Designers

Well-crafted designs capture benefits for builders, buyers, and business

Even good builders can have bad results if they are working toward the wrong product. Designers have the job of giving builders the opportunity to do the right thing well.

"If you do the wrong things with good materials and good workmanship, it is still wrong. You must do the right thing with good materials and good workmanship."

Joseph Lstiburek, Building Science Corporation

QUICK TIPS | DESIGNERS

- Building America brings you the results of research, real-world experience, and dialogue with builders from over 25,000 homes nationwide (as of early 2004).
- System design and building science offer you tools and techniques to improve housing performance without sacrificing style and appeal, avoid problems plaguing new homes, find cost savings to help your company's bottom line, and give consumers satisfaction in their investment.
- Seek the help of a home energy rating professional or engineer to avoid reinventing many of the solutions that have already been found and optimize your designs.
- Review the many technologies discussed in this chapter for help in selecting the applications right for you.

Building Science and the Systems Approach

Perhaps the most important step in designing any form or function is recognizing that the design is for the entire product. No one piece can be changed without affecting all related pieces. This simple proposition applies to all systems and allows for all kinds of trade-offs. In cars, without any loss in performance, lightweight frames may be translated into smaller brakes, a smaller engine, and smaller tires. Or, that same change may be used to produce more speed.

In houses, this systems approach recognizes the interaction of windows, attics, foundations, mechanical equipment, and all other components and assemblies. Changes in one or a few components can dramatically change how other components perform. Recognizing and taking advantage of this fact, and applying appropriate advances in technology to components, can result in cost and performance payoffs, both for the builder and buyer of new homes.

Building America has embraced the systems approach and combined it with the technology development and testing that make up building science. As with other scientific disciplines, building science provides an intelligent approach to understanding complex systems and diagnosing problems. Over time, knowledge, tools, and tests are developed that make the science and the product more efficient and more powerful. You can learn more about the U.S. Department of Energy's (DOE) Building America program at www.buildingamerica.gov *(adapted from Florida Solar Energy Center Web site www.fsec.ucf.edu/bldg/science/basics/index.htm).*

INTRODUCTION
Taking action in your community

HOMEOWNERS
Shopping for value, comfort, and quality

MANAGERS
Putting building science to work for your bottom line

MARKETERS
Energy efficiency delivers the value that customers demand

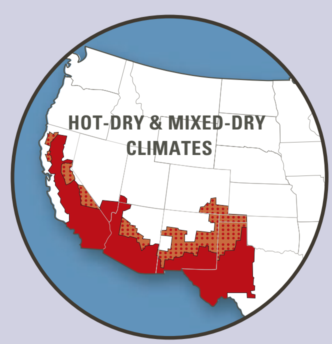
SITE PLANNERS & DEVELOPERS
Properly situated houses pay big dividends

DESIGNERS
Well-crafted designs capture benefits for builders, buyers, and business

SITE SUPERVISORS
Tools to help with project management

TRADES
Professional tips for fast and easy installation

CASE STUDIES
Bringing it all together



Four steps can help to manage risks and take advantage of system trade-offs.

1) **Give builders the right target.** Recognize you are designing a complete product—a system—and ensure the product is right for the hot-dry and mixed-dry climates.

2) **Take care of the basics.** The basics are proven, cost-effective technologies that include good windows, insulation, moisture management, and ventilation. Make sure the house has adequate overhangs for shade and rain deflection. Guidelines for many of the basics are included later in this chapter.

3) **Take only what you need.** Size heating and cooling equipment, ducts, and fans to match the load. If equipment sizing is normally done by a subcontractor, ensure the sub uses the procedures listed in this document to properly size equipment. Proper sizing of heating and cooling equipment is a huge opportunity to save money and increase profit.

4) **Put everything in its place.** Be sure there is a place for everything the house requires and show it on your plans. Do not leave it to chance where ducts will be placed or even where plumbing will run. If there are places that should not be tampered with, for example a duct chase, make it clear the space is off limits to plumbers, electricians, and others who need to create routes through buildings.

Building Science and the Systems Approach: Problem Prevention

Moisture, mold, and material degradation are examples of problems that building science can help solve. High temperatures create a need for cooling. High humidity adds to discomfort and is a source of moisture. Humid air and a cold surface result in condensation that can add up to discomfort, material failure, and high repair costs.

Leaky ducts located in attics or crawlspaces create air pressure differences that can draw in humid air through cracks and holes and deliver it into the house. Humid air inside a cool space encourages the occupant to turn down the thermostat for more cooling. This cycle can result in moisture forming as condensation on or in ducts, walls, and other assemblies. Accumulated moisture supports mold growth and leads to rotting, warping, and staining.

The result is that a small problem in one assembly (leaky ducts) that is inexpensive to fix during installation, can lead to big problems in framing, interior finish, and human health. Moisture problems may have causes other than leaky ducts, but many unintended problems can be avoided in a similar fashion.

Building Science and the Systems Approach: Reaps Rewards

There is more than avoiding problems to encourage you to use a systems approach. For example, trade-offs from installing energy-saving measures can help save construction costs for heating and cooling equipment. If good windows, adequate insulation, and efficient heating and cooling equipment are installed, the heating and cooling equipment capacity can also be smaller than typically used and shorter duct runs are possible. All of this can add up to reduced costs in heating and cooling equipment that offset the cost of the other measures. Using trade-offs to improve economics, durability, and comfort is essential to successful business and design.

"Understand the theory of your construction…then be sure to question your engineer (or subcontractor) as to whether it's all really necessary. If you don't get a straight, understandable answer, find an engineer who will give you one. Remember, it doesn't cost the engineer a penny to over-design. But ultimately someone foots the bill."

Tim Garrison, CEO of ConstructionCalc, made an important point about the cost of overdesigning structural components. He is quoted here because his point is equally valid for HVAC and other equipment *(adapted from Nation's Building News Online, 27 April 2004, www.nbnnews.com).*

You can learn more about Building America and download additional copies of this document at **www.buildingamerica.gov**

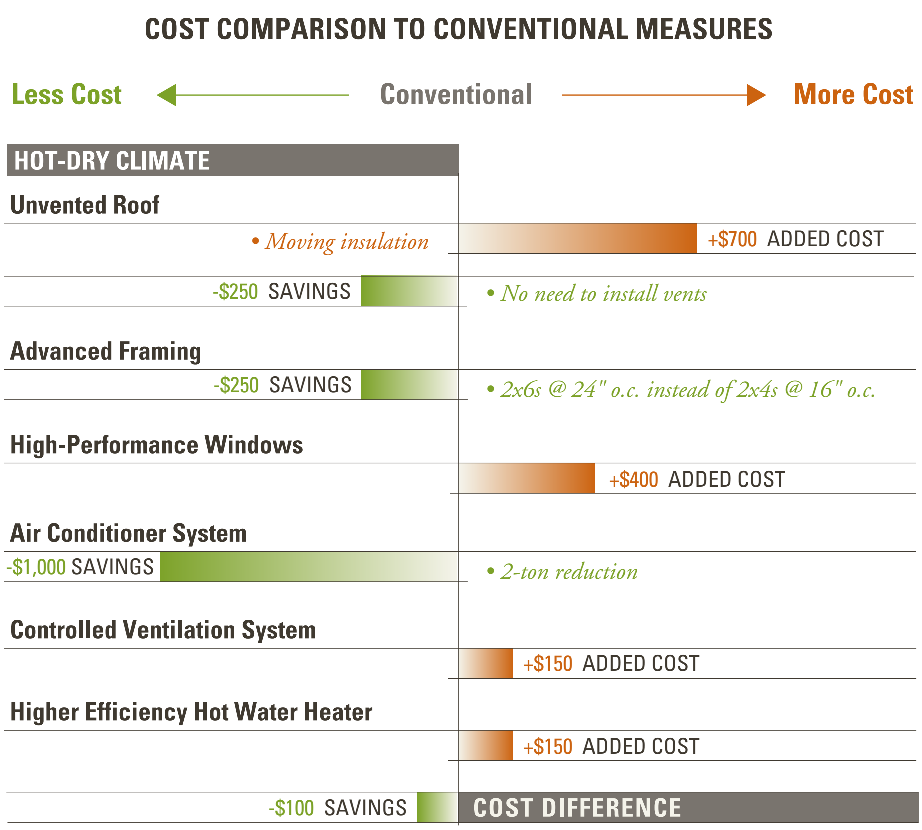
The challenge to designers is to carefully select new technologies, consider their cost and rewards for your overall system, and use the changes that make sense. Building America has taken this systems approach to designing energy-efficient houses. This document presents you with information that will give you a straight-forward approach to designing houses that qualify for ENERGY STAR®. Design information is provided for a variety of measures and components in the remainder of this section. Put in the recommended measures and your houses should qualify. You may also qualify using other trade-offs. Suggestions from Building America's experience are also included that will improve the health and comfort of your homes.

The Cost of Doing Business

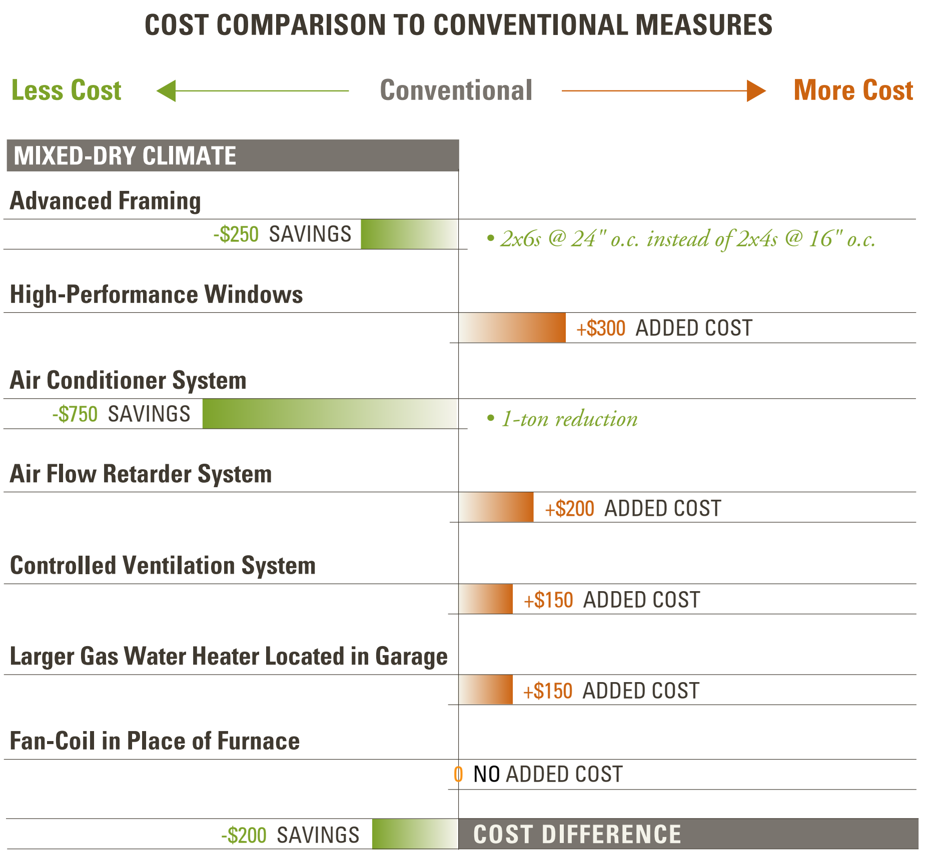
The cost of building homes is different for every builder. Technique, experience, subcontractors, suppliers, and the size of purchases can all make a difference in how much a home costs to build. Even a builder's accounting methods can influence how costs are reported. These variables all apply to energy-efficiency measures and contribute to the difficulty of providing cost estimates that apply to more than a limited example over a short period of time.

In addition to variability, other considerations apply to costs. First, the cost of higher quality housing represents an added value and holds the potential of a higher profit. Second, a tremendous benefit of the systems approach described above is that the costs of energy-efficient measures can often be offset by savings in other areas. And finally, buyers can recover any additional costs through reduced utility bills, increased resale value, and for some, better mortgage terms.

FIGURE 1: Cost Comparisons of Energy Efficient Measures to Conventional Practice in the Hot-Dry and Mixed-Dry Climates



Some builders say that meeting ENERGY STAR qualifications does not increase their costs. However, they must focus on higher quality installations. Other builders suggest additional costs up to $1,500 to the consumer, but it's unclear if these values apply beyond their experience. The chart at left shows an estimate of costs made in the year 2000 for homes built in the hot-dry and mixed-dry climates using a design with calculated savings of 50% for heating and 30% for cooling. The example is intended to show how costs and savings trade off, rather than to provide estimates of dollar savings.



Source: Edminster, Pettit, Ueno, Menegus, and Baczek 2000.

HERS Ratings and Qualifying for ENERGY STAR

Best Practice: Building America recommends working with a Home Energy Rating System (HERS) professional, architect, or engineer early in the design process to help select and size materials and equipment. The building scientists can be especially helpful in right sizing heating and cooling equipment. By forming a relationship with a rater who later will inspect the construction site, designers can get valuable feedback about what works and what house features require more detailed information for the site supervisor and the trades. Find out more about HERS raters at www.natresnet.org.

The best use of a HERS rater involves working with your rater in creating your design. When following this path, the rater analyses your construction plans, in addition to at least one on-site inspection and test of the home. The plan review allows the home energy rater to view technical information such as orientation (if known), shading area, proposed equipment ratings, and insulation levels. The on-site test involves blower door testing. Results of these tests, along with inputs derived from the plan review, are entered into a computer simulation program to generate the HERS score and the home's estimated annual energy costs, based on heating, cooling, and hot water heating requirements. Building America also recommends testing ducts for air leaks.

A HERS rating is an evaluation of the energy efficiency of a home, compared to a computer-simulated reference house (of the identical size and shape as the rated home) that meets minimum requirements of the International Energy Conservation Code (IECC). More information on the code can be found at www.energycodes.gov. The HERS rating results in a score between 0 and 100, with the reference home assigned a score of 80. From the 80-point level, each 1 point increase in the HERS score results

HERS RATER
Building America recommends working with a HERS rater or building scientist early in the design process.

DUCT TESTING
Building America recommends testing ducts for air leaks.

in a 5 percent reduction in heating, cooling, and hot water energy usage (compared to the reference house). An ENERGY STAR qualified new home, which is required to be 30% more efficient, must attain a HERS score of at least 86.

Your HERS rater can be a tremendous resource in the design phase. Raters who are trained in building science may help to solve construction problems. One important job your rater can help with is to work with the mechanical contractor to correctly size heating/cooling equipment, perform room-by-room calculations to determine the supply air needed for each room, and work with the mechanical contractor on duct sizes and lay out. This is likely to eliminate callbacks due to comfort complaints and can save substantial money by right-sizing the heating and cooling equipment. During the design stage, the rater can suggest alternatives to attain desired performance levels in the areas of energy, comfort, durability, and health.

Selecting a HERS rater is much like selecting any other professional services provider, such as an architect, accountant, or engineer. Be sure you are comfortable with the rater's communication skills, experience, training, and references before making a selection.

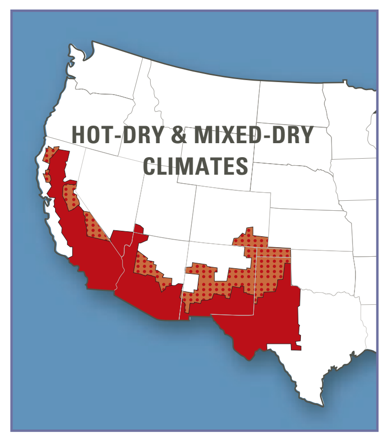
Best Practice: Building America recommends that every house receive a site inspection and diagnostic tests from a HERS rating professional. The information gained from these tests can help to isolate specific problem areas that can be solved with further training, more explicit details, better building materials, or other production changes.

SITE INSPECTION
Building America recommends that every house receive site inspections and diagnostic tests.

Hot and Dry

The recommendations in this Best Practices guide apply to the entire hot-dry and mixed-dry climate regions. If you aren't sure that your project is within these climate regions, check *Appendix IV* to see a listing of counties and their climate zones, or work with a HERS rater to confirm your zone.

FIGURE 2.



Hot-dry and mixed-dry climates bring several challenges for home building. The intense solar radiation imposes a large thermal load on houses that can increase cooling costs, affect comfort, and damage home furnishings. This chapter contains some of the best methods to minimize the impact of solar radiation on the building, its mechanical system, its occupants, and their furnishings.

Annual precipitation in these climates is less than 20 inches. Nevertheless, a brief period of heavy rain can deposit several inches of water onto a building. Improper irrigation can be a major moisture source, leaks can cause significant damage, and indoor sources of moisture can be a problem. If water collects in an area that cannot quickly dry, deterioration of the building will occur.

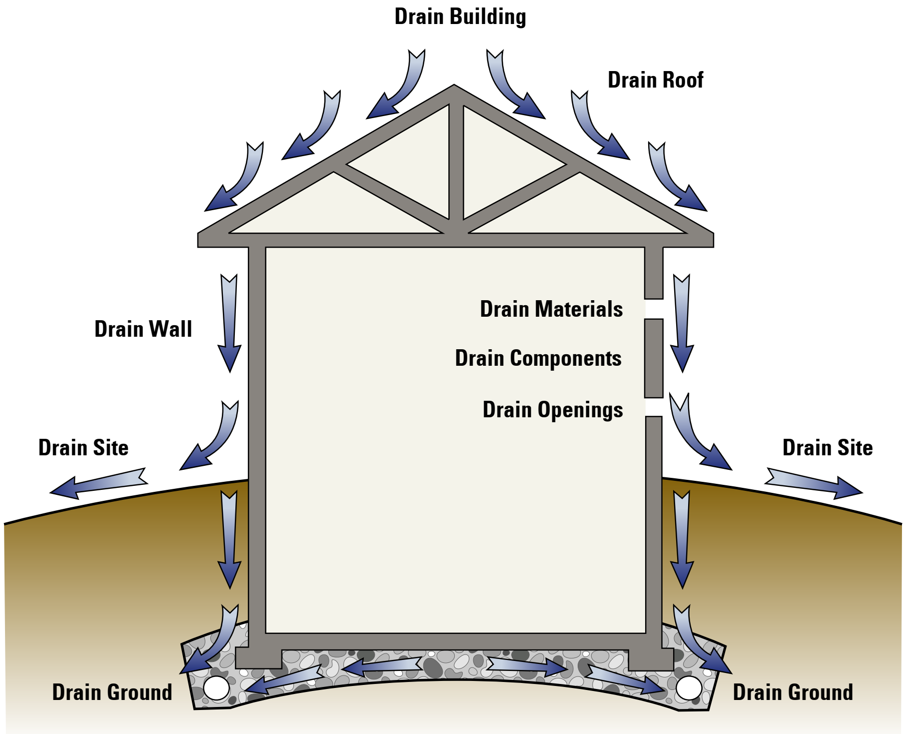
Managing fire risk, particularly in terms of exterior claddings and landscaping, is an important issue associated with the dry climate.

Design Best Practices for Hot-Dry and Mixed-Dry Climates

Housing types vary greatly throughout the United States and in the hot-dry and mixed-dry climates. In the face of this diversity, this document does not recommend a single set of measures for achieving the 30% energy savings in space conditioning, water heating, and reaching ENERGY STAR qualification. We do recommend following the principles included in these Best Practices and adjusting these practices and your designs to make them work together. We also recommend working with a building scientist such as a Home Energy Rating Professional to help with the transition.

The best practices described in this manual are intended to give builders and designers recommendations resulting from Building America's work on over 25,000 homes. Building scientists have tried and tested these measures on actual homes in the field. This does not mean that every measure will be for you. However, as builders start aiming for higher performing homes, details become more important. It may not make sense to install the best practice in every instance. Sometimes you can get away with less. But making this decision should involve an evaluation of the risks of not using the best practice, and questioning how the overall house system may be impacted.

FIGURE 3: Drainage



Adapted from Lstiburek 2003

Site – Drainage, Pest Control, and Landscaping

Additional planning information related to overall site development is presented in the *Site Planners* chapter.

Drainage

Moving moisture away from a building is critically important to maintaining structural integrity.

Best Practice: Grading and landscaping should be planned for movement of building run-off away from the home and its foundation, with roof drainage directed at least 3 feet beyond the building, and a surface grade of at least 5% maintained for at least 10 feet around and away from the entire structure. This topic is also discussed in the *Site Planners* chapter.

GRADING
Plan grading and landscaping to direct run-off away from the home and its foundation.

Pest Control

Termites are a serious menace in the hot-dry and mixed-dry climates.

Best Practice: Based on local code and Termite Infestation Probability (TIP) maps, use environmentally appropriate termite treatments, bait systems, and treated building materials for assemblies that are near soil or have ground contact (see www.uky.edu/Agriculture/Entomology/entfacts.htm).

TERMITES
Use environmentally appropriate termite treatments.

Landscaping

Landscaping is a critical element to the marketability of a house. But plants must be placed to avoid interfering with visual inspections of termite access. Planting can also be used to shade foundations and reduce cooling loads.

Best Practice: Plantings should be held back as much as 3 feet and no less than 18 inches from the finished structure, with any supporting irrigation directed away from the finished structure. Plantings may be selected to shade the foundation edge, especially on the southwest corner of the structure. Choosing drought-tolerant plantings results in less irrigation and less chance for irrigation water to create a moisture problem in the house. Decorative ground cover—mulch or pea stone, for example—should be thinned to no more than 2 inches for the first 18 inches from the finished structure. More landscaping information can be found on DOE's Web site at www.eere.energy.gov/consumerinfo/factsheets/landscape.html.

PLANTINGS
Select draught-tolerant plantings and keep them at least 18 inches from the foundation.

Foundation Measures

Slabs are a common foundation system in the hot-dry and mixed-dry climates. Building foundations should be designed and constructed to prevent the entry of moisture and other soil gases. Moisture may cause structural decay and can contribute to human health and comfort problems. Radon that enters a home exposes occupants and may cause lung cancer.

Best Practice: Slabs require 6-ml polyethylene sheeting directly beneath the concrete that accomplishes vapor control and capillary control for the slab. The vapor retarder should continuously wrap the slab as well as the grade beam. Other solutions may work for the grade beam, such as applying damp proofing. A moisture retarder is needed between the stem wall and framing.

VAPOR CONTROL
Achieve vapor and capillary control with 6-mil polyethylene sheeting directly below the slab.

Best Practice: A sand layer under the slab should never be placed between a vapor retarder and a concrete slab. Cast the concrete directly on top of the vapor barrier. Differential drying and cracking is better handled with a low water-to-concrete ratio and wetted burlap covering during initial curing.

CASTING CONCRETE
Cast the concrete directly on top of the vapor retarder, with no sand in between.

Best Practice: Sub-slab drainage should consist of a gravel capillary break directly beneath the slab vapor retarder.

DRAINAGE
Place a gravel capillary break directly beneath the slab vapor barrier.

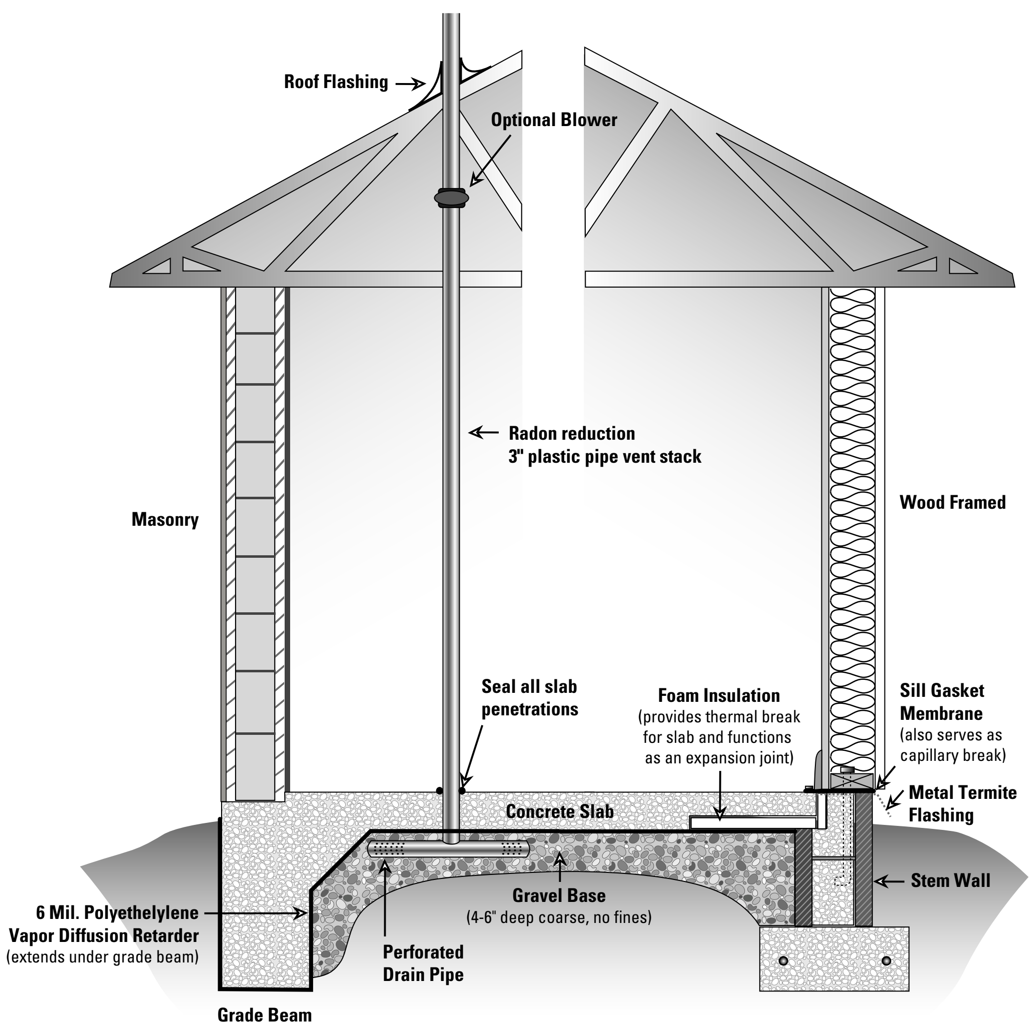
In addition to other benefits, the gravel and vapor barrier are important first steps to radon control. The gravel provides a path for radon and other soil gas to escape to the atmosphere rather than being drawn into the house. And the vapor retarder helps to block soil gas entry into the house. Where gravel is scarce, builders often pour slabs onto sand. When sand or other native fill is used, a 3- or 4-inch perforated and corrugated pipe loop can be use for both drainage and radon control.

Or drainage matting may be installed over sand. Both approaches are described in a U.S. Environmental Protection Agency (EPA) document described in the following list., *Building Radon Out* (2001).

Radon-resistant construction practices are described in the following documents:

- *ASTM WK2469 New Standard (Formerly E1465-92)(draft) Guide for Radon Control Options for the Design and Construction of New Low-Rise Residential Buildings*
- *Model Standards and Techniques for Control of Radon in New Residential Buildings* (U.S. EPA 1994)
- *Building Radon Out: A Step-by-Step Guide on How to Build Radon-Resistant Homes* (U.S. EPA 2001) available on the Web at www.epa.gov/199/iaq/radon/images/buildradonout.pdf.

FIGURE 4: Typical Building Slab Foundation



Adapted from Building Science Corporation

Best Practice: Other than identifying areas that have had radon problems, it is not possible to predict radon levels in houses prior to construction, so it is important to include inexpensive radon control measures. One measure recommended by the EPA to control potentially high radon levels and other soil gasses, is a passive soil gas stack connected to a perforated drain pipe embedded in the gravel under the slab. The stack may also be attached to a perforated pipe loop or mat. If it turns out the house has unacceptable radon levels, a fan can be added to the stack to actively draw soil gas away from the house. To determine potential radon levels in the county in which you are building, visit the EPA's radon potential map at www.epa.gov/radon/zonemap.html.

RADON
Houses built in areas with potentially high radon levels can install a soil gas stack to draw soil gas away from the home.

For information about local variation in radon levels you can find local contacts at the following EPA Web site: www.epa.gov/iaq/whereyoulive.html. The EPA divides counties into one of three zones based on radon level potential. The EPA recommends that all homes built in Zone 1 (high radon potential) areas have radon reduction systems.

Foundation Energy Performance

Slabs are a common foundation system in the Southwest.

Best Practice: In the hot-dry portion of these climate zones, slabs are generally not insulated, even at the perimeter, because of the low overall heating load. Slabs in the mixed-dry climate should be insulated at the perimeter with one inch of borate-treated foam board insulation or rigid glass fiber insulation.

SLAB FOUNDATIONS
Slabs are generally not insulated in the hot-dry climate. In the mixed-dry climate slabs should be insulated at the perimeter.

Crawlspace Foundation Systems

Although not prevalent, some houses in the hot-dry and mixed-dry climates are built with crawlspaces.

Best Practice: Crawlspaces should be built as a conditioned space. Insulation should be applied to exterior walls and vents to the exterior should not be installed. The crawlspace should receive conditioned air from at least one supply duct, and transfer grills should allow for the transfer of air back to the living space. Other features include a ground cover that is continuous and sealed to the perimeter walls and piers, air sealing of the exterior walls, and sealed air distribution ducts. If a heating system is installed in the crawlspace, use only a sealed combustion appliance. For more information see:

CRAWLSPACES
Crawlspaces should be built as a conditioned space.

- The addendum to the *Site Supervisors* chapter, look for the section entitled: *Details for Mechanically Vented Crawlspaces*.
- Yost, Nathan. May 2003. "The Case for Conditioned, Unvented Crawl Spaces." *Building Safety Journal*. Available on the BSC Web site at: www.buildingscience.com/resources/articles/24-27_Yost_for_author.pdf

Radon measures for crawlspaces can be found in the references on the previous page.

Structural Moisture Control

Annual precipitation in the hot-dry and mixed-dry climates is less than 20 inches. However, often the precipitation comes in heavy doses as part of intense storms. And moisture can come from other sources, such as landscape irrigation and indoor activities. In some regions, periodic humidity is also present.

Two types of rain management systems have been identified: barriers and screens. Barriers rely on exterior cladding to drain water and are best used with water-resistant building materials, such as masonry block or concrete. Screens have multiple lines of defense against water entry and are used with wood, brick, and gypsum-based materials. Both barriers and screens rely on lapped flashings to direct water to the exterior at critical areas such as seams, windows, and penetrations. In both systems, it is essential that materials are lapped shingle fashion to direct water down and out, away from the wall assembly.

Best Practice: Roof and wall assemblies must contain surfaces that will drain water in a continuous manner over the entire area of the building. Water must have a path that will take it from its point of impact, around any elements such as windows, doors, and seams, all the way to the exterior ground, sloping away from the house.

Best Practice: In areas with potentially high winds and heavy rains install four inch to six inch "peel and seal" self adhering water-proofing strips over joints in roof decking before installing the roof underlayment and cover.

Water Leakage

One critical point of concern is water leakage around windows. The *EEBA Water Management Guide* offers examples of many window flashing applications. The window flashing examples here are taken from the *Trades* chapter. These examples are for homes with housewrap and plywood or OSB sheathing.

Best Practice: Specify that flashing be installed for all windows and doors. Window and door flashing details should be designed to match specific wall assemblies and claddings.

Flashing systems should be designed in accordance with the ASTM standard entitled *Standard Practice for Installation of Exterior Windows, Doors, and Skylights* (ASTM 2002). In addition to the standard and the EEBA guide, see DOE's *Technology Fact Sheet on Weather-Resistive Barriers* (DOE 2000), available on the Web at www.eere.energy.gov/buildings/documents/pdfs/28600.pdf.

Extreme Weather

Parts of the hot-dry and mixed-dry climates can be vulnerable to catastrophic high-wind, heavy-rain events, hurricanes and tornadoes. Parts of Oklahoma and Texas are part of "tornado alley," a section of the country prone to tornados. Proper structural fastening and impact resistant windows, doors, and skylights are critical to surviving high winds. Proper use of roofing materials can help roofs withstand high winds and protect against severe rains. This document does not provide detailed information on disaster survival but the following sources provide structural details and guidance and a listing of building materials acceptable for high wind areas.

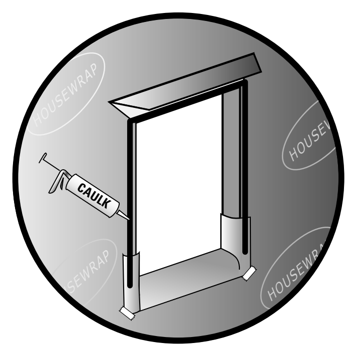
- Federal Emergency Management Agency. *Building a Safe Room Inside Your Home*. www.fema.gov
- Federal Alliance for Safe Homes – FLASH, Inc. Designed primarily for Florida, this Web site contains generally-applicable information about building to resist high winds, wild fires, and floods. *Blueprint for Safety*. www.blueprintforsafety.org
- Institute for Business and Home Safety. The IBHS has building guidelines and public information. www.ibhs.org
- U.S. Department of Energy. A training program for home inspectors to identify hazards. www.eere.energy.gov/weatherization/hazard_workshop.html

VAPOR BARRIERS
Roof and wall assemblies must contain elements that, individually and in combination, permit drying of spaces inside of walls.

WATER-PROOFING ROOF DECKING
Install water-proofing strips over joints in roof decking.

WINDOW FLASHING
Flashing should be installed for all windows.

FIGURE 5:
Window Flashing Building Tips



Complete instructions for window flashing are provided in the *Trades* chapter of this handbook.

Vapor Management

Water has many guises and water in its liquid state is not the only problem. Water can also cause problems as vapor. The problem is especially bad when vapor gets trapped within an assembly, such as a wall; turns to its liquid form (condenses); and wets structural assemblies. Condensation can also form in and on ductwork, especially when air conditioning cools duct surfaces that come in contact with humid air, such as in an attic or crawlspace. Humid crawlspaces and attics are less of a problem in the hot-dry and mixed-dry climates than in other climates, but problems can arise under humid weather conditions or in areas with high ground moisture. The recommendations below are intended to help control both liquid water and vapor.

Best Practice: Do not install impermeable coverings, such as vinyl wallpaper, on exterior walls and do not install vapor retarders on the framing side of gypsum board or other wall coverings. Use unfaced insulation.

Best Practice: Water soaking through wood can carry with it contaminants that interfere with the ability of housewraps and building papers and felts to resist water. One step in the solution is to backprime all wood cladding to avoid water saturation and migration. This practice also makes the wood much more durable.

Best Practice: Creating an air space between the cladding and the drainage plane effectively increases the durability of both components. With some exterior finishes, such as bricks, an air space is even more important. An air space stops the capillary movement of moisture, stops the contamination of the drainage plane via contact with the cladding, and allows for better drying. Information on housewrap and building paper performance behind brick and stucco can be found at www.buildingscience.com/resources/walls/brick_stucco_housewraps.pdf

Best Practice: If building paper or felt is used in areas prone to severe rain, install two layers. The use of two layers was once common and provides better than twice the performance of one layer. By providing a double drainage plane, they offer increased resistance to leakage at fasteners and allow for more flexible installation.

Best Practice: Installation is key for all types of housewraps. The sheets must be lapped, shingle-style, especially over and around windows, doors, and other penetrations (and their flashing systems). Use manufacturer-specified fasteners and space them closely enough to provide required support.

Additional information on moisture control can be obtained from:

- DOE's *Technology Fact Sheet on Weather-Resistive Barriers*, available on the Web at www.eere.energy.gov/buildings/info/documents/pdfs/28600.pdf.
- Building Science Consortium's Web site at www.buildingscience.com/housesthatwork/buildingmaterials where you can compare wraps and other materials.
- www.buildingscience.com/resources/walls/problems_with_housewraps.htm
- The following article provides an overview of house wraps and was a key source for this section: Straube, John. 2001. "Wrapping it Up," *Canadian Architect*. May, 2001. Available at www.cdnarchitect.com.
- The National Association of Home Builders Research Center's *Moisture Protection of Wood Sheathing* is available on the Web at www.nahbrc.org/docs/mainnav/moistureandleaks/792_moisture.pdf.

IMPERMEABLE COVERINGS
Impermeable coverings inside the house are not recommended.

BACKPRIMING
Backprime all wood cladding to avoid water saturation.

AIR SPACE
Creating an air space between the exterior finish and the drainage plane effectively increases the durability of both components.

TWO LAYERS OF BUILDING PAPER OR FELT
Consider installing two layers of building paper or felt to create a double drainage plane.

CAREFUL INSTALLATION
Pay close attention to lapping, especially around windows and doors, as well as the proper use of fasteners.

Housewrap, Building Paper, or Felt – Your Choices for Wrapping it Up

Housewrap, building paper, or impregnated felt should be part of the exterior wall system that protects the building from water penetration. None of the materials are waterproof, but are intended to shed rainwater that penetrates exterior cladding. The surface formed by these materials is called a drainage plane, house membrane, or rain barrier. They are used to shed liquid water that may penetrate siding or roofing and to prevent liquid water from wicking through them, while remaining sufficiently vapor permeable ("breathable") for outward drying (Straube 2001). By helping to keep building materials dry, these membranes improve building durability, decrease maintenance costs, and reduce the risk of moisture-related problems such as pests, mold, and rot.

Building Paper is a Kraft paper sheet impregnated with asphalt to increase its strength and resistance to water penetration. It is primarily employed as a drainage layer. It is graded according to a test of the amount of time required for a water-sensitive chemical to change color when a boat-shaped sample is floated on water. Common grades include 10, 20, 30, and 60 minutes. The larger the number, the more resistant the paper is to water.

Building Felts have been in use over a hundred years. Originally made from rags, today's felts are made of recycled paper products and sawdust. The base felt is impregnated with asphalt. Ratings for felt harken back to the traditional weight of the material before the oil crisis of the 1970s. At that time 100 square feet of the material (1 square) weighed about 15 pounds. Modern #15 felt can weigh from 7.5 to 12.5 pounds per square depending on the manufacturer.

Housewrap typically refers to specially-designed plastic sheet materials. Housewrap comes in a variety of materials and can be perforated or non-perforated. If joints and connections are sealed, housewraps can serve as air retarders to reduce air leakage. Housewraps are highly resistant to tearing, unlike building paper. Non-perforated wraps tend to have higher liquid water resistance because the holes between plastic fibers are very small.

Most building paper is UV-resistant, whereas recommended housewrap exposure limits may vary by manufacturer. Check with manufacturers if outdoor exposure will exceed a month. One person can usually install building paper, while housewrap requires two people. However, housewrap is available in wide sheets that can cover an entire one-story wall surface in a single pass.

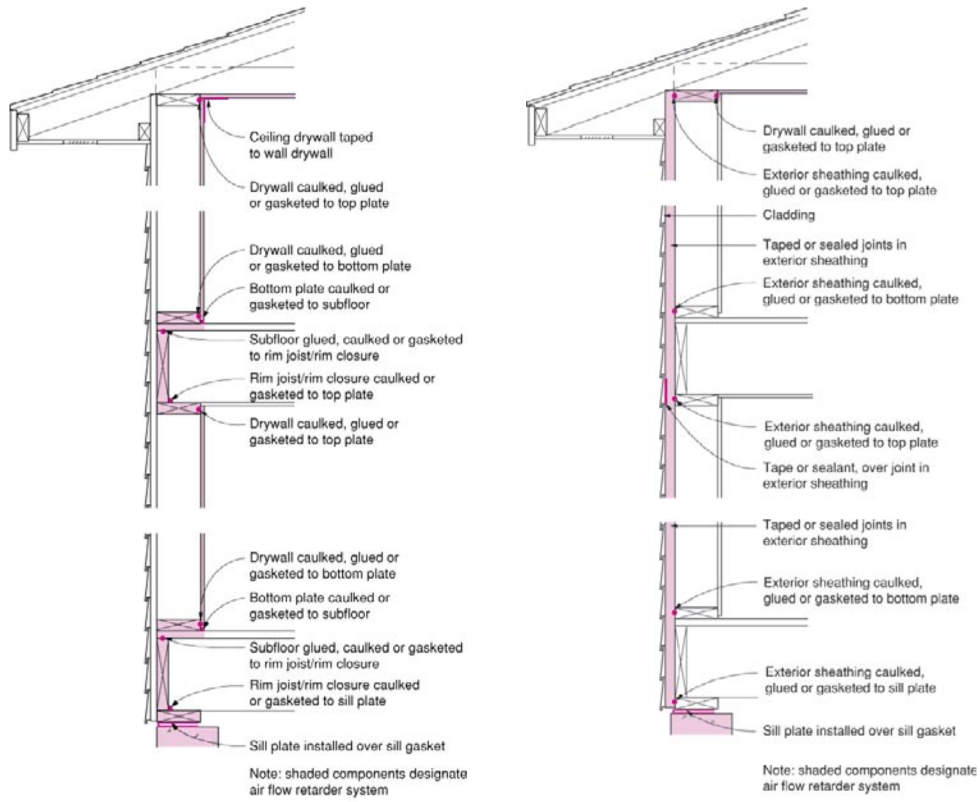
Adapted from Straube 2001.

Roof and wall assemblies must contain elements that, individually and in combination, permit drying of spaces inside of walls and other assemblies. Exterior housewraps, including building paper, will allow vapor to pass through and should be installed on the exterior of sheathing. Interior walls should be painted but not covered with plastic vapor retarders (on the framing side of gypsum board) or impervious coatings, such as vinyl wallpaper.

A more recent and graphical reference on moisture control is the EEBA *Water Management Guide* (Lstiburek 2003), available for sale from the EEBA Bookstore, on the Web at www.eeba.org/bookstore.

Structural Air Sealing

FIGURE 6: Envelope Air Sealing



Building Science Corporation

Best Practice: Use either interior gypsum board, exterior sheathing, or both as a continuous air flow retarder. Exterior stucco may also serve as an air flow retarder. Carefully seal big and little holes. Pay particular attention to sealing shared walls and attic spaces between garages and houses.

A tight building envelope is necessary to control the movement of air in and out of building assemblies. Air infiltration can contribute to problems with moisture, noise, dust, and the entry of pollutants, insects, and rodents. Using mechanical ventilation as a superior approach to supplying fresh air is discussed in the section on Mechanicals, Electrical, and Plumbing.

Moisture-laden air moving into wall or roof assemblies may lead to condensation and result in deterioration of moisture sensitive materials. Airflow retarders can be installed on the interior or the exterior side of the envelope or on both sides. Insulation made up of batt or loose fill products does not seal against air leakage. Rigid foam board insulation can be used as both a moisture and air retarder.

Controlling air movement through the building envelope requires sealing both the "big" holes and the "little" holes. The big holes occur behind bathtubs and showers on exterior walls, behind fireplaces, and where soffits or utility walls (double wall with chase) meet exterior walls or ceilings. Recessed lights collectively can be a really big hole in the ceiling assembly. These big holes are responsible for wasted energy (high utility

ENERGY STAR THERMAL BYPASS CHECKLIST

The checklist stipulates 13 areas that require special attention to insulation and air barrier continuity.

1) Exterior walls behind tubs and showers
2) Floors over garages
3) Attic knee walls
4) Attic hatch openings and drop-down stairs
5) Cantilevered floors
6) Duct shafts
7) Flue Shafts
8) Piping shafts and penetrations
9) Dropped ceilings and soffits
10) Fireplace walls
11) Staircase framing on exterior walls
12) Recessed lighting
13) Whole-house fan penetrations

AIR SEALING

Be sure to seal shared walls and attic spaces between garages and houses.

bills) and condensation that can cause mold and wood decay. These holes are easy to seal during the framing stage but only when someone has the responsibility for making sure it gets done. Only airtight recessed lights (ICAT-rated) should be used in ceilings leading to unconditioned spaces.

The little holes occur between framing members (such as band joist to sill plate), around electrical boxes, and where plumbing or wiring penetrate the envelope. All penetrations leading to unconditioned spaces should be sealed with foam or caulk. See the *Trades* chapter, *Building Tips* on air sealants and the instructions for plumbers, electricians, and framers. Also see the sections later in this chapter for plumbing and electrical.

When air sealing drywall, gypsum board acts as an interior air flow retarder. The gypsum board is sealed to the framing members at the perimeter of exterior walls and around penetrations such as doors, windows, and attic hatches. The gypsum board is also sealed to electrical boxes on exterior walls. Air cannot move through the gypsum board and the taped corners.

There are many approaches and practices to sealing buildings. Many details and photographs of air sealing techniques can be found on the Building Science Corporation Web site at www.buildingscience.com/housesthatwork/airsealing.htm, in the EEBA *Builders Guides*, and in the DOE *Technology Fact Sheet on Air Sealing* available on the Web at www.eere.energy.gov/buildings/documents/pdfs/26448.pdf.

Best Practice: One area to pay attention to for sealing is the intersection of the walls and roof. This area may involve an attic, cathedral ceiling, knee walls, all of the above, or other examples of complex roof lines. Figures 7 and 8 show knee wall examples. Tight sealing of this intersection may require blown-in foam.

Best Practice: Another area needing special attention for occupant health and safety is sealing shared walls and ceilings between attached garages and living spaces. Carefully seal any penetrations, block air pathways through the attic, and weatherstrip any doors.

Structural Thermal Performance

Properly installed insulation is like your favorite winter comforter for keeping heat where it's wanted. Any interior insulation type is acceptable that has vapor permeability. These include cellulose, fiberglass, and foam. Foam can also serve as an air retarder, but air sealing must be accomplished by a separate component or system when cellulose or fiberglass is used.

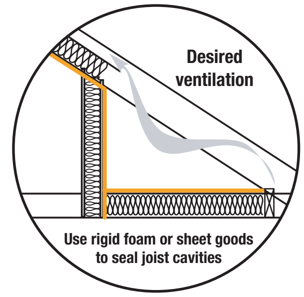
The following descriptions of insulation were adapted from DOE's Fact Sheet on Insulation available on the Web at www.ornl.gov/sci/roofs+walls/insulation/ins_08.html.

INTERSECTIONS OF WALLS & ROOF

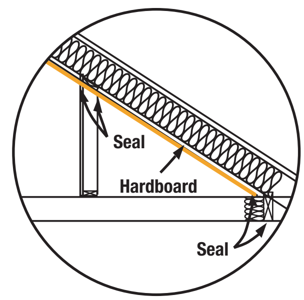
Tight sealing of the intersection of the roof and wall may require blown-in foam.

FIGURE 7 & 8: Knee Walls

Figures 7 and 8 show possible approaches to sealing knee walls.



Seal knee wall to create a continuous air barrier. Knee walls can be sealed following the wall and attic floor.



In new homes, it is preferred to seal along the sloping edge of the attic roof.

SHARED WALLS & CEILINGS WITH GARAGES

Pay special attention to the shared walls and ceilings between attached garages and living spaces.

Blankets

Blankets in the form of batts or rolls are flexible products made from mineral fibers, typically fiberglass. They are available in widths suited to standard wall, floor, and attic framing spaces. Continuous rolls can be hand-cut and trimmed to fit. They are available with or without vapor retarder facings. High-density fiberglass batts are about 15% more effective than traditional batts. Even if you choose to use other types of insulation, such as blown or sprayed in cellulose or foam, batts can be installed in areas that may become inaccessible as construction unfolds. These areas could include behind-shower inserts, stairs, or rim joists. Batts also make good dams in attics around access points or other areas where blown-in insulation should be held back.

Best Practice: When fiberglass batt insulation is specified, use high-density, unfaced batts. Batt facing is a vapor retarder and can trap moisture inside walls. Check local code requirements

INSULATION
Use high-density batts, when fiberglass batt insulation is specified.

FIGURE 9: Insulation


Blown-in wall insulation


Batt insulation


Reflective insulation


Spray-in foam insulation. Soy-based foams are now available
(Photo: Building Science Corporation)

Blown-In

Blown-in, loose-fill insulation includes loose fibers or fiber pellets that are blown into building cavities or attics using special pneumatic equipment. Another form includes fibers that are co-sprayed with moisture or an adhesive that allows them to set in walls and makes them resistant to settling. The blown-in material can provide some resistance to air infiltration if the insulation is sufficiently dense.

Foamed-In-Place

Foamed-in-place polyurethane foam insulation can be applied by a professional applicator using special equipment to meter, mix, and spray into cavities. Polyurethane foam makes an excellent air seal and can be used to reach hard-to-get-at places.

Rigid Insulation

Rigid insulation is made from fibrous materials or plastic foams that is pressed or extruded into sheets and molded pipe-coverings. These provide thermal and acoustical insulation, strength with low weight, and coverage with few heat loss paths. Such boards may be faced with a reflective foil that reduces heat flow when next to an air space. Foil facing also makes the board nearly impervious to water and vapor and so should be used with caution. Rigid foam insulation may be used in combination with other insulation types, such as on the exterior of walls that are filled with cellulose or fiberglass. Foam sheets that may be in contact with the ground should be borate-treated for termite resistance *(see Figure 10 on page 17 for an example of rigid foam insulation).*

Reflective Insulation Systems

Reflective insulation systems are fabricated from aluminum foils with a variety of backings such as roof sheathing, craft paper, plastic film, polyethylene bubbles, or cardboard. The resistance to heat flow depends on the heat flow direction; this type of insulation is most effective in reducing downward heat flow and requires an air space adjacent to the reflective surface. Reflective systems are typically located between roof rafters, floor joists, or wall studs. Reflective insulation placed in walls must be perforated. If a single reflective surface is used alone and faces an open space, such as an attic, it is called a radiant barrier. Radiant barriers are sometimes used in buildings to reduce summer heat gain and winter heat loss. They can be effective in the hot-dry and mixed dry climates at reducing peak cooling loads, especially if ductwork or cooling equipment is located in the attic. All radiant barriers must have a low emittance (0.1 or less) and high reflectance (0.9 or more). Additional information on radiant barriers is available in the following sources:

- *FPC Residential Monitoring Project: New Technology Development – Radiant Barrier Pilot Project*, available at the FSEC Web site at www.fsec.ucf.edu/bldg/pubs/rbs/index.htm
- DOE's *Radiant Barrier Attic Fact Sheet*, available on the Web at www.ornl.gov/sci/roofs+walls/radiant/rb_01.html

How Much Insulation Do You Need?

This is an excellent question to ask your Home Energy Rater. The answer depends on your location, the overall design, and the efficiency of other building features. The ENERGY STAR Web site contains Builder Option Packages (BOPS) that recommend insulation levels on a county by county basis. The BOPS can be found at www.energystar.gov. Examining the ENERGY STAR BOPs provides some examples of how insulation can be traded off with other features such as efficient windows and HVAC systems. DOE can also help with insulation recommendations for each zip code. Visit the Web site below. Have in hand the first three digits of your zip code, the type of heating system that you are considering, and local energy costs for electricity or natural gas. The calculator will recommend an insulation level.

www.ornl.gov/sci/roofs+walls/insulation/ins_16.html

If you prefer to work with a map, the following DOE Web site will give you recommended insulation levels.

www.eere.energy.gov/consumerinfo/energy_savers/r-value_map.html

These recommendations are only guidelines and are limited in scope. The more complex or advanced your design, the more you should rely on specific calculations.

Frame Walls

Best Practice: Best practice for frame wall construction involves advanced framing techniques. However, these techniques are not required to achieve 30% space conditioning energy savings in the hot-dry and mixed-dry climates. If you want to gain greater efficiency, more information on advanced framing can be found in the guidance provided in this document for code officials, in the *EEBA Builders Guides*, in DOE's *Fact Sheet on Wall Insulation*, and on the Web at www.buildingscience.com/housesthatwork/advancedframing/default.htm. If advanced framing is to be used, a detailed plan should be developed showing framing placement.

ADVANCED FRAMING
Consider advanced framing techniques when contructing walls.

Building America sponsored work by the Building Science Consortium and the U.S. Army Construction Engineering Research Laboratory to develop an inset shear panel for advanced framing in seismic regions. Information on the inset shear panel is available at www.buildingscience.com/resources/walls/default.htm.

External walls with 2x4 framing may achieve 30% energy space conditioning savings in the hot-dry and mixed-dry climates and should include the following features:

- Examples of exterior finish can include stucco over paper (paper to have perm rating of <1 perm) backed with lath, vinyl siding, or cementitous board.
- A housewrap should be installed as an air and water barrier.

- Insulation may be R-13 (high-density) friction-fit, unfaced fiberglass insulation or blown-in cellulose insulation.
- Frame walls between the garage and the conditioned space, including bonus rooms, should have unfaced insulation.
- Rim joists: unfaced R-13 friction-fit batt insulation cut to fit.
- Penetrations: Foam seal or caulk all top-plate penetrations and exterior wall penetrations.
- In addition to sealing all penetrations, air leakage through the walls should be controlled by sealing the gypsum board. Pay particular attention to air-sealing penetrations to garages and porches.
- Do not install vapor barriers or retarders on the framing side of wall board on exterior walls.

Masonry Walls

Masonry walls may be finished with stucco, wood, or other claddings. Best practices to improve thermal efficiency include the following:

- Semi-vapor permeable rigid insulation should be installed on the interior of wall assemblies and should be unfaced. Foil facing and polypropylene skins should be avoided.
- Wood furring should be installed over rigid insulation. The rigid insulation should be continuous over the surface of the wall, except for a 2x4 furring at the intersection with the ceiling. This blocking attaches directly to the masonry block and serves as draft and fire stop. The rigid insulation abuts the blocking but does not cover it or extend behind it.
- Foam seal or caulk all top plate penetrations and exterior wall penetrations.
- Electrical boxes can be surface mounted to the masonry, avoiding chipping or chiseling. The rigid insulation, furring, and gypsum board will build up around the box for a flush finish.
- Use pressure treated lumber to frame out sub-jambs and spacers within window and door rough openings.
- As with other walls, penetrations to the exterior or through top and bottom plates should be foam sealed or caulked.
- In addition to sealing all penetrations, air leakage through the walls should be controlled by sealing the gypsum board. Pay particular attention to air-sealing penetrations to garages and porches.
- When pouring the slab take care to create a seat in the concrete to accept the block and seats in the concrete to act as drain pans where exterior doors and sliding doors will be located.

FIGURE10: Masonry Walls with Interior Rigid Insulation

More information on masonry construction can be found in the *Builders Guides* (Lstiburek 2002) and on the Web at the Building America *Houses that Work* section of the Building Science Corporation Web site www.buildingscience.com/housesthatwork/hothumid/orlando.htm. Look for the *Orlando Profile*. Window flashing details can be found in the ASTM standard entitled *Standard Practice for Installation of Exterior Windows, Doors, and Skylights* (ASTM 2002) and the *EEBA Water Management Guide* (Lstiburek 2003). The *Water Management Guide* also contains information on other approaches to draining masonry assemblies. The *Trades* chapter contains a building tips sheet for masonry walls.

Concrete Walls

Some builders are beginning to use poured concrete walls for residential construction. For more information on this approach see *Builder System Performance Package Targeting 30%-40% Savings in Space Conditioning Energy Use* prepared by CARB (CARB 2004).

Windows

Best Practice: Specify efficient windows to control solar energy gains and to help reduce heating and cooling loads. Some Building America experts recommend that, nationwide, windows be used with a U-factor of 0.35 or lower and a SHGC of 0.35 or less. Note that ENERGY STAR qualification can be met with windows at less stringent ratings.

WINDOWS
Specify efficient windows to control solar energy gains and to help reduce heating and cooling loads.

Windows are a prominent feature of any wall. High-performance windows can be an easy way to achieve ENERGY STAR qualification. Efficient windows will add expense to your project, but will provide tremendous value in comfort, durability, and energy savings. High-performance windows add so much to energy efficiency that smaller cooling and heating equipment can often be specified, which may recapture much of the cost. A voluntary rating system developed by the National Fenestration Rating Council (NFRC) provides performance information for about half the windows sold. The NFRC label contains ratings for the following features. You can find more information about the NFRC on the Web at www.nfrc.org.

- U-factors take into account the entire window assembly and rate how well the window prevents heat from passing through the window. The lower the U-factor the better the window performs at stopping heat flow. U-factors are the inverse of R-values used to measure the effectiveness of insulation. U-factor values for windows generally fall between 0.20 and 1.2.
- SHGC is the solar heat gain coefficient, which measures how well the window blocks heat caused by sunlight. The lower the SHGC rating the less solar heat the window transmits. This rating is expressed as a fraction between 0 and 1.
- Visible transmittance (VT) measures how much light comes through a window. VT is expressed as a number between 0 and 1. The bigger the number the more clear the glass.
- Air leakage through a window assembly is included on most manufacturers' labels, but is not required. The AL rating is expressed as the equivalent cubic feet of air passing through a square foot of window area (cfm/sq.ft.) The lower the AL, the less the window leaks. A typical rating is 0.2.
- Another optional rating is Condensation Resistance (CR), which measures the ability of a product to resist the formation of condensation on the interior surface of that product. The higher the CR rating, the better that product is at resisting condensation formation. While this rating cannot predict condensation, it can provide a credible method of comparing the potential of various products for condensation formation. CR is expressed as a number between 1 and 100, with a higher value representing more resistance to the formation of condensation.

FIGURE 11: NFRC Window Label

Energy efficient windows are comfortable to sit near and provide protection for furniture and window treatments.

ENERGY STAR qualifies specific windows in addition to qualifying houses. ENERGY STAR divides the U.S. into four climate zones. For ENERGY STAR's south/central climate region, which is not identical to the climate zones of the Building America and DOE's Building Codes Program, all windows and doors qualifying for the ENERGY STAR label must have a U-factor rating of 0.40 or below and a SHGC rating of 0.40 or below, skylights must have a U-factor of 0.60 or below and an SHGC rating of 0.40 or less. You need not use ENERGY STAR-labeled windows to qualify a total house for an ENERGY STAR label.

The Efficient Windows Collaborative operates a Web site that can help designers and consumers choose windows. The Web site includes a tool that allows users to analyze energy costs and savings for windows with different ratings. Visit the Web site at www.efficientwindows.org/index.cfm.

The Web site also has fact sheets with comparisons for each state. These fact sheets could make effective marketing tools. Also described on the Web site is a book entitled *Residential Windows: A Guide to New Technologies and Energy Performance* (Carmody et al. 2000), which offers homeowners, architects, designers, and builders a fascinating look at the state of the art in window technology. Emphasizing energy performance, the book covers every aspect of window design and technology: the basic mechanisms of heat transfer; new products and rating systems; the effects of window frame material and installation; and how to make the best decisions when purchasing windows.

OVERHANGS
Design roofs with overhangs to shade and protect windows and doors.

Overhangs

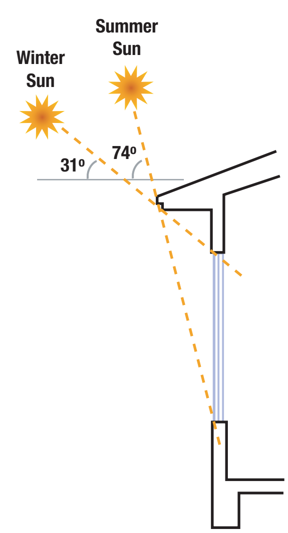
Best Practice: Design roofs with overhangs to shade and protect windows and doors. Overhangs may take the form of eaves, porches, or other design features such as awnings, pergolas, or trellises.

Single glazing is not recommended, but when a house has clear single glazing, light-colored interior shades, overhangs, and combinations of shading devices significantly reduce energy costs. Naturally, a completely shaded house has the best performance in a hot climate.

Reliance on any form of shading is not nearly as important when windows with a low solar-heat-gain coefficient are used. Using a low-solar-gain low-E coating results in great energy cost reductions for all conditions even with no shading. This is because the glazing itself provides the necessary control of solar radiation, so shading measures become less important in terms of energy use. For a description of the interactions between window performance and shading, see the Efficient Windows Collaborative Web site at www.efficientwindows.org.

Overhangs should be sized to account for differences in sun angles, elevation, window height and width, and wall height above the window. Free and low-cost computer programs and tools are available to help. For example a free program telling you the angle of the sun for any point in the country is available at www.susdesign.com/sungangle/. Latitude, longitude, and elevation data can be obtained at www.wunderground.com. Overhang dimensions can be calculated at www.susdesign.com/overhang/index.html. For a listing of free and available-for-purchase energy models, including solar design tools, see DOE's Building Technology Program Web site at www.eere.energy.gov/buildng/index.cfm?flash=yes. Click on

FIGURE 12: Overhangs



Sun angles for Albuquerque, New Mexico. A four foot window would need an overhang extending 19 inches with 12 inches of wall above the window.

Software Tools on the lower right side. A low-cost sun angle calculator is available from the Society of Building Science Educators at www.sbse.org/resources/sac/index.htm.

Overhangs also provide protection from rain, hail, and the effects of overheating and ultraviolet radiation on siding and windows.

Ceilings and Roofs

As indicated earlier, ceilings, roofs, and attics represent complex building assemblies. In addition to the sealing and insulation approaches shown in the *Air Sealing* section, here are additional insulation guidelines. These guidelines apply to traditionally ventilated attics. Unvented attics must be tightly sealed and are not described in detail in this guide.

- If attic access is provided, it must be insulated and weather-stripped.
- Use baffles to allow ventilation air to freely flow past insulation.
- Install an "energy" truss for more headroom at the eave to avoid compressing insulation and allow for consistent attic coverage.
- Use dams to hold insulation away from openings and storage areas. Thick batt insulation makes an excellent dam. Waxed cardboard, foam sheathing, and other sheet goods can also be used as dams.
- Only recessed lights rated for "insulated ceiling and air tight" (ICAT) should be installed in ceilings. See the section on electrical for more information.

Builder GW Robinson of Gainesville, Florida, was able to go from two HVAC units—a 5-ton unit for the house and a 1.5-ton unit for the bonus room—to a 4-ton HVAC unit for the whole house, by giving extra thought to duct layout, specifying duct layout on the floor plans and using zone dampers and return air pathways in each room of his up-to 4,500 ft^2 houses.

Heating, Ventilating and Air Conditioning (HVAC)

Best Practice: For the best results in comfort, efficiency, and durability, HVAC system design for both equipment and ducts must be integrated in the overall architectural design. Work closely with your HVAC engineer, HVAC contractor or HERS rater to properly design, size, and select your HVAC equipment. If done properly, you will save money and go a long way with this single step toward improved energy efficiency and comfort and substantial cost savings.

HVAC
Integrate HVAC system design in the overall architectural design.

A well-designed house should have an HVAC system properly sized to its demands. Proper equipment sizing ensures a comfortable environment and provides opportunities to recapture some of the expense of an efficient building envelope. Rules of thumb for equipment sizing do not work in modern homes and should not be used.

Unfortunately, rules of thumb are still prevalent. A Florida survey points out some of the practices of HVAC contractors (Viera, Parker, Klonbergo, Sonn, and Cummings 1996). Although only a small percentage of Florida's HVAC contractors responded, the survey found that about one-third of respondents size air conditioning and duct capacities based on square footage or other rules of thumb. Compounding the problem, the rules were not consistently applied. Some respondents provided twice as much capacity as others for a given square footage of floor area. Over one-third of respondents indicated intentional oversizing of HVAC equipment on some jobs, in order to avoid complaints, accommodate future expansions, enable quicker cooling down of homes, and to allow for lower cooling set points by homeowners.

"'The recommended changes in our practices meant we were able to downsize our equipment by a half-ton,' explains Andrew Nevitt, Medallion's head architect. 'Our contractors were concerned that they'd experience increased callbacks because of comfort issues.' That hasn't been the case. Medallion is building all its homes to reach ENERGY STAR performance levels and is working with Building America to learn practices that will push the performance of its homes even further."

As reported in *Professional Builder* 3/1/03.

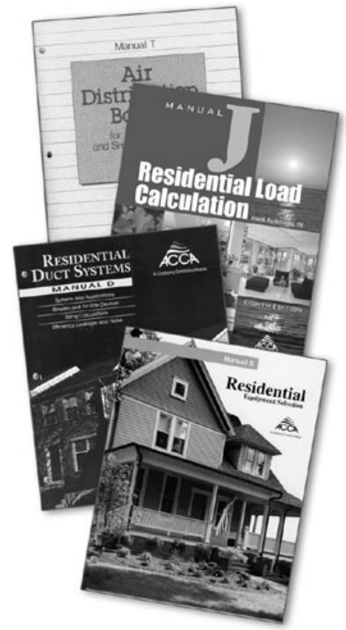
Sizing Air Conditioners

Best Practice: Right-size air conditioners and other HVAC equipment.

One estimate states that a Manual J calculation takes about 30 to 60 minutes for an average home, using the measurements from construction drawings. Manual S calculations require an additional 15 to 30 minutes (SBIC 2003). A single calculation can work for multiple use of the same plans.

RIGHT-SIZING
Right size air conditioners and other HVAC equipment.

FIGURE13: ACCA Manuals



Photos by ACCA

Four Sources for HVAC Design

The Air Conditioning Contractors of America (ACCA) has published simple but effective methods for determining loads and sizing ductwork and heating and cooling equipment.

- **Manual J** tells you how to calculate loads.
- **Manual D** tells you how to size ducts.
- **Manual S** guides you through the selection of appropriate heating and cooling equipment to meet identified loads.
- **Manual T** gives you the basics for small buildings.

For more information or to purchase these documents on the Web, go to **www.acca.org**.

Air Conditioner and Heat Pump Ratings

Best Practice: Central air conditioners should be rated at a minimum of 13 Seasonal Energy Efficiency Ratio (SEER) for air cooling and heat pumps should be rated at a minimum of 7.6 Heating Season Performance Factor (HSPF) for heating.

RATINGS
Central air conditioners should be rated at a minimum of 13 SEER and heat pumps should be rated at a minimum of 7.6 HSPF.

In September 2006 DOE will begin enforcing a 13 SEER standard for all residential central air conditioners. For more information on this standard, visit www.eere.energy.gov/buildings/appliance_standards.

Consider using SEER-14 air conditioning equipment to achieve performance levels greater than 30% savings. Equipment with SEER ratings up to 20 are now available. Currently, ENERGY STAR-labeled central air conditioners have a minimum rating of SEER 12.

Heat pumps are preferable to electric resistance heating in all but part of the hot-dry and mixed-dry climates, where there are fewer than 500 annual heating degree days. A unit with a HSPF of 7.7 or more will reduce the electric consumption during heating by more than 50% relative to electric resistance heating. The new standard will require that central heat pumps have a minimum rating of 7.7 HSPF. Lists of all ENERGY STAR-rated appliances can be found at www.energystar.gov/index.cfm?c=appliances.pr_appliances.

Central Gas-Fired Furnace

Best Practice: Sealed combustion gas furnaces should be specified for central gas-fired heating systems. ENERGY STAR labels furnaces that meet a minimum Annual Fuel Utilization Efficiency (AFUE) of 90.

Sealed Combustion

Sealed combustion means than an appliance acquires all air for combustion through a dedicated sealed passage from the outside, to a sealed combustion chamber, and all combustion products are vented to the outside through a separate, dedicated sealed vent.

Mechanical Ventilation

Best Practice: Building America recommends that whole-house mechanical ventilation be provided as specified in ASHRAE standard 62.2. Recommended ventilation systems for indoor air quality include mechanical exhaust fans, systems that supply air, or a combination of the two.

- Base Rate Ventilation: controlled mechanical ventilation at a minimum base rate of 15 CFM for the master bedroom, plus 0.01 CFM for each square foot of conditioned area, and 7.5 CFM for each additional bedroom, should be provided, as listed in ASHRAE 62.2.
- Spot Ventilation: intermittent spot ventilation of 100 CFM should be provided for the kitchen; all kitchen range hoods must be vented to the outside (no recirculating hoods). Intermittent spot ventilation of 50 CFM or continuous ventilation of 20 CFM, should be provided for each washroom/ bathroom. Fans should be quiet, with a sound rating of less than 1.5 sonnes.

Central fan-integrated supply ventilation can be an easy and inexpensive way to provide outside air to the HVAC system. This system provides fresh, filtered, outside air in a controlled amount using the existing HVAC delivery system for even distribution and mixing.

A New Standard in Residential Ventilation

In Autumn 2003, the American Society of Heating, Refrigerating And Air-Conditioning Engineers (ASHRAE) established a new standard for indoor ventilation in residences. The standard is *ASHRAE 62.2, Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings* (ASHRAE 2003). The following information is adapted from the forward that is published with the Standard:

> The standard contains three main sets of requirements and a host of secondary ones. The three primary sets involve whole-house ventilation, local exhaust, and source control. Whole house ventilation is intended to dilute the unavoidable contaminant emissions from people, materials, and background processes. Local exhaust is intended to remove contaminants from specific rooms, such as kitchens and bathrooms, where pollutant sources are produced. And source control measures are included to deal with other anticipated sources. The standard's secondary requirements focus on properties of specific items, such as sound and flow ratings for fans and labeling requirements.
>
> The standard is principally about mechanical ventilation, but its purpose is to provide acceptable indoor air quality. The most effective way for keeping exposure to pollutants low is to keep them from being released to the general indoor environment in the first place.

ASHRAE is planning to publish guidance documents on meeting this standard.

GAS FURNACES
Specify sealed combustion gas furnaces for central gas-fired systems.

VENTILATION
Integrate mechanical ventilation into the HVAC system.

Air Intake being installed in a porch overhang to provide fresh air to attic HVAC.

Most of the Building America teams have designed and field-tested these ventilation systems. The systems involve exterior air intakes, ductwork running to the return air side of the HVAC system, dampers to allow control of the air intake, and electronic controls to ensure that the HVAC fans operate frequently enough to draw in adequate fresh air. For an example of these systems, see www.buildingscience.com/resources/mechanical/air_distribution.pdf for more detailed information.

Compact Air Distribution System

Best Practice: Make duct runs as short as possible.

An efficient building envelope and efficient HVAC equipment allow for a compact air distribution system. Conditioned air may be discharged from inside walls (see the discussion in the next section on chase design) or from ceiling diffusers up to 12 feet from the window wall in most cases without compromising comfort. Such "inside throw" layouts cut ductwork runs, saving money and reducing the amount of ductwork that may run in unconditioned space.

Seal All Ducts and Air Handlers

Best Practice: Seal all ductwork seams and connections to air handlers with UL181-approved water-based mastic and seal drywall connections with caulk or foam sealant.

Sealing ductwork is very important. Leaky ductwork in an unconditioned attic or crawl space can draw unhealthy air into the air distribution system. Sealing ducts with mastic is desirable even for ducts located in conditioned spaces. Properly sealed ducts make sure air gets to the spaces intended, rather than leaking into a plenum space. It also minimizes the chances of

FIGURE 14: Outside Vents

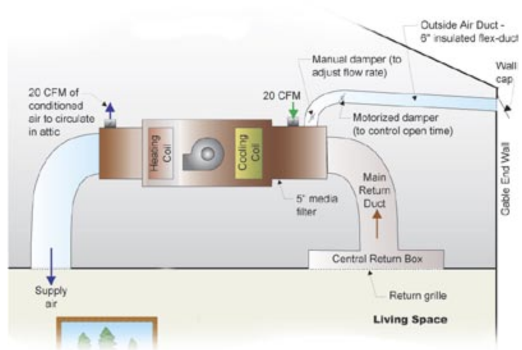


FIGURE 15: Duct Run Configurations

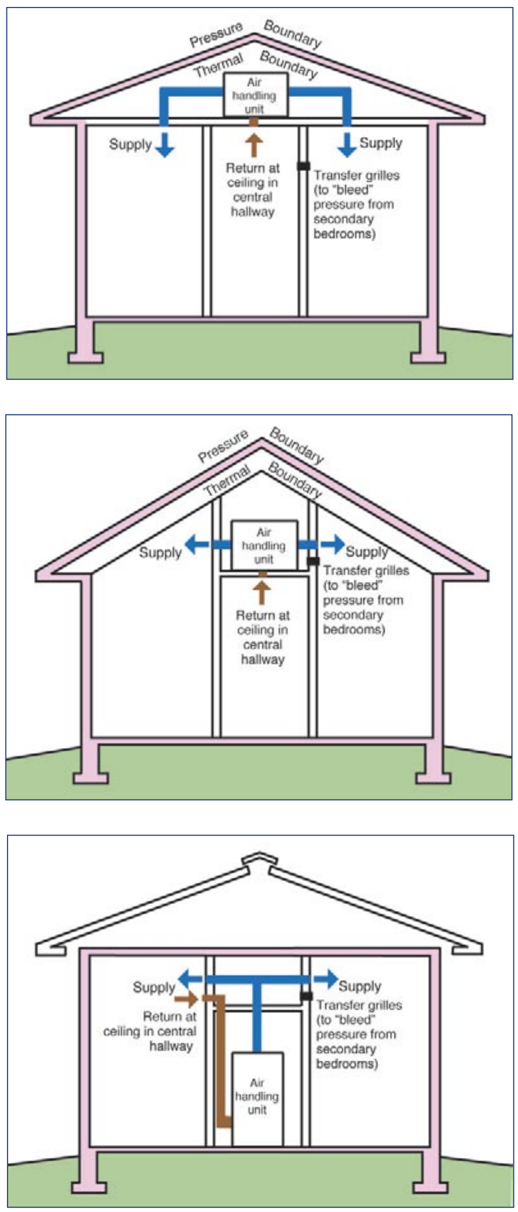


Figure 14 and 15 Source: Building Science Corporation

Efficiency Measures for Air Conditioners, Heat Pumps, and Furnaces

The **Seasonal Energy Efficiency Ratio (SEER)** is a measure of equipment energy efficiency over the cooling season. It represents the total cooling of a central air-conditioner or heat pump (in Btu) during the normal cooling season as compared to the total electric energy input (in watt-hours) consumed during the same period.

The **Heating Season Performance Factor (HSPF)** is a measure of a heat pump's energy efficiency over one heating season. It represents the total heating output of a heat pump (including supplementary electric heat) during the normal heating season (in Btu) as compared to the total electricity consumed (in Watt-hours) during the same period.

The **Annual Fuel Utilization Efficiency (AFUE)** measures the amount of fuel converted to heat at the furnace outlet in proportion to the amount of fuel entering the furnace. This is commonly expressed as a percentage. A furnace with an AFUE of 90 could be said to be 90% efficient.

DUCT RUNS
Make duct runs as short as possible.

DUCT SEALING
Seal all ductwork and air handlers with mastic and seal duct boots to sheetrock connections.

FIGURE 16: Mastic

Mastic provides the most reliable duct sealing method for new construction.

creating pressure differentials from space to space that would induce airflow through the envelope. The process of sealing each joint reduces the chances of unconnected ductwork, a surprisingly common mistake.

Mastic provides the most reliable duct sealing method for new construction. All ductwork, including the air handler compartment (which typically has many leaky joints), should be mastic sealed.

DOE research has found that some tapes perform adequately for sealing ducts, particularly fiberglass duct board. However, good performing tapes may be difficult to identify and traditional duct tape (cloth-backed rubber adhesive tapes) should never be used to seal ducts, even if it meets UL ratings. Do not use sealing tapes for structural purposes. Tapes have low tensile strength and should not be used to mechanically support ducts. A technical report (Walker, Sherman, Modera, and Siegel 1998) on duct sealants can be found on the Web at http://ducts.lbl.gov/Publications/lbl-41118.pdf and a less technical article (Sherman and Walker 1998) on similar research can be found at www.homeenergy.org/archive/hem.dis.anl.gov/eehem/98/9807.html.

"Sealing the ducts with mastic is I think the single most important thing that anyone should do. Sealing gets leakage rates down to about 2%. Not doing duct sealing on new construction is extremely short sighted. Mastic will last the life of the system, while conventional duct tape can fail within a year."

Lucian Kragiel, Co-owner of Atlantic Design and Construction

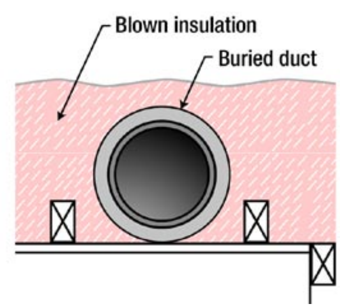
Ducts and Air Handlers in Conditioned Space or Ducts Buried in Insulation

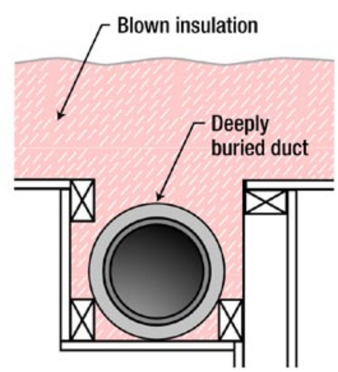
Best Practice: Ducts and air handlers should be placed in conditioned spaces to the extent possible. High temperatures can be found in unconditioned spaces and create an unfavorable environment for ducts and air handlers. California recognizes crawlspace placement of ducts as preferable to putting ducts in attics.

DUCT RUNS
Ducts and air handlers should be placed in conditioned spaces to the extent possible.

Best Practice: As an alternative to placing ductwork in conditioned space, Building America research has shown that in the hot-dry and mixed-dry climates, burying attic ducts in insulation is acceptable. The approach is described in California's *2005 Building Energy Efficiency Standards Residential Compliance Manual* (CEC 2005). The new standards take affect in October 2005.

DUCTS BURIED IN INSULATION
Based on Building America research, California's Title 24 includes provisions for buried and deeply buried ducts in attics.





Ducts and air handlers perform best when placed within conditioned space. Keeping ducts inside conditioned space may require one of several strategies, such as:

1) Placing ducts in a chase designed to run through a central corridor below the attic or on top of the ceiling through the attic. If the chase runs through the attic, it must fit within the roof truss design and will be covered with insulation. For more information on designing and building an interior chase see the report, *Design and Construction of Interior Duct Systems* (McIlvaine, Beal, and Fairey 2001), available on the Web at www.fsec.ucf.edu/bldg/baihp//pubs/interior_ducts.pdf.

2) Insulating and sealing the underside of the roof sheathing to create a conditioned attic. This strategy requires tightly sealing the roof structure, especially where it connects with the walls, to avoid the entry of outside air. This technique essentially requires building a non-vented roof assembly. For more information on this technique see www.buildingscience.com/resources/roofs/unvented_roof_summary_article.pdf. This approach may require a variance from local code officials.

3) In houses with a crawlspace, insulating and sealing the exterior walls of the crawlspace so that it becomes a conditioned space, such as a mini basement. This strategy requires treating the crawlspace much like a living space with conditioned air supply, moisture control, and air returns to

the HVAC system. More information on this approach can be found at www.buildingscience.com/housesthatwork/hothumid/montgomery.htm.

Air handlers should be placed inside conditioned space. One approach is to build a conditioned closet with sealed access from the garage. In addition to improving the efficiency of the equipment, this approach adds additional square footage to the conditioned space.

California Title 24 residential building standards requires that duct sealants meet UL 181, UL 181A, UL 181B, or UL 723 (for aerosol sealants). The California Energy Commission has approved a cloth-backed duct tape with a special butyl adhesive (CEC 2005).

FIGURE 17: Air Handler in Conditioned Space

Standards for Duct Sealants

Underwriters Laboratories, Inc. (UL) publishes several standards that relate to duct sealants, the most important of which is UL 181. It deals with ducts in general, with UL 181A covering field-assembled duct-board, and UL 181B covering flex duct systems. Each standard includes test procedures for sealants. Duct tapes and packing tapes that pass UL 181B are labeled "UL 181B-FX." Mastics can pass 181A or B and are labeled "UL 181A-M" or "UL 181B-M." Foil tapes are designated with a P.

Most tapes that are labeled 181B-FX are duct tapes. UL 181A and 181B appear to do a good job of testing for safety, tensile strength, and initial adhesion. However, they may not do a good job of rating how well sealants seal typical duct leaks or how well they stay sealed under normal conditions.

Adapted from Sherman and Walker 1998

Duct Insulation

Best Practice: Ducts in unconditioned spaces must be insulated.

INSULATING DUCTS
Ducts in unconditioned spaces must be insulated.

To the extent possible, ducts should be placed inside conditioned space. In conditioned spaces, they require minimal insulation. If the ducts are placed in unconditioned spaces, due to the extreme summer temperatures in these spaces, 10% to 30% of the energy used to cool the air can be lost to conduction through the duct surfaces. Therefore, they must be insulated. ENERGY STAR recommends R-8 insulation levels for supply ducts in unconditioned attics and R-4 in crawl spaces (EPA 2000, available on the Web at www.energystar.gov/ia/new_homes/features/DuctInsulation1-17-01.pdf) (based on Treidler et al. 1996).

Transfer Grilles and Jump Ducts

Best Practice: Use jump ducts and transfer grilles and other return pathways to maintain balanced pressure in rooms that are often isolated from the rest of the house by a closed door, such as a bedroom.

BALANCED PRESSURE
Use jump ducts and transfer grilles and other return pathways to maintain balanced pressure in bedrooms and other isolated rooms.

To maintain balanced pressure, air must be returned from each room to the central HVAC equipment. One way to do this would be to add a ducted return from each room. However, this would be expensive and consume a lot of space. A cost-effective approach is to provide a central return and make sure that there are transfer grilles or transfer ducts, of adequate size, that allow air to pass from individual rooms to the central return even when doors are closed. Figure 18 illustrates different approaches to creating paths to equalize air pressure and allow air to return to HVAC equipment. When designing registers and transfer grilles, place them high on the wall in areas where furniture may block air movement.

FIGURE 18: Jump Ducts

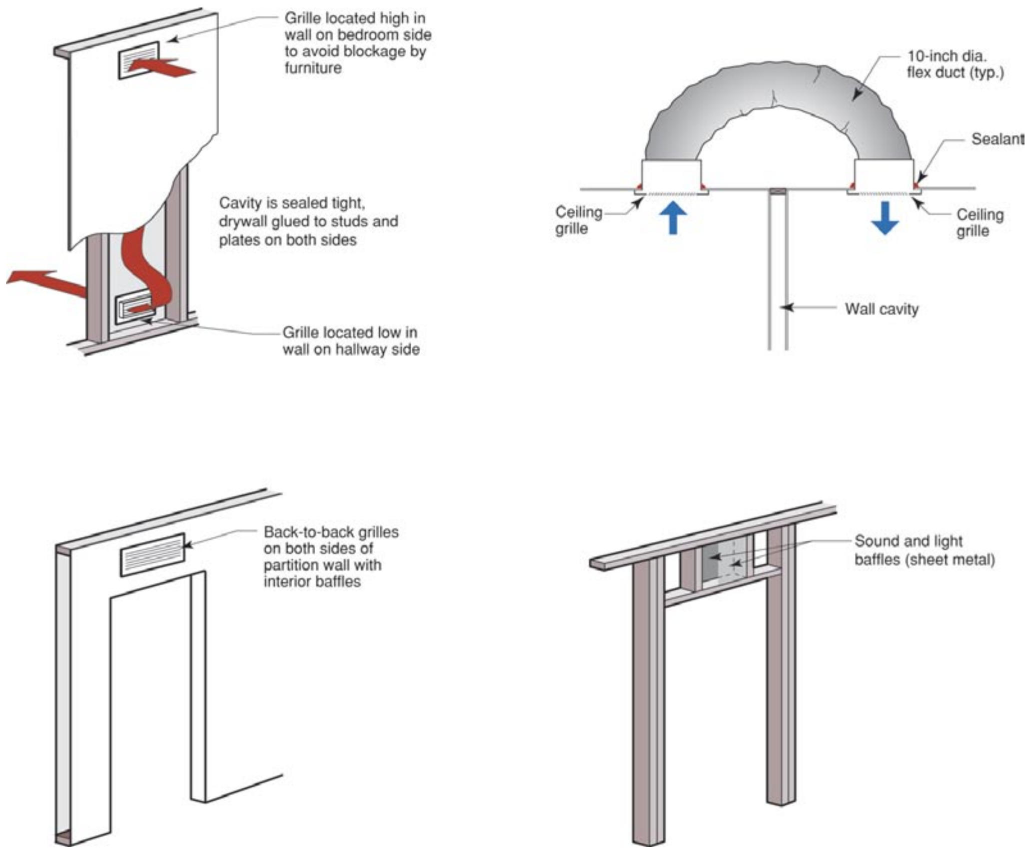


FIGURE 19: Jump Ducts

Source: IBACOS

Draw Duct Layouts on Plans

Best Practice: Clearly identify on plans and drawings the locations, sizes, and types for all duct work and registers, including the heating and cooling supply ducts, passive return air ducts or transfers, the locations for the mechanical ventilation air inlet (at least 8 feet away from any exhausts or condensers), and all exhaust outlets. If chases or other spaces are to be dedicated to duct runs, indicate this on the plans.

This level of detail can be referenced in contract documents so you know exactly what you will be getting. These documents can provide guidance in the field for proper installation.

DUCT WORK LOCATION
Clearly identify on plans and drawings the locations, sizes, and types for all duct work and registers.

Energy Performance and Commissioning

Best Practice: Air conditioners and heat pumps should be evaluated after installation with a duct pressure test and, if needed, a smoke test to identify the location of leaks. Procedures are discussed in the *Site Supervisors* chapter.

Building Science Corporation has identified performance testing as a key reason for substantial reductions in callbacks (BSC 2003).

EVALUATION
Evaluate air conditioners and heat pumps after installation.

Occupant Health and Safety

The following best practices should be included in the house design:

- All combustion appliances in the conditioned space must be sealed combustion or power-vented. Specifically, any furnace inside conditioned space shall be a sealed-combustion 90%+ (AFUE of 90 or greater) unit. Any water heater inside conditioned space shall be power vented or power-direct vented. Designs that incorporate passive combustion air supply openings or outdoor supply air ducts not directly connected to the appliance should be avoided. Gas cooking ranges shall follow the practices described in the second bullet.

- Use sealed-combustion gas fireplaces to eliminate the threat of harmful combustion gases from entering the house. All fuel-burning fireplaces should have sealed combustion and be properly vented to the outside. If not properly vented and sealed, the fireplace can produce harmful combustion pollutants that may be emitted into the home, such as carbon monoxide, nitrogen dioxide, and sulfur dioxide.

- Provide filtration systems for forced air systems that provide a minimum atmospheric dust spot efficiency of 30% or MERV of 6 or higher. MERV (Minimum Efficiency Reporting Value) is a measure of an air filter's efficiency at removing particles. A fiberglass panel filter may have a MERV of 4 or 5. Critical areas in hospitals may use a MERV 14 filter. Electronic air cleaners should be used with caution because the ozone they produce may affect sensitive individuals.

- Indoor humidity should be maintained in the range of 25% to 60% by controlled mechanical ventilation, mechanical cooling, or dehumidification. See www.buildingscience.com/resources/moisture/relative_humidity_0402.pdf.

- Carbon monoxide detectors (hard-wired units) shall be installed (at one per every approximate 1,000 square feet) in any house containing combustion appliances and/or an attached garage.

- Maximize hard surface areas (tile, vinyl, hardwood) to better manage dust for health purposes. For slab-on-grade houses, it also reduces the cooling loads.

- Information relating to the safe, healthy, comfortable operation and maintenance of the building and systems that provide control over space conditioning, hot water, or lighting energy use shall be provided to occupants.

Mechanicals Management and Appliances

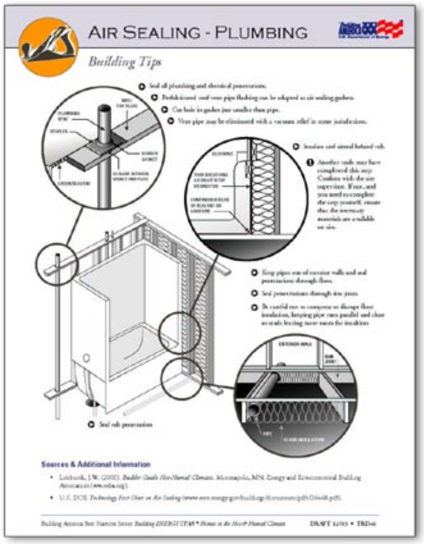
Plumbing

Water heater efficiency is described by the energy factor rating. The Consumers' Directory of Certified Efficiency Ratings, Gas Appliance Manufacturers Association (GAMA) provides a concise listing of energy factors for water heaters of all fuel types at www.gamanet.org.

Best Practice: Do not install plumbing in exterior walls. Seal around plumbing penetrations in all exterior surfaces, surfaces that border on unconditioned spaces, and

PLUMBING SEALING
Seal plumbing penetrations in exterior surfaces and keep plumbing out of exterior walls.

FIGURE 20: Additional Plumbing Air Sealing Building Tips can be found in the *Trades* Chapter.



between floors. Use fire-resistant sealant in plates between floors.

Best Practice: Because of the dominance of warm temperatures in the hot-dry and mixed-dry climates, water heaters are best kept out of living spaces, where heat losses could add to the cooling load. A garage location may also save money by eliminating the need for power-vented equipment. Water heaters can be located freestanding or enclosed within a closet in the garage. If enclosed, ventilation grilles will be needed to provide combustion air.

Air admittance vents may be accepted in some jurisdictions and can help reduce the quantity of needed vent pipes. More information can be found at www.toolbase.org.

Best Practice: Be sure to specify insulation requirments for pipes, especially pipes that will be covered by the slab, or will otherwise be inaccessible.

Water Heaters

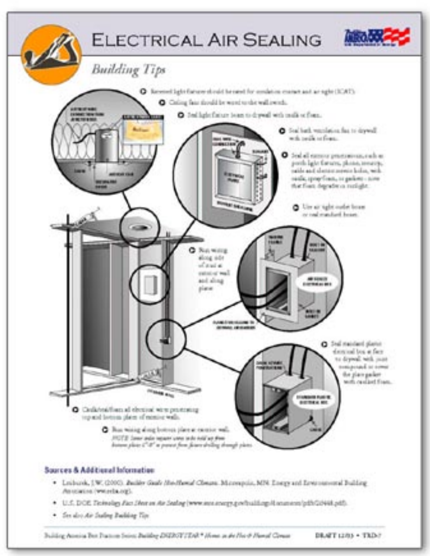
Water heaters come in many shapes, sizes, and efficiencies. The Oregon Department of Energy maintains a list of high-efficiency water heaters that qualify for state tax credits. The list contains high-efficiency gas combustion water heaters, instantaneous (tankless) water heaters, and water heating heat pumps. You may consider these products for your projects. The tax credits only apply to Oregon installations by Oregon taxpayers. See the list at: http://www.energy.state.or.us/res/tax/appheat.htm.

Electrical

Best Practice: Seal around wires penetrating all exterior surfaces, surfaces that border on unconditioned spaces, and between floors. Use fire-resistant sealants between floors. If recessed downlights are to be used they should be rated for insulated ceilings and airtight (ICAT).

ICAT is a combination of two standards. The first is ASTM E283, the standard for testing restricted air movement (ASTM 2004) and the second is Underwriters Laboratory standard for direct burial in insulation contained in the Luminaires

FIGURE 21: Additional Electrical Air Sealing Building Tips are available in the *Trades* chapter.



WATER HEATERS
Keep the water heater away from living spaces to avoid adding to the cooling load. If it will be located in a living space, use a power-vented water heater.

SPECIFY INSULATION REQUIREMENTS
Be sure to specify insulation requirements for pipes, especially pipes that will be inaccessible.

ELECTRICAL SEALING
Seal all wire penetrations.

standard (UL 1598). The ICAT standard originated in the State of Washington building code and now, as part of the International Energy Efficiency code, covers almost 75% of the country's population. See the *Trades* chapter for *Building Tips* for electricians for more information.

Consider the use of recessed downlights and other fixtures that qualify for ENERGY STAR labels. Highly energy-efficient recessed downlight fixtures that have undergone stringent testing are available for purchase at the following DOE sponsored Web site: www.pnl.gov/cfldownlights/. The lights featured are ICAT rated and hard-wired for compact fluorescent bulbs. Fixed prices have been negotiated for the featured fixtures. Using compact fluorescent lamps in lighting fixtures will reduce energy usage and lower the cooling load.

Appliances

Major appliances meet high-energy efficiency standards using current appliance ratings. Only those appliances in the top one-third of the DOE Energy Guide rating scale should be selected (see list at: www.eere.energy.gov/consumerinfo/energy_savers/appliances.html). One approach is to use appliances with the ENERGY STAR label.

Sources & Additional Information

- Air Conditioning Contractors of America. *Manual D: Residential Duct Systems*. ACCA, Arlington, VA. www.acca.org.
- Air Conditioning Contractors of America. *Manual J: Residential Load Calculation, Eighth Edition*. ACCA, Arlington, VA. www.acca.org.
- Air Conditioning Contractors of America. *Manual S: Residential Equipment Selection*. ACCA, Arlington, VA. www.acca.org.
- Air Conditioning Contractors of America. *Manual T: Air Distribution Basics for Residential and Small Commercial Buildings*. ACCA, Arlington, VA. www.acca.org.
- American Society of Heating, Refrigerating, and Air-Conditioning Engineers, INC (ASHRAE). 2003. *ASHRAE Standard: Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings*. ASHRAE, Atlanta, GA.
- ASTM. 2002. S*tandard Practice for Installation of Exterior Windows, Doors, and Skylights*. ASTM E2112-01.
- *ASTM 2003 WK2469 New Standard (Formerly E1465-92) Guide for Radon Control Options for the Design and Construction of New Low Rise Residential Buildings*.
- ASTM 2004. *Standard Test Method for Determining Rate of Air Leakage through Exterior Windows, Curtain Walls, and Doors Under Specified Pressure Differences across the Specimen*. ASTM E283-04.
- Building Science Corporation (BSC). 2003. 9. *BSC Final Report: Lessons Learned from Building America Participation, February 1995-December 2002*. National Renewable Energy Laboratory, Golden, CO.
- Building Science Corporation. 2003b. 1.C.2.1 *Report Expert Meeting Summary*. National Renewable Energy Laboratory, Golden, CO.
- CARB (Consortium for Advanced Residential Buildings). 2004. NREL/SR-550-34560. National Renewable Energy Laboratory, Golden, CO. Available at www.buildingamerica.gov.
- Carmody, John, Stephen Selkowitz, Dariush Arasteh and Lisa Heschong. 2000. *Residential Windows: A Guide to New Technologies and Energy Performance*. W. W. Norton and Company, New York. www.wwnorton.com/npb/welcome.htm.
- California Energy Commission. 2005. *2005 Residential Compliance Manual*. Sacramento, CA. www.energy.ca.gov/2005publications/CEC-400-2005-005/CEC-400-2005-005-CMF.pdf.
- Edminster, Ann, Betsy Pettit, Kohta Ueno, Stephanie Menegus, and Steven Baczek. 2000. “Case Studies in Resource-Efficient Residential Building: The Building America Program.” *2000 ACEEE Summer Study Proceedings*. ACEEE, Washington, D.C.
- Garrison, Tim. 2004. *Nation’s Building News Online*, 27 April 2004. www.nbnnews.com.
- Institute for Business and Home Safety. The IBHS has building guidelines and public information. www.ibhs.org.
- Lstiburek, Joseph. 2004. *EEBA Builders Guide: Hot-Dry and Mixed-Dry Climates*. EEBA, Minneapolis, MN. www.eeba.org/bookstore.

- Lstiburek, Joseph. 2003. *EEBA Water Management Guide*. EEBA, Minneapolis, MN. www.eeba.org/bookstore.

- McIlvaine, Janet, David Beal, and Philip Fairey, III. 2001. *Design and Construction of Interior Duct System. Report Number FSEC-PF-365-01*, Florida Solar Energy Center, Cocoa, FL. www.fsec.ucf.edu/bldg/baihp//pubs/interior_ducts.pdf.

- Parker, D.S., J. R. Sherwin and M. T. Anello, 2001. *"FPC Residential Monitoring Project: New Technology Development — Radiant Barrier Pilot Project," Contract Report FSEC-CR-1231-01*, Florida Solar Energy Center, Cocoa, FL. www.fsec.ucf.edu/bldg/pubs/rbs/index.htm.

- Rudd, Armund. 2003. *Refrigeration System Installation and Startup Procedures, and Air Conditioning System Efficiency*. Building Science Corporation, Westford, MA. www.buildingscience.com/resources/mechanical/air_conditioning_equipment_efficiency.pdf.

- Sherman, Max and Iain Walker. 1998. "Can Duct Tape Take the Heat?" *Home Energy*, Berkeley, CA. www.homeenergy.org/898ductape.title.html.

- Straube, John. 2001. *Canadian Architect*. "Wrapping it Up". May, 2001. www.cdnarchitect.com.

- (SBIC) Sustainable Buildings Industry Council. 2003. *Green Building Guidelines: Meeting the Demand for Low-Energy, Resource-Efficient Homes*. U.S. DOE. Washington, D.C. document available at www.SBICouncil.org.

- Treidler, B., M.P. Modera, R.G. Lucas, J.D. Miller. 1996. *Impact of Residential Duct Insulation on HVAC Energy Use and Life-Cycle costs to Consumers.* ASHRAE Transactions: Symposia, AT-96-13-4. American Society of Heating, Refrigerating, and Air Conditioning Engineers, Atlanta, GA.

- U.S. Department of Energy. 2000. *Technology Fact Sheet on Weather Resistive Barriers*. DOE/GO-102000-O769, Washington D.C. Available on the Web at www.eere.energy.gov/buildings/documents/pdfs/28600.pdf.

- U.S. Environmental Protection Agency. 1994. *Model Standards and Techniques for Control of Radon in New Residential Buildings*.

- U.S. Environmental Protection Agency. 2000. *Duct Insulation: Air Distribution System Improvements*. EPA 430-97-028. Washington, D.C. www.energystar.gov/ia/new_homes/features/DuctInsulation1-17-01.pdf.

- United States Environmental Protection Agency. 2001. *Building Radon Out: A Step by Step Guide on How to Build Radon Resistant Homes*. www.epa.gov/199/radon/images/buildradonout.pdf.

- Vieira, Robin K., Parker, Danny S., Klongerbo, Jon F., Sonne, Jeffrey K., Cummings, Jo Ellen. 1996. "How Contractors Really Size Air Conditioning Systems." Florida Solar Energy Center, Cocoa, FL. www.fsec.ucf.edu/bldg/pubs/ACsize/index.htm.

- Walker, I., M. Sherman, M. Modera, and J. Siegel. 1998. *Leakage Diagnostics, Sealant Longevity, sizing and Technology Transfer in Residential Thermal Distribution Systems*. Lawrence Berkeley Natonal Laboratory, Berkeley, CA. http://ducts.lbl.gov/Publications/lbl-41118.pdf.

- Yost, Nathan. May 2003. "The Case for Conditioned Unvented Crawl Spaces." *Building Safety Journal*. www.buildingscience.com/resources/articles/24-27_Yost_for_author.pdf.

Web Sites Not Included with Published Documents Above

(See Appendix V for more information on Web sites.)

- www.blueprintforsafety.org
- www.buildingamerica.gov
- www.buildingscience.com/housesthatwork/airsealing.htm
- www.buildingscience.com/housesthatwork/buildingmaterials.htm
- www.buildingscience.com/housesthatwork/hothumid/montgomery.htm
- www.buildingscience.com/housesthatwork/hothumid/orlando.htm
- www.buildingscience.com/resources/mechanical/advanced_space_conditioning.pdf
- www.buildingscience.com/resources/moisture/relative_humidity_0402.pdf
- www.buildingscience.com/resources/roofs/unvented_roof_summary_article.pdf
- www.buildingscience.com/resources/walls/problems_with_housewraps.htm
- www.buildingscience.com/resources/walls/default.htm
- www.certainteed.com/pro/insulation
- www.eere.energy.gov/buildings
- www.eere.energy.gov/consumerinfo/energy_savers/appliances.html
- www.eere.energy.gov/consumerinfo/energy_savers/r-value_map.html
- www.eere.energy.gov/consumerinfo/factsheets/landscape.html
- www.eere.energy.gov/weatherization/hazard_workshop.html
- www.efficientwindows.org/index.cfm
- www.energycodes.gov
- www.energy.state.or.us/res/tax/appheat.htm
- www.energystar.gov/index.cfm?c=bop.pt_bop_index
- www.epa.gov/iaq/whereyoulive.html
- www.epa.gov/radon/zonemap.html
- www.fema.gov
- www.fsec.ucf.edu/bldg/science/basics/index.htm
- www.fsec.ucf.edu/bldg/pubs/rbs/index.htm
- www.gamanet.org
- www.nahbrc.org/docs/mainnav/moistureandleaks/792_moisture.pdf
- www.natresnet.org
- www.nfrc.org
- www.ornl.gov/sci/roofs+walls/insulation/ins_16.html
- www.ornl.gov/sci/roofs+walls/radiant/rb_01.html
- www.pnl.gov/cfldownlights/
- www.sbse.org/resources/sac/index.htm
- www.susdesign.com/sunangle
- www.toolbase.org
- www.uky.edu/Agriculture/Entomology/entfacts.htm
- www.wunderground.com