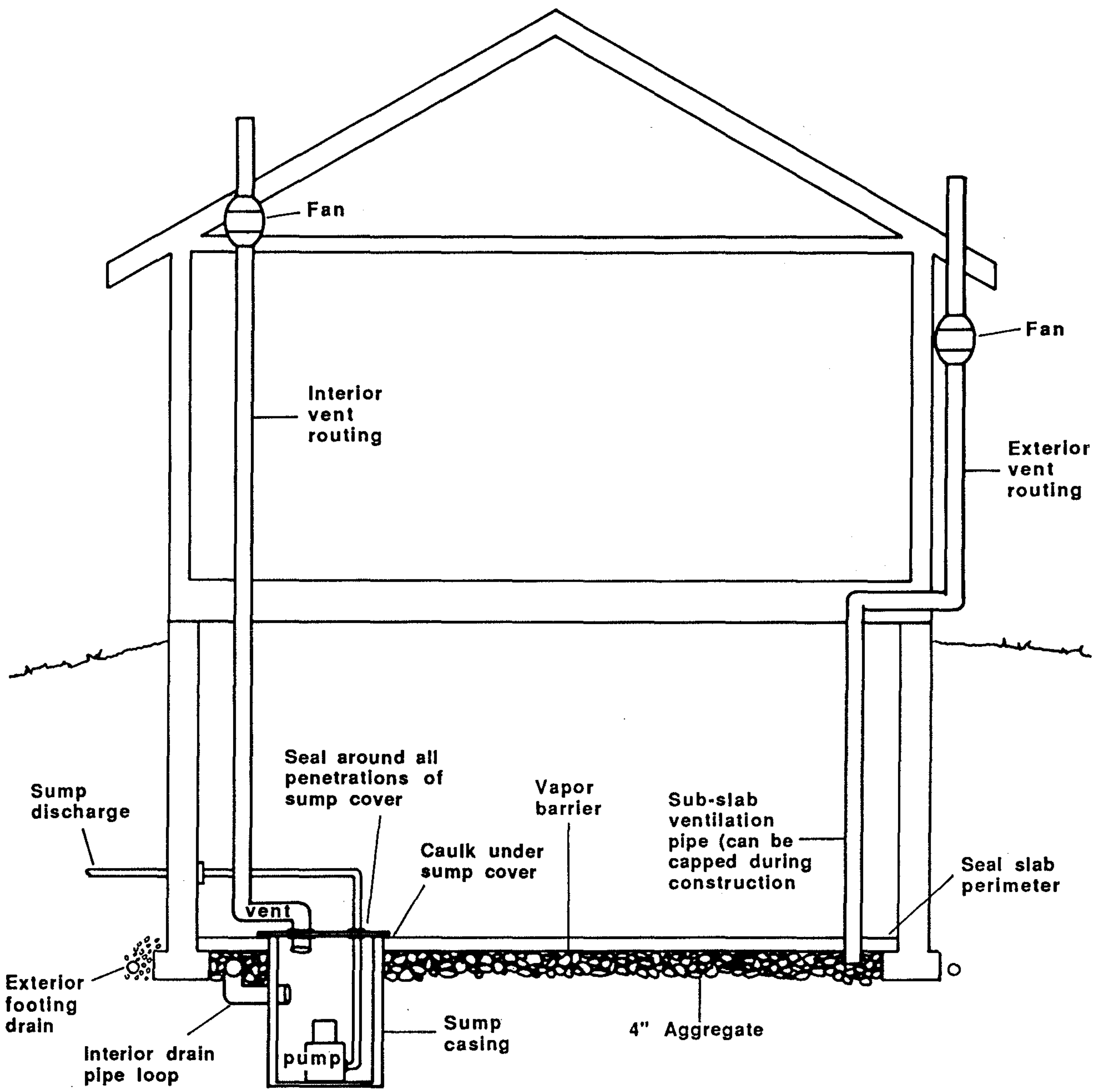


Figure 8. Designing a house to minimize the likelihood of radon problems, and to simplify future radon mitigation if it does become a problem, is quite easy.

Techniques to minimize radon entry into a new house usually focus on the foundation and basement slab floor. They include installing a polyethylene moisture barrier under the basement floor slab; putting steel mesh, fiber mesh and re-bar (reinforcement bar) into the slab to reduce cracking; installing expansion joint material where the foundation wall and slab meet; caulking cracks around any penetrations in the foundation floor or walls; removing grade stakes and screed boards as the slab is being finished (otherwise they will eventually rot and leave a channel into the sub-slab gravel); sealing the sump cover; waterproofing the outside of the foundation wall; and providing adequate foundation drainage.

With slab-on-grade construction, use a monolithic pour if possible, and with crawl spaces place a polyethylene moisture barrier on the ground in the crawl space.

To reduce the likelihood of negative pressure in a house (this can increase radon concentrations by increasing soil gas emissions), provide outside make-up air for all combustion appliances, including fireplaces and wood stoves; provide replacement air for clothes dryers; follow general strategies to reduce air leakage (see discussion, pages 18-19); ventilate crawl spaces; and, where practical, install heat recovery ventilators rather than conventional exhaust-only ventilation fans.

To facilitate future radon mitigation—if it ever becomes necessary—the most important strategy is to install four inches of crushed stone or gravel under the basement slab. If high radon levels are ever found, a 4" hole can be drilled into the slab and a pipe inserted into the sub-slab gravel and vented either up through the roof or out through a wall. If high radon levels are considered likely, a 4" **standpipe** can be installed before the slab is poured so the radon mitigation system can be put in place without having to drill through the concrete floor later. If such a pipe is installed, it is a good idea to label it as a sub-slab radon ventilation pipe so that in the future it is not confused with a drainpipe.

Details showing how these techniques can be incorporated into your foundation design are included in the **Recommended Construction Practices** section of this manual (starting on page 39). For more information on radon and indoor air quality issues, including recommended practices for reducing radon problems and a list of approved radon testing and mitigation companies, contact the Maine Radiation Control Program:

Maine Radiation Control Program
Department of Human Services
Augusta, ME 04333
Phone: 800-232-0842

4. Moisture Control

Controlling moisture in buildings involves a two-part strategy: 1) keeping water from entering the house, and 2) effectively keeping water vapor out of insulated cavities. Keeping water from leaking into the house requires the use of standard quality construction techniques, with particular attention paid to roof flashing, ice dam preventive measures, foundation drainage and foundation wall damp-proofing.

Construction details to prevent leaks are shown in the **Recommended Construction Practices** section of this manual. Follow manufacturers' recommendations for flashing details with skylights, windows and doors. Also, make sure all plumbing is properly installed and protected from possible freezing and rupture, which would obviously introduce water into the house.

Dealing with the second part of the moisture control equation—water vapor—can be more difficult. As a vapor (gas), water doesn't cause any direct problems. The problem occurs when conditions allow the water vapor to **condense** into liquid water inside a wall or ceiling cavity, or on an inside surface, such as window glass.

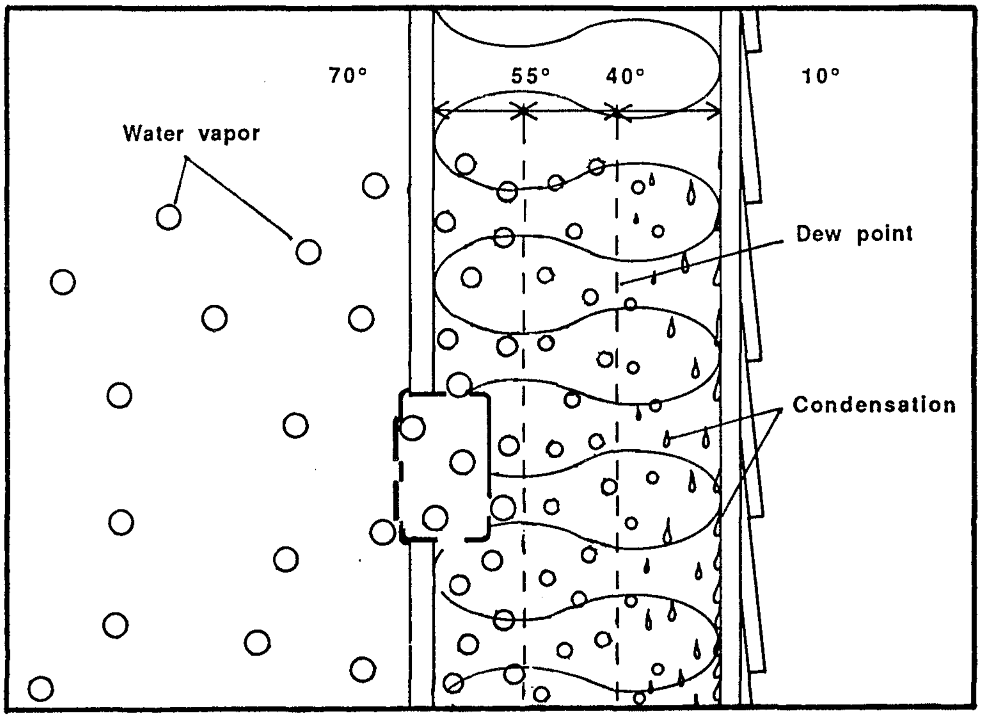


Figure 9. Air moving through the wall cavity will cool down. As it cools, the relative humidity of the air increases. When the dew point temperature is reached (100 percent relative humidity), condensation will occur.

All air contains some water vapor. The amount of water vapor it contains is measured by its humidity. As a mass of air is cooled down, its ability to hold water vapor drops (that's why cold winter air is always drier than warm summer air).

Relative humidity is the amount of water vapor in a sample of air relative to the maximum water vapor carrying-capacity of the air, at a given temperature. If the air mass cools, the actual quantity of water vapor in it remains the same, but the carrying capacity for water vapor is reduced, thus, the relative humidity increases.

As the temperature of the air continues to decrease, the **dew point** temperature is eventually reached. This is the temperature at which the relative humidity reaches 100 percent. If the temperature drops lower than the dew point, the excess water vapor condenses out as liquid. This liquid water can lead to the rotting of wood and the degradation of the R-value of insulation.

During the winter, it is much cooler outside the house than inside. If warm air containing water vapor is able to move through the wall cavity toward the outside, it will cool. Depending on the initial relative humidity of the air and the outside temperature, the dew point may be reached inside the wall, ceiling, or floor cavities (see **Figure 9**), allowing condensation to occur, soaking the insulation and potentially rotting framing members. *Air barriers are meant to prevent this potentially damaging air flow from occurring.*

Even if warm inside air cannot readily flow into construction cavities, water vapor is sometimes able to **diffuse** through materials into the wall cavity. The ability of water vapor to diffuse through different materials is measured by the **permeance** of the materials. The permeance, or **perm ratings**, of different materials are shown in **Table 8**. In general, materials with perm ratings of 1 or less are considered adequate **vapor barriers**.

To prevent water vapor condensation within wall cavities, there are a number of important rules, some of which apply to construction of the house and some of which apply to living in the house.

TABLE 8.
Perm Ratings of Common Materials

Type	*Material*	*Perm Rating*
Masonry	Concrete block (8")	2.4
	Brick masonry (4")	0.8
Exterior Wall Materials	Plywood, exterior	0.7
	Pine, tongue-and-groove	4.5
	Clapboards	8.0
Interior Wall Materials	Gypsum drywall (1/2")	40
	Plywood, interior	1.9
Insulation	Extruded polystyrene (1")	1.2
	Expanded polystyrene (1")	2.0 - 5.8
	Batt insulation, unfaced (1") fiberglass, cellulose, mineral wool	116
Vapor Barriers	Polyethylene (4-mil)	0.08
	Polyethylene (6-mil)	0.06
	Aluminum foil (1-mil)	0.0
	Foil facing on batt insulation	0.5
	Kraft facing on batt insulation	1.0
	Foil facing on rigid insulation	0.0
Paints and Wallpaper	Latex primer sealer	6.3
	"Vapor retarder" paint	0.6
	Primer plus one coat flat oil paint on plaster	1.6 - 3.0
	Enamel paint on smooth plaster	0.5 - 1.5
	Standard wallpaper	20
	Vinyl wallpaper	1.0
Papers and Housewraps	15-lb building felt	5.6
	Air barrier (Tyvek®, Typar®, etc.)	10-40

Source: ASHRAE *Handbook of Fundamentals*, 1997, pp. 24.16-24.17.
Permeance (Perm) = grain/hr, ft², in. Hg

First, follow the practices discussed previously in the air leakage section to keep the building envelope as tight as possible. Studies have found that most of the water vapor that gets into wall cavities is carried by air moving through the wall, rather than as the water vapor gradually diffusing through interior building surfaces. Eliminating air leakage is, therefore, an excellent defense against problems caused by condensing water vapor. In fact, this is the principle behind the **airtight drywall approach** to construction (**ADA**), discussed on page 28.

Second, in building the house, you should install a vapor barrier on the *warm* side of the wall, ceiling, and floor cavities (toward the living space). The most common vapor barrier is 4- to 6-mil polyethylene. If using foil-faced rigid insulation on the inside of studs or rafters, the foil facing can serve as the vapor barrier. To be most effective, this vapor barrier should be continuous with edges taped and puncture holes kept to a minimum (for an alternative, see discussion on ADA).

If you use foil-faced rigid insulation on the inside of studs or rafters, be sure to tape the joints with a vapor barrier tape. Refer to the **Recommended Construction Practices** section for air/vapor barrier detailing.

Third, try to eliminate any obvious *sources* of water vapor. Do not store large quantities of freshly cut firewood in a basement—drying wood releases a large quantity of water vapor.

Install exhaust ventilation fans or heat recovery ventilators in areas where large quantities of water vapor are generated (kitchens and bathrooms).

Make sure clothes dryers are vented to the outdoors. Do not use an unvented kerosene heater (in addition to releasing potentially dangerous combustion gases into the house, these also release large quantities of water vapor). And be sure that the foundation is properly protected from leakage (a wet basement floor can add a great deal of water vapor to the air as the water evaporates).

Fourth, if possible, build wall and ceiling assemblies so that the materials used are progressively more permeable to moisture, moving from the inside toward the outside. If moisture does get into a wall or ceiling, it will have a better chance of escaping if higher permeance materials are installed on the exterior portions of walls and ceilings.

For this reason, experts recommend that if foil-faced rigid insulation is used on the outside of a wall assembly, it should be at least 2" in thickness. This insures that the innermost foil facing will remain warm enough to prevent water vapor from condensing on it. If the rigid insulation is thinner, say 1/2" foil-faced insulation, the inner facing will not have as much R-value between it and the cold outdoor air. This inner facing will, therefore, become colder and is more likely to allow condensation to occur, possibly causing damage.

Related to the idea of keeping a potential vapor barrier warm enough so that water vapor will not condense on it, is a rule that originated in Canada. The 1/3:2/3 rule insures that the vapor barrier will remain warm enough to prevent condensation problems. The 1/3:2/3 rule states that 1/3 of the R-value of the total installed insulation should be to the warm side of

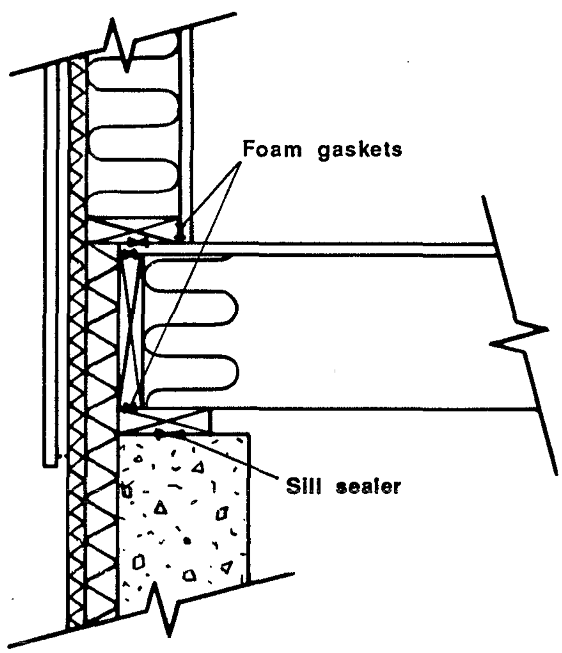


Figure 10. In ADA construction, the framing and drywall are carefully sealed to prevent air leakage into the wall and ceiling cavities.

the vapor barrier and 2/3 of the R-value must be to the cold side—toward the outdoors.

Fifth, unheated areas and some cavities should be ventilated. Important areas to ventilate include unheated attics, the air space under the roof sheathing in insulated cathedral ceilings, and crawl spaces (see discussion, page 29).

Ventilating these spaces will allow trapped water vapor to escape.

Finally, homeowners should keep humidity levels between 30 and 50 percent (relative humidity) during the winter months. The higher the relative humidity, the more likely it is that condensation will occur in wall or ceiling cavities—or on cooler interior surfaces such as window glass.

From a health perspective, relative humidity levels also should be kept between 30 and 50 percent. At levels above or below that range, some homeowners may suffer respiratory problems resulting from allergies, bacteria or viruses. A humidity gauge or digital hydrometer can be used to monitor humidity levels.

Airtight Drywall Approach (ADA)

As mentioned above, research by building scientists has shown that the movement of air—and its contained water vapor—through cracks, gaps, outlet boxes and other places is the primary way moisture gets into wall and ceiling cavities. This water vapor can condense, causing rot and the degradation of the R-value of insulation. Much more water vapor gets into wall and ceiling cavities through this mechanism than by diffusing through wall surfaces. For this reason, a number of Canadian building scientists developed a construction technique in the early 1980s that places less emphasis on vapor barriers and more emphasis on blocking air movement through walls and ceilings.

In this Airtight Drywall Approach to construction (ADA), vapor barriers are still recommended, but they are down played relative to air barriers. The ADA method employes the interior finished drywall as the air barrier. The drywall must be gasketed and sealed at all joints to be effective. This includes sealing the drywall

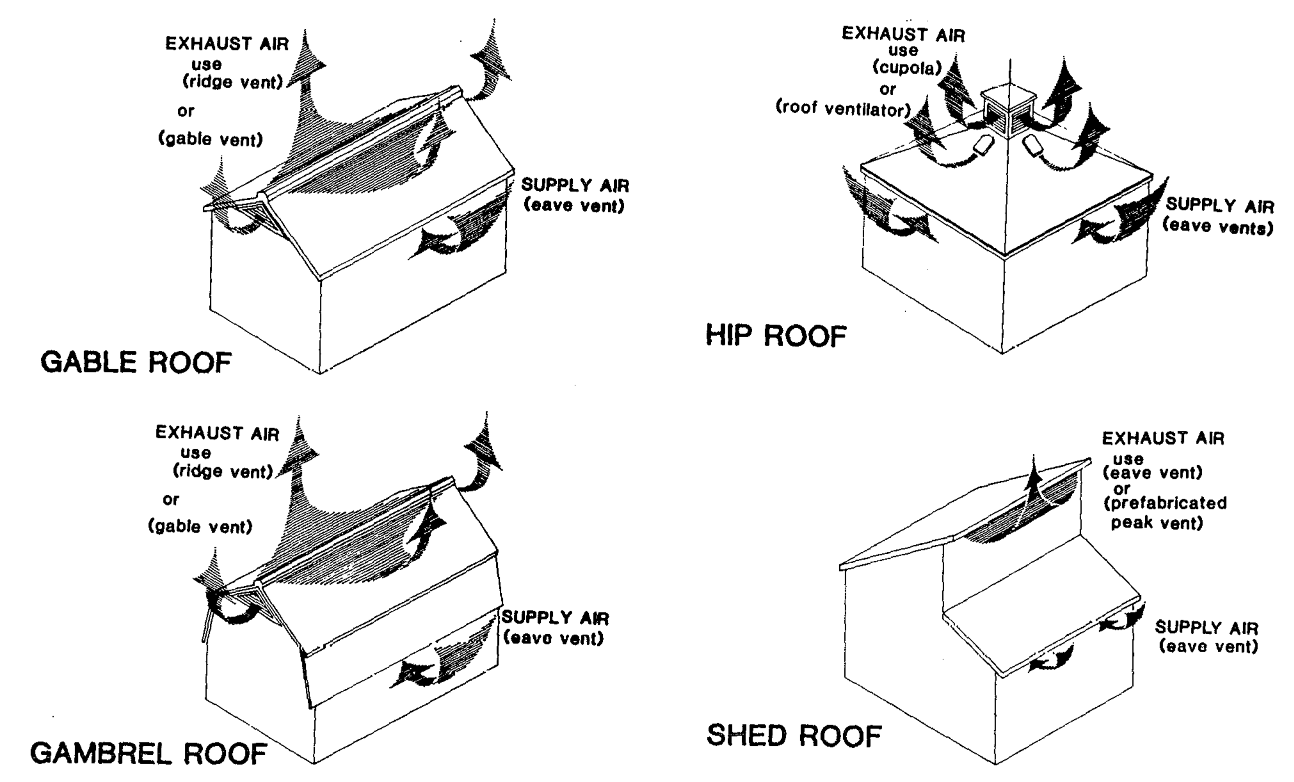


Figure 11. Proper roof ventilation is important. When soffit and ridge vents cannot be used, specialized roof ventilators or cupolas may be required.

to all electrical outlets and switch boxes, placing special gaskets at between the back of the drywall and framing members at windows, doors, and upper and lower plates. Please refer to **Figure 10** for more details.

The vapor barrier is then painted on the interior surface of the drywall. This system works well, but requires specialized knowledge to complete. Refer to the bibliography at the end of this guide for detailed references on ADA construction.

5. Ventilation of Building Cavities

Ventilation acceptable indoor air quality were introduced in the **Indoor Air Quality** section of this manual (page 20).

Also important is ventilation of roofs and, in some cases, crawl spaces. This type of ventilation is an important strategy in moisture control and was referred to in the previous section. It is almost always passive ventilation, that is, it is done without motors or fans.

Roof Ventilation

Proper ventilation of roofs will carry away any moisture that may accumulate in the insulation. Equally important, roof ventilation usually plays an important role in preventing ice dam formation. Finally, roof ventilation can play an important roll in keeping roof and attic spaces cooler during warm weather. Almost all roofs should be ventilated, no matter what roof style is used: gable, gambrel, mansard, hip or shed (see exceptions on page 30).

Proper roof ventilation requires both inlet and outlet vents. The inlet vents should be at the bottom of the roof and the outlet vents at the top so that the natural buoyancy of heated air provides the driving force for the ventilation. Typical ventilation configurations for the most common roof designs are shown in **Figure 11**. Ventilation is most effective when there is a full ridge along the peak of the roof. The inlet vents are provided as continuous soffit vents in the soffits of the eaves, and a continuous ridge vent provides the outlet, as shown in **Figure 12**.

Gable-end vents can be used as the outlet vents in place of ridge vents, or as both inlet and outlet vents. Though not as effective as continuous soffit and ridge vents, gable-end vents with continuous soffit (inlet) vents are usually satisfactory. Gable-end vents are least effective when used by themselves to provide both inlet and outlet ventilation.

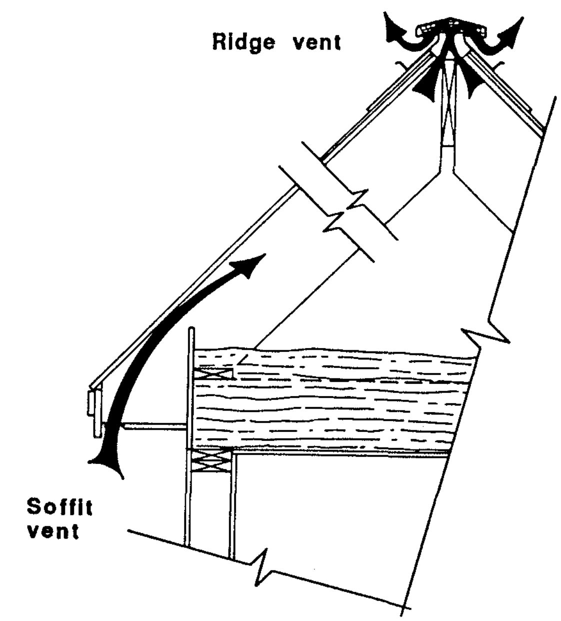


Figure 12. Optimal roof ventilation is provided with continuous soffit and ridge vents — whether for an unheated attic or cathedral ceiling application.

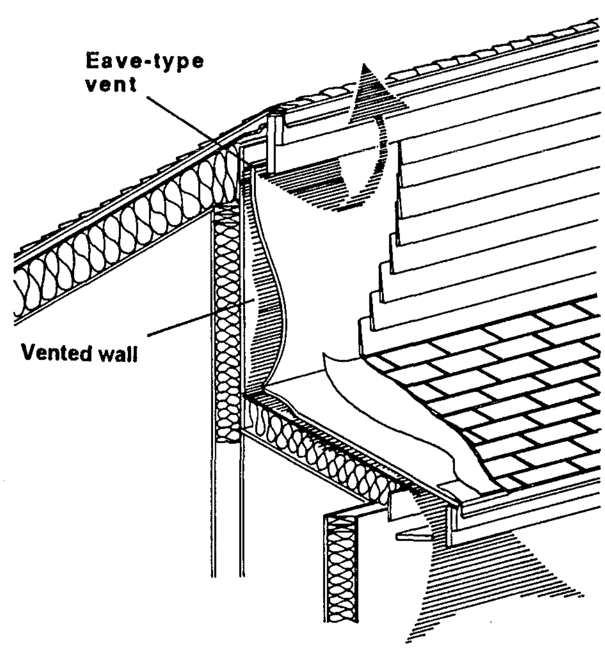


Figure 13. Providing adequate roof ventilation for a shed roof abutting a wall can be difficult. One option is to vent the roof air space into a vented wall.

Proper ventilation of mansard and hip roofs is more difficult because there is not a continuous ridge running the full length of the roof. Cupolas and/or roof ventilators must be used as outlet vents at or near the peak of the roof.

Shed roofs that abut walls are very difficult to ventilate because even specially designed venting products can be readily clogged with snow during the winter. An option for venting these shed roofs is to build vent space within a wall, as shown in **Figure 13**. Warm air rising up the shed roof passes into an air space between the wall sheathing and siding where it can rise to a ridge vent at the peak.

Inlet and outlet vent areas should be the same. A general rule for the area required is one square foot of combined inlet and outlet vent (net free vent area—see below) for every 300 ft^2 of area to be vented. For example, if ridge and soffit vents are used in combination for a house with a 1000 ft^2 unheated attic, a total net free vent area of 3-1/3 ft^2 should be provided, one-half of this in the soffit areas and one-half in the ridge.

If a vapor barrier is *not* used in the ceiling (some builders insist a vapor barrier should not be installed in this location, though most experts argue otherwise), twice the net free vent area is required: 6-2/3 ft^2 for this example.

If two gable-end vents are used for this example, one-half of the required free vent area would be installed in each of the two gable ends, 1-2/3 ft^2 if there is a vapor barrier in the ceiling or 3-1/3 ft^2 if no vapor barrier is used in the ceiling.

These rules refer to the **net free vent** area, which takes into account the area taken up by louvers and/or screening. If the free vent area is not stamped on the vent you are using, contact the manufacturer for this information. If you are unable to obtain a value for the free vent area of a vent device, assume that 50% of its gross measured area is free vent area.

With insulated cathedral ceilings or the sloped section of ceiling/roof in Cape Cod style houses, vent spacers are required under the roof sheathing to keep the insulation away and provide a continuous channel for ventilation. The air space under the roof sheathing should be at least 1" thick to provide adequate air flow.

Providing adequate roof ventilation above and below roof windows and at roof hips and valleys can be quite difficult. Above and below roof windows, one-inch holes can be drilled through the rafters near the top to allow some lateral air flow around the roof window. At hips and valleys, the hip rafters and valley rafters can be dropped down to provide an air space at the top for air flow into adjacent rafter bays where the air can flow up and out the ridge vent. Roof ventilation details, including use of vent spacers, are shown in the **Recommended Construction Practices** section of this manual.

As an exception to this practice of ventilating all sections of roofs, some insulation installers are now dense packing cellulose insulation into these spaces, leaving no space for ventilation. Apparently this practice works well, allowing a higher insulating value in these sloped ceiling/roof spaces. This should not be done with fiberglass, rock wool, or any other insulation that allows air to flow through it when installed. Contact your nearest low-income weatherization organization or the Federal Funds Division at Maine State Housing Authority for more information about this practice.

Another exception to venting roofs is often referred to as a warm roof. This roof type is insulated with rigid insulation or stressed-skin panels (rigid insulation laminated to other materials, such as plywood or drywall), the wood roof decking is applied on top of the rigid insulation, and then the roof shingles or other roofing material is installed. No vent space is built into the roof assembly.

This warm roof construction—the use of dense-pack cellulose or any type of rigid insulation—may not be acceptable to local code officials, so talk with the appropriate officials before beginning construction. In addition, there is concern by some that excessive heat buildup may shorten the life of shingles. As a result, you might find that shingle manufacturers will not

warranty their shingles on a warm roof; they may insist on roof ventilation.

Crawl Space Ventilation

The need for crawl space ventilation is an area of debate in the building industry today. Some building codes recommend that crawl spaces be vented during the summer months to allow water vapor to escape. If a moisture barrier is used on the ground, one 8" x 16" vent is recommended for each 350 ft^2 of floor area, according to this theory, with a minimum of four vents. Without a moisture barrier, the vent area should be at least double that. Screened vents should be open during the summer months and closed in the winter.

However, there is growing support that crawl spaces and unheated basements *not* be vented during the summer (or winter). Experts argue that venting a crawlspace during the summer introduces more moisture than it expels. They contend that because 1) the incoming air has a high relative humidity and 2) surfaces in the crawl space or unheated basement are generally cool, excessive condensation will occur.

These experts suggest no crawl space ventilation is required if a full 6-mil polyethylene (or equivalent) ground cover is place on the crawl space floor. If for some reason a full ground cover is not in place, the crawl space should be ventilated as suggested above. Refer to the **Recommended Construction Practices** section for details of providing moisture protection and ventilation in crawl spaces.

6. Windows

Windows and glass doors (terrace and patio doors) may account for as much as a third of the heat loss from a typical house. They are the building components with the least resistance to heat loss (the lowest R-value). As a result, they offer great potential for improving overall energy efficiency. In fact, new state-of-the-art windows provide more than double the insulating value called for by Maine's Residential Energy Standards: up to R-4.0.

Until the mid-1980s, the only way to boost energy efficiency of windows was to add extra layers of glazing or to increase the thickness of the air space between the layers of glazing. In recent years, however, there have been significant advances in window technology and dra-

TABLE 9.
Glazing Configurations and R-Values*

Glazing Configuration	*R-Value*
Single glazing	1.0
Double glazing, 3/16" air space	1.7
Double glazing, 1/2" air space	2.0
Triple glazing, 1/2" total air space	2.3
Triple glazing, 1" total air space	2.6
Double glazing, 1/2" air space, low-E	2.1
Triple glazing, low-E plastic interpane, 1/2" total air space	2.3
Double glazing, 1/2" total air space, low-E, argon gas fill	2.1
Triple glazing, low-E plastic interpane, 1/2" total air space, argon gas fill	2.5

*Applies to glazing only and includes edge losses, 3' x 4' size.

TABLE 10.
Air Leakage Values for Different Windows from One Manufacturer

Window Type	*Air Leakage (cfm/ft)*
Casement	.03
Awning	.07
Double-hung	.17
Slider	.13
European-style combination side and bottom hinged	.01
Roof window	.03
Sliding patio door	.17
Hinged terrace door	.07
Hinged French doors	.10

matic increases in window R-values.

The most important development has been the introduction of low-emissivity (low-E) coatings for windows. A thin metal layer is applied to one of the layers of glass or to a plastic film suspended between the layers of glass. This coating allows most of the short wavelength infrared energy from the sun to pass through, but blocks the escape of long-wavelength infrared emanating from the inside of the house. Low-E windows add almost as much R-value as an extra layer of glass, while being less expensive and less bulky to incorporate into windows.

Another major advance has been the use of a gas other than air in the space between the layers of glass in an insulated glass window. Argon is the most common gas used in this application, and it is now offered as an option by several major window manufacturers. Different glazing configurations and their resultant R-values are compared in **Table 9** (page 31). These are average values; slight differences in air space thickness, type of coating and window design may result in somewhat different values with different products or manufacturers. In evaluating windows, read through manufacturers' literature carefully.

A new method of calculating R-values and U-factors was introduced by window manufacturers in 1990. The new method takes into account edge losses and, thus, gives a more accurate indication of R-values and U-factors. If you have questions about the insulating value of windows, talk with your dealer or call the Energy Division.

Along with the glazing configuration, the type of window and its construction also have a big effect on energy efficiency—primarily due to air tightness. Casement windows, for example, are typically five times as tight as double-hung windows. Windows and doors are tested for air tightness by manufacturers under carefully controlled conditions. The measured air tightness, in cubic feet of air per linear foot of crack (cfm/ft), should be listed on manufacturer's literature. Of the most common window types, casements and awnings are generally the tightest, followed by sliders and double-hung windows, but you will find considerable vari-

ation from manufacturer to manufacturer depending on the weatherstripping and closure details used. There may also be differences in air tightness with different frame materials: wood, vinyl-clad wood and metal. The air leakage values of different window models offered by one particular manufacturer are listed in **Table 10**.

When choosing windows, be sure to study energy efficiency carefully. Compare different brands and also different styles offered by the same manufacturer. For very little added cost, the energy efficiency can be boosted dramatically—beyond the levels called for by Maine's Energy Efficiency Standards.

With operable windows, always buy pre-hung units to ensure tight-fitting weatherstripping and snug operation. With fixed glazing, you can site-build windows and achieve comparable tightness to manufactured units. A detail is shown in the **Recommended Construction Practices** section on site-building a tight window (page 67).

Another way to increase the insulating value at windows is to install and use **window insulation**. This special insulation can be in the form of soft insulated shades or rigid insulated shutters. The material should include a vapor barrier membrane close to its inside service. These tight-fitting, interior shades or shutters are drawn over the window glass on cloudy winter days and during the night. In addition, they can be drawn to control solar gain through window glass.

The R-values of these materials can be significant—as much as an additional R-4 above the window itself—but the increased R-value is only effective if the window insulation is drawn in place over the window glass.

The Maine Energy Efficiency Standards do not recognize window insulation as method of complying with the required R-value of windows—the insulating value of windows themselves must be at least R-2. However, window insulation can be a cost-effective way of reducing heat loss or unwanted solar gain through the glass.

These insulating devices also often serve as cosmetic window coverings, a feature that most home occupants welcome.

7. Doors

Like windows, exterior doors can be big energy wasters, both due to heat loss through the doors and air leakage around poorly sealing units. The biggest decision in buying a door, from an energy perspective, is whether to buy a solid wood door or an insulated door. Solid wood doors are generally preferred from an aesthetic standpoint, but they provide less resistance to heat flow. A 2" thick solid wood door insulates to about R-2.2. With a wood storm door, the total R-value can be boosted to about 3.5. An insulated metal or fiberglass door, by contrast, can provide between R-2.2 and R-6, without a storm door. Furthermore, metal and fiberglass doors generally seal more tightly and are less likely to warp with weather exposure. Warping can greatly reduce the air tightness in wood doors. Metal doors with magnetic weatherstripping are generally the tightest because of the refrigerator-like seal between door and jamb. High quality foam gaskets and adjustable thresholds are also used to tightly seal doors.

If an air-lock entry is used, the energy penalty for installing a wood door will be reduced, but the energy performance will still be lower than with an insulated metal door. No matter which type of door you decide on, be sure to buy only pre-hung units. Factory-installed weatherstripping is far better than what you can provide with site-built doors, and the tolerances will generally be much tighter.

8. Heating Considerations

How successful you are in building a tight, energy-efficient house is measured by its heating requirements. An 1800 square-foot home built to the Maine Energy Efficiency Standards will cost an average of about $600 per year to heat with oil, assuming an average efficiency boiler or furnace (about 80% steady-state efficiency, #2 oil at $0.90 per gallon, 8000 heating degree days). That compares with average heating costs of about $1100 for the same house built using older practices (R-11 walls, R-19 ceilings, no foundation insulation,

etc.). By going beyond the present standards (with high-performance windows, for example), heating costs can be reduced to less than $500 per year. Refer to **Appendix A** for information on calculating the heat load of a house.

Keeping heating bills down depends on three important factors: 1) the energy efficiency level of the house; 2) occupant behavior—beyond the scope of this manual; and 3) the heating system used—its efficiency and fuel type. You can maximize your investment in an energy efficient house by heating it with a high-efficiency heating system. New oil-fired furnaces and boilers deliver heat at about 80 percent efficiency

New gas-fired heating systems are at least 78 percent efficient. Condensing gas furnaces can be as high as 95 percent efficient.

While installing a high-efficiency heating system may not be quite as important in a energy-efficient house as it is in a poorly insulated one, it usually makes a great deal of sense. The extra expense of buying a 90 percent efficient boiler or furnace rather than one that is 80 percent efficient will usually be paid back in just five to seven years in a house built to Maine's Energy Efficiency Standards.

A thorough discussion of available high-efficiency heating systems is beyond the scope of this manual, but several important points should be made.

Electric resistance heating is generally the cheapest type of heating system you can *install* (from an initial cost standpoint), but the most expensive to *operate*. Given electricity prices in most of Maine—and projections for the future—electric resistance heat should be avoided in almost all cases. Even electric heat pumps, which deliver more heat per unit of electricity consumed, seldom make sense in Maine. They are significantly more expensive to install than oil- or gas-fired systems, and their performance drops dramatically in cold weather (below about 30°F).

With oil-fired furnaces and boilers (furnaces heat air for hot-air distribution, while boilers heat water for hot water distribution), efficiencies over 80 percent can be achieved with quality heat exchangers and high-speed **flame-retention burners**.

With gas-fired furnaces and boilers, look for **condensing** or **pulse combustion** systems with efficiencies over 90 percent.

As mentioned in the **Indoor Air Quality** section of this manual (page 20), direct vent combustion furnaces and boilers minimize the risk of backdrafting hazardous combustion gases into the house. These systems draw in their own combustion air from outside through a dedicated pipe and exhaust flue gases directly to the outdoors, without any interaction with air in the house.

In planning the heating system, pay particular attention to controls. Setback thermostats can reduce heating bills dramatically: Each 1°F night setback can save up to 1 percent on yearly heating bills.

If there are portions of the house that will be used little or that have different heating requirements, put them on separate **zones** controlled by their own thermostats.

For some boiler heating systems, it may make sense to consider specialized **reset controls** or modulating aquastats, which regulate boiler temperatures according to outside temperatures. Instead of always circulating 180° water through baseboard radiators, a reset control lowers the water temperature when heating demands are lower—this reduces heat losses from the boiler and saves fuel.

Many homeowners building new houses want a fireplace or wood stove—usually for aesthetic reasons as much as for energy cost reasons. Wood stoves are far more energy efficient than fireplaces, and should be recommended over fireplaces whenever possible. In fact, conventional fireplaces—without combustion air supplies, tight-fitting dampers and glass doors—usually waste more heat than they provide. Even though a fireplace may warm the area immediately around it, using the fireplace may actually make the heating system work harder, because the fireplace pulls large volumes of air out of the house. This lost air is

TABLE 11.

Typical Appliance Operating Costs (Annual)

Appliance	*Average Existing Appliance(s)*	*Very Energy-Efficient New Appliance(s)*
Water heater (electric)	$780	$455
Water heater (natural gas)	288	231
Refrigerator (manual defrost)	79	50
Refrigerator/freezer (frost-free)	209	116
Freezer (manual defrost)	130	72
Freezer (frost-free)	231	130
Air conditioner (central)	260	130
Air conditioner (1 room)	50	33
Electric range	100	94
Gas range, natural gas	50	30
Clothes washer (incl. water heating)	159	79
Clothes dryer (electric)	115	100
Clothes dryer (gas)	40	30
Dishwasher (incl. water heating)	115	80
Color television	43	22
Household lighting	130	44-86

Note: Operating costs assume electricity at .13¢/kWh, gas at 75¢/therm.

Source: American Council for an Energy-Efficient Economy, Washington, D.C. and Department of Economic & Community Development, Energy Division.

replaced through infiltration of cold outside air, which must be heated.

In a tight house, it may be necessary to open a window to provide adequate draft if there is not a combustion air supply for the fireplace. Refer to the **Air Leakage** section on measures that can be taken to make fireplaces more efficient.

Most wood stoves on the market are fairly energy efficient. The highest efficiency wood stoves have **catalytic combustors** in them to fully burn flue gases before they go up the chimney, which both cuts down on pollution and boosts efficiency.

Sizing Heating Systems

Heating systems are often oversized. This is more likely to happen in energy-efficient houses. Heating contractors are accustomed to installing in 100,000 to 150,000 Btu/hr furnaces or boilers, and they have trouble accepting the idea that a new house may only require 30,000 to 50,000 Btu/hr. If too large a system is installed, it will operate inefficiently because of the frequent cycling on and off. Furthermore, frequent on-and-off cycling reduces the life of the heating plant. For highest efficiency and greatest comfort, a heating system should be oversized by no more than 20 percent. How-

ever, if you are using a boiler for domestic hot water as well, you may need more capacity.

To size a heating system, you or your heating contractor need to know what the expected maximum heating load for the building will be. On a cold day, how many Btus per hour will it take to keep the house comfortable? An architect or heating contractor should be able to tell you the **heating outdoor design temperature** for your area. In Maine, heating design temperatures range from 0 to -15°F (these are 97-1/2 percent design temperatures considered adequate for heating system sizing, meaning that 97-1/2 percent of the time during the three coldest months of the year, temperatures will not drop lower). Heat loss and heating load calculations are covered in **Appendix A**.

9. Appliances and Lighting

As we build more energy-efficient houses, the *percentage* share of the total energy bill due to water heating, electrical appliances and lighting increases. In very efficient (non-electrically heated) homes it is not unusual for electricity bills to exceed heating bills. Fortunately, there is significant opportunity for keeping electric costs down by choosing high-efficiency water heaters, appliances and lighting.

Typical annual operating costs for home appliances are shown in **Table 11**. Both the costs for average existing appliances and very efficient new appliances are shown.

In some cases, significant savings can be realized by switching from electricity to gas; this may be the case with water heaters and dryers. While the savings will be greatest with natural gas, higher cost liquefied propane (LP) gas will usually also save money over electricity.

Gas ranges with standing pilots (pilots lights that burn constantly) should be discouraged in energy-efficient homes for two reasons. First, the standing pilot wastes energy unnecessarily relative to a gas range with an electronic ignition. Second, the gas-fired standing pilot can lead to contribute to air pollution if it is improperly adjusted.

With a gas or electric range, a vented range hood (vented to the outside) should be operated while a range burner or the oven is being used. This will facilitate the venting of combustion and cooking by-products to the outdoors, making the indoor air healthier.

Gas water heaters should be either direct vent or mechanically vented for indoor air quality reasons. These units can be slightly more efficient than conventional types, but, more importantly, they are safer to operate in a tight, energy efficient house.

With water heating, you should also consider an **indirect-fired water heater** that operates off an oil- or gas-fired boiler or furnace. This is a very efficient type of water heater and should not be confused with the older **tankless coil** water heater, which wastes energy during the summer months when the heating system is not being used. Indirect-fired water heaters allow the boiler or furnace to operate for short spurts during which time the water in the separate tank is heated via a separate heat exchanger.

When shopping for appliances to outfit new houses, carefully study the **Energy Guide labels**. Energy Guide labels are required on all new refrigerators, freezers, water heaters, clothes washers, clothes dryers, dishwashers and room air conditioners. These labels display the yearly average energy cost to operate the appliance and provide a comparison with the energy costs of similarly sized models. If you are a builder, discuss appliances with your clients and, where features and style suffice, help them select those that are the most energy-efficient.

In the area of lighting, there have been many technological changes in the past ten years, opening the door to dramatic energy savings. With tube fluorescent lights, we have seen the introduction of quiet, flicker-free electronic ballasts and improved-color lamps that make this type of lighting much more acceptable in the residential environment.

An even more exciting development was the introduction of **compact fluorescent lamps**. The light quality from compact fluorescent lamps is similar to that from incandescent

lamps, yet they consume about one-quarter as much electricity for a given amount of light, and they last ten times as long. There are two basic types of compact fluorescent lamps: lamp-only units that plug into suitable ballasts, and units with integral ballasts that can simply be screwed into standard light bulb sockets.

In new construction, when deciding on fixtures to install, it makes sense to buy fixtures specially made for the plug-in compact fluorescent lamps. These fixtures have built-in ballasts; if the lamp fails it can be inexpensively replaced. With fixtures designed for standard incandescent light bulbs, you can to ensure that compact fluorescent lamps (with integral ballasts) will fit.

For outdoor lighting, there are high-pressure sodium and metal halide lamps that are even more energy efficient than outdoor incandescent lamps. Unlike a few years ago, the light quality from these **high-intensity discharge (HID) lamps** is now acceptable for outdoor residential lighting. In fact, some metal halide lamps are now even suitable for indoor use. You might also want to look carefully at your outdoor lighting requirements. Outdoor spaces around houses are often over lit, and savings might be achieved by using fewer or lower-wattage lamps.

In addition, there have been advances in the area of lighting controls. There are sound- and motion-activated controls, programmable controls, that can be operated from a remote location by telephone, and controls that adjust lighting intensity relative to daylight levels. While most of the interest in energy-efficient lighting has so far been limited to commercial and industrial buildings, interest is growing among home owners.

Part 4. Recommended Construction Practices

The details shown on the following pages provide examples of construction details you may use to satisfy Maine's Residential Energy Efficiency Standards. These details are not meant to be portrayed as the only options available to you. If you have any questions on these details, or on specific details you are using or plan on using, contact the Energy Division.

1. Foundations

Foundations are often an overlooked area in energy-efficient construction. If foundations are not insulated to levels commensurate with the rest of the building, they can account for as much as 20 percent of the building's total heat loss. That is easy to understand when you consider that an 8-inch concrete wall insulates no better than a single pane of glass! By following Maine's Energy Efficiency Standards, heat loss attributable to foundations should drop to just 5-10 percent. Today's energy prices easily justify the money spent to insulate foundations properly.

There are three basic types of foundations commonly found in Maine, all of which can be

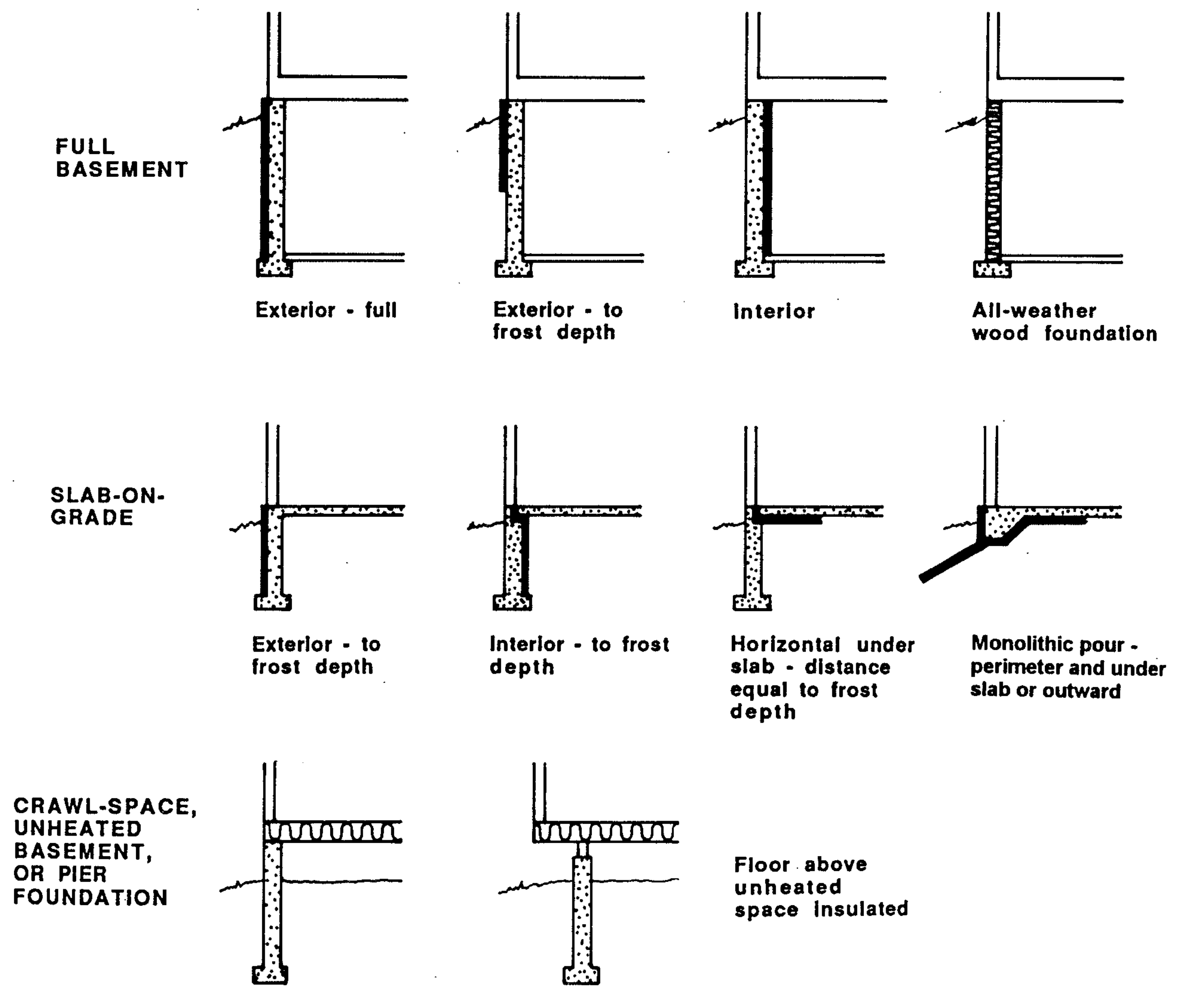


Figure 14. Foundation types and insulation configurations.

effectively insulated. These foundation types and the general insulation strategies available for each are shown in **Figure 14**. As covered in **Table 1** (page 2), foundation walls enclosing heated spaces must be insulated to at least R-10 (R-value for the insulation only), and the insulation must extend down at least to the design frost depth (see **Table 4**, page 5).

With slab-on-grade foundations, R-10 insulation must be used in one of two configurations: 1) either around the full perimeter extending down to the design frost depth, or 2) around the full perimeter of the slab itself and horizontally or diagonally beneath or away from the slab for a distance equivalent to the design frost depth.

In the case of unheated basements or crawl spaces, the floor above the unheated space must be insulated to R-19.

When foundation insulation will be in contact with the ground (on the outside of the foundation wall or under the slab), extruded polystyrene is recommended. It is resistant to moisture and offers adequate compressive strength characteristics. For use under the slab, specify higher density extruded polystyrene if several densities are available. Rigid fiberglass and expanded polystyrene can also be used for below-grade applications, though the R-value and compressive strength are somewhat lower. To achieve R-10 with rigid fiberglass, you will need more than 2" of thickness, probably 2-1/2", but check the rated per-inch R-value of the insulation.

For interior insulation, a 2x4 stud wall is typically constructed and insulated with 3 1/2" fiberglass batt insulation. As an alternative, rigid insulation can be fastened to the inside of a foundation wall. Whenever rigid plastic insulation or a plastic or other flammable air or vapor barrier is used on the inside of a basement wall, a fifteen minute fire-rated material must cover the flammable material or plastic. Two common materials that satisfy this requirement are 1/2" drywall or 3/4" plywood.

Protection from moisture is a very important consideration for full foundation walls, especially when the basement is to be used as living space. Leaks and drainage problems are very common, particularly when the surrounding soil drains poorly. You should always follow recommended practices for preventing leaks and other moisture problems.

On the outside of the foundation wall, a layer of water-repellent foundation coating should be sprayed or trowelled on. Break off all foundation-form ties and fill voids before applying the foundation coating to ensure good protection.

To help insure that leaks do not occur in the **dampproofing** layer or other areas, water should be able to drain away from the wall. At the surface, slope the ground away from the wall at a minimum slope of 5 percent (6" in 10'). Against the wall, crushed stone, gravel or sand will allow water to flow down to the footing drain rather than build up pressure against the wall surface.

To aid in drainage, a specialized **drainage mat** may be installed between the foundation and the ground (outside the insulation if the foundation is insulated on the exterior). This drainage mat intercepts any groundwater or runoff flowing toward the foundation and allows it to quickly drain down to the footing drains and be carried away. Moisture never comes in direct contact with the foundation insulation or foundation wall, so leaks are very unlikely. A number of different foundation drainage products are available, including a loose woven wire mesh with filter fabric, and a corrugated plastic with filter fabric.

Insulating a concrete foundation on the *exterior* rather than the interior has a number of advantages. It allows the **thermal mass** of the concrete to be used in storing heat, which can be important if passive solar heating has been designed into the house.

Exterior foundation insulation also helps protect the foundation wall from the effects severe thermal shock. With the insulation on the exterior, the foundation is not exposed to as great a temperature range over the seasons.

With proper attention to drainage, frost

heaving will rarely, if ever, be a problem.

Several different exterior foundation insulation options are shown in the following illustrations. In **Figure 15**, a 2" layer of extruded polystyrene is installed on the outside of the foundation wall, extending all the way down to the top of the footing. Apply the dampproofing layer first, then glue the rigid insulation on with the appropriate adhesive (refer to insulation manufacturer's recommendations) or suitable concrete nails and large plastic washers. On the outside of the insulation, you can install a drainage mat, as described above.

The foundation insulation must be protected from sunlight and abrasion where it extends above grade. Use a stucco coating, metal flashing, pressure-treated plywood or a specialized hardboard covering made for protecting foundation insulation. This protective coating should extend below grade by six inches. When using stucco coatings, use a high quality material designed specifically for the type of insula-

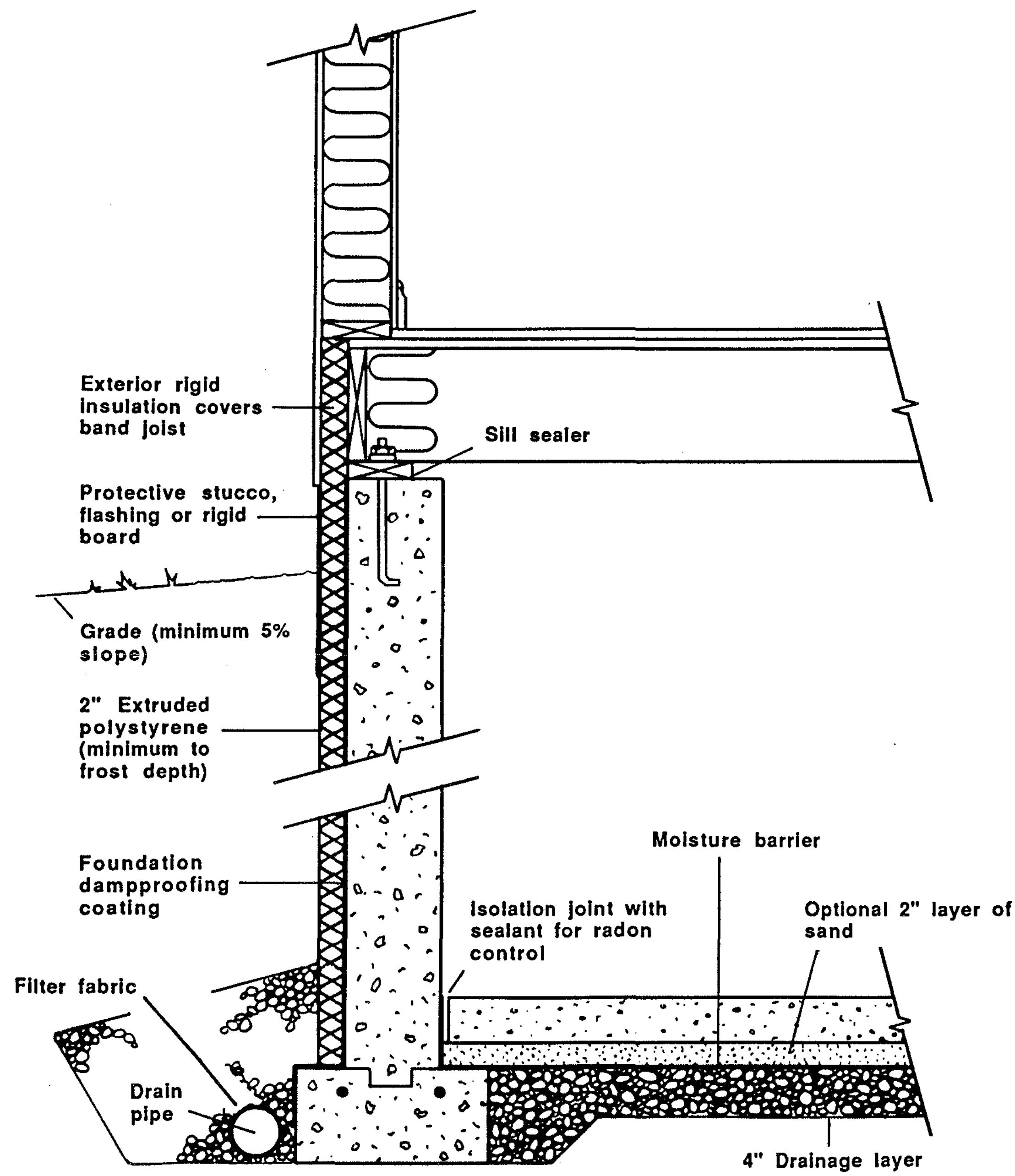


Figure 15. Foundation insulation for full basement with exterior insulation extending all the way down to footing.

tion being coated.

In general, the most difficult construction detail is at the top of the wall where the framing begins. In **Figure 15** (page 41) the band joist is insulated on the outside. In this detail, the wall plate extends out over the floor deck the thickness of the insulation (2" in this case). With 2x6 walls, 3-1/2" of the wall thickness is still resting on the deck, which is adequate. With a 2x4 wall, this detail could not be used.

Another alternative for exterior foundation insulation is shown in **Figure 16**, with a **water table trim** piece used to extend the wall out to cap the rigid insulation. In this case, the rigid insulation usually only extends up to the top of the foundation wall, so the band joist must be well insulated on the interior, as shown.

Standard foundation construction practices are shown in these illustrations, including a drainage layer of crushed stone under the slab, an optional layer of sand under the slab (to protect the moisture barrier and help the concrete cure properly), an isolation joint at the edge of the slab for radon control (see discussion, pages 22-24), and perforated drainage pipe surrounded by crushed stone outside the footing. Be sure to carefully seal any likely air leakage areas (see pages 15-19).

Use a **saturated foam sill sealer** between the pressure-treated sill and the concrete frost wall. Because the foam is open-celled, it can be fully compressed, but at gaps where the foam is expanded the resin within it forms an excellent seal.

While the insulation is shown extending all the way down to the footing depth, the Maine Energy Efficiency Standards require that it extend down only to the frost depth. This is because heat loss through the foundation wall decreases with depth. To take into account the differing heat loss with depth, some experts recommend a **stepped insulation** configuration for foundations, as shown in **Figure 17.** In this detail, one inch of extruded polystyrene insulation extends all the way down to the footing, while a second layer extends only down to the frost depth.

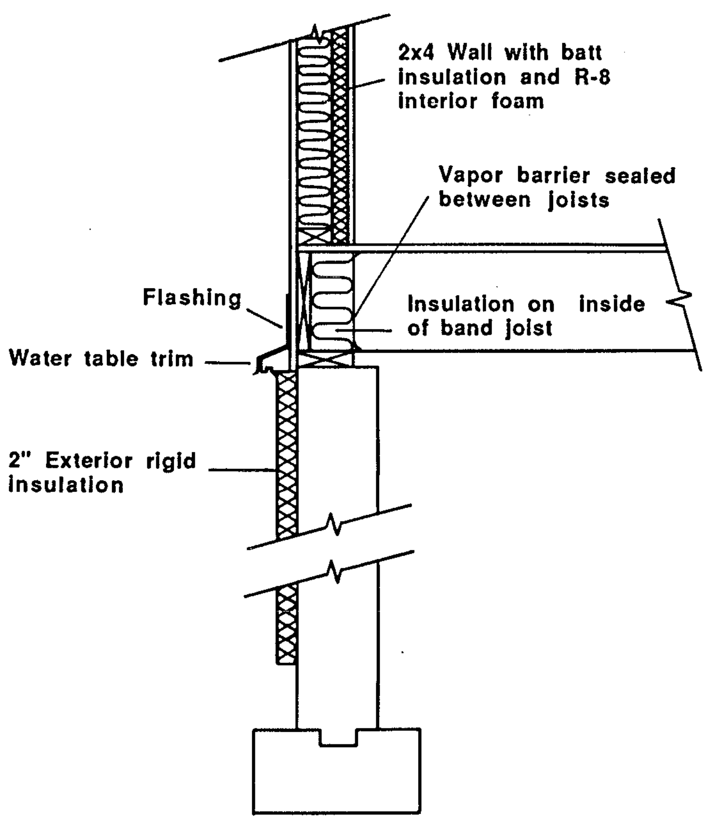


Figure 16. Water table trim can be used to extend the outer wall surface out and shed rain away from the exterior foundation insulation.

Figure 17 shows a different configuration at the band joist. As in **Figure 15**, the band joist is insulated on the exterior with a full two inches, but the 2x6 wall overhangs the floor deck by only one inch. The other inch of rigid insulation over the band joist is an extension of exterior rigid insulation on the wall.

Some builders and homeowners like to install an inch of rigid insulation under the basement floor slab as well. This is not required by the Maine Energy Efficiency Standards, and it will do little to reduce energy costs, but it will help to make the basement space slightly more comfortable if it is to be used as living space.

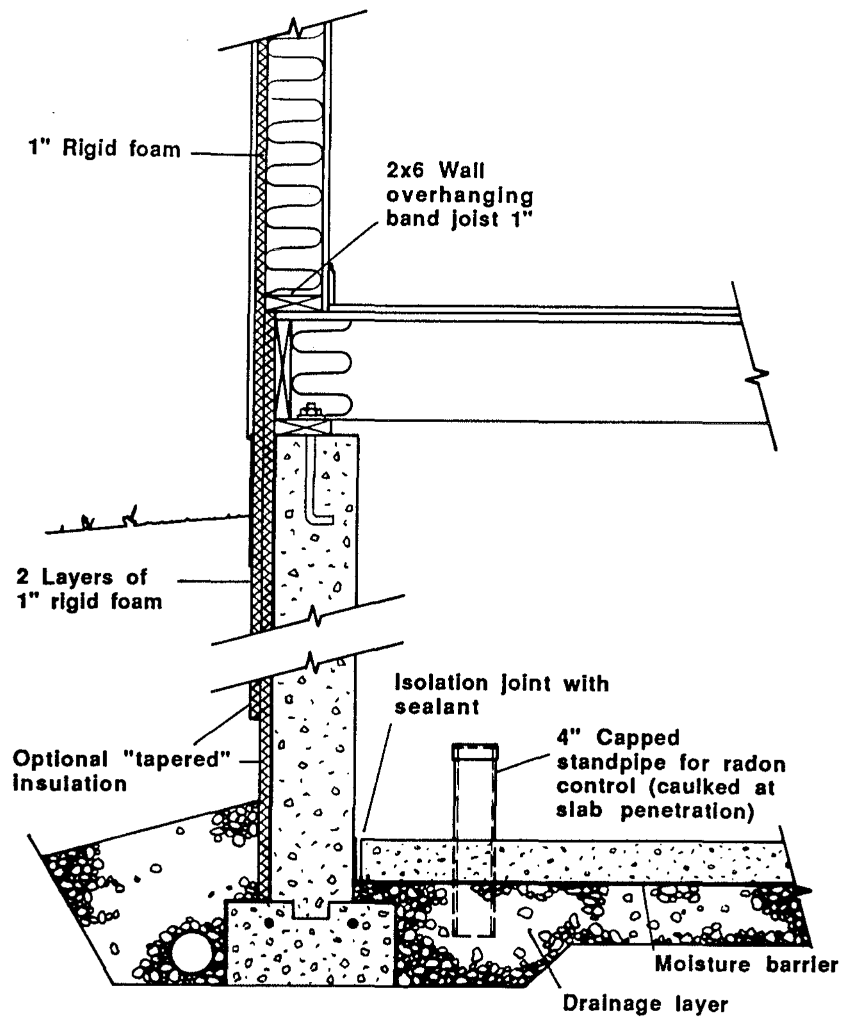


Figure 17. "Tapered" foundation insulation, with one layer of rigid foam insulation continuous with exterior foam insulation on the wall.

Figure 17 shows several techniques for controlling radon. The standpipe is a section of 4" PVC pipe extending through the slab and into the 4" layer of crushed stone. The standpipe should be set in place before the slab is poured. After the concrete has set, caulk around the pipe with a high quality caulk that works well with masonry; then cap the pipe. If later radon is determined to be a problem, this pipe can be extended out through a wall in the basement or up through the roof and fitted with an in-line fan to depressurize the sub-slab area and prevent radon-laden air from infiltrating into the basement. At the edge of the slab, leave a 1/2" isolation joint between the slab and foundation wall. After the concrete has cured, seal this gap with backer rod and/or masonry-compatible caulk. *Whenever possible, use poured concrete for foundations rather than hollow block, because the poured concrete is far less permeable to air and radon.*

A detail incorporating *interior* foundation insulation is shown in **Figure 18**. In this case, the wall framing extends to the outside of the floor deck, with the wall sheathing extending down over the pressure-treated sill. A 2x4 wall is constructed on the inside of the foundation wall and insulated with fiberglass batt insulation. The frame wall is generally built about an inch away from the concrete wall, allowing for unevenness in the concrete wall. The top of the frame wall is secured to the underside of the

floor joists, as shown. At the band joist, insulation has to be cut and fit between the floor joists. The recommended technique is to fill the ends of the joist cavities with fiberglass batt insulation to keep heat from flowing down through the sill and into the cold concrete, and then to add fitted pieces of foil-faced rigid foam insulation to the interior or the fiberglass. The foil-faced insulation is caulked to the floor joists to provide a good air/vapor barrier.

Fiberglass insulation can be installed between the studs placed inside the concrete wall. The insulation should be covered on the inside with a carefully installed polyethylene air/vapor barrier.

Instead of insulating the inside of the foundation wall with fiberglass, you can attach 2" strapping to the wall and install 2" rigid foam insulation between the strapping, as shown in **Figure 19**. The strapping has to be a full 2" deep to be even with the inside

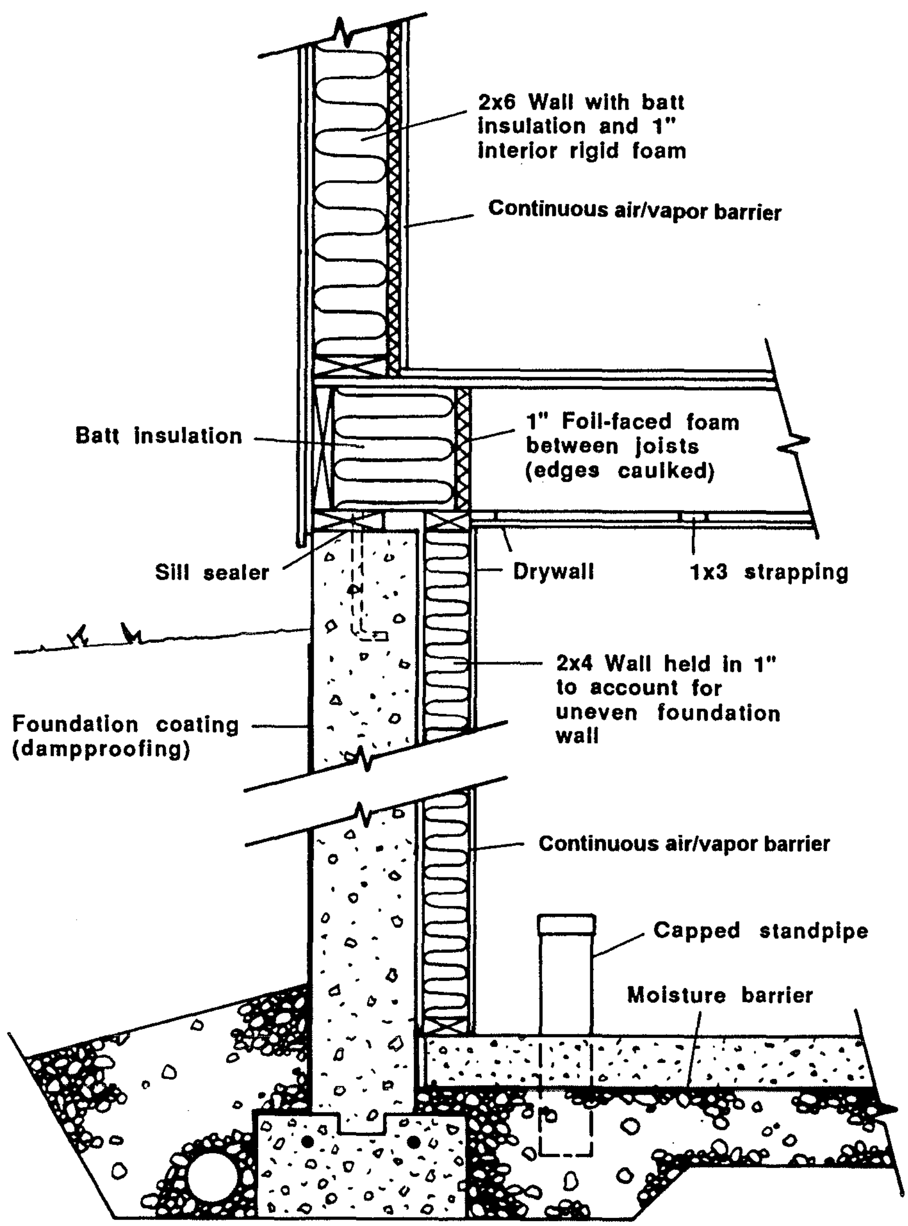


Figure 18. Interior foundation insulation with insulated 2x4 studwall.

face of the foam insulation.

If an all-weather wood foundation is being used, it should be built and insulated according to American Plywood Association (APA) specifications. The same minimum R-10 insulation levels are required. Before proceeding with a wood foundation, talk with a building inspector or builder in your area who is familiar with the construction technique.

There are a number of insulation options that may be used with slab-on-grade foundations. In **Figure 20**, a full-perimeter frost wall is insulated on the exterior down to frost depth with R-10 insulation. As with the full basement details shown previously, the 2x6 wall can either overhang the foundation, or water table trim can be used to extend the wall 2" out at the foundation level. As long as the exterior frost wall insulation extends down to frost level, insulation under the slab is not required by the Energy Efficiency Standards. However, if this insulation is installed, it will make the floor temperature slightly more comfortable.

In **Figure 21**, 2" extruded polystyrene insulation covers the perimeter edge of the

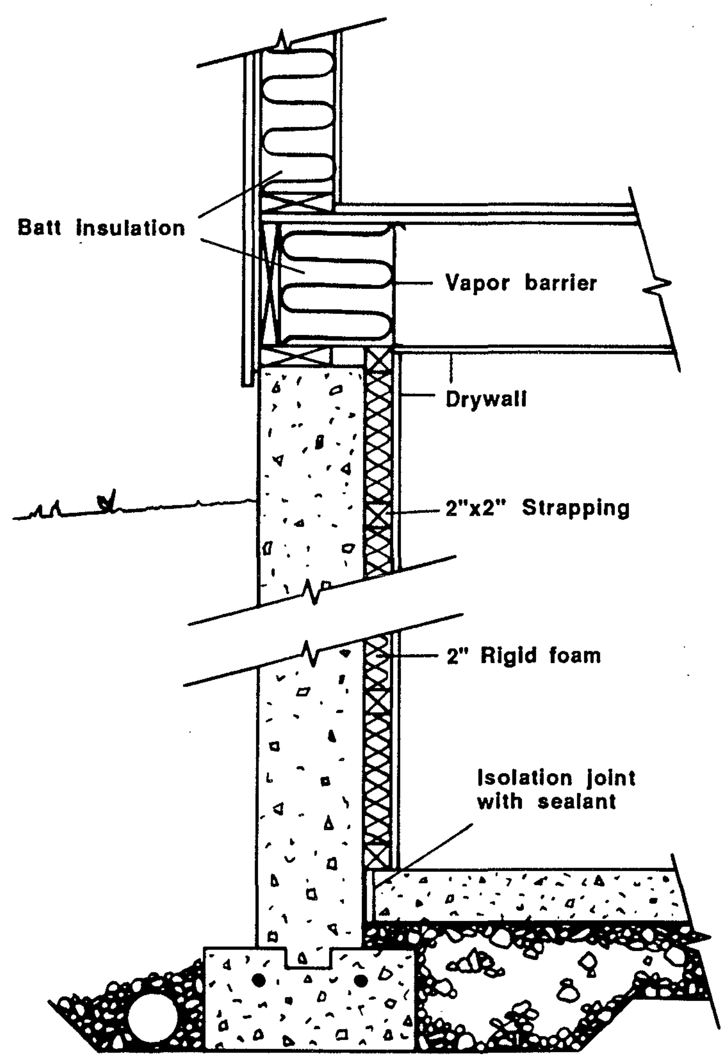


Figure 19 . Interior foundation insulation using strapping and rigid foam insulation.

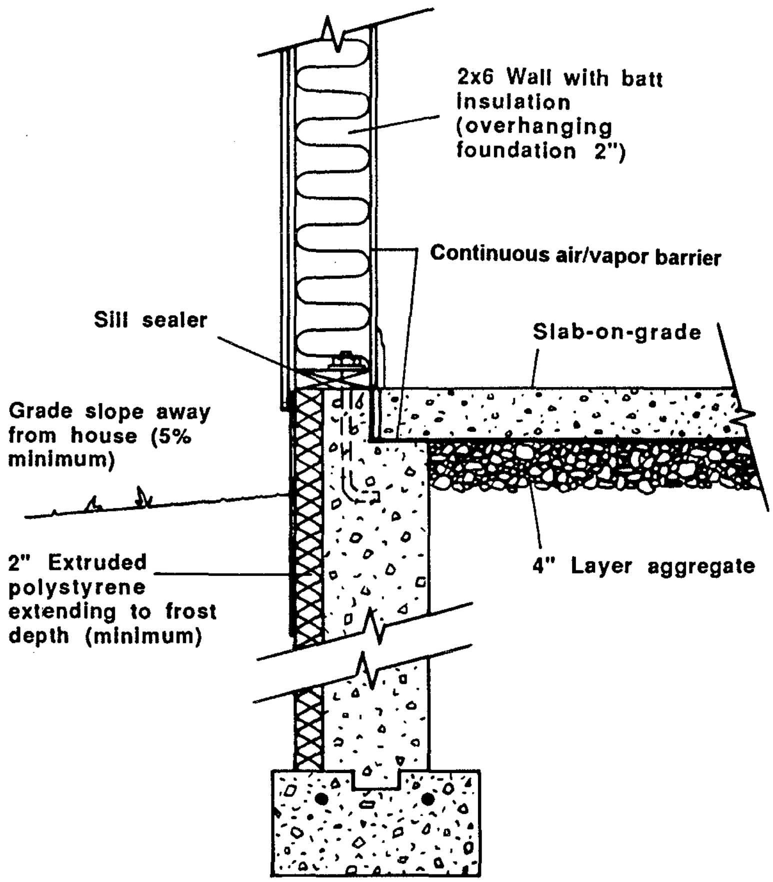


Figure 20. Slab-on-grade foundation with exterior insulation on frost wall extending down to the footing.

slab and then extends under the slab for a distance at least as great as the frost depth. The insulation may extend under the full slab, but this is not required.

As an alternative, the rigid insulation may cover the above-grade perimeter and then extend diagonally outward from the frost wall for a distance equal to the frost depth.

In **Figure 22**, the rigid insulation covers the perimeter edge of the slab, then extends down along the *inside* of the frost wall to the footing (frost depth).

Finally, with a monolithic floating slab, the insulation should cover the perimeter edge of the slab/footing and then extend under the slab for a distance equal to the frost depth, as shown in **Figure 23**. As mentioned previously, the detail for slab-on-grade construction, and especially monolithic slabs, R-10 insulation must be used in one of two configurations: 1) either around the full perimeter extending down to the design frost depth, or 2) around the full perimeter of the slab itself and horizontally or diagonally beneath or away from the slab for a distance equivalent to the design frost depth.

If the house is to have a crawl space, it will either be heated or unheated. Heated crawl spaces are insulated using basically the same methods used for full foundations, with either exterior or interior insulation extending down to the frost depth. Because exterior or interior insulation used for this purpose is in contact with the ground, use rigid extruded polystyrene.

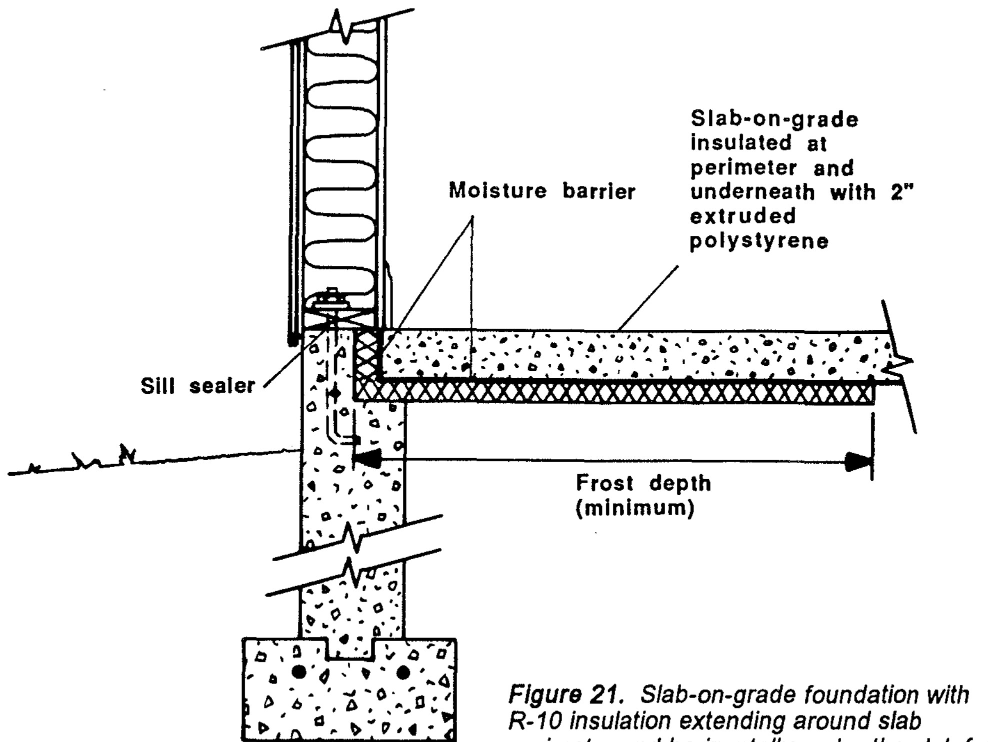


Figure 21. *Slab-on-grade foundation with R-10 insulation extending around slab perimeter and horizontally under the slab for a distance at least equal to the frost depth.*

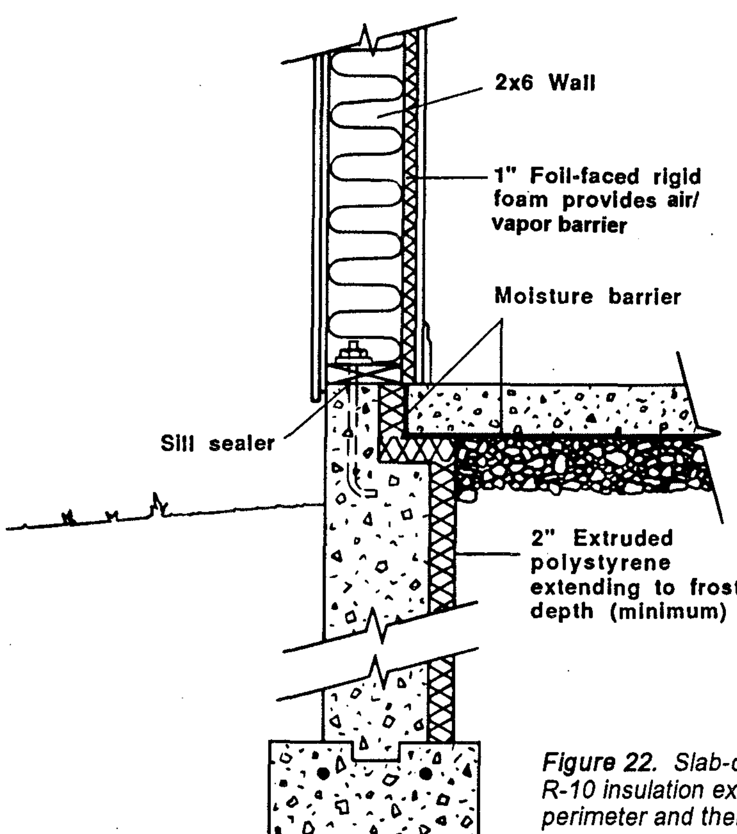


Figure 22. *Slab-on-grade foundation with R-10 insulation extending around slab perimeter and then down the inside of the frost wall .*

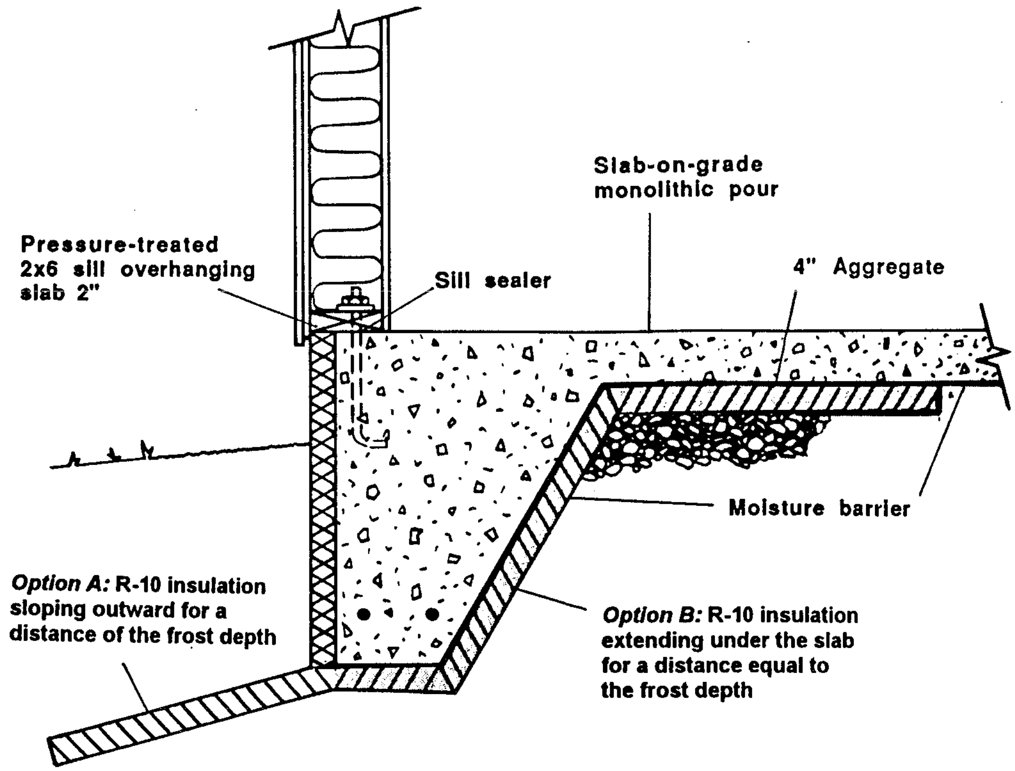


Figure 23. *Monolithic floating slab with R-10 insulation used in one of two configurations: 1) either around the full perimeter of the slab itself to the design frost depth, or 2) around the full perimeter of the slab itself and horizontally or diagonally beneath or away from the slab for a distance equivalent to the design frost depth. Two options for configuration 2, Option A and Option B, are shown above. One or the other of these options may be used, there is not need to use both.*

In general, heating the crawl space will tween the subfloor and the barrier.

The fiberglass floor insulation can be held in place with wire or strapping under the joists. If using kraft or foil-faced fiberglass, the facing must be installed upward.

When planning an unheated basement, think about whether the basement might be finished off as a living area in the future. If so, it might be worth spending the extra money during construction to insulate the space as if it were heated.

If operable vents are installed in the crawl space, you need at least an 8" x 16" vent for every 350 ft^2 of crawl space floor area, with a minimum of two vents for adequate cross flow. The vents should have screens and covers so that they can be closed during the winter months. Please see page 31 for a discussion about the usefulness of crawl space vents. To keep moisture from seeping up from the ground, place a sheet of 6-mil polyethylene on the ground, and fasten it (no need to seal it) to the frost wall 6 inches up above the ground level. If the crawl space is to be used at all, protect the plastic with strips of single-coverage rolled roofing.

If the house is to be built on piers, the same insulation details can be used as with a crawl space, except that the floor joists should be covered on the underside, because they will be more exposed to the elements. The insulation can be either fiberglass or several layers of rigid insulation as long as the total R-value is at least R-19. Use of rigid insulation is shown in **Figure 25**. With fiberglass batt insulation, it generally makes sense to completely fill the joist cavity, even though it will provide more than the required R-19.

Overhanging floors, as in raised ranch

houses, must also be insulated to R-19. A typical detail with 2x10 joists and 2x6 walls is shown in **Figure 26**. In this case, R-30 fiberglass is used, filling up the entire joist cavity. Blocking should be installed close to the inside of the lower wall; insulation is installed in the overhanging floor to the blocking. Caulk the blocking where it rests on the wall top plate, where it abuts floor joists, and where the subfloor above rests on it. Install an air/vapor barrier on top of the subfloor over the overhanging section of floor and on the inside of both 2x6 walls.

3. Walls

Exterior walls must be insulated to a minimum of R-19 in order to comply with the Maine Energy Efficiency Standards. The most common technique for achieving this is to build the exterior walls with 2x6s rather than 2x4s and insulate with R-19 fiberglass batts. Other cavity-fill insulation may be used if it has at least an R-19, as shown in **Figure 27**.

Because 2x6s offer greater strength than 2x4s, you have the choice of framing at 24" on center (o.c.) rather than the 16" o.c. used with 2x4 walls. Even with 2x6s, some builders prefer to use 16" o.c. so that 1/2" drywall will

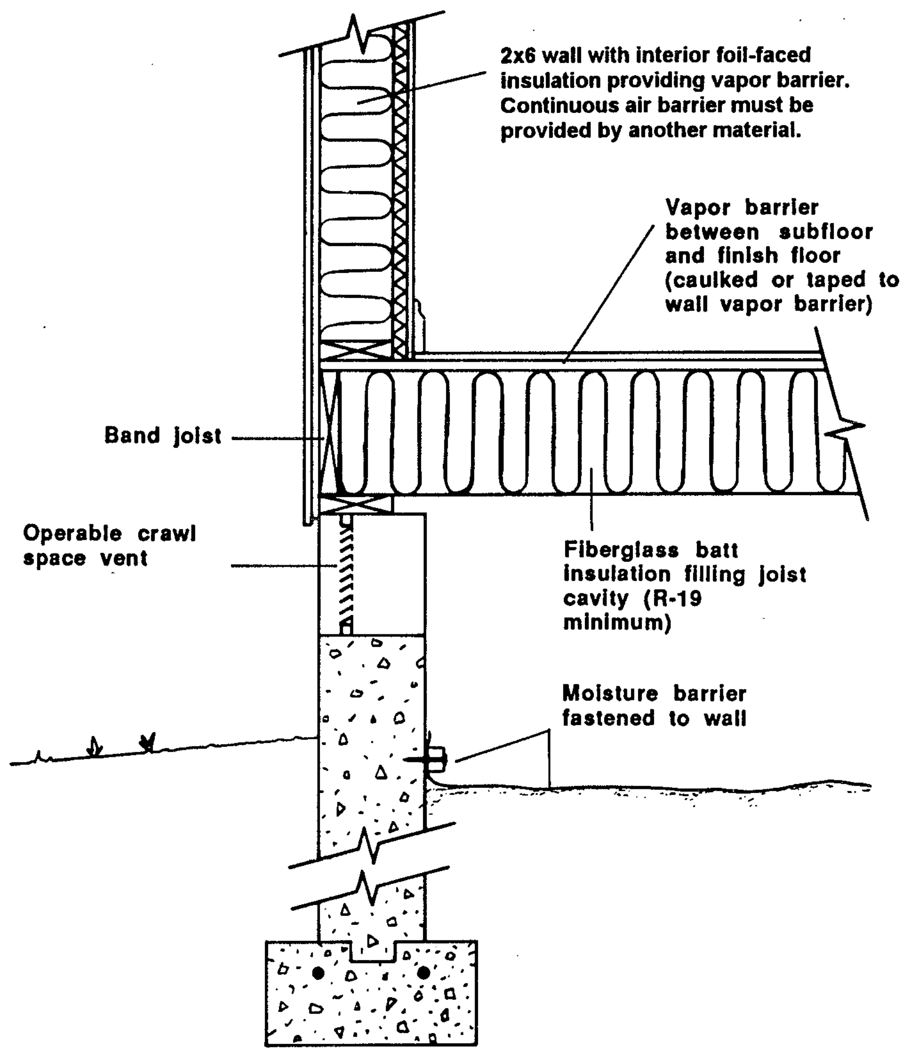


Figure 24. Floor insulation (R-19 minimum) over an unheated crawl space or basement.

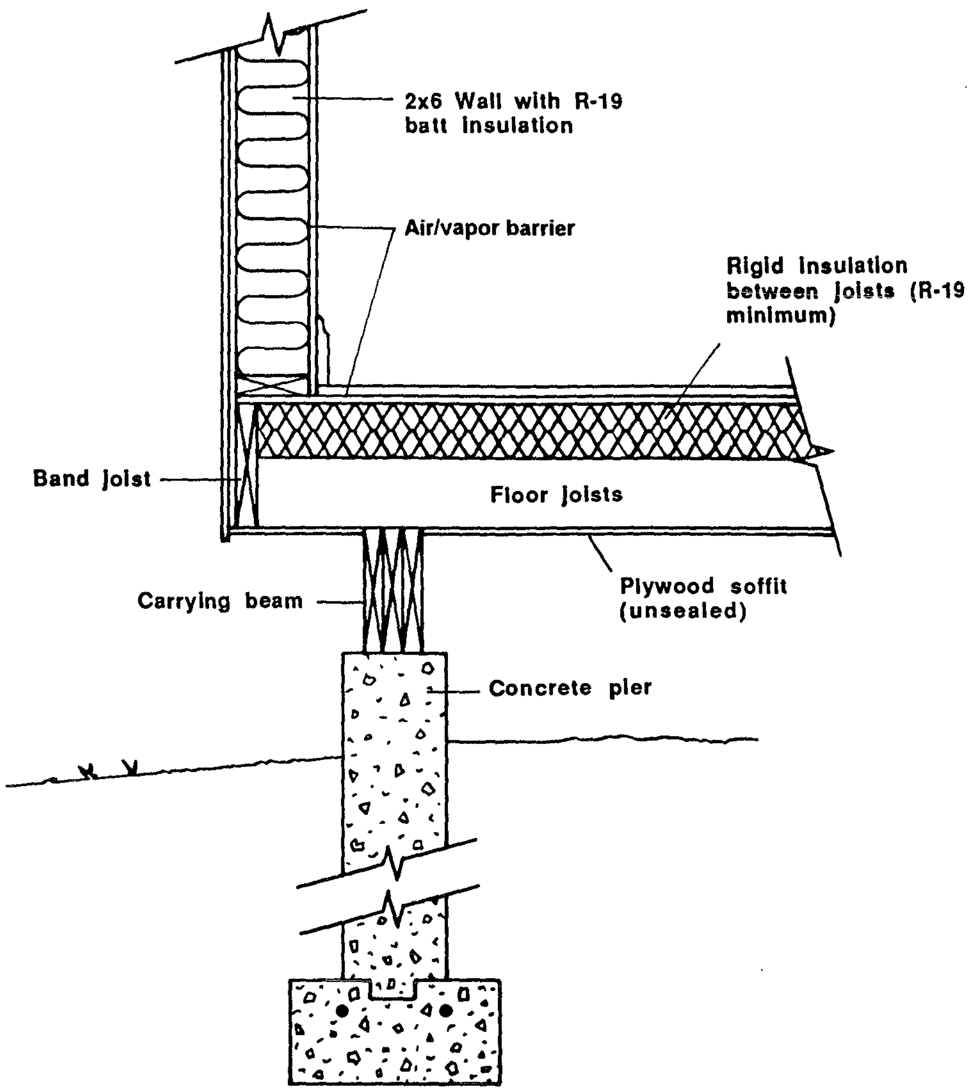


Figure 25. Pier foundation with expanded polystyrene insulation fitted between floor joists (fiberglass is more commonly used).

feel more solid. Other builders frame at 24" o.c. and use 5/8" drywall.

Still others frame the studs 24" o.c. and then strap the walls horizontally with the strapping at 16" o.c. With this option, the air/vapor barrier can be installed against the studs. This gives the air/vapor barrier a bit more protection than if it is placed to the inside of the strapping.

If you choose to build with 2x4s, the Maine Energy Efficiency Standards can be met by adding a layer of rigid foam insulation on either the inside or the outside of the studs, as shown in **Figure 28**. If you use standard fiberglass batts providing R-11, the rigid insulation must provide R-8, or 1 1/2" of polyisocyanurate insulation. If you use higher-density unfaced 3-5/8" fiberglass batts or cellulose providing R-13, you can get by with 1" polyisocyanurate insulation (R-6 per inch). If you want to use extruded polystyrene, expanded polystyrene or rigid fiberglass, you will have to use 1-1/2" to 2", depending on the R-value of the product, even with the higher R-value cavity-fill insulation.

A related question is whether to put rigid foam insulation on the inside or the outside of the framed walls. There are differences of opinion.

Those who prefer the rigid foam on the

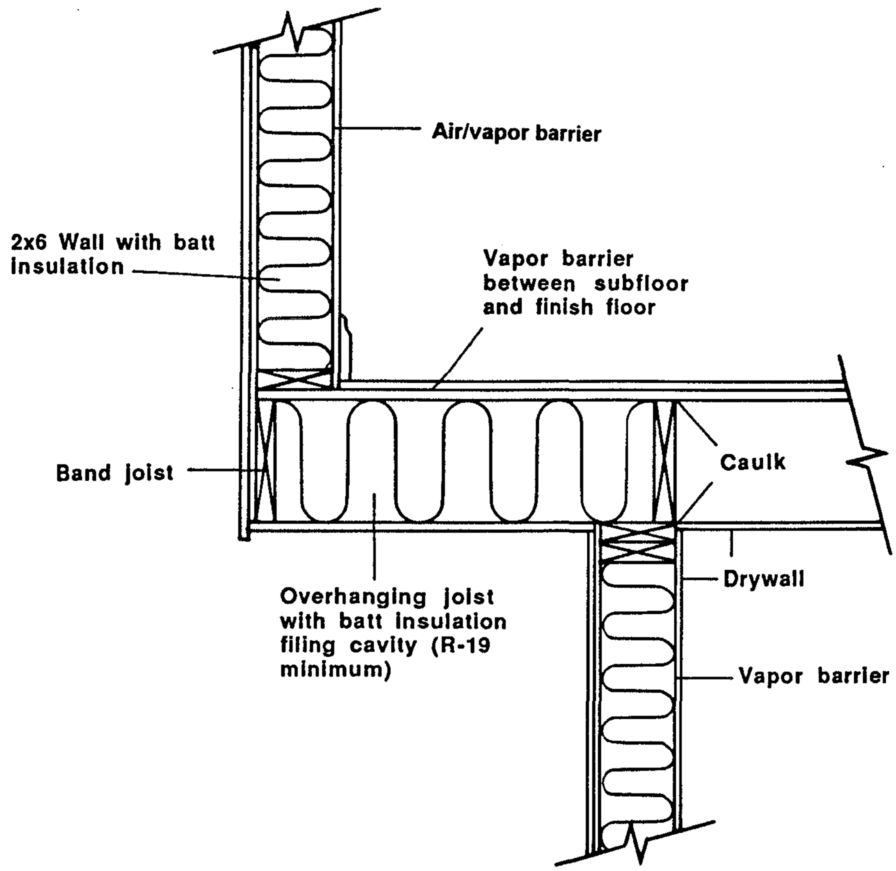


Figure 26. Overhanging upper floor in raised ranch house. Particular care is required at the transition to the insulated floor cavity.

outside—the outsiders—argue that it provides a more complete barrier to heat loss, uninterrupted by interior partition walls where they connect with the exterior walls.

Others—the insiders—argue that putting foam insulation on the outside, particularly if it is foil-faced, will increase the risk of moisture problems in the wall cavity, because moisture cannot escape. By installing the foam on the inside, the foil facing can provide the vapor barrier (edges must be taped). To provide adequate racking strength with exterior foam insulation, either use let-in metal bracing (when the foam is installed directly against the studs), or install the plywood sheathing against the studs and the foam outside that.

With rigid foam insulation on the exterior, there is also some concern about damage to the siding. High rates of expansion and contraction during the daily cycles and high temperature buildup may weaken wood siding and reduce the durability of paints. For this reason, when using exterior foam insulation, it is strongly recommended that vertical strapping be installed under the siding to provide a channel for air flow—sometimes called a **vented rain screen**—as shown in **Figure 29**. The air space should be screened at the top and bottom. This

vented rain screen also prevents driving rain from penetrating into the interior portions of the wall cavities.

If you choose to go beyond the insulation requirements of Maine's Energy Efficiency Standards, you can build a 2x6 wall with batt insulation *and* add a layer of foam insulation. With one inch of foil-faced insulation, this can provide up to an R-25 nominal insulation value. If you are considering going to this level of energy efficiency in the walls, be sure other components of the house are comparably well insulated.

When only cavity-fill insulation is used in the wall system, a considerable

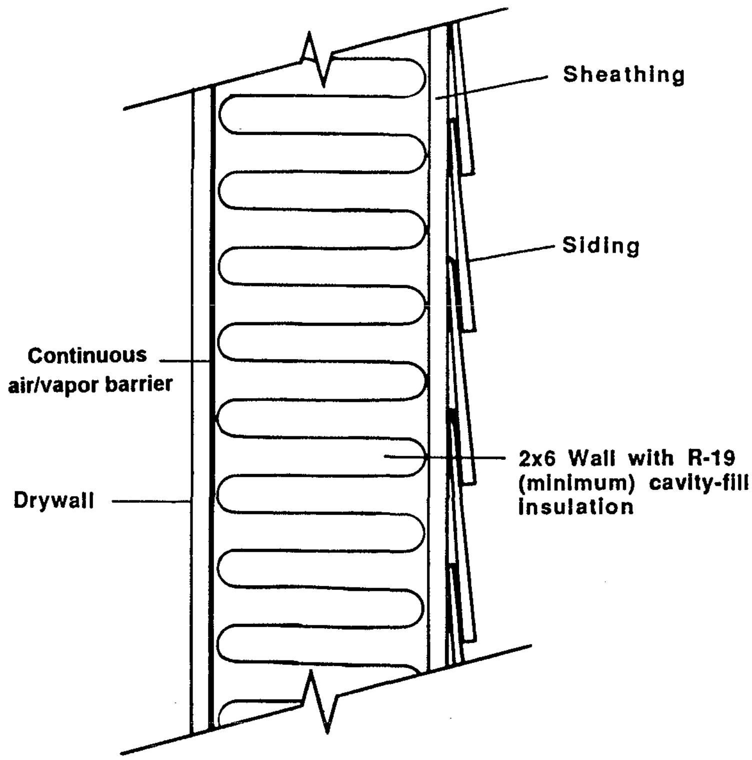


Figure 27. Standard R-19 wall section using 2x6 studs and cavity-fill fiberglass or cellulose insulation.

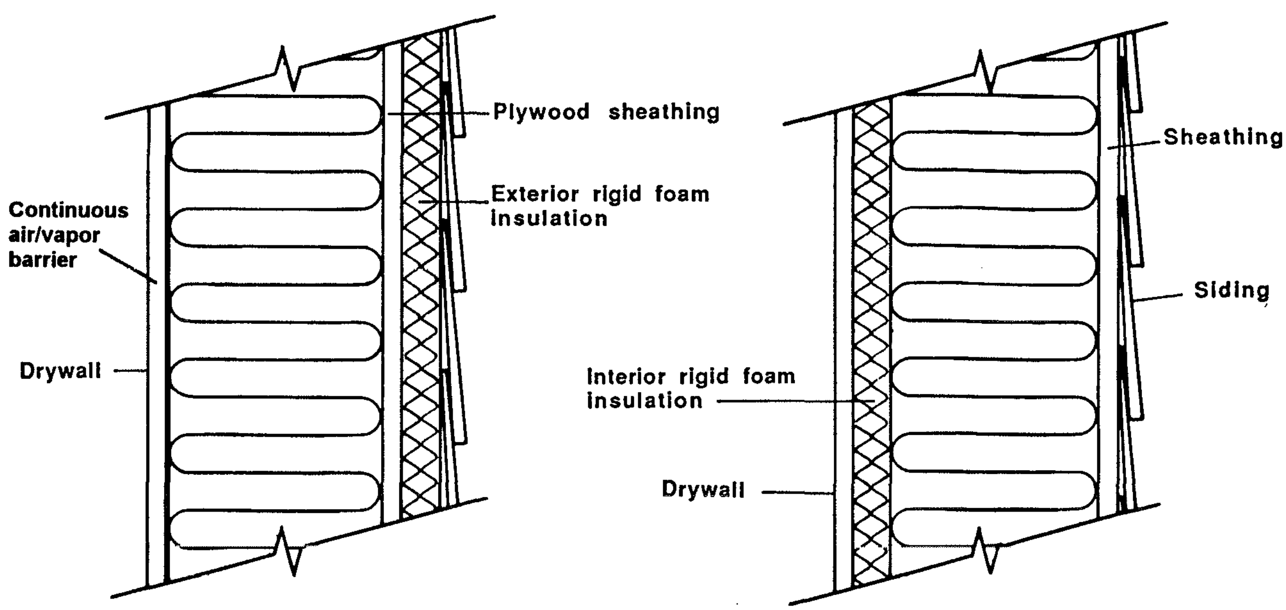


Figure 28. Rigid foam insulation can be installed on the inside of the wall or outside. While putting it on the outside is more common, more and more builders have begun putting it on the inside for various reasons. With a layer of rigid foam, the R-19 wall insulation requirements can be satisfied with a 2x4 wall.

amount of heat is lost through the studs. For this reason it makes sense to plan corners and interior partition wall intersections carefully. Corners and partition wall intersections that result in a minimum of bypass heat loss through the wood are shown in **Figure 30**. Three studs make up the corner detail, providing a complete nailing base for drywall and plywood sheathing. Most importantly, you don't end up with a hidden pocket that is difficult or impossible to insulate after sheathing is installed.

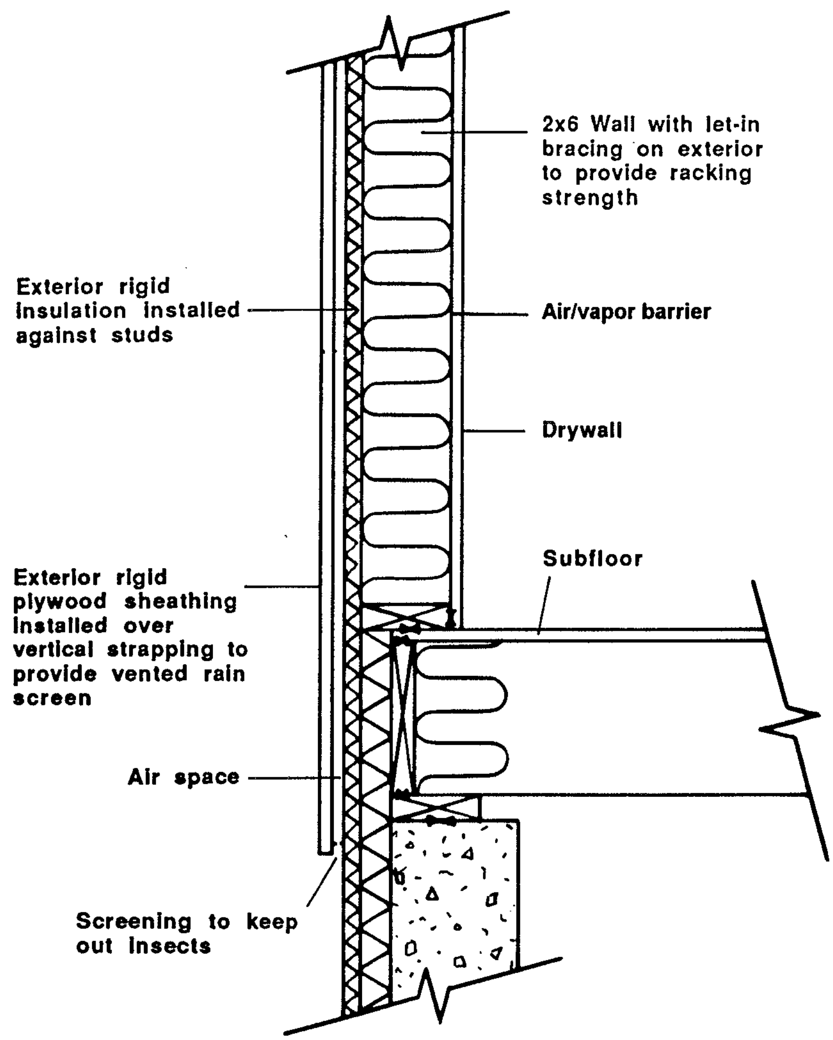


Figure 29. Rain screen detail to provide ventilation behind siding.

Where 2x4 interior partition walls intersect with exterior walls, a 2x6 can be placed sideways centered on the 2x4 wall. This option provides a 1" nailer on both sides of the 2x4 wall for drywall and does not produce a difficult-to-insulate hidden pocket in the exterior wall (See **Figure 30**). This technique also uses one less stud than conventional partition-wall intersections use.

When framing interior partition walls, it is a good idea to cut a 1' to 2' wide strip of polyethylene and tack it to the flat surface of the 2x6 before tilting up the 2x4 partition wall section. Then, when you install the air/vapor barrier on the exterior wall, seal this strip of air/vapor barrier to it. This option provides a continuous air/vapor barrier on the exterior wall, providing a tight seal at partition walls.

The details used at the bottom of the first-floor wall will depend on the foundation insulation configuration. Refer back to the foundation section (page 39) for appropriate details.

Where upper floors intersect with exterior walls, the band joists also need to be insulated. Either fiberglass batts or blocks of rigid foam insulation (or both) can be installed against the band joist between the second-story floor joists, as shown in **Figure 31**. If insulating this cavity with fiberglass, you also will need to cut and fit pieces of polyethylene vapor barrier, which can be tedious. It may be easier to use sections of foil-faced rigid foam that can be caulked in

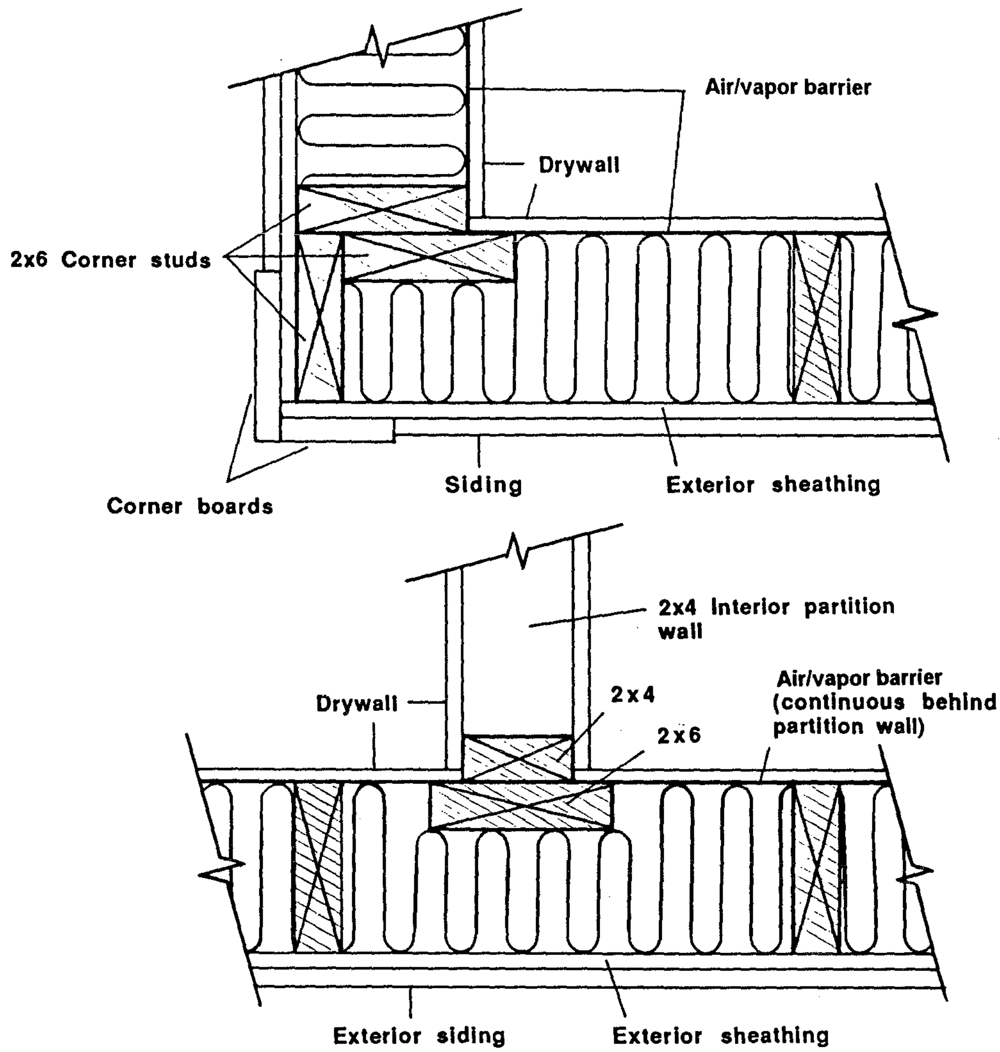


Figure 30. With exterior wall corners and intersections with interior partition walls, eliminate pockets that will be hard to insulate once the exterior sheathing is put up.

place to serve as the vapor barrier, as shown in the center illustration.

If rigid foam sheathing is used on the outside of the wall, you do not need as much insulation on the inside of the band joist, as shown in the bottom illustration. Because of the possibility of rot, do not install foil-faced foam on both the outside and inside of the band joist. If the exterior walls are being insulated with wet-spray cellulose or another spray-in-place insulation product, these joist spaces can easily be insulated at the same time.

When constructing headers over windows and doors, allow for insulation between the framing members, as shown in **Figure 32.** (Depending on the header span and structural loading, the headers may need to be solid wood, allowing no space for insulation.) The space between the two headers can be filled with batt or rigid insulation. If rigid insulation is used, the headers can be prefabricated.

Be sure to leave 1/2" inch all the way

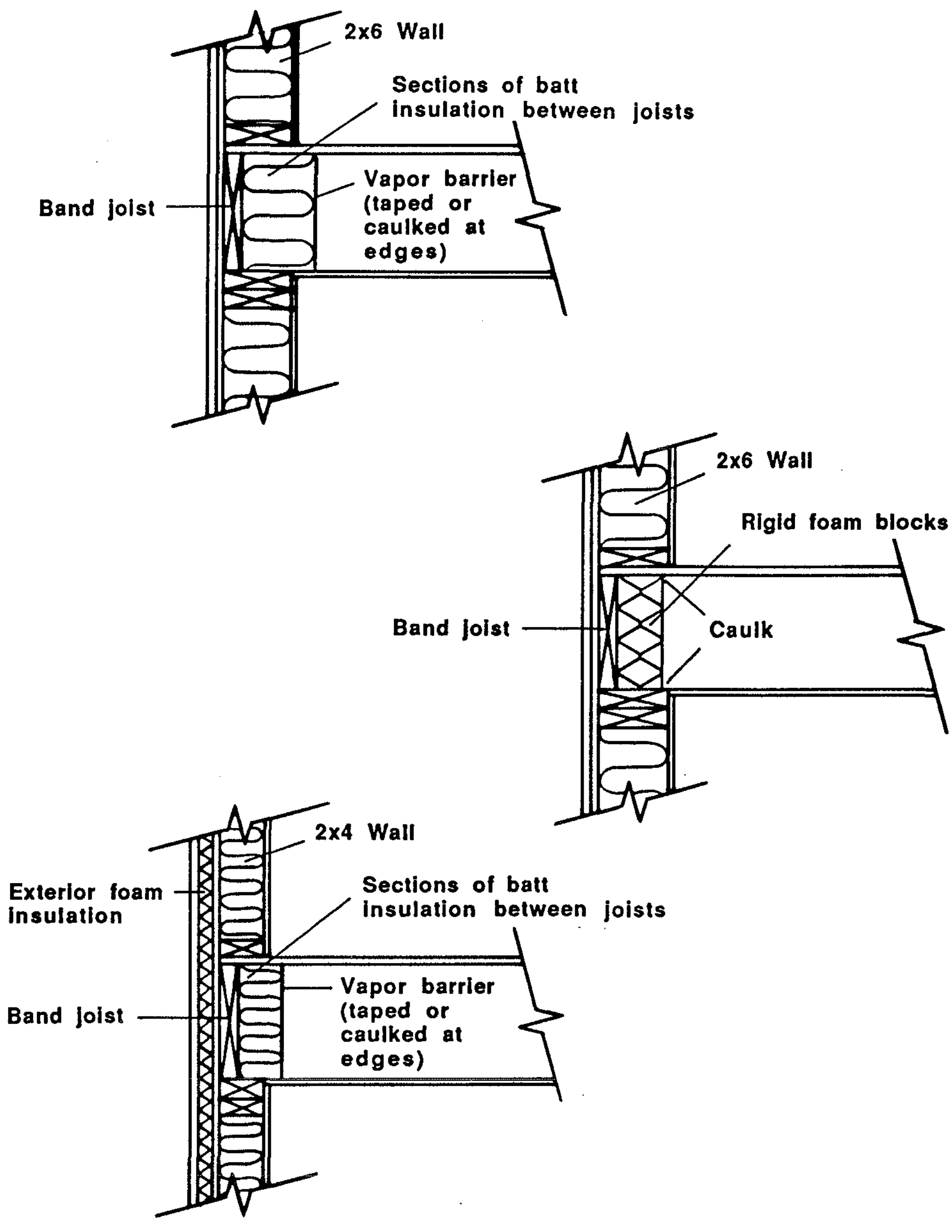


Figure 31. The band joists for upper floors must be insulated to eliminate bypass heat leaks. Several options are shown.

around rough openings to accommodate foam sealing of window and door jambs (see discussion on installing windows and doors, page 67).

Insulation and air/vapor barrier details at the walls/roof juncture can be very tricky. These techniques are covered in the following section.

• • •

A rule that originated in Canada—the 1/3:2/3 rule—insures that the vapor barrier in a wall or ceiling will remain warm enough to prevent condensation problems. The 1/3:2/3 rule states that 1/3 of the R-value of the total installed insulation should be to the warm side of the vapor barrier and 2/3 of the R-value must be to the cold side—toward the outdoors. This rule can be used as a guide for wall and ceiling/roof construction. For example, a wall can be constructed with 2x6s and unfaced fiberglass place between the studs. A plastic air/vapor barrier can then be installed on the inside of

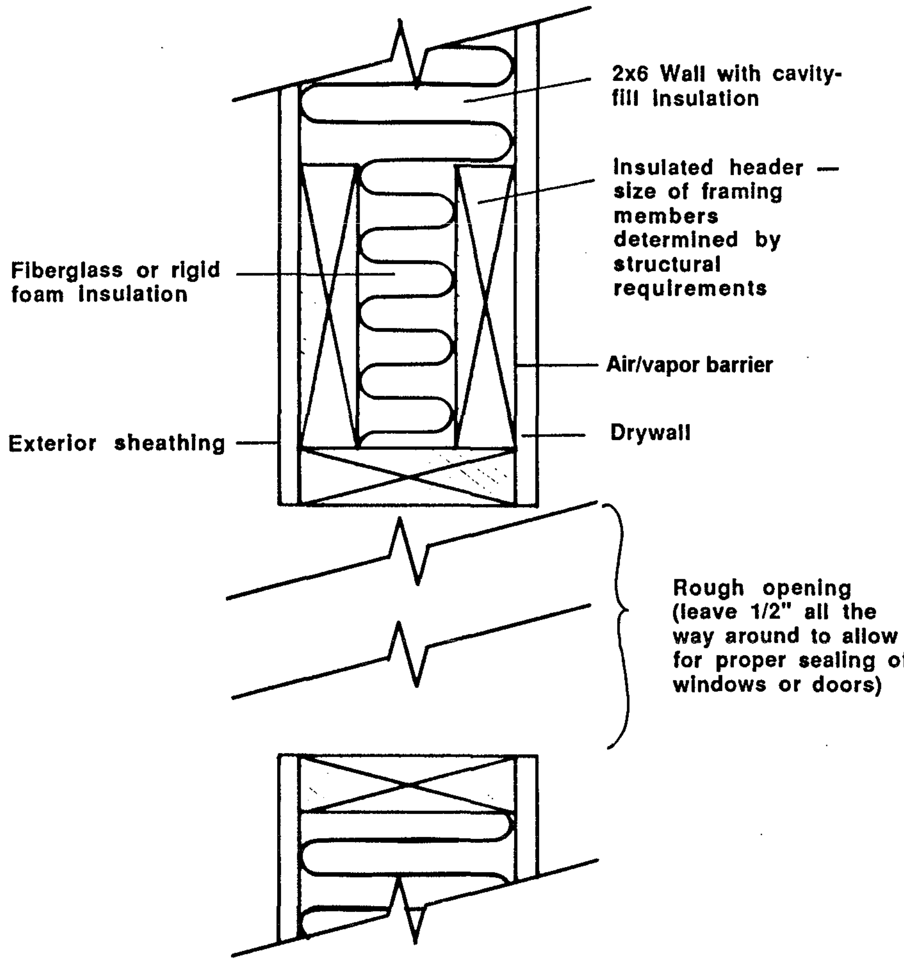


Figure 32. Headers over windows and doors should be insulated. If cavities are left at the time of framing, don't forget to go back and insulate them later.

these 2x6 studs. Then 2x2s can be fastened horizontally to the inside of the 2x6s. Two inches of insulation can be installed between these 2x2s and then drywall placed to the inside of them.

Electrical wiring can be run within the 2x2 framing members, inside of the plastic air/vapor barrier without puncturing it.

This method complies with the 1/3:2/3 rule in that 1/3 of the total wall R-value is to the warm side of the air/vapor barrier and 2/3 of the R-value is to the cold side of the barrier.

4. Roof Details

Insulated Flat Ceilings:

The Maine Energy Efficiency Standards call for ceilings to be insulated to R-38. The standards apply to both flat ceilings beneath unheated attics and sloped ceilings in Cape Code style houses and cathedral ceiling applications. However, special definitions apply to ceiling insulation in the Standards, as discussed in Tables 1 through 3.

With unheated attics, when the flat ceiling is

to be insulated, providing R-38 is relatively easy. If loose-fill cellulose or fiberglass are being used, a 12" nominal thickness is required. Because the full depth of insulation cannot be installed at the roof edge when it is framed in the conventional manner (see **Figure 33**), the Standards allow the insulation to be reasonably compressed at the eaves. Nominal R-38 insulation can be compressed to a depth of 7" at the eaves.

If you modify the roof framing, however, it will not be necessary to compress the insulation at the eave area. As shown in **Figures 34** and **35**, the rafter bottoms can be raised and cut to fit onto a **rafter plate** *on top of* the ceiling joists, rather than resting directly on the wall top plate. In this way, full-thickness R-38 insulation can be used at the eaves, and an air channel above the insulation can be provided.

Depending on the thickness of the ceiling joists, the loose-fill or batt insulation may come up to the top of the joists or may fully cover them.

If relatively small joists are used, make sure some insulation is placed over the upper rafter plate.

If you are using loose-fill cellulose or fiberglass to insulate the flat ceiling, install a baffle to keep the insulation from falling down into the soffit where it can restrict air flow into the soffit vents. (Even if using batt insulation,

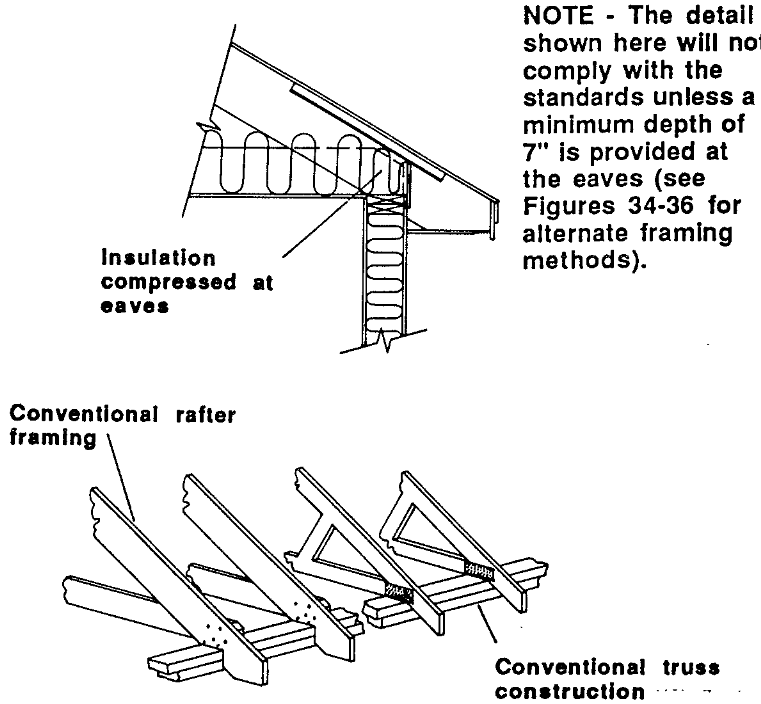


Figure 33. With the conventional approach to roof framing, insulation at the roof edge is compressed and loses some of its insulating ability.

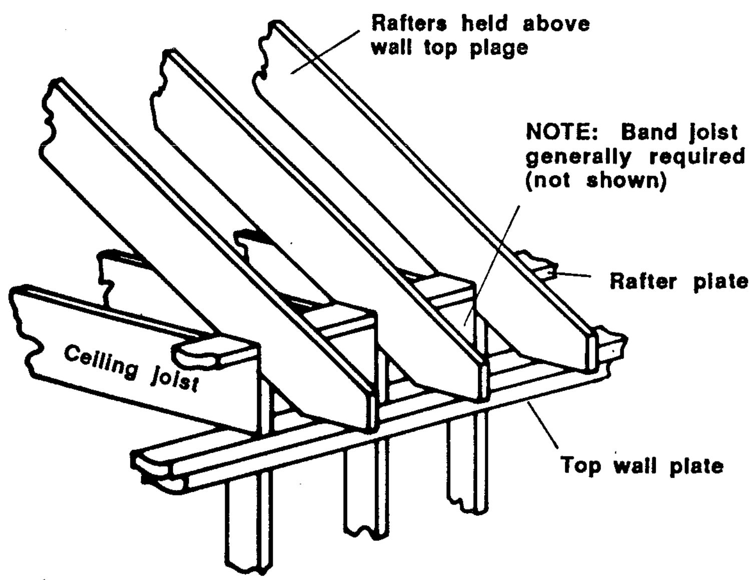


Figure 34. A better approach for unheated attics is to raise the rafter tails by setting them on an upper "rafter plate" rather than directly on the wall top plate. In this way, insulation at the roof edge does not have to be compressed.

a baffle may be a good idea because it will help reduce air flow *through* the insulation, which can reduce its effective R-value.) For the baffle, you can nail sections of plywood to the wall sheathing between the rafters to contain the insulation, as shown in **Figure 35**.
If 2x12 or 2x10 joists are used, a baffle may not be necessary—the rafter plate and wall sheathing should adequately contain the insulation. If there is the chance that the insulation will completely fill the space under the roof sheathing near the eave (unlikely with the raised rafters), vent spacers should be installed against the roof sheathing at the eave area.

If using roof trusses for insulated flat ceiling systems, you can solve the problem of compressed insulation at the eaves in one of two ways, shown in **Figure 36**. You can specify either **raised-heel trusses** or **cantilevered trusses**, which extend out over the walls. (The insulation depth achievable at the edge of the wall depends on the roof pitch and extent of overhang.) With raised-heel trusses, you may be able to extend the wall sheathing all the way up to the rafter chord of the truss, as shown.

Insulated Sloped Ceilings:

Achieving R-38 insulation levels with insulated cathedral ceilings is a little more difficult than it is with flat ceilings. Depending on the rafters used, you may need to use a combination of batt insulation and rigid foam insulation. Maine's Energy Efficiency Standards allow you use the rated insulation value in achieving the R-38 requirements even if the insulation is compressed (see discussion, page

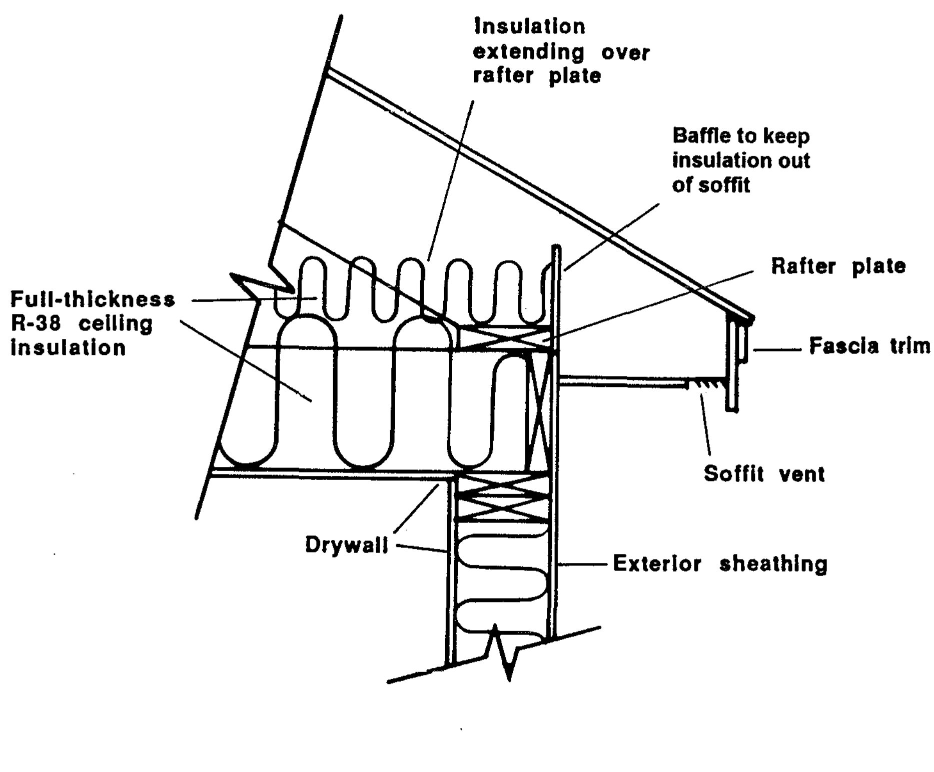


Figure 35. Raising rafter tails is particularly important with smaller ceiling joists. As shown, insulation can be placed on top of the rafter plate to maintain full thickness. With loose-fill insulation, a baffle may be required to keep insulation out of the soffit.

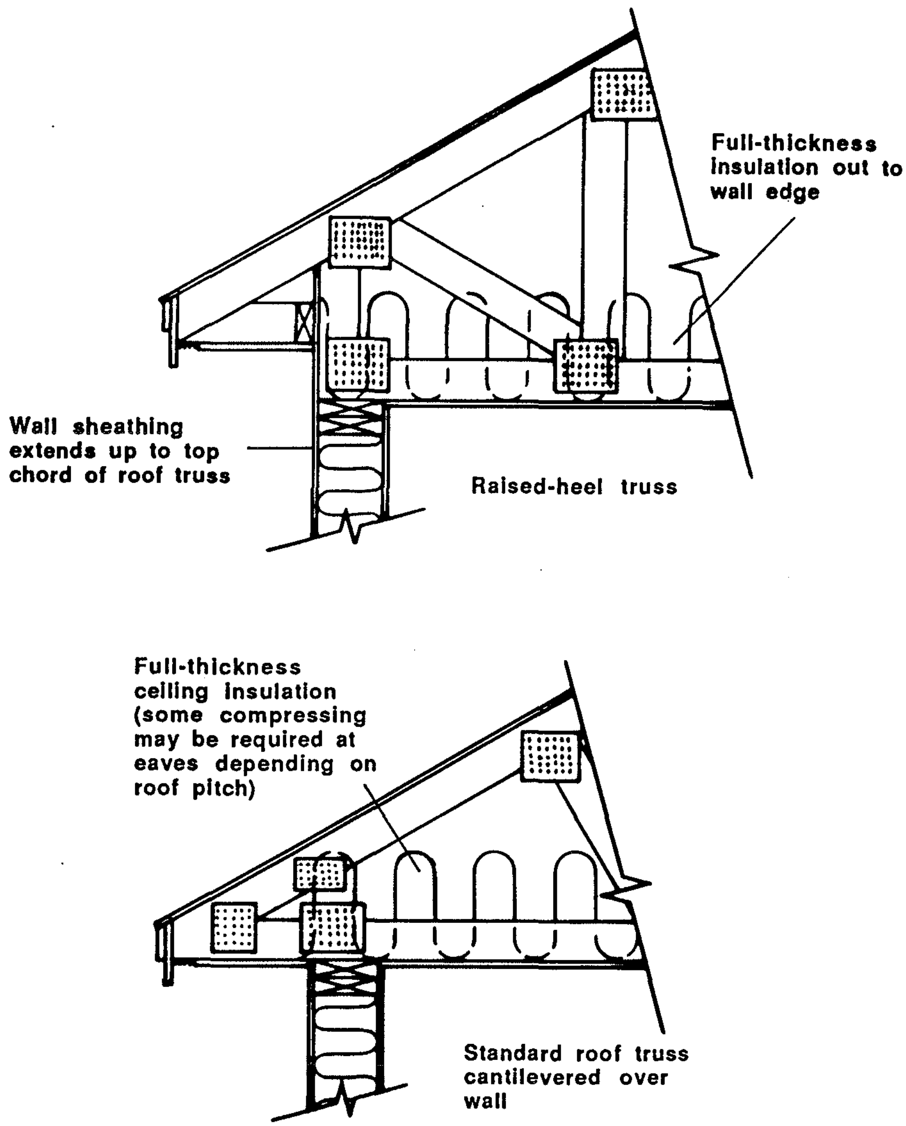


Figure 36. Cantilevered and raised-heel trusses allow you to obtain adequate insulation at the eaves. Check with your truss supplier about designs that will suit your needs.

3). With 2x12 rafters, for example, you can compress (R-38) fiberglass batt insulation to fit into a reduced rafter cavity that has a vent spacer under the roof sheathing for ventilation. Refer to **Table 2** (page 3) for complete requirements and definitions.

In the simplest complying roof (shown in **Figure 37**), 2x12 rafters are used, with fiberglass batt insulation compressed to fit snugly against vent spacers under the roof sheathing. The vent spacers are necessary to allow air flow up along the roof sheathing from soffit to ridge vents. In this detail, blocking is cut and installed between the rafters against the top wall plate to hold the insulation in place and funnel the air up over the insulation. The blocking or baffle is very important even with batt insulation because it keeps the air from flowing through the insulation, which reduces the effective R-value and may cause condensation problems. The blocking or baffle should extend up to the vent spacers.

If you are using smaller rafters than 2x12s, you will need to add additional insulation to

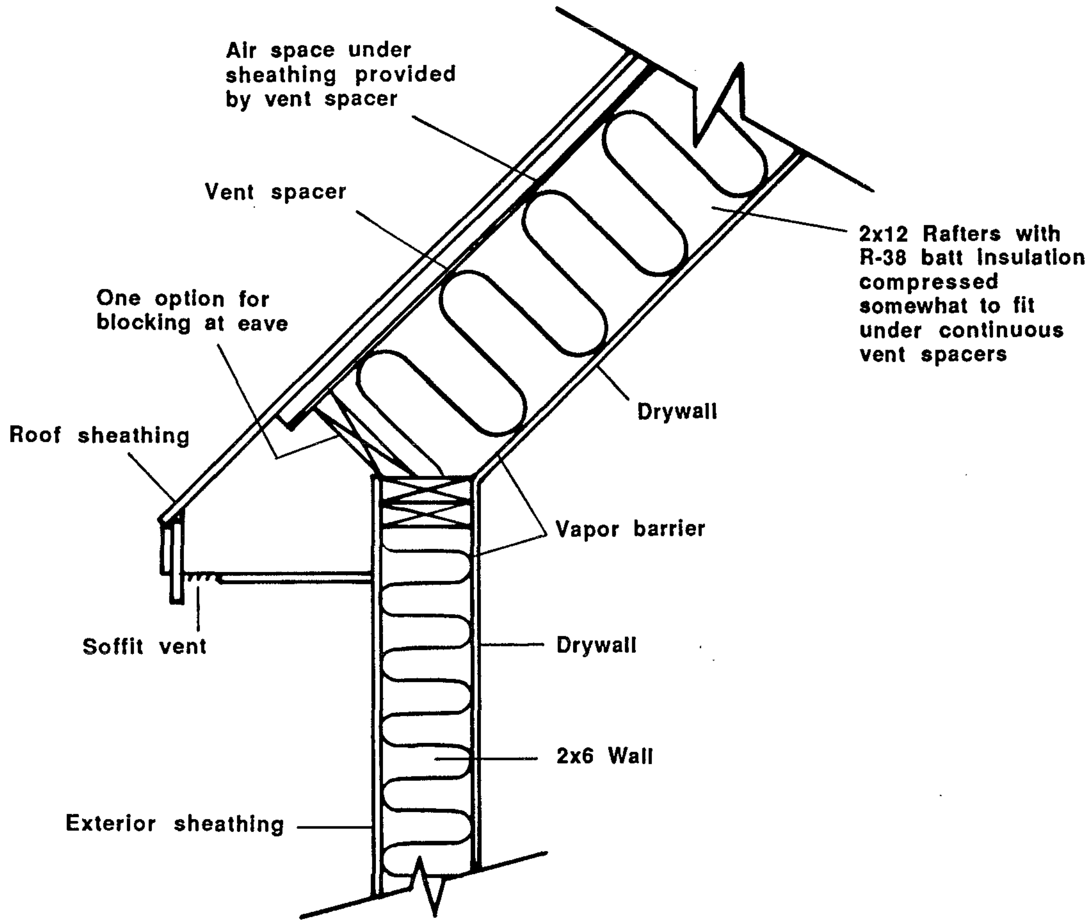


Figure 37. With insulated cathedral ceilings, you can satisfy the insulation requirements with 2x12 rafters, even though the insulation must be somewhat compressed to provide an air space under the roof sheathing.

meet the specified R-38. While false rafters and batt insulation can be used to bring the insulation level up to R-38, the most common strategy is to use a layer of rigid insulation on the inside of the roof/ceiling assembly. When using 2x10s and R-30 fiberglass or cellulose, the Standards call for an additional R-8. An inch and one-half of polyisocyanurate insulation will provide this, as shown in **Figure 38**. With lower-R-value rigid insulation, such as extruded polystyrene, you will need and additional two inches to achieve an R-38 total.

To achieve a true R-38 in an insulated sloped ceiling without compressing R-38 batt insulation (and thereby reducing its R-value), you will need to use a deeper rafter. Some

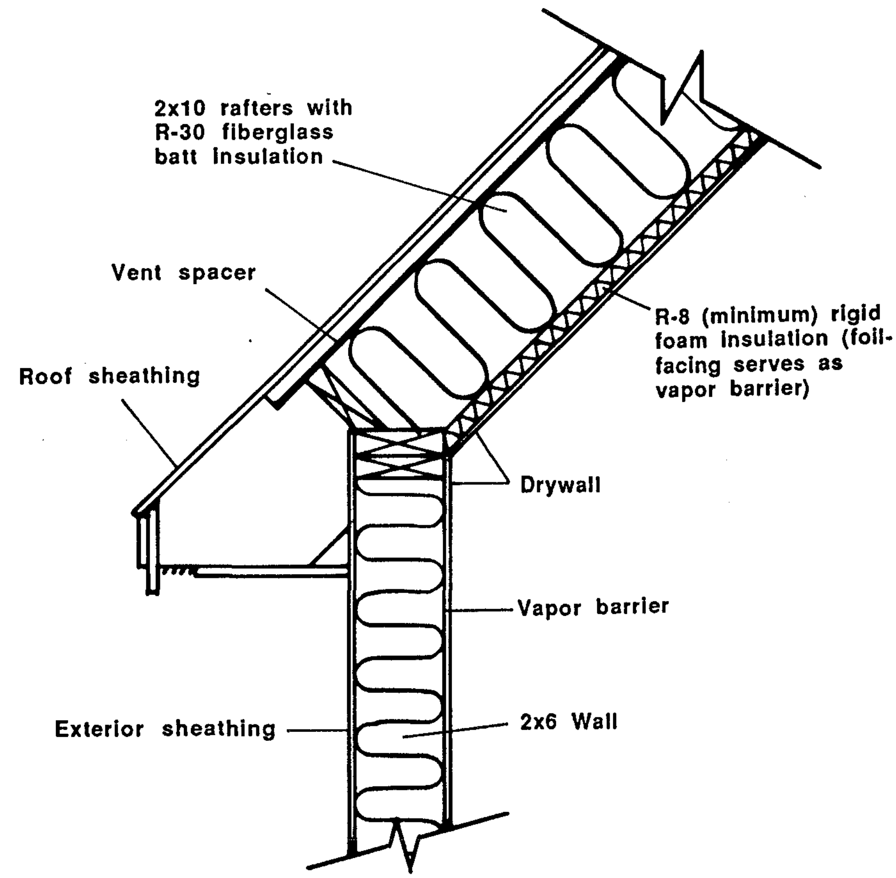


Figure 38. With 2x10 and smaller rafters, you will need rigid foam insulation in addition to batt insulation between the rafters.

contractors are using laminated wood **I-Joists.** These are available up to 16" deep and in lengths up to 28 feet. Because of their construction, they are far stronger than solid wood rafters, and they are much less likely to warp or twist. While their primary use is as floor joists, some builders of very well homes use them for rafters as well. A detail using 14" I-joists as rafters with full-thickness R-38 insulation is shown in **Figure 39**.

The detail provides a full 2" air channel above the insulation as shown in the cross-section detail. If using this type of product, follow manufacturer's recommendations on installation, blocking, safe storage and handling. While very strong when loaded on edge, I-joists are very weak when flat. Improperly picking up a long I-joist could cause it to break.

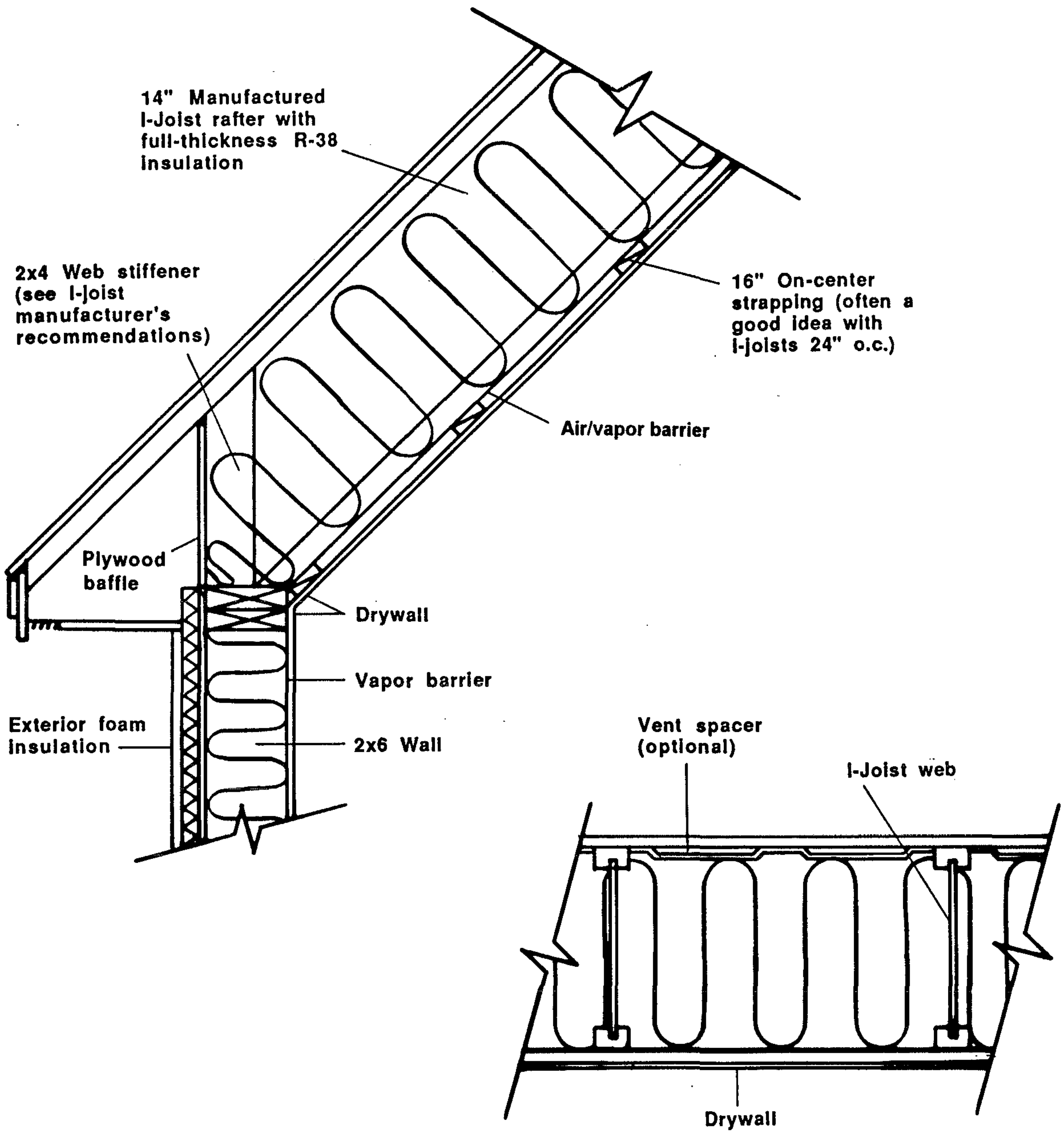


Figure 39. For true R-38 insulation in cathedral ceilings, you can use laminated wood "I-beams" for rafters. The 14" I-joists shown allow 12" insulation to be used without compression, even with a 2" air space under the roof sheathing.

Another alternative that allows you to use full-thickness R-38 batt insulation is to install raised-heel scissor trusses, as shown in **Figure 40**. While the ceiling pitch will generally be shallower than the roof pitch with this system, the effect is the same on the interior. Check with your truss manufacturer for scissor truss options.

Many building scientists still feel that proper roof ventilation is important, although some are no longer insisting on it (see discussion of dense-packed cellulose, below). The most

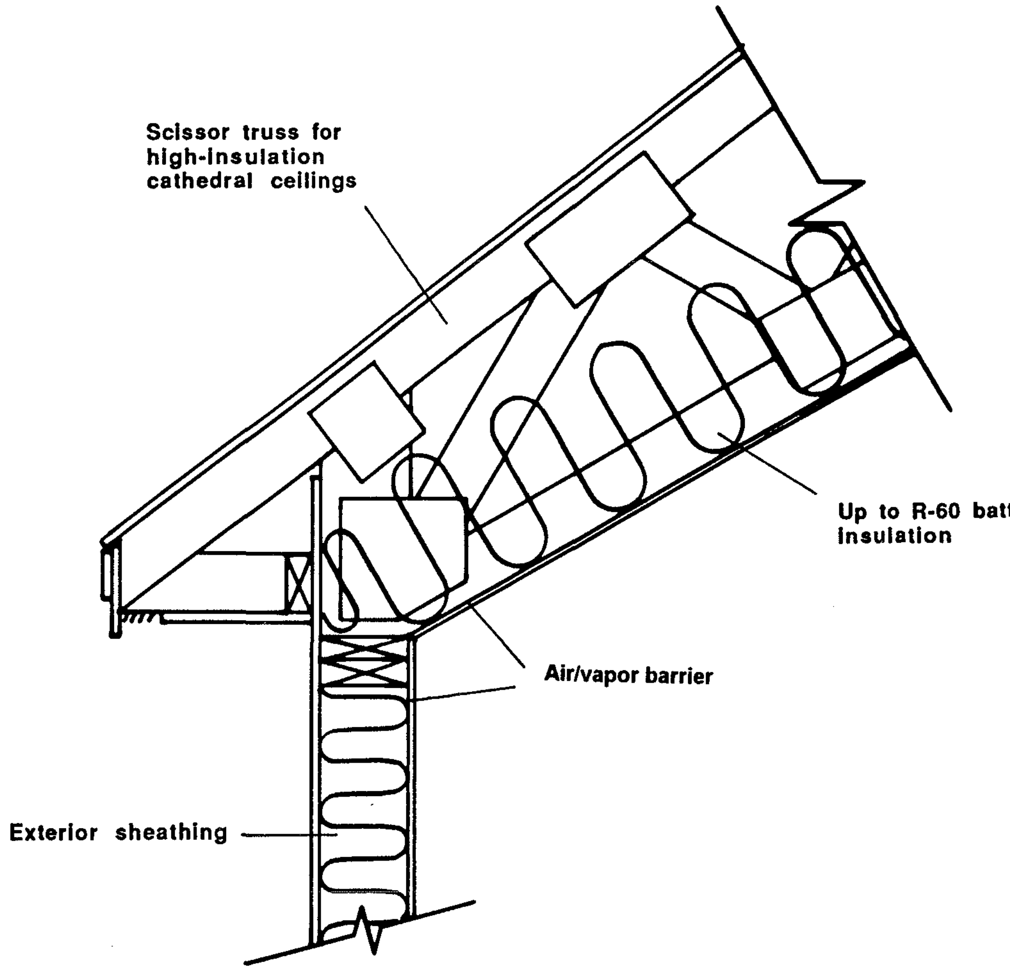


Figure 40. Raised-heel scissor trusses can be used to allow very high levels of insulation with cathedral ceilings — up to R-60.

effective strategy for effective ventilation is to provide continuous soffit and ridge vents. Soffit vents are generally built by providing two separate soffit boards with a 2" gap, spanned either with screening or a specialized metal soffit vent, as shown in **Figure 35**.

The general rule for roof ventilation is to provide one square foot of combined inlet and outlet vent area for every 300 ft^2 of area to be vented. Refer to complete ventilation discussion (pages 29-31) for more information on venting and calculations of required vent areas. Gable-end vents, though not as effective as a continuous ridge-vent/soffit-vent combination, are a viable alternative. If using a ridge vent, buy one of the commercially available products

that effectively blocks rain, snow, and insects.

The most difficult roof ventilation details are those around roof windows and at roof valleys and hips. To ventilate the rafter bays around roof windows, the best option is to drill 1" holes near the upper edge of the rafters both above and below the roof windows, as shown in **Figure 41.** Though not as effective as a full air space at the top of the rafter cavity, these holes will allow some lateral air flow into adjacent rafter cavities. Unfortunately, most vent spacers are designed to allow air to flow primarily upward along the roof sheathing. Look for vent spacers that provide lateral as well as vertical air flow.

At rafter hips and valleys, the best option is to use hip and valley rafters that do not extend all the way up to the tops of the other rafters. By leaving a one-inch gap at the top of these rafters, as shown in **Figure 42**, air will be able to flow into adjacent rafter cavities, making its way up to the ridge vent area. To achieve this, hip or valley rafters can be constructed so that their bottom edges are flush with the bottom edges of the rafters abutting them. Because the abutting rafters are cut at an angle, a space will be left at the top of the hip or valley rafters.

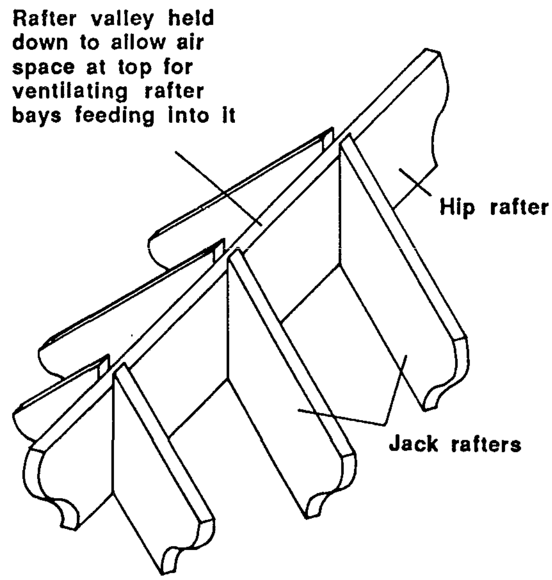


Figure 42. Roof hips and valleys can be difficult to properly ventilate. One effective strategy is to use shallower hip and valley rafters, leaving an air space under the roof sheathing at those places.

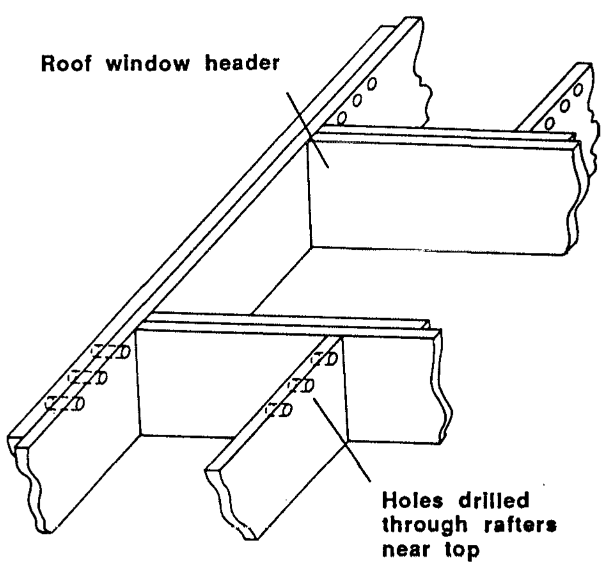


Figure 41. Holes can be drilled at the upper edge of the rafters to ventilate the rafter cavities above and below roof windows.

• • •

As a result of many building scientists feeling that roof ventilation is not always necessary, some insulation contractors are installing dense-packed cellulose insulation into roof/ ceiling cavities, leaving no space for ventilation (see page 29 for more details). This practice is apparently working well, resulting in a uniform R-value and no long-term moisture problems. In addition, the cellulose insulation in a dense-packed state acts as a good air barrier. Before trying this method, consult an expert or call the Energy Division.

5. Stress Skin Panel Construction

Stress skin panels have emerged as a viable alternative to the standard practice of framing and insulating walls and roofs. When properly installed, these one-component panels offer both high insulation values and low air leakage. Stress skin panels were first used in residential construction for enclosing and insulating timber

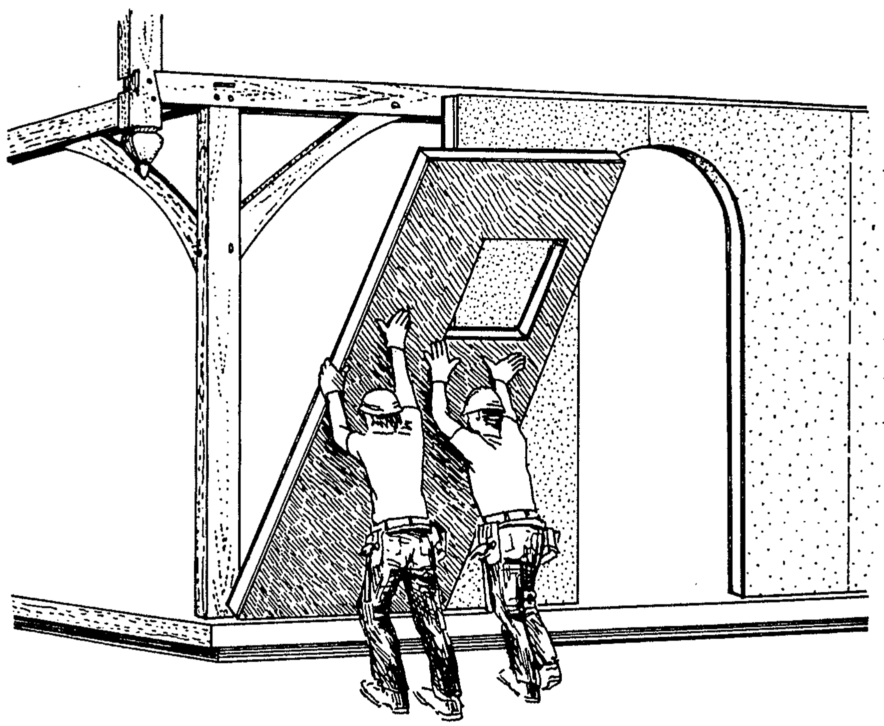


Figure 43. Stress skin panels are often used to fully enclose and insulate timber frame buildings. The panels provide an all-in-one wall and roof system.

frame houses. In this application, panels are installed on the outside of the frame, fully enclosing it with the insulated wall or roof system (see Figure 43). Stress skin panels for timber frame buildings generally have an inner skin of drywall, a core of rigid expanded polystyrene (EPS) or polyurethane foam, and an outer skin of plywood or oriented strand board (OSB). When secured to the frame, the panels provide a nearly finished inner wall surface and exterior sheathing, ready for siding or roofing. Varying thicknesses are available, providing R-values from R-15 to R-40.

More recently, stress skin panels have been used in "frameless" houses, where the panels provide the structure as well as insulation system. In this application, the panels are often called structural panels. Plywood or OSB is used as both the inner and outer skin of the panels. Structural **splines** are used to join the panels, with wall and roof sections held together by floor joists, rafters and other structural components, as shown in **Figure 44**. Because the inner skin of structural panels is plywood or OSB, a layer of drywall must be installed to comply with fire codes. Because of the large open spans achievable, however, drywall application can generally be done before interior partition walls are built, greatly simplifying drywall installation and finishing.

With structural stress skin panels, manufacturers generally provide either ready-to-erect kits or fully erected shells, ready for finishing. Each manufacturer has its own specific installation guidelines and details for joining and sealing panels, which must be followed. Sealing between panels with foam sealant is particularly important for the prevention of heat loss and moisture migration through the wall or roof.

As mentioned above, both EPS and polyurethane-core panels are available. Each has its advantages and disadvantages. EPS is more spongy than polyurethane, its R-value is lower on a per-inch basis, and there is some concern

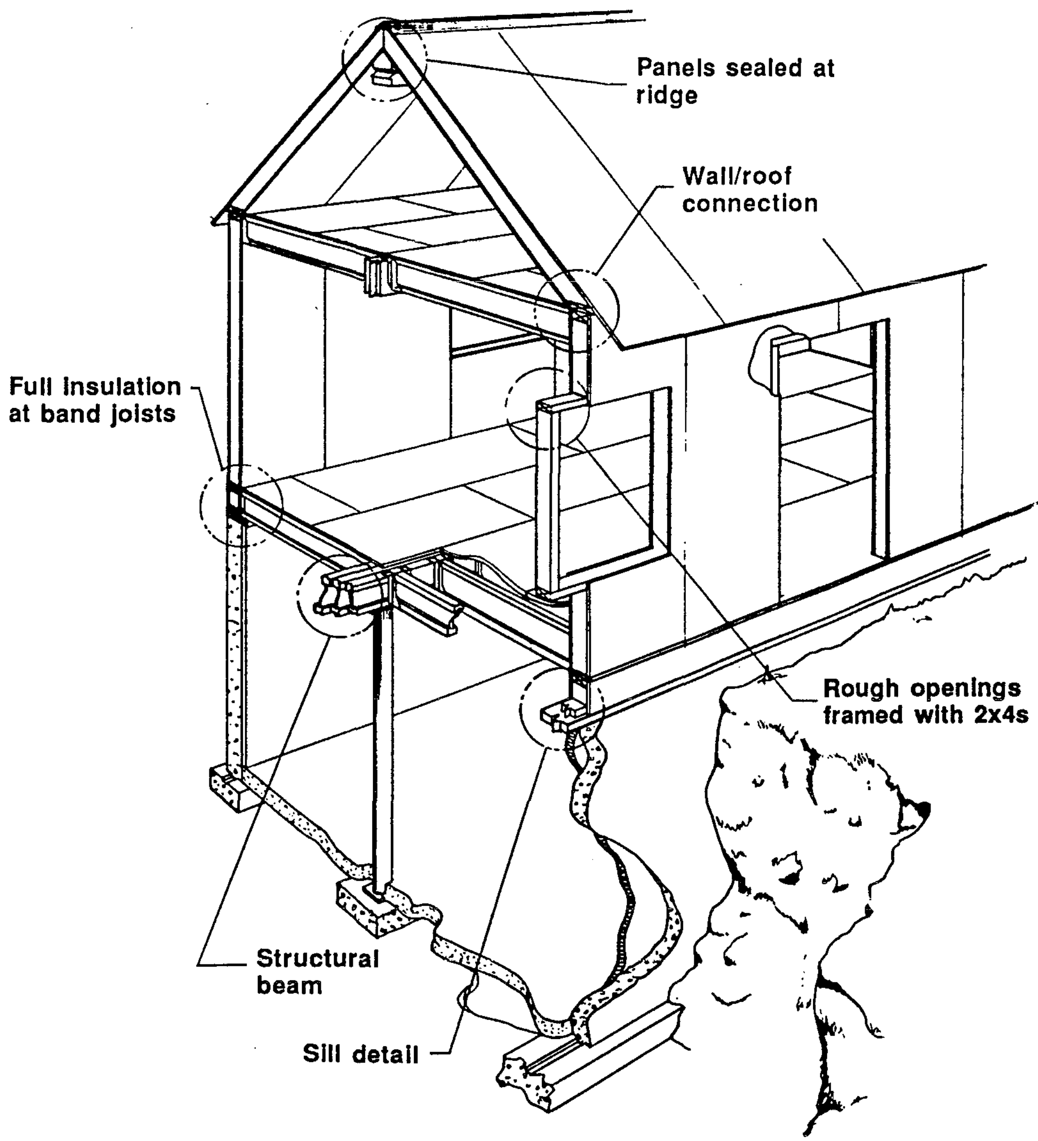


Figure 44. With structural stress skin panel construction, panels with waferboard on both sides are joined together with splines. There is no "frame" as such.

about the fire safety of EPS. On the other hand, polyurethane is more expensive and is produced with CFCs, which are damaging to the protective atmospheric ozone layer.

Building with rigid panels can keep labor costs down and enable houses to be erected and closed in very quickly. Stress skin panels that meet Maine's Energy Standards are readily available. Greater energy efficiency is often achieved with stress skin panel houses compared to conventional homes with comparable R-values. This results from the lack of bypass heat loss through framing members and the increased air tightness that can be achieved with stress skin panels.

6. Installing Windows and Doors

As mentioned previously in this manual, windows and doors provide one of the best opportunities for exceeding the energy efficiency standards called for by the Residential Energy Efficiency Standards. Windows are available with overall insulating values up to R-2.5, and exterior doors are available that insulate to R-5. Minimizing heat loss through windows and doors is not solely a question of

which model you buy; it also depends on the quality of installation. Air leakage around windows and doors often accounts for more heat loss than the heat being transmitted through the surface of the units.

Always follow window and door manufacturer's instructions when installing the units. Specific details may vary from one manufacturer to another and from one style to another. The key to tight installation of windows and doors is sealing between the jamb and the rough opening. While fiberglass insulation can be used here, it does *not* provide an air seal. Foam sealant provides the best seal and it provides a good R-value. Choose a low-expanding foam sealant; they are not as likely to bulge window or door jambs as the high expanding foam.

When sizing the rough opening and installing the window or door, make sure there is enough space between the jamb and rough opening to insert the nozzle for the foam sealant (3/8" to 1/2"). Apply a continuous bead of foam sealant in the gap, working from the outside to the inside, welding the jamb to the jack studs, header and sill (see **Figure 45**). Apply the foam in several beads, allowing the foam to cure between applications (usually a minimum of one-half hour).

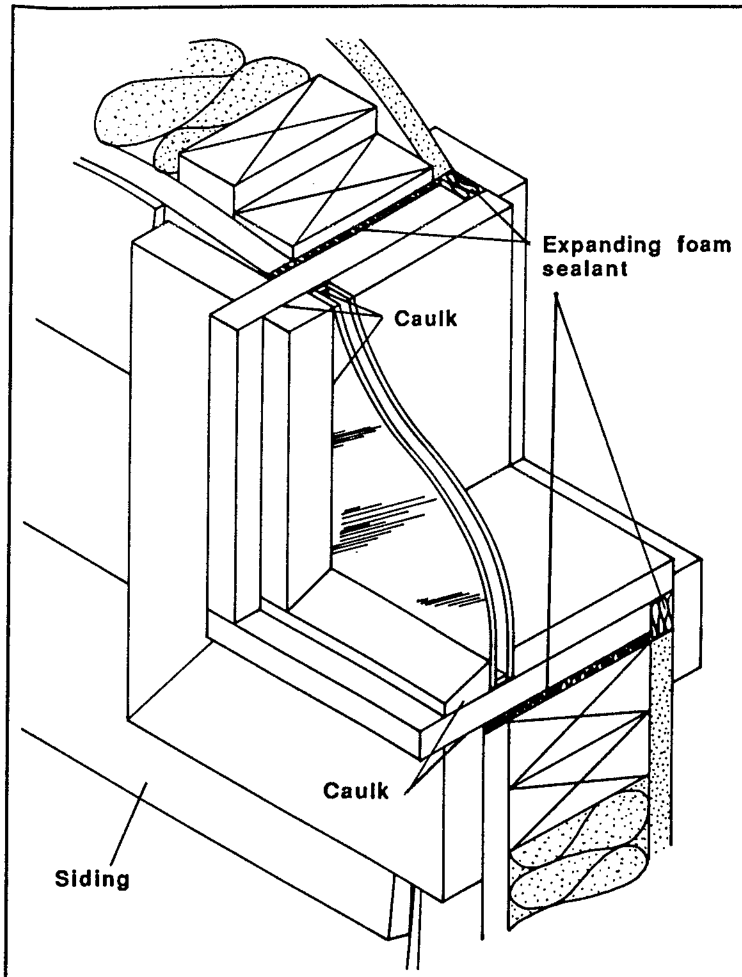


Figure 46. With site-built fixed-glass windows, proper sealing is crucial to prevent both air leaks and water leaks.

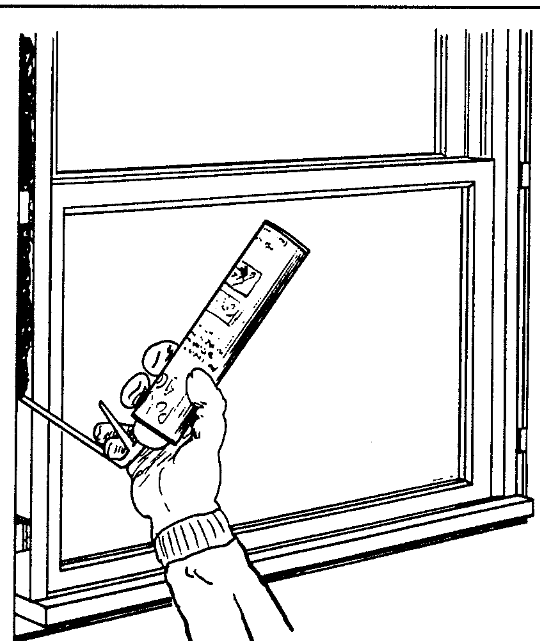


Figure 45. Carefully seal around windows.

If high-expanding foam is used, be extremely careful to apply the foam only in single beads and allow full curing between applications. If expansion of the foam warps the jamb, making window operation difficult, relieve the pressure by making a kerf with a handsaw through the foam. Always check window and door operation before installing drywall.

Operable windows and doors should always be purchased pre-hung to achieve greatest tightness. Fixed windows, however, can be built on-site without large air tightness penalties. The details you use for sealing site-built fixed windows will depend on the placement and design. One alternative is shown in **Figure**

46. Leave a gap between the window jamb and the rough opening, as shown, and seal it with low-expanding foam sealant, as described above. It is important to properly caulk site-built windows, both to minimize air leakage and to prevent water leaks. Primary caulking points are shown in the illustration.

As an additional measure to ensure tightness, interior window and door casings can be caulked in place. Apply a bead of high quality caulk on the interior jamb edge and on the drywall where the casing will sit. However, if the window or door jamb has been properly sealed, caulking is not required.

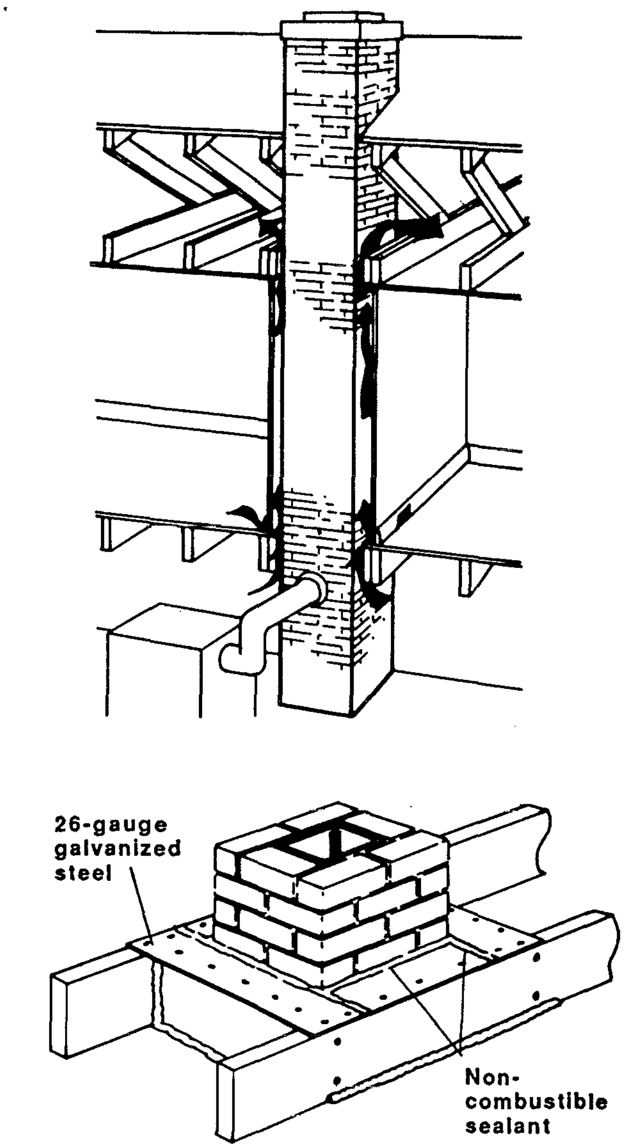


Figure 47. Chimney penetrations through insulated ceilings and roofs can be very tricky to properly seal. Leave an air space next to the chimney and seal above and below the penetration with 26-gauge galvanized steel and noncombustible sealant.

7. Other Measures to Reduce Air Leakage

Keeping natural air leakage to a minimum in new construction requires careful attention to details throughout the construction process. Framing should be done carefully to ensure tight fits. Use high quality air sealing products as described throughout this guide. A number of particularly troublesome air sealing locations

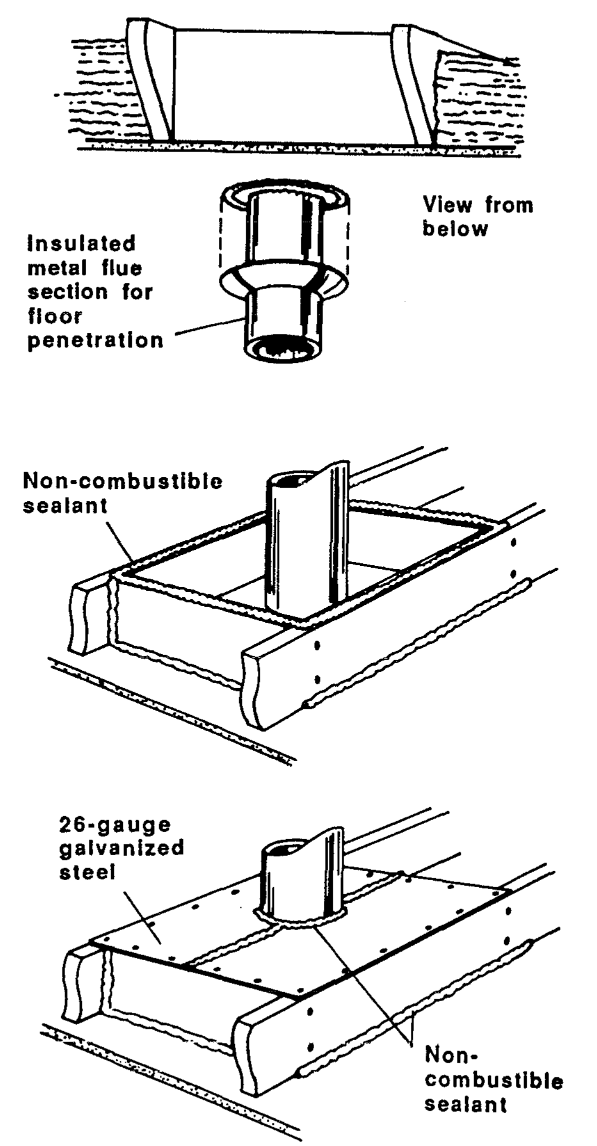


Figure 48. Metal flue penetrations should also be sealed with sheet metal and noncombustible sealant. Use specially made insulated metal flue sections for floor penetrations.

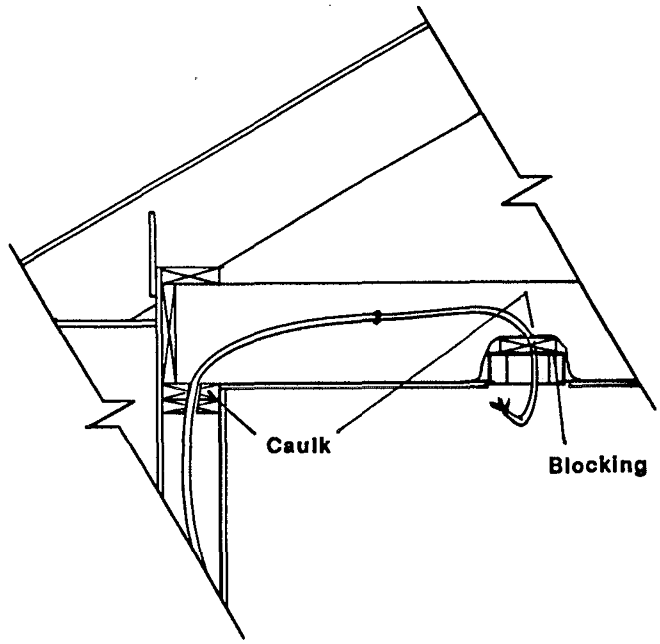


Figure 49. Install ceiling-mounted lighting fixture receptacles on blocking between rafters below the air/vapor barrier. Seal the wiring penetration with caulk.

and the recommended practices are shown in the illustrations below. More comprehensive references on how to seal houses are included in the Appendix.

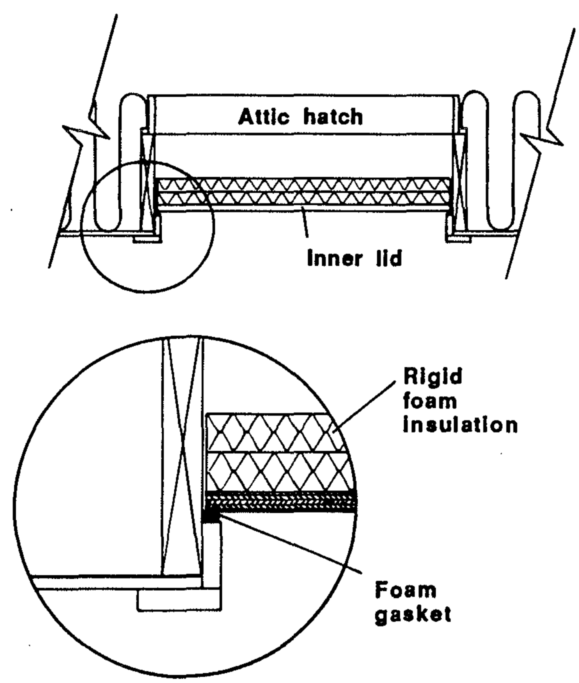


Figure 50. Carefully insulate and weatherstrip attic hatch covers, or eliminate them altogether and provide an access door from the outside through a gable end. The illustration shows one way to add an extra layer of rigid insulation—mounted on plywood beneath the hatch cover.

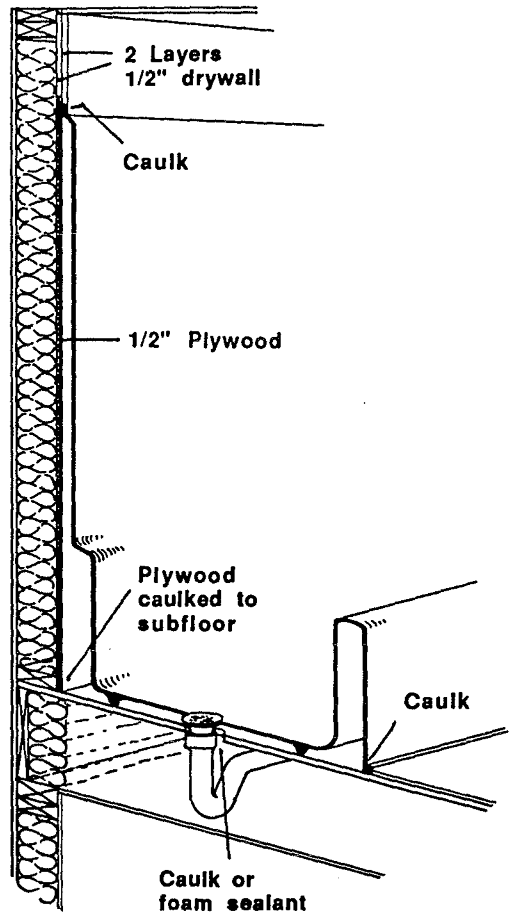


Figure 51. Bathtubs and showers can provide considerable air leakage if mounted directly against open stud cavities. To solve this problem, install 1/2" plywood against the studs where the tub or shower will be installed, sealing the edges with foam gasketing or caulk. Above the unit, install 1/2" drywall, caulking the plywood-drywall joint. Then cover that layer and the tub/ shower flange with a second layer of drywall and caulk the tub lip.

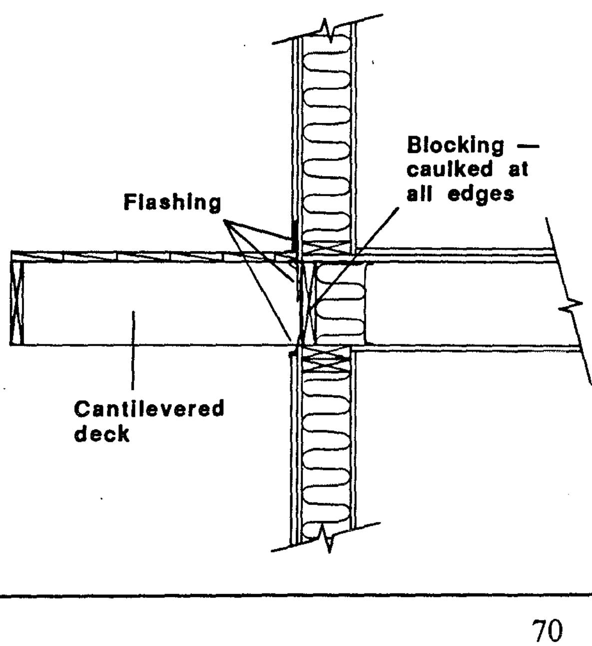


Figure 52. If a deck is cantilevered out over the wall by extending floor joists, be especially careful about air leakage. Install blocking between the joists as shown and seal the blocking to the joists, the top wall plate and the subfloor above. Provide overlapping sections of flashing to shed rain.

Appendix A
Heat Loss Calculations

Determining a building's heating load can be important for a number of reasons, including sizing heating systems and calculating annual heating loads (if you want to determine how much oil, gas or wood is required for the heating season, for example). To calculate heat loss you should start by measuring the areas of all the different components of the building envelope and calculating the heat loss coefficient (**U-factor**) of each of those areas. Organize the information onto a worksheet such as **Worksheet A** on Page 74 (which you can photocopy). If there are several types of walls with different R-values, you will need one line for each type. If several *different* building components have the same total R-values (for example, the floor over an unheated crawl space and an insulated cathedral ceiling), you can combine these areas onto one line on the worksheet.

To calculate the U-factor for a component of the building for use in Worksheet A, you need to add up the R-values of each part of that building component. Refer to a chart of R-values of building materials, such as the one shown in Appendix B (more complete R-value listings are available in many publications). In walls and ceilings where there are studs, joists or rafters along with the insulation, the average R-value should take both the insulation area and the wood framing area into account. For stud walls with the studs 16" on center (o.c.), the studs comprise 20% of the wall area and the cavities 80%. For a stud wall 24" o.c., the studs comprise 15% and the cavities 85%. For rafters and joists, assume that 16" o.c. framing comprises 15% and the cavities 85%. For a 24" o.c. floor, ceiling or roof, the framing comprises 10% and the cavities 90%.

The R-values of a sample 2x6 wall system with exterior rigid foam insulation are added up in **Table A** below. Two columns are used to account for the lower insulation value through the studs. Component R-values are listed and then added together These are in turn multiplied by the stud ratio multipliers and the two results are added, as shown in the table. The overall U-factor is found by dividing the R-value into one (U=1/R).

This total corrected U-factor is entered onto Worksheet A and multiplied by the measured area for that wall component. By carrying out similar calculations for the rest of the building components, the worksheet can be completed. With windows and doors, you may be able to use U-factors supplied directly by manufacturers.

Table A

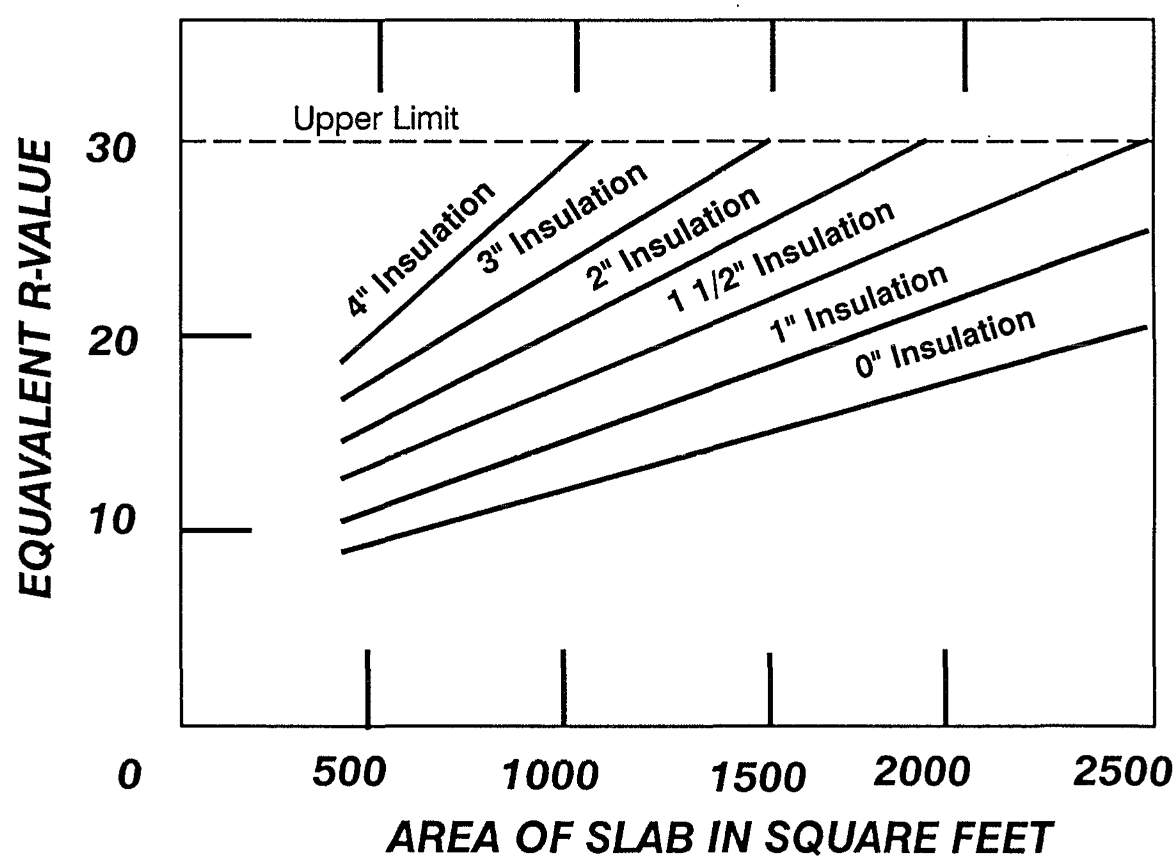
Wall Component	*Cavity R-value*		*R-value through Studs*
Inside air film	.68		.65
1/2" Drywall	.45		.45
Fiberglass batt insulation	19.00		0.00
2x6 studs	0.00		6.90
1/2" plywood sheathing	.50		.50
1" Extruded polystyrene	5.00		5.00
1/2" bevel siding	.81		.81
Outside air film	.17		.17
Total R-Value	26.61		14.48
Stud Ratio Multiplier	x .8		x .2
Total Corrected R-value	21.288	+	2.896
			= **24.184**

Foundations can be a difficult part of heat loss calculations. Accurate heat loss calculations depend on many variables, including soil type. For quick a heat loss calculation for a full basement, you can divide the foundation into above-grade and below-grade areas. For the above-grade part, simply add up the total R-Value as described previously. For the below grade portion, add up the R-values and multiply the total R-value by 1.5 to take into account the reduced heat loss through the ground. Enter each of these components in Table A above. This will provide a *conservative* estimate of total foundation heat loss, and it should suffice for most heating load determinations.

With slab-on-grade construction, a different calculation procedure should be used. If the slab is insulated according to the Maine Residential Energy Standards (insulation covering the perimeter of the slab and extending horizontally under the slab for a distance equal to the design frost depth), the R-value you should use in the heat loss calculations depends on the thickness of the insulation and the area of the slab. With extruded polystyrene insulation, you can use the graph below to determine the "equivalent" R-value of the entire slab.

By adding up all the heat loss (U x A) values, you obtain the total surface heat loss through the building envelope in Btu/°F hr. You still need to deal with the heat loss caused by air leakage. To make that calculation, you need to calculate the total conditioned, above grade volume of the house and then assign a number for air tightness in air changes per hour (ACH). The air tightness can be

EQUIVALENT R-VALUES FOR SLABS INSULATED WITH DIFFERENT THICKNESSES OF EXTRUDED POLYSTYRENE



Note: It is assumed that the insulation covers the edge of the slab and extends under it from the edge a distance equal to the local depth of frost or more.

measured with a blower door, or it can be estimated. By building to Maine's Residential Energy Standards, the air exchange rate will be between 0.2 and 0.6 ACH, with an average figure of 0.4 ACH. Calculate the air exchanged every hour by multiplying the total volume by the ACH estimate. Fill in Worksheet A with this information. For the U-factor, use the constant 0.018 Btu/ft^3, °F hr.

Once all the information is put into Worksheet A, the total heat loss numbers (UxA) can be added to arrive at the building's total **heat loss coefficient** in Btu/°F hr. (see number 1 on the bottom of Worksheet A on the next page). With that number, you can easily compute either hourly heating load for sizing heating systems, or total heating requirements on a yearly basis. To compute hourly heating load using Worksheet A, plug in values for the heating outdoor design temperature (see page 35; some values are shown in **Table D**) and inside temperature, and multiply the resultant ΔT by the building's heat loss coefficient (see number 2 on the bottom of Worksheet A on the next page).

This will tell you the amount of heat output required from the heating system to maintain the desired inside temperature (70°F) when the outside temperature is the heating design temperature.

To calculate heating requirements for a full year, we need to use **heating degree day** information. Degree-day numbers are used by fuel companies to determine when they need to make deliveries. Each day the high and low temperature is recorded and averaged (high + low ÷ 2). If that average is below 65°F, the difference is the number of degree days for that day. By adding those numbers for the year, yearly degree days can be calculated. In Maine, annual heating degree-days range from 7,000 to 10,000. Values for several cities are shown in **Table B**. Use Worksheet A to compute the annual heating load (see number 3 on the bottom of Worksheet A on the next page).

There is still one more step in determining annual fuel use: converting Btus to quantity of fuel. In Worksheet A, plug in values for the heat content of your fuel (Btu/gal for oil; Btu/ccf for natural gas, Btu/cord for wood, etc.) and the efficiency at which it is burned. Refer to **Table C** for the heat content of common fuels. Heating system efficiencies (Annual Fuel Utilization Efficiency) can be obtained from equipment manufacturers or dealers (see number 4 on the bottom of Worksheet A on the next page).

Table B
Annual Heating Degree-Days

Augusta	7826
Bangor	8220
Caribou	9770
Eastport	8246
Lewiston	7690
Millinocket	8533
Portland	7570

Table C
Heat Content of Common Fuels

Fuel Source	Btu content
Heating oil	139,000 Btu/gallon
Natural gas	1030 Btu/cubic foot
LP gas	91,600 Btu/gallon
Mixed hardwood	24 million Btu/cord
Electricity	3412 Btu/kWh

Table D

Heating Outdoor Design Temperature (97.5%)

Augusta	-3
Bangor	-6
Caribou	-13
Eastport	-4
Lewiston	-2
Millinocket	-9
Portland	-1
Waterville	-4

WORKSHEET A

Heading Load Calculations

Assumptions (fill in):

Air changes per hour (ACH) ____________

Heating outdoor design temperature (97.5%) ____________

Inside design temperature ____________

ΔT (inside design temp. – heating outdoor design temp.) ____________

Average annual heating degree-days (HDD) ____________

HDD Correction factor (C_f), (Use 0.62 for 7000 HDD, 0.69 for 8000 HDD, and 0.67 for 9000 HDD) ____________

Heating system efficiency ____________

Fuel type and heat content ____________

Building Envelope Heat Loss:

Building Component	U-Factor (Btu/ft², °F hr) x	Net Area (ft²) =	Heat Loss Coefficient (Btu/°F, hr)
		Total	

Air Leakage Heat Loss:

Air changes per hour (ACH) x	House Volume (ft³) x	.018 (Btu/ft³, °F hr) =	Heat loss coefficient (Btu/°F, hr)

1. Total Heat Loss Coefficient (Btu/°F hr) ____________
   (Total surface loss plus air leakage)

2. Heating Load at Heating Design Temperature (Btu/hr) ____________
   (Total heat loss coefficient x ΔT)

3. Total Annual Heat Requirement (Btu/yr) ____________
   (Total heat loss coefficient x 24 x HDD x C_f)

4. Total Fuel Requirement (Gallons oil/yr, or ccf gas/yr, or cords wood/yr) ____________
   (Total annual heat requirement x heating system efficiency ÷ But content of fuel/unit)

APPENDIX B

R-Values of Common Building Materials

Material	R/Inch	R/thickness
Insulation Materials		
Fiberglass		
Batt	3.17	
Blown	2.20	
Rock Wool		
Batt	3.17	
Blown	3.10	
Cellulose		
Loose-fill (blown)	3.2	
Wet-spray	3.5	
Vermiculite	2.13	
Rigid Fiberglass (<4 lb/ft^3)	4.00	
Expanded Polystyrene (beadboard)	4.00	
Extruded Polystyrene	5.00	
Polyurethane (foamed-in-place)	6.25	
Polyisocyanurate (foil-faced)	6.00	
Phenolic Foam	8.00	
Construction Materials		
Concrete Block 4"		0.80
8"		1.11
12"		1.28
Brick 4" common		0.80
4" face		0.44
Poured Concrete	0.08	
Soft Wood Lumber	1.25	
2" nominal (1-1/2")		1.88
2x4 (3-1/2")		4.38
2x6 (5-1/2")		6.88
Cedar Logs and Lumber	1.33	
Sheathing Materials		
Plywood/Waferboard	1.25	
1/4"		0.31
3/8"		0.47
1/2"		0.63
5/8"		0.77
3/4"		0.94
Fiberboard	2.64	
1/2"		1.32
25/32"		2.06
Fiberglass (3/4")		3.00
(1")		4.00
(1-1/2")		6.00
Extruded Polystyrene (3/4")		3.75
(1")		5.00
(1-1/2")		7.50
Foil-faced Polyisocyanurate (3/4")		4.5
(1")		6.00
(1-1/2")		9.00
Siding Materials		
Hardboard (1/2")		0.34
Plywood (5/8")		0.77
(3/4")		0.93
Wood Bevel Lapped		0.80
Aluminum, Steel, Vinyl (hollow backed)	0.61	
(1/2" Insulating board backed)		1.80
Brick 4"		0.44
Interior Finish Materials		
Gypsum Board (drywall 1/2")		0.45
(5/8")		0.56
Paneling (3/8")		0.47

Material	R/Inch	R/thickness
Flooring Materials		
Plywood	1.25	
(3/4")		0.93
Particle Board		
(underlayment)	1.31	
(5/8")		0.82
Hardwood Flooring	0.91	
(3/4")		0.68
Tile, Linoleum		0.05
Carpet (fibrous pad)		2.08
(rubber pad)		1.23
Windows*		
Single glass		0.91
w/storm		2.00
Double insulating glass		
(3/16" air space)		1.61
(1/4" air space)		1.69
(1/2" air space)		2.04
(3/4" air space)		2.38
(1/2" Low-E)		3.13
(w/suspended film)		2.77
(w/2 suspended films)		3.85
(w/suspended film and low-E)		4.05
Triple insulating glass		
(1/4" air spaces)		2.56
(1/2" air spaces)		3.23
Addition for tight fitting drapes, shades, or closed blinds		0.29
Doors		
Wood Hollow Core Flush (1-3/4")		1.80
Solid Core Flush (1-3/4")		2.17
Storm Door – wood, 50% glass		1.25
metal		1.00
Metal Insulating (1.75" with urethane — assuming no windows)		5.3
Air Films		
Interior Ceiling		0.61
Interior Wall		0.68
Exterior		0.17
Air Spaces		
1/2" to 4" approx.		1.00
1/2" to 4" w/one surface fairly reflective		2.36
1/2" to 4" w/ one surface highly reflective		3.48
Misc.		
6-mil Polyethylene Vapor Barrier		0.00
Air Barrier		0.00

* Window R-Values are now calculated according to a standard method. Check with manfacturer for latest listings of R-values and U-factors.

COMPARING HEATING FUEL COSTS

Scale	Values
Heating Equivalent Cost in $/MBTU	6, 8, 10, 12, 14, 16, 18, 20, 22, 24, 26, 28
Natural Gas @ 75% Eff. in $/Therm	.50, .60, .70, .80, .90, 1.00, 1.10, 1.20, 1.30, 1.40, 1.50, 1.60, 1.70, 1.80, 1.90, 2.00, 2.10
Natural Gas @ 95% Eff. in $/Therm	.60, .70, .80, .90, 1.00, 1.10, 1.20, 1.30, 1.40, 1.50, 1.60, 1.70, 1.80, 1.90, 2.00, 2.10, 2.20, 2.30, 2.40, 2.50, 2.60, 2.70
Fuel Oil @ 85% Eff. in $/Gallon	.70, .90, 1.10, 1.30, 1.50, 1.70, 1.90, 2.10, 2.30, 2.50, 2.70, 2.90, 3.10, 3.30
LP Gas @ 75% Eff. in $/Gallon	.50, .60, .70, .80, .90, 1.00, 1.10, 1.20, 1.30, 1.40, 1.50, 1.60, 1.70, 1.80, 1.90, 2.10
LP Gas @ 95% Eff. in $/Gallon	.60, .70, .80, .90, 1.00, 1.10, 1.20, 1.30, 1.40, 1.50, 1.60, 1.70, 1.80, 1.90, 2.00, 2.10, 2.20, 2.30, 2.40, 2.50
Mixed Hardwood @ 50% Eff. in $/Cord	70, 90, 110, 130, 150, 170, 190, 210, 230, 250, 270, 290, 310, 330, 350
Mixed Hardwood @ 70% Eff. in $/Cord	90, 110, 130, 150, 170, 190, 210, 230, 250, 270, 290, 310, 330, 350, 350, 370, 390, 410, 430, 450
Coal @ 60% Eff. in $/Ton	90, 110, 130, 150, 170, 190, 210, 230, 250, 270, 290, 310, 330, 350, 370, 390, 410, 430
Electricity @ 100% Eff. in $/KWH	.025, .03, .035, .04, .045, .05, .055, .06, .065, .07, .075, .08, .085, .09, .095, .10
Heating Equivalent Cost in $/MBTU	6, 8, 10, 12, 14, 16, 18, 20, 22, 24, 26, 28

ASSUMPTIONS

Natural Gas (100,000 BTU/Therm)	@75% Efficiency $/MBtu = 13.3 X $/Therm	@95% Efficiency $/MBtu = 10.5 X$/Therm
#2 Fuel Oil (138,000 BTU/Gallon)	@85% Efficiency $/MBtu = 8.5 X $/Gallon	
LP Gas (93,000 BTU/Gallon)	@75% Efficiency $/MBtu = 14.3 X $/Gallon	@95% Efficiency $/MBtu = 11.3 X $/Gallon
Mixed Hardwood (24MBtu/Cord)	@50% Efficiency (airtight woodstove) $/MBtu = ($/Cord) / 12	@70% Efficiency (stove with catalytic converter) $/MBtu = ($/cord) / 16.8
Coal (12,500 Btu/Pound)	@60% Efficiency $/MBtu = ($/Ton) / 15	
Electricity (3412 Btu/KWH)	@100% Efficiency (electric resistance heat) $/MBtu = 293 X $/KWH	

The cost of various sources of energy are expressed in different ways, making comparison difficult. The preceding chart will enable you to compare the cost of various heating fuels on the basis of their Heating Equivalent Cost as expressed in dollars per million BTU ($/MBTU). To use the chart, read across the fuel price row until you come to the current cost per unit of that fuel. Then, read either up or down to the Heating Equivalent Cost row, to determine the price per MBTU.

For example, you might want to know how the cost of heating with wood compares with the cost of heating with oil. If mixed hardwood is to be burned in a standard airtight stove at 50% efficiency and is available at $100/cord, the Heating Equivalent Cost is $8.33/MBTU. If fuel oil, to be burned in a new heating system at 85% efficiency, is available at $.85/gallon, its Heating Equivalent Cost is $7.23/MBTU. Therefore, at these prices, oil is cheaper than wood. If, on the other hand, you had an older oil heating system that was only 65% efficient, its heating equivalent cost would be $9.78/MBTU, and wood would be less expensive to burn. As you can see, the efficiency of the equipment and fuel cost both effect the Heating Equivalent Cost.

If you are considering switching fuels, remember the cost of the heating equipment. If the difference between the Heating Equivalent Costs is small, it may take many years of fuel savings to pay for installing a new heating system. Also, remember that some fuels have incidental costs associated with them, such as cutting and splitting of firewood or annual maintainence for oil fired equipment. Environmental damage caused by the production or use of the fuel is another cost that this chart doesn't address. Finally, the best way to lower your heating costs is to make your home more energy efficient. Not only will this reduce the amount of fuel you use each heating season, it will also lessen the impact of annual price fluctuations by reducing the amount of fuel you need to buy during the heating season, when prices are at their peak.

Appendix D
Glossary

Air barrier: An air-impermeable material installed on the warm side of a building assembly, such as a wall, to stop the flow of air and its contained water vapor into the building assembly. Air barriers may be made of polyethylene plastic, drywall, rigid insulation, dense-pack cellulose insulation, or a combination of materials.

Air Changes per Hour (ACH): Measurement of the rate of natural air leakage in a building. The number of times an hour that the entire house volume of air is replaced with outside air.

Air inlet vents: Small vents installed to penetrate through the building envelope for the purpose of providing replacement air. Generally used in conjunction with exhaust ventilators.

Air-Leakage heat loss: The heat loss resulting from the leakage of conditioned air into and out of a building. One of the two major types of heat loss from a building, the other being **surface or transmission heat loss.**

Airtight Drywall Approach (ADA): A method of construction for moisture control and durability that uses sealed drywall as the air barrier and special paint as the vapor barrier.

Air-to-air heat exchanger or Heat Recovery Ventilator: Device for supplying and partially preheating fresh outdoor air as stale indoor air is exhausted. Fan-operated. Both through-the-wall and whole-house units are available.

Air/Vapor barrier: A material that is used as an **Air barrier** and a **Vapor barrier.** In new construction, polyethylene plastic often is used as an air/vapor barrier when it is installed just to the outside of the interior finish material, such as drywall. In order for this air/vapor barrier to serve as an effective *air* barrier, the plastic must be sealed at joints and at all penetrations, such as electrical boxes and plumbing pipes.

Backdrafting: Potentially dangerous situation in which combustion gases (from furnace, boiler, gas water heater, fireplace, etc.) exhaust into the house instead of up the chimney. Caused by negative pressure in the house—often a result of exhaust-only fans operating in a tight house or leaky return ductwork.

Backer rod: Foam "rope" that is used for sealing around wall penetrations, sealing between framing members and as a backing for caulk in deep cracks.

Blower door testing: Method of measuring air leakage by depressurizing the house with a large fan and instrumentation set into an exterior door opening. Also an excellent device for finding air leaks in the envelope of a building.

Cantilevered truss: Roof truss that overhangs the walls so that a greater thickness of insulation can be installed at the eaves.

Catalytic combustor: Device built into some wood stoves to increase combustion efficiency.

Compact fluorescent lamp: High-efficiency fluorescent lamp that is about the same size as an incandescent light bulb. Some include integral ballasts and can be screwed into standard light bulb sockets.

Condensation: Change of state from gas to liquid. Water vapor often condenses into liquid water as an air mass is cooled.

Condensing furnace or boiler: High-efficiency heating system that extracts heat out of water vapor that would otherwise escape up the chimney. Efficiencies are usually above 90 percent.

Dampproofing: Exterior foundation treatment to reduce the likelihood of moisture seeping through the wall into the basement. *Waterproofing* provides more complete protection, but is usually not required.

Dew point: The temperature at which a volume of air reaches 100% relative humidity and water vapor begins condensing.

Diffuse: The process by which water vapor and other gases move through a solids as a result of vapor pressure differences. The rate of diffusion is determined by the material's permeability or perm rating and the vapor pressure differentials.

Direct Vent Combustion Appliance (Sealed Combustion): A combustion appliance that 1) is vented directly to the outdoors and 2) received all its combustion supply air directly from the outdoors through a dedicated pipe. Eliminates the possibility of **backdrafting.**

Drainage mat: A porous mat installed against the outside of the foundation wall to drain groundwater and runoff away from the wall surface and down to footing drains.

Duct mastic: A special long-lasting, heat resistent material used for sealing ductwork joints. Should be used instead of duct tape.

Energy Guide Labels: Labels on most new appliances providing information on yearly energy costs. Useful for comparing appliances.

Expanding foam sealant: A polyurethane foam that is applied from a can or canister. Used for sealing around windows, doors and wall penetrations.

Flame retention burner: A relatively new type of oil burner commonly used in boilers and furnaces. By more effectively mixing air and oil droplets, a heating system with a flame retention burner requires less air flow and, therefore, loses less heat up the chimney.

Foam gaskets: Foam strips or rolls used to seal between framing members (under wall plates, for example), behind drywall, etc. Especially important with ADA construction.

Heat loss coefficient: A measurement of a building's heat loss expressed in Btu/°F hr.

Heating degree-day: A unit that represents a 1°F deviation from a fixed reference point (usually 65°) in the average daily outdoor temperature. If the average outside temperature is 45°, 20 degree-days would be tallied for that day (65° - 45°). By adding up degree-days, monthly and annual degree-day totals can be obtained.

Heating outdoor design temperature: The outdoor temperature used when sizing heating systems.

Heat Recovery Ventilator or Air-to-air heat exchanger: Device for supplying and partially preheating fresh outdoor air as stale indoor air is exhausted. Fan-operated. Both through-the-wall and whole-house units are available.

High-Intensity Discharge (HID) lamps: High-efficiency light source, including high-pressure sodium, low-pressure sodium and metal halide lamps.

House wrap: A material, usually made of spun-bonded plastic, used for covering the outside of buildings before the finished siding is installed. Acts as temporary protection from the weather until the finished siding is installed. Allows water vapor to pass through it only if it is above the **dew point temperature**.

I-Joist: A manufactured laminated-wood joist that has greater strength than standard lumber. Available in greater widths and lengths than standard lumber. Sometimes used as rafters when high insulation levels are required.

Indirect-fired water heater: A storage-type water heater that uses heat from a standard boiler. Much less expensive to operate than **tankless coil** water heater.

Magnetic declination: The difference between true north (or south) and magnetic north (or south). For solar siting, true directions should be used. If using a compass, you need to correct for the magnetic declination.

Net free vent area: Actual ventilation area provided by a screened or louvered vent—accounting for air blockage by screening and louvers.

Passive solar: A building design to collect, store and distribute solar energy without fans and pumps.

Permeance: Ability of a material to allow water vapor to diffuse through it.

Perm rating: Measurement of a material's ability to transmit water vapor by means of diffusion.

Pulse combustion: Combustion system used in some gas furnaces and boilers to achieve very high efficiency.

Rafter Plate: Plate installed on top of ceiling joists to raise rafter tails above the wall plate and thereby allow thicker insulation at the eaves.

Raised-heel truss: A roof truss design that allows full-thickness ceiling insulation at the eaves.

R-value: Measurement of a material's ability to retard heat transfer. Inverse of U-factor ($U = 1/R$).

Relative humidity: The amount of water vapor in a sample of air over the maximum the sample can hold at a given temperature, expressed as a percentage.

Reset control: Also called modulating aquastat. A control that regulates boiler water temperature relative to outside temperature. When it is not as cold out, lower-temperature water can be circulated through hot-water radiators. The reset control automatically regulates the boiler water temperature.

Sealed combustion (Direct Vent): A combustion appliance that 1) is vented directly to the outdoors and 2) received all its combustion supply air directly from the outdoors through a dedicated pipe. Eliminates the possibility of **backdrafting**.

Sill sealer: Foam gasket or insulation material for sealing between sill and foundation wall.

Saturated foam sill sealer: Foam gasket impregnated with non-hardening sealant to provide highest quality sill sealer.

Splines: Wood or plywood strips for joining stress skin panels.

Stress skin panels: Building panels for enclosing timber frame buildings or building "frameless" houses. Laminated system with exterior sheathing, insulation and inner wall surface.

Standpipe: Pipe set into the crushed stone before a slab is poured. Usually capped for later use in ventilating radon if a problem shows up.

Stepped insulation: Foundation insulation strategy where full-thickness insulation is used over the upper part of the wall, and thinner insulation is used below.

Surface or Transmission Heat Transfer: The transfer of heat energy from one material to another by the motion of adjacent atoms and molecules.

Sun Angle: Angle of the sun above horizontal as it moves across the sky. Used in designing solar heating systems.

Suntempering: Simple passive solar design utilizing moderate areas of south-facing glass. There are no special measures taken to store and distribute solar heat.

Tankless coil: Inefficient type of water heater operating off a boiler. As hot water is used, the boiler must fire to heat it. Particularly wasteful in the summer.

Timber frame construction: Construction technique in which large timbers are used to provide structural strength in a building.

Thermal mass: Masonry or other material for storing heat in passive solar heating system.

U-factor: Measurement of the heat transmission through a building component in Btu/°F, hr. Inverse of R-value.

Vented rain screen: Air space provided by strapping between sheathing and siding to allow for pressure equalization as a mean of preventing driving rain from penetrating the innermost components of a wall.

Vapor barrier (sometimes called vapor retarder): Thin film—usually polyethylene or foil— for retarding the movement of water vapor by means of diffusion. Installed on inner (warm) side of insulation.

Vent spacer: Baffle material for ensuring an air space under the roof sheathing. Used primarily in insulated cathedral ceilings.

Water table trim: Trim used at the bottom of a wall to shed water out over protruding foundation insulation.

Wet-spray cellulose: Relatively new type of insulation that is sprayed into open wall cavities. Somewhat higher R-value than fiberglass and better at sealing around wires, etc.

Window insulation: Soft insulating shades or rigid insulating shutters (unusually mounted on the interior) that can be closed to 1) increase the insulating value of window or 2) to block unwanted solar heat gain. These products are made especially for this purpose.

Zones: Separately controlled conditioned areas in a building, each controlled by its own thermostat.

Appendix E
For More Information

References

Periodicals

Energy Design Update
37 Broadway, Suite 1
Arlington, MA 02174
Monthly newsletter featuring energy-efficient materials and techniques. No advertising!

Journal of Light Construction
RR 2, Box 146
Richmond, VT 05477
Monthly publication featuring discussion of practical residential construction problems and techniques.

Fine Homebuilding
The Taunton Press
63 South Main Street
Box 355
Newton, CT 06470-9974
Monthly magazine with a mix of practical and esoteric construction articles.

Home Energy Magazine
2124 Kittredge, Suite 95
Berkeley, CA 94704
Bimonthly magazine for energy conservation professionals.

Books

Building Foundation Design Handbook
Underground Space Center, Univ. of Minnesota, 1989
500 Pillsbury Drive, SE
Minneapolis, MN 55455
The most complete reference available on foundation design and construction.

Builders Field Guide
NY-STAR Certified Home Program
41 State Street, Suite 1011
Albany, NY 12207
Good, well illustrated guide for new construction.

The Passive Solar Energy Book
E. Mazria
Rodale Press, 1979
Emmaus, PA 18099-0017
Although dated, it's still the most comprehensive book on incorporating solar heating with building design.

Air Sealing Homes for Energy Conservation
Marbek Resource Consultants, 1985
Ottawa, Ontario, Canada
Canadian publication on air sealing.

Modern Carpentry
Willis H. Wagner
Goodhardt
123 West Taft Drive
South Holland, IL 60473
Comprehensive carpentry text.

Super Insulated Retrofit Book
B. Marshal and R. Argue
Renewable Energy in Canada, 1981
Toronto, Canada
Detailed guide to converting conventional homes to superinsulated standards. Includes several case studies.

Air-to-Air Heat Exchangers
Directory and Buyer's Guide
Cutter Information Corporation, 1987
1100 Massachusetts Avenue
Arlington, MA 02174
Guide to available equipment as of 1987.

Resource Efficient Housing Guide
Rocky Mountain Institute, 1987
1731 Snowmass Creek Road
Snowmass, CO 81654

Healthy House Catalog
Housing Resource Center, updated annually
1820 West 48th Street
Cleveland, OH 44102

Residential Load Calculation: Manual J
Air Conditioning Contractors of America
1712 New Hampshire Avenue, NW
Washington, DC 20009

Residential Duct Systems
Air Conditioning Contractors of America
1712 New Hampshire Avenue, NW
Washington, DC 20009

The Airtight House
James K. Lischoff and Joseph Lstiburek
Iowa State University Research Foundation
EES Building
Harbor Road
Iowa State University
Ames, IA 50011

Visual Handbook of Building and Remodeling, 2nd ed.
1998
CharlieWing
Rodale Press
Emmaus, PA 18098

Appendix F
The Performance Compliance Alternative

The easiest method of compliance with the Maine Energy Efficiency Standards is by using the prescriptive approach discussed in Part 1 of this manual. This method prescribes the required R-values for the various building parts. For example, a house complies by the prescriptive standard if it has R-38 ceilings, R-19 walls and floors, and R-2 windows. A particular house built according to the *prescriptive* standards is called a **standard building.**

In an effort to allow flexibility in design of houses, those writing the Maine Energy Efficiency Standard approved the **performance compliance alternative.**

A house may comply with the Standards by the performance compliance alternative if the energy usage of the proposed building design is not greater than that of a standard building design. In other words, if it is properly demonstrated that the proposed building will not use any more energy than it would if were a standard building (built to the prescriptive standards), it is deemed to be in compliance.

The applicant must properly calculate the annual energy performance of the proposed building and a comparable standard building. The standard building design used for the comparison must be substantially identical to the proposed building design in the following ways:

a) Function and design requirements;
b) Size, shape, geometry, and orientation;
c) Operating schedule, temperature, humidity, ventilation, and footcandles; and
d) Internal heat gains from occupants and equipment.

The comparative analysis of the energy usage of the standard building and the proposed must be done with identical energy analysis procedures. In addition:

a) The annual energy usage from each source must be expressed as total Btu usage of condition floor area of the standard and proposed buildings.
b) The analysis procedure must account for the energy usage for the operation of the building—both standard and proposed—and its energy systems for a full year of operation.
c) The comparative energy usage analysis must be based on identical outdoor weather conditions, including tempera ture, solar gain, wind, and humidity.
d) The comparative energy usage analysis must provide technical data on the proposed building design, the standard building design, and the data used to verify that the requirements of the Maine Energy Efficiency Standard are met.