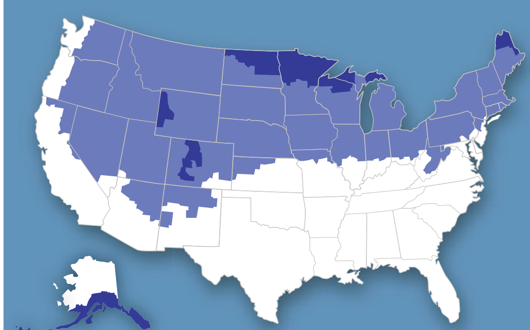
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

BUILDING TECHNOLOGIES PROGRAM

VOLUME 12.

BUILDING AMERICA BEST PRACTICES SERIES



COLD & VERY COLD CLIMATES

BUILDERS CHALLENGE GUIDE TO

40% Whole-House Energy Savings in the Cold and Very Cold Climates

PREPARED BY

Pacific Northwest National Laboratory
& Oak Ridge National Laboratory

February 2011

Building America U.S. Department of Energy

February 2011 • PNNL-20139

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Builders Challenge Guide to 40% Whole-House Energy Savings in the Cold and Very Cold Climates

PREPARED BY

The Building America Research Teams

Building America Industrialized Housing Partnership
led by the Florida Solar Energy Center

Building Industry Research Alliance
led by ConSol

Building Science Consortium
led by Building Science Corporation

Consortium for Advanced Residential Buildings
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Integrated Building and Construction Solutions

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Preface

This best practices guide is the twelfth in a series of guides for builders produced by the U.S. Department of Energy's Building America program. This guidebook is a resource to help builders design and construct homes that are among the most energy-efficient available, while addressing issues such as building durability, indoor air quality, and occupant health, safety, and comfort. With the measures described in this guide, builders in the cold and very cold climates can build homes that have whole-house energy savings of 40% over the Building America benchmark with no added overall costs for consumers.

The best practices described in this document are based on the results of research and demonstration projects conducted by Building America's research teams. Building America brings together the nation's leading building scientists with over 300 production builders to develop, test, and apply innovative, energy-efficient construction practices. Building America builders have found they can build homes that meet these aggressive energy-efficiency goals at no net increased costs to the homeowners. To recognize builders who are producing the most efficient, sustainable, and comfortable homes on the market, DOE created the Builders Challenge. Homes that qualify for the Builders Challenge must achieve a 70 or lower on the EnergySmart Home Scale (E-Scale), which is described in this document.

This document represents a step up from our first cold best practices document (*Volume 3. Builders and Buyers Handbook for Improving New Home Efficiency, Comfort, and Durability in the Cold and Very Cold Climate*), which aimed at achieving energy-efficiency savings of 15% above the benchmark, a home built to the 1993 Model Energy Code, the code in effect at the time of the program's inception. Building America has continued to develop systematic building strategies that meet more challenging efficiency goals over time. The Building America research projects described in this guide achieve energy savings of 40% greater than the Building America benchmark home.

The national energy and building codes are revised on a 3-year cycle. The most recent versions are the 2009 International Energy Conservation Code (IECC) and the 2009 International Residential Code (IRC). The recommendations in this document meet or exceed the requirements of the 2009 IECC and 2009 IRC. Beginning in fiscal year (FY) 2011, Building America research projects are using the 2009 IECC as the benchmark for analysis of home energy efficiency.

Building America welcomes reader feedback on all volumes of the Best Practices Series. Please submit your comments via e-mail to George James (George.James@ee.doe.gov)

You can learn more about Building America and download additional copies of this document, other best practices, research reports, and case studies at

www.buildingamerica.gov

The Building America recommendations provided in this guide meet or exceed the code requirements of the 2009 International Energy Conservation Code (2009 IECC) and the 2009 International Residential Code (2009 IRC).

Acknowledgments

The U.S. Department of Energy's Building America program comprises public-private partnerships that conduct systems research to improve overall housing performance, increase housing durability and comfort, reduce energy use, and increase energy security for America's homeowners. Program activities focus on finding solutions for both new and existing homes, as well as integrating clean onsite energy systems that will allow the homebuilding industry to provide homes that produce more energy than they use. In addition to the DOE management and staff, the Building America program includes several consortia, four DOE national laboratories, and hundreds of builders, research organizations, manufacturers, and service providers. Building America also co-manages the ENERGY STAR Program along with the U.S. Environmental Protection Agency, and works with other federal agencies to coordinate research efforts and disseminate findings. Together, all of these partners make the program a valuable source of knowledge and innovation for U.S. home builders.

The DOE Building America program funded the development of this series of handbooks. DOE also funded the Building America consortia and national laboratories to conduct the research that forms the basis of these best practices. The consortia that conducted the research described in this report are listed to the right. These were the Building America research teams through fiscal year 2010. The consortia have taken on the hard work of applied research, field testing, training builders, and transforming results into best practices. Most of the drawings, descriptions, photos, and case studies in these guides originated with these research partners.

Hundreds of builders across the country have chosen to work with Building America and its partners on research projects to further our understanding of building science. These builders deserve thankful recognition for their dedication to continually improving the quality and energy efficiency of the homes they build and for their contributions to our understanding of how buildings work. Five builders from the cold climate are showcased in case studies in this document: Devoted Builders of Kennewick, Washington; East Liberty Development, Inc., and S&A Homes of Pittsburgh, Pennsylvania; Nelson Construction of Farmington, Connecticut; Rural Development, Inc., of Turners Falls, Massachusetts; and Shaw Construction of Grand Junction, Colorado, and the City of Aspen, Colorado. Examples from these and other cold climate builders are used throughout the document to illustrate construction best practices.

FY2010 Building America Research Teams

These Building America research teams partner with all segments of the building industry to conduct research and demonstration projects that develop, analyze, and test strategies and technologies for improving building performance and energy efficiency. Building America teams who participated in the preparation of this document included

Building America Industrialized Housing Partnership
led by the Florida Solar Energy Center
www.baihp.org

Building Industry Research Alliance
led by ConSol www.bira.ws

Building Science Consortium
led by Building Science Corporation
www.buildingscienceconsulting.com

Consortium for Advanced Residential Buildings
led by Steven Winter Associates, Inc.
www.carb-swa.com/index.html

Integrated Building and Construction Solutions
www.ibacos.com

National Association of Home Builders Research Center
www.nahbrc.com

Several national laboratories participated in this project. Pacific Northwest National Laboratory and Oak Ridge National Laboratory led the writing and production of this document. The National Renewable Energy Laboratory made its library of Building America documents available to the authors, reviewed this guide, and posted it to the Web. Scientists at Lawrence Berkeley National Laboratory reviewed the document as well.

The authors and DOE wish to thank the many contributors who have made this project a success. We would especially like to thank graphic artist Christina Van Vleck who designed this document and prepared many of its illustrations.

Contents

Chapter 1.
Welcome

"Teaming with Building America is a great marketing tool because we can honestly say we are building houses better."

Chris Nelson, President of Nelson Construction, Farmington, Connecticut

Constructing energy-efficient, durable, and comfortable homes makes economic sense—for the builder, the consumer, the real estate professional, and the environment. In a time of significant challenges for the real estate community, Building America builders have made an important discovery—their homes are selling while their competitors' homes are not. They are making some other exciting discoveries as well. They are having fewer callbacks and complaints. Instead, buyers are calling to thank them for lower utility bills. Builders of all sizes are discovering the benefits of teaming with Building America. In fact, nine of the nation's ten largest builders in 2009 were Building America partners.

Learn what hundreds of builders across the country have already discovered—it isn't difficult to build energy-efficient homes that are more healthy, durable, and comfortable to live in, while cutting energy bills nearly in half. Building America will help show you how.

This guide can help you apply Building America research to your own projects to achieve energy savings of 40% over the Building America benchmark (a home built to the 1993 Model Energy Code). Using these whole-house building principles, your homes will meet and exceed the new 2009 International Energy Conservation Code (2009 IECC) and the 2009 International Residential Code (2009 IRC). Whether you're a multi-state builder with managers, sales staff, designers, site superintendents, and installers on your staff,

(top) Nelson Construction worked with DOE's Building Science Consortium to achieve HERS scores in the low 50s on houses such as the one above in Farmington, Connecticut.

(bottom) East Liberty Development, Inc., and S&A Homes teamed with DOE's IBACOS research team to build six highly efficient homes in inner-city Pittsburgh as part of a neighborhood revitalization.

The 2009 IECC and 2009 IRC mandate a significant increase in energy efficiency in new home construction. Changes in these codes represent an approximate 15% improvement in energy efficiency over the 2006 IECC. This guide will help builders meet and exceed these new requirements. The 2009 IECC and 2009 IRC requirements are noted in green throughout this guide.

Building America welcomes reader feedback on all volumes of the Best Practices Series.

Please submit your comments via e-mail to: George James (George.James@ee.doe.gov).

or a small builder wearing many of these hats yourself, this guide can help you understand and apply the latest building science to differentiate yourself in a struggling new-construction market and to meet the new tougher energy codes.

Break open this guide and you'll find the following:

Chapters 2 through 4 provide the data to make the case to upper management, yourself, and your shareholders for the value of energy-efficient construction, including research on consumer preferences, competitive advantage, and incentives. Here you'll also find business management tools, sales training tips, and marketing strategies.

Chapters 5 and 6 explain the whole-house approach to building science and special considerations for building in the cold and very cold climate.

Chapters 7 through 9 provide construction recommendations to architects and engineers based on Building America research, with guidance on best practices for meeting and exceeding code in regard to moisture management, insulation, and air sealing of home foundations, walls, and roofs. Guidance is also provided on windows, heating, air conditioning, ventilation, plumbing, and electrical systems. Occupant safety and health related to equipment installation issues are discussed in Chapter 10. Chapter 11 provides guidance on inspecting and commissioning. Chapter 12 covers construction contracts, scheduling, and training. Chapter 13 provides a useful checklist of all of these recommendations. Chapter 14 provides handy two-page how-to field guides on specific energy-efficiency measures for installers.

Throughout the ensuing chapters, real-life examples are highlighted from exceptional builders in the cold and very cold climates. Case studies at the back of the report tell how five builders achieved significant energy savings using Building America practices.

Finally, appendices provide a homebuyers' checklist, a DOE–sponsored resource for meeting codes, a glossary, and acronym list.

For More Information

You can learn more about Building America and download additional copies of this document, other best practices, case studies, and research reports at www.buildingamerica.gov.

Chapter 2.

The Business Case for Building High-Performance Homes

The number one reason identified by builders for building energy-efficient homes is to differentiate themselves from their competition (NAHBRC 2007). Builders who use Building America principles are among the most successful in the United States today.

Builders and Building America

Building America has worked with production builders since 1995 to improve the energy efficiency, durability, comfort, environmental performance, and quality of new homes. Building America and its partners have conducted building science field research with builders throughout the country to test techniques, materials, and processes in real-world situations. As of August 2010, the program has contributed directly to the energy-efficient construction of more than 42,200 homes, and builders and vendors that have worked with Building America have influenced over a million new homes.

Nine of the nation's ten largest builders are Building America partners. Twenty-three of Building America's 350+ builder partners made *Builder Magazine*'s Builder 100 list of the top 100 builders of 2009 (based on home sale closings). While new home starts in 2009 dropped to their lowest on record since 1959, twelve of Building America's partners moved up in the Builder 100 rankings.

Qualifying for programs such as DOE's Builders Challenge and ENERGY STAR provides an easy way to show consumers that your company's homes are a cut above the competition.

"Working with Building America helped us understand there is serious return on investment when you put these energy-efficiency features into your house."

Todd Winnor, project manager,
S&A Homes, Pittsburgh

Building America U.S. Department of Energy

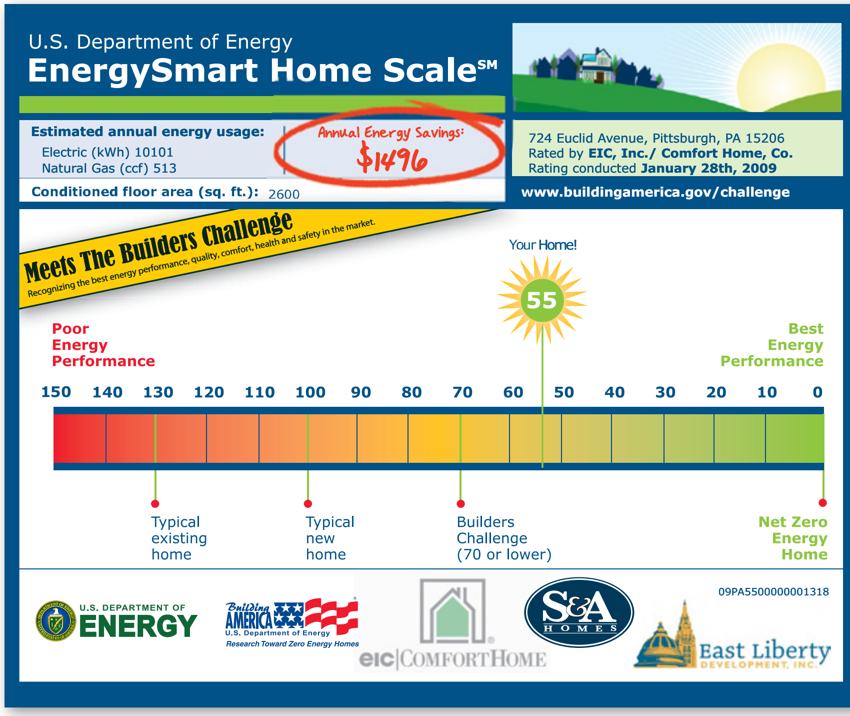
Learn more about Building America at www.buildingamerica.gov.

CHAPTER TOPICS

Building America builders ranked highest in overall customer satisfaction in 11 of 17 new home markets and were among the top three in all 17 markets surveyed by J.D. Power in 2010. Building America builders Shea Homes and Standard Pacific Homes each took highest ranks in three markets and KB Homes took highest rank in two markets. Building America builders also ranked in the top three in all 17 markets in J.D. Power's new-home quality study. Other Building America partners that placed highly include Centex, David Weekley Homes, Del Webb, DR Horton (shown here), John Wieland, K. Hovnanian, Lennar, Pardee Homes, Pulte, Ryan, and Ryland (J.D. Power press release 9/15/2010).

Builders Challenge

The Builders Challenge label prominently features the EnergySmart Home Scale (or E-Scale), which shows a Home Energy Rating System (HERS) score. A house built to the 2006 IECC would score 100; a home that uses no more energy than it can produce with onsite generation such as solar panels would have a HERS score of 0. Builders Challenge homes must score 70 or lower.



The Business Case for Energy Efficiency

The world of new home construction is not the same place it was five years ago. The pace of new construction is still down in most markets. The good news is the public's awareness of energy efficiency is up and in most markets around the country builders who emphasize energy-efficient construction have found that they are outselling their competition.

The business case for high-performance, energy-efficient construction is straightforward and is based on the following points:

1. Consumers prefer energy-efficient homes.
2. Builders can use energy efficiency and other high-performance features to gain competitive advantage. Consumer preference and competitive advantage lead to more and faster sales.
3. Building America homes can meet energy-efficiency goals at no net increased costs to homeowners when added costs are balanced with utility savings.
4. New state and federal building codes are now a driving force in energy-efficient construction.

> "In this hypercompetitive market, green features have become a crucial selling point, since new-homebuyers are seeking to save on energy costs, as well as to increase the value of their home."

Dale Haines, senior director of the real estate and construction industries practice at J.D. Power and Associates *(J.D. Power press release 9/15/2010)*.

Consumer Preferences

McGraw Hill Construction (2009) reports that "green building has grown in spite of the market downturn. Green seems to be one area of construction insulated from the downturn, and we expect green building will continue to grow over the next five years, despite negative market conditions, to be a $96–$140 billion market." Most of the features listed by McGraw Hill in defining a green building involved energy efficiency. The report notes that green construction can help differentiate builders and stabilize their business in a struggling market. McGraw Hill also found word-of-mouth referrals are the most likely way that consumers learn about green home builders (McGraw Hill Construction 2009).

Surveys show that consumers want energy efficiency and they are willing to pay for it:

- 87% of homebuyers said a greener, more energy-efficient home is a priority in a *Better Homes and Gardens Magazine* survey (Patterson 2010).
- 94% of builders report that their buyers want more energy-efficient new homes; 55% said buyers specifically want ENERGY STAR® homes (NAHB 2009).
- Most builders (69%) indicated that some of their buyers are willing to pay extra for green amenities; 9% indicated that most were. 25% of builders said buyers want homes with more recycled materials and less material use overall (NAHB 2009).
- 91% of homebuyers preferred an energy-efficient home with lower utility bills to a cheaper home (sales price 2% to 3% lower) without the energy-efficient features (Rice 2009).
- Homebuyers are willing to pay on average $6,000 more for their new home to save $1,000 annually on energy costs (Rice 2009).
- 86% of Americans would choose one home over another based on its energy efficiency. Yet 78% of the homeowners polled said no one talked to them about energy efficiency during the buying process (*National Builder News*, April 9, 2007).
- Energy improvements topped the list of how homeowners would spend an extra $5,000 on their new homes (NAHBRC 2009).
- 90% of new homebuyers are willing to spend more for energy efficiency—up to $17,000 more (McGraw Hill 2007).
- 84% listed energy efficiency as the most important factor in their appliance purchases (Maynard 2009).

Building America Partners on *Builder Magazine* Top 100 List 2009

Ranking	Building America Partner
1	D.R. Horton
2	Pulte
3	Lennar
5	KB Home
6	Centex
7	K. Hovnanian
8	Habitat for Humanity Int'l
9	The Ryland Group
10	Beazer Homes USA
11	Meritage Homes Corp
12	Standard Pacific Corp
13	Taylor Morrison Homes
17	David Weekley Homes
18	Weyerhaeuser Real Estate Co
20	Shea Homes
29	William Lyon Homes
32	WCI Communities
44	Mattamy U.S. Group
63	John Wieland Homes and Neighborhoods
64	ICI Homes
67	Heartland Homes
71	Castle & Cooke
90	Ideal Homes

Nine of the nation's ten largest builders are Building America partners. Twenty-three of Building America's 350+ builder partners made *Builder Magazine's* Builder 100 list of the top 100 builders of 2009 (based on home sale closings) in a very difficult year for U.S. home builders.

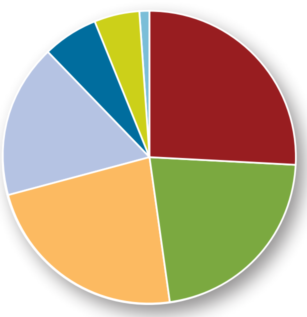
"The downturn of the housing market—along with intensified competition for a very limited pool of homebuyers—has reinforced the importance of customer focus for new-home builders. Many builders that were unable to maintain this focus consistently have had to exit the marketplace."

Dale Haines, senior director of the real estate and construction industries practice at J.D. Power and Associates. "
(J.D. Power press release 9/15/2010)

Nelson Construction of Farmington, Connecticut, teamed with Building America research partner Building Science Corporation to cut energy use by 50% compared to the Building America benchmark.

How homeowners would spend an extra $5,000 on their new homes

(Figure source: NAHBRC)



- **26% would pay for energy improvements**
- 22% for new countertops
- 23% for other
- 17% for upgraded flooring
- 6% for upgraded appliances
- 5% for upgraded bathroom features
- 1% for new siding

"The longer they [builders] wait to build energy-efficient houses, the further behind they are going to be. It's definitely what buyers are looking for. It is better to be proactive than reactive."

Rich Coyle, vice president for building science at DR Horton's Sacramento division

Competitive Advantage

Competitive advantage is critical, especially in a down market when buyers are few and their choices abound for new and existing homes.

In 2009, Nelson Construction experienced a high volume of sales at its Hamilton Way development in Farmington, Connecticut, in a market that had almost completely stopped. Nelson built 10 Builders Challenge homes and all sold within 2 months of completion.

"My utility bills went through the roof in 2009. Anyone who was looking to buy was definitely considering what kind of performance their house was going to get," said Peter Baker, a senior associate with Building Science Corporation who helped Nelson achieve energy savings of 50% over the Building America benchmark.

Building America analysis predicted annual utility savings of $2,429 to $3,070 on the 2,960- to 3,540-square foot homes, compared to the Building America benchmark, based on local utility rates of $0.16/kWh or $1.60/therm.

"'Building Better' is now the tag line for Nelson Construction. It has become part of our company identity that we build energy-efficient, healthy, sustainable homes," said Chris Nelson, president of Nelson Construction.

Nelson adds: "Now we have a marketing advantage. We are looked at as one of the experts in the industry related to energy efficiency. From the developer's side, it helps us get approvals, which is really a big deal and nothing we were thinking about when we decided to do this. Towns want to work with builders who are doing things better."

Cost-Neutral Energy Savings

Building America case studies prove that energy-efficient construction does not have to cost more for homebuyers. Tradeoffs in building material choices, streamlining of processes, and tax incentives and rebates can minimize cost increases for builders.

Building America builders have experienced upfront cost savings in numerous ways that balance out against the increased costs of some energy-efficiency measures. For example, they have used advanced framing techniques, which cut down on lumber costs; designed on a 2-foot grid to reduce materials cost and waste; downsized HVAC equipment through better insulation and air sealing of the building envelope and right sizing of equipment; and substituted rigid foam for structural panel sheathing for better performance at neutral cost. They've cut labor costs by spray foaming rather than individually caulking rim joists, by shortening and simplifying duct runs, and by moving ducts out of awkward crawlspaces and attics into conditioned space. Builders have reduced construction time and money by prefabricating duct components on the ground and by factory-building frame wall components or using structural insulated panels (SIPs). They've streamlined processes, realized savings from vendors, reduced or eliminated callbacks, and cut back on costly schedule overruns through good upfront planning with integrated management techniques, ongoing training of subcontractors, and interim and final inspections and commissioning.

Case Studies Prove Homebuyers Profit

In 2007 through 2010, Building America researchers worked with five builders in the cold climate to build more than 161 homes that met or exceeded 40% energy savings. In each of those projects, homeowners' utility bill savings yielded a net profit each year, after subtracting increased mortgage costs. Researchers from Building Science Corporation modeled one house plan from each builder using EnergyGauge and BEopt software. Table 2.1 shows the energy cost savings calculated for each builder's home, the incremental increase in the annual mortgage to cover the costs of the energy-efficiency features versus the cost of a mortgage for a typical house, and the net annual cash flow to the homebuyer. In every case the homebuyer came out ahead, with net gains ranging from $277 to $1,392 per year. These examples show how homebuyers can realize a positive return from energy-efficiency improvements no matter how the stocks and bonds markets are doing.

Table 2.2 details costs associated with one builder's choices in energy-efficient features. The builder, Rural Develoment, Inc., spent $11,800 more per unit to add energy-efficiency measures they had not incorporated into previous projects, including a solar water heater, triple-pane windows, and double-stud walls. Some changes may actually cut costs; in this case switching from an oil boiler to a high-efficiency gas space heater saved the builder $5,000 per unit. When these costs are added to the sale price of the home (at a 10% markup) and incorporated into a 30-year mortgage at 7% interest, it adds $1,050 per year to the homeowner's mortgage but calculated utility savings are $2,192 annually per home, so the homeowner actually nets a profit of $1,142 per year.

Energy-Saving Features Are "In"

Energy-saving features are "in" according to builders polled by the National Association of Home Builders at the 2010 NAHB International Builders' Show in Las Vegas, in January 2010. When builders were given a list of 40 features and asked which ones they were likely to include in new homes, five of their top ten choices were energy-related. "Builders will focus heavily on energy-saving features. Things we thought were consumer necessities—such as granite countertops in the kitchen or home offices—are not on the list," Rose Quint, assistant vice president for NAHB's Survey Research Economics and Housing Policy Group, told media at the 2010 NAHB International Builders Show (RREA 2010).

Items most likely to be found in new homes for 2010 (NAHB):

1. Walk-in closet in master bedroom
2. Separate laundry room
3. Insulated front door
4. Great room
5. Low-E windows
6. Linen closet
7. Programmable thermostat
8. Energy-efficient appliances and lighting
9. Separate shower and tub in master bedroom
10. Nine-foot ceilings on first floor (instead of 2-story foyer)

"We sold all of our homes in less than two months. The people who were buying our homes wanted to buy something that was built better."

Chris Nelson, president of Nelson Construction, Farmington, Connecticut, who teamed with Building America on 10 homes that sold at $649,000 and up in a dead market.

Table 2.1. Cold Climate Case Study Costs and Savings

Every Building America project yielded net annual gains for homeowners, after deducting increased mortgage costs from annual utility bill savings.

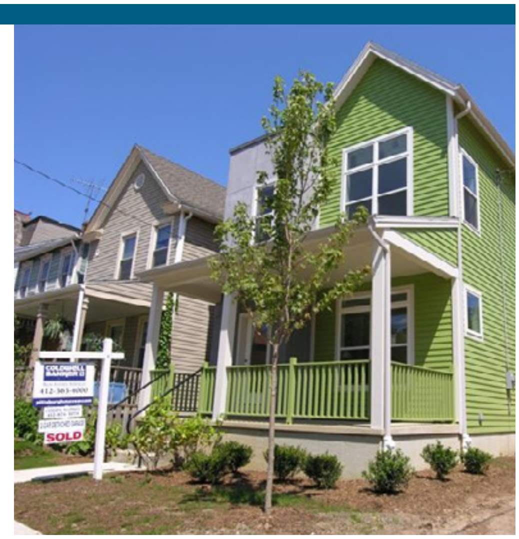
Builder	Cost Increase for Energy Improvements	Added Annual Mortgage Cost for Energy Efficiency	Annual Utility Bill Savings vs. Benchmark	Net Annual Cash Flow
Devoted Builders	$10,000	$809	$1,333	$524
East Liberty Development, Inc./S&A Homes	$9,900	$792	$1,699	$907
Nelson Construction	$25,740	$2,055	$3,447	$1,392
Rural Development, Inc.	$11,850	$1,050	$2,192	$1,142
Shaw Construction	$6,200	$498	$775	$277
In every case study, the energy-efficiency improvements are actually money makers for the homeowners.				
Utility bill savings relative to the Building America benchmark were calculated by Building Science Corporation using EnergyGauge and BEopt 0.8.6 software. Cost increases are based on builder estimates and additional data sources such as RS Means, DEER, supplier cost bids, etc. A 10% markup is assumed and the cost is converted into an annuity assuming a 7% loan over 30 years. Inflation, incentives, and rebates are not considered. For multi-family buildings, costs are estimated per-unit costs. The Building America benchmark is a home built to the 1993 Model Energy Code.				

Table 2.2. How Much Does it Cost to Reach 40% Energy Savings?

One Example in the Cold Climate

The example shown here is for a typical 1,390-ft², 2-story, 3-bedroom, 2-bath, home built by Rural Development, Inc. (RDI), in Greenfield, Massachusetts. Estimated costs for energy-efficiency measures are listed in the table below. As shown, when increased mortgage costs are balanced against utility savings, the homeowner comes out ahead $1,142 each year.

Energy-Efficiency Feature	Added Cost, per Home, Over Builder's Conventional Practice
Double-wall construction	$2,500
R-50 attic insulation	$300
R-40 floor insulation	$540
Triple-pane windows	$3,000
Solar water heating system	$9,750
Heating system	($5,000)
Ventilation system	$450
100% CFL lighting	$114
ENERGY STAR appliances	$190
Total	**$11,844**
Annual cost (when incorporated into a 30-year loan at 7% interest)	$1,050
Annual utility bill savings	$2,192
Net Annual Cash Flow to Homeowner	**$1,142**
Conclusion: These energy-efficiency improvements are actually money makers for the owner of this home.	
Cost estimates were provided by the builder. A 10% markup is assumed; incentives and rebates are not considered.	



S&A Home's highly efficient Building America homes in Pittsburgh sold for $216,000 to $305,000 in a challenged neighborhood, where median prices had been well under $100,000.

Federal, State, and Local Incentives and Tax Credits

Incentives can help offset costs as builders transition to more energy-efficient construction materials. A wide range of incentives and tax credit opportunities are available at the federal, state, and local level. In addition to financial incentives for energy-efficient homes, some local governments offer streamlined permitting processes for green and energy-efficient projects.

For information on what is available to you, visit the Database of State Incentives for Renewables and Efficiency (DSIRE), at www.dsireusa.org. DSIRE is a comprehensive source of information on state, local, utility, and federal incentives, tax credits, and policies that promote renewable energy and energy efficiency. Established in 1995 and funded by the U.S. Department of Energy, DSIRE is an ongoing project of the North Carolina Solar Center and the Interstate Renewable Energy Council.

Although the $2,000 Federal tax credit for building a new energy-efficient home expired on December 1, 2009, other tax credits for specific measures still exist; see www.energystar.gov/index.cfm?c=tax_credits.tx_index.

For new home construction, until December 31, 2016, a tax credit covering 30% of the cost (with no upper limit) is available for geothermal heat pumps, small residential wind turbines, and solar energy systems. Also available until December 31, 2016, is a 30% tax credit with up to $500 per 0.5 kW of power capacity for residential fuel cells and micro-turbine systems. This site provides easy-to-follow information about eligibility and applying for these tax credits.

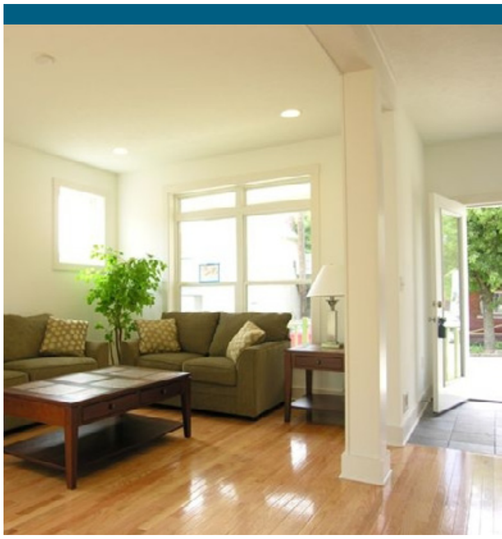
The ENERGY STAR "Special Offer/Rebate Finder" website below enables a user to enter a zip code to receive accurate information about rebates and sales tax exemptions or credits for qualified products. These include most major appliances, residential ventilation fans, heating and cooling equipment, insulation, roof products, windows, doors, lighting, water heaters, and office equipment. See www.energystar.gov/index.cfm?fuseaction=rebate.rebate_locator.

ENERGY STAR has more information for builders interested in qualifying homes through ENERGY STAR's new home program at www.energystar.gov/index.cfm?c=bldrs_lenders_raters.nh_benefits_builders.

Builders can check ENERGY STAR's New Homes Partner Locator page for state contacts for locally administered builder incentives for new ENERGY STAR homes at www.energystar.gov/index.cfm?fuseaction=new_homes_partners.locator.

"The market is tough and these are spec homes. People who bought were buying for energy efficiency, because of the location, and because of the quality."

Eric Jester, project manager of East Liberty Development, Inc. who worked with the Building America team IBACOS and builder S&A Homes on an urban in-fill project, which sparked a turnaround in a struggling Pittsburgh neighborhood with increased housing values, decreased vacancy rates, and a 60% drop in crime rates.



"We benefitted greatly from this project, not only from the exposure, but from learning what it takes to get to the 40% mark."

Todd Winnor, project manager
S&A Homes, Pittsburgh

In a 2010 study of 16,400 new homebuyers, market research organization J.D. Power found that new-home builders are increasingly using green and energy efficiency features as a selling point—65% of new home builders identified the green features of their homes to homebuyers in 2010, up from 48% in 2009, and 61% of new homebuyers perceived their new home as environmentally friendly, compared with only 31% in 2009.

For More Information on the Business Side of Building

2009 IECC. 2009. *International Energy Conservation Code*, International Code Council (ICC), Washington, D.C. www.iccsafe.org/Store/Pages

2009 IRC. 2009. *International Residential Code - One and Two-Family Dwellings*, International Code Council (ICC), Washington, D.C. www.iccsafe.org/Store/Pages

Builders Magazine. 2009. "Builder 100." www.builderonline.com

Caufield, John. 2010. "Hard Landing, The housing market may have finally hit bottom in 2009," Builder Online, posted May 4, 2010, www.builderonline.com/sales/hard-landing.aspx

Dakin, Willard, David Springer, and Bill Kelly. 2008. "Case Study: The Effectiveness of Zero Energy Home Strategies in the Marketplace." In *Proceedings of the 2008 ACEEE Summer Study on Energy Efficiency in Buildings*, American Council for an Energy-Efficient Economy, Washington D.C.

J.D. Power and Associates. 2010. "Satisfaction with New-Home Builders and New-Home Quality Reach Historic Highs, as Home Builders Respond to Tough Market Conditions by Improving Products and Service," press release 09/15/2010, http://businesscenter.jdpower.com/news/pressrelease.aspx?ID=2010177

Maynard, Nigel F. 2009. "New Survey Finds Energy, not Water, Drives Appliance Purchases." *Builder Magazine*, March 27, 2009. www.builderonline.com/appliances/survey-finds-energy-drives-appliance-purchases.aspx

McGraw Hill Construction. 2009. 2009 Green Outlook: Trends Driving Change. http://construction.com/market_research/reports/GreenOutlook.asp.

Nation's Building News. 4/9/07. "Builders Need to Make Energy Efficiency a Selling Point." Energy Pulse Survey by Shelton Group, reported in *Nation's Building News Online*. National Association of Home Builders. www.nbnnews.com/NBN/issues/2007-04-09/Front+Page/index.html

Nation's Building News. 4/16/07. "In a Down Housing Market, Green Demand Exceeds Supply." *Nation's Building News Online*. National Association of Home Builders. www.nbnnews.com/NBN/issues/2007-04-16/Front+Page/index.html

National Association of Home Builders (NAHB). 2009. "Baby Boomers Want Convenience and Energy Efficiency in New Homes According to New Survey," news release 9/15/2009 www.nahb.org/news_details.aspx?sectionID=1196&newsID=9696/

NAHBRC. 2007. B*uilding America Challenge Survey of Builders and Consumers*. Proprietary survey commissioned by DOE and conducted by the NAHBRC as part of the Annual Consumer Practices Survey. National Association of Home Builders Research Center, Upper Marlboro, MD.

Patterson, Jean. 2010. "Buyers seek smarter and smaller homes, survey says," *The Seattle Times*, Feb. 8, 2010, http://seattletimes.nwsource.com/html/homegarden/2011019068_cozyhomes09.html

Register Real Estate Advisors. January 25, 2010. "What do homebuyers want in 2010?" http://rrea.com/news/what-do-homebuyers-want-in-2010-builders-hope-they-know/

Rice, Alison. 2009. "Consumers Rethink Home-Buying Priorities," *Builder 2009*. January 22, 2009. www.builderonline.com/housing-trends/consumers-rethink-home-buying-priorities.aspx

Codes as Drivers

New building energy codes are now a driving force in energy-efficient construction.

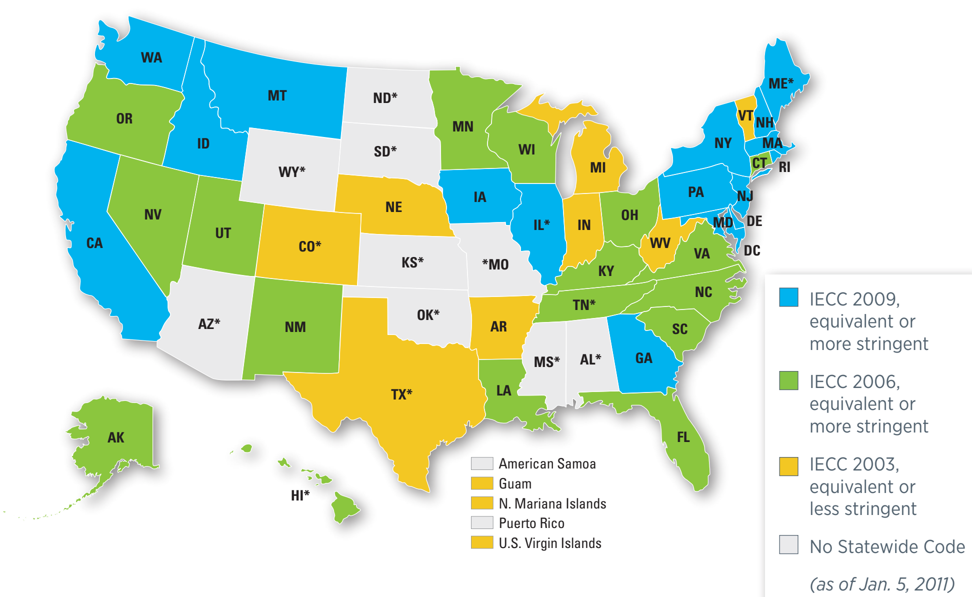
The International Energy Conservation Code

The 2009 International Energy Conservation Code (2009 IECC) was published in December 2008 and has gotten a boost in adoption from the American Recovery and Reinvestment Act (ARRA) of 2009. States seeking funding for building programs through the Act must show that they have adopted building energy codes for residential buildings that meet or exceed the 2009 IECC. The provisions of the 2012 IECC were finalized at the Final Action Hearings in November 2010.

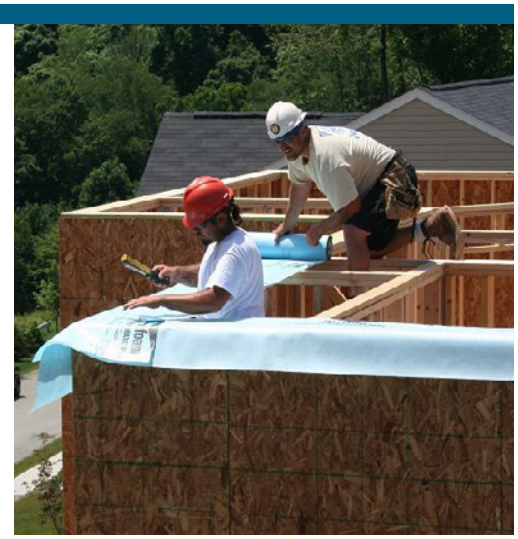
State Energy Codes

There are 34 states that are wholly or partially in the cold or very cold Building America climate zones (which correspond to IECC climate zones 5, 6, 7, and 8; see maps in Chapter 5.) The status of residential energy code adoption in each state (as of January 5, 2011) is summarized in the map below. Several of these states have recently undertaken or are in the process of adopting building energy code revisions and many expect to adopt IECC 2009 by June 2013 including the following: CT, FL, HI, MI, MN, NC, NE, NM, NV, OH, OR, SC, TX, UT, VA, VT, WI, and WV. Table 2.3 provides additional details on each state's energy code adoption status and planned activities. (See www.energycodes.gov/states for up-to-date state information on energy code adoption).

Status of Residential Energy Codes in Cold Climates



*Adoption by county/jurisdiction above state-mandated minimum



"Working on this project with Building America made me realize this is the way of the future. There is no getting around this. For years, builders tried to save dollars here and there. Code changed big time in 2009 and a lot of builders were not ready for it. Working with Building America has put us ahead of the curve," said Todd Winnor, project manager, S&A Homes, Pittsburgh.

"Everyone needs to understand that the difference between the way we have been building in the past and the way we have to build now is night and day. Everyone complains about what a pain the change in codes is, but I think we have to start being smarter about how we build."

Todd Winnor, project manager
S&A Homes, Pittsburgh

For More Information on Codes

2009 IECC. 2009. *International Energy Conservation Code*, International Code Council (ICC), Washington, DC.
www.iccsafe.org/Store/Pages

2009 IRC. 2009. *International Residential Code - One and Two-Family Dwellings*, International Code Council (ICC), Washington, DC.
ww.iccsafe.org/Store/Pages

Building Energy Codes Program. U.S. Department of Energy Office of Energy Efficiency and Renewable Energy,
www.energycodes.gov

Table 2.3. Status of Energy Code Adoption in U.S. Cold Climate States (as of August 2010)

States	Statewide Residential Code	Adoption by Local County/Jurisdiction	Notes
Alaska	State Specific	Mandatory	The Building Energy Efficiency Standard (BEES) uses the 2006 International Energy Conservation Code, with Alaska-Specific Amendments. The state code includes an optional performance-based compliance approach that is completely separate from the IECC. A home that receives an energy rating and achieves a level of four stars using the AKwarm™ method meets the state code. The Alaska Housing Finance Corporation reports that code compliance is "most often shown" by this method.
Arizona	None	Voluntary	Many jurisdictions have adopted the IECC editions and some have adopted advanced energy codes.
California	State Specific	Mandatory	State-developed code, Part 6 of Title 24, which exceeds 2009 IECC. (New 2008 Standard, became effective Jan. 1, 2010)
Colorado	2003 IECC	Yes	Mandatory in any area that does not adopt or enforce local codes.
Connecticut	2006 IECC	Mandatory	2006 IECC with amendments effective August 1, 2009.
Iowa	2009 IECC	Mandatory	
Idaho	2009 IECC	Mandatory	2009 IECC effective January 2011
Illinois	2009 IECC	Mandatory	
Indiana	State	Mandatory	State code based on 92 MEC, currently updating to the 2009 IECC
Kansas	None	Yes	Homebuilders or realtors must disclose information about the home energy performance parameters on the Kansas Energy Efficiency Disclosure Form
Massachusetts	2009 IECC	Mandatory	2009 IECC with amendments
Michigan	2003 IRC	Mandatory	2003 IRC with reference to 2004 IECC supplement, currently in the process of updating to 2009 IECC
Minnesota	State	Mandatory	Based on 2006 IRC with amendments, very prescriptive
Missouri	None	Voluntary	None statewide. State-owned single-family and multi-family residential buildings must comply with the latest edition of the MEC or ANSI/ASHRAE Standard 90.2-1993.
Montana	2009 IECC	Mandatory	

States	Statewide Residential Code	Adoption by Local County/Jurisdiction	Notes
Nebraska	2003 IECC	Mandatory	
New Hampshire	2009 IECC	Mandatory	
New Jersey	2009 IECC	Mandatory	2009 IECC with amendments.
New Mexico	2006 IECC	Mandatory	In the process of adopting a new residential code that is 20% more stringent than the 2006 IECC. Currently out for public review.
Nevada	2006 IECC	Mandatory	
New York	2009 IECC	Mandatory	2009 IECC with amendments, effective December 2010.
North Carolina	2006 IECC	Mandatory	2006 IECC with amendments. No HVAC trade-offs are allowed and 0.40 SHGC or better required in all climate zones.
North Dakota	None	Voluntary	2006 IRC and IECC contingent upon local adoption effective August 1, 2009.
Ohio	2006 IECC	Mandatory	With alternative prescriptive path www.com.state.oh.us/dic/Documents/bbst_PARTA-Residential.pdf
Oregon	State	Mandatory	State-developed code based on the 2006 IRC.
Pennsylvania	2009 IECC	Mandatory	
Rhode Island	2009 IECC	Mandatory	2009 IECC became effective July 1, 2010.
South Dakota	None	Voluntary	2006 IECC is voluntary.
Utah	2006 IECC	Mandatory	2009 IECC for multi-family high-rise and low-rise buildings. 2006 IECC for one- and two-family dwellings.
Vermont	State	Mandatory	Based on the 2000 IECC with amendments. 2009 IECC rulemaking due by January 1, 2011.
Washington	State	Mandatory	State-developed code based on 2009 IECC, effective Jan. 1, 2011.
Wisconsin	State	Mandatory	State developed code meets/exceeds 2006 IECC.
West Virginia	State	Mandatory	2003 IECC with amendments. 2006 IECC is encouraged.
Wyoming	None	Voluntary	Adoption by jurisdiction, City of Cheyenne adopted 2006 IRC.

Chapter 3.
Business Management Tools

Builders learn quality management concepts at a Building America workshop, conducted by Building America research team lead IBACOS.

For builders who want to build high-performance homes and achieve a healthy bottom line, sound business systems are a critical part of the picture.

This chapter introduces the following four practices to aid in construction planning and management:

- quality management
- integrated design
- value engineering
- prototype development.

Each of these four practices has value on its own, but they work best when applied as part of an overall management system suited to an individual business.

Quality Management

Three terms are often used when describing quality programs: quality management, quality assurance, and quality control. These terms are described below, based on the definitions provided by the American Society for Quality (www.asq.org).

- **QUALITY MANAGEMENT:** a process for achieving maximum customer satisfaction at the lowest overall cost to the organization while continuing to improve the building process. A quality management system documents the structure, responsibilities, and procedures required to achieve your company's goals. A related term—total quality management—refers to all members of an organization participating in improving processes, products, services, and the culture in which they work.

> "We have seen a direct impact on our quality through the Building America program. We are able to build a better product because of our consistent approach [in implementing Building America practices]."

Josh Robinson, vice president of Operations for Pulte, North Inland Empire Division of California

CHAPTER TOPICS

New Tradition Homes in Washington State, incorporates these elements in its quality management program: an in-house building science team, a corporate commitment to energy efficiency, ongoing training of staff, participation in federal and regional energy-efficiency programs, a dedicated air sealing contractor, third-party performance testing, in-house marketing research, and an ongoing, interactive relationship with their heating, ventilation, and air conditioning (HVAC) contractor.

- **QUALITY ASSURANCE:** the planned and systematic activities that provide confidence that a product fulfills requirements for quality. These activities may include tests, such as blower door tests, inspections, checklists, and systematic training.

- **QUALITY CONTROL:** the operational activities used to fulfill requirements for quality. These activities include evaluations, such as statistical studies to evaluate product variation, expected failure rates, and corrective actions.

Many companies formalize their quality management processes and practices. Other companies simply incorporate tools into their business practices that help to improve quality. Some companies choose to become certified under third-party quality assurance programs. The important point is to plan for quality.

Building America's Integrated Building and Construction Solutions (IBACOS) research team has developed comprehensive quality management guidelines for builders. The recommendations encompass all facets of the builder's organization including leadership, strategic planning, customer satisfaction, performance management, jobsite responsibilities, safety, workforce development, quality construction processes, and trade contractor and supplier partnerships. This operations evaluation is based on the National Association of Homebuilders Research Center's National Housing Quality Program. The recommendations can be found in Appendix D of the report, *Achieving 30% Whole-House Energy Savings Level in Marine Climates*, prepared by Building America's research teams (DOE 2006) and available at http://apps1.eere.energy.gov/ buildings/ publications/pdfs/ building_america/39743.pdf.

In accordance with these guidelines, Building America recommends that a quality management approach include these four ingredients:

- **TRAINING AND EDUCATION** – for builders, trades, and sales staff (including participating in certification programs); see Chapter 12 for more information on training

- **OPERATIONAL EVALUATION** – described above and in DOE 2006

- **PERFORMANCE-BASED STANDARDS** – described throughout this guide; examples include DOE's Builders Challenge and EPA's Thermal Bypass Checklist

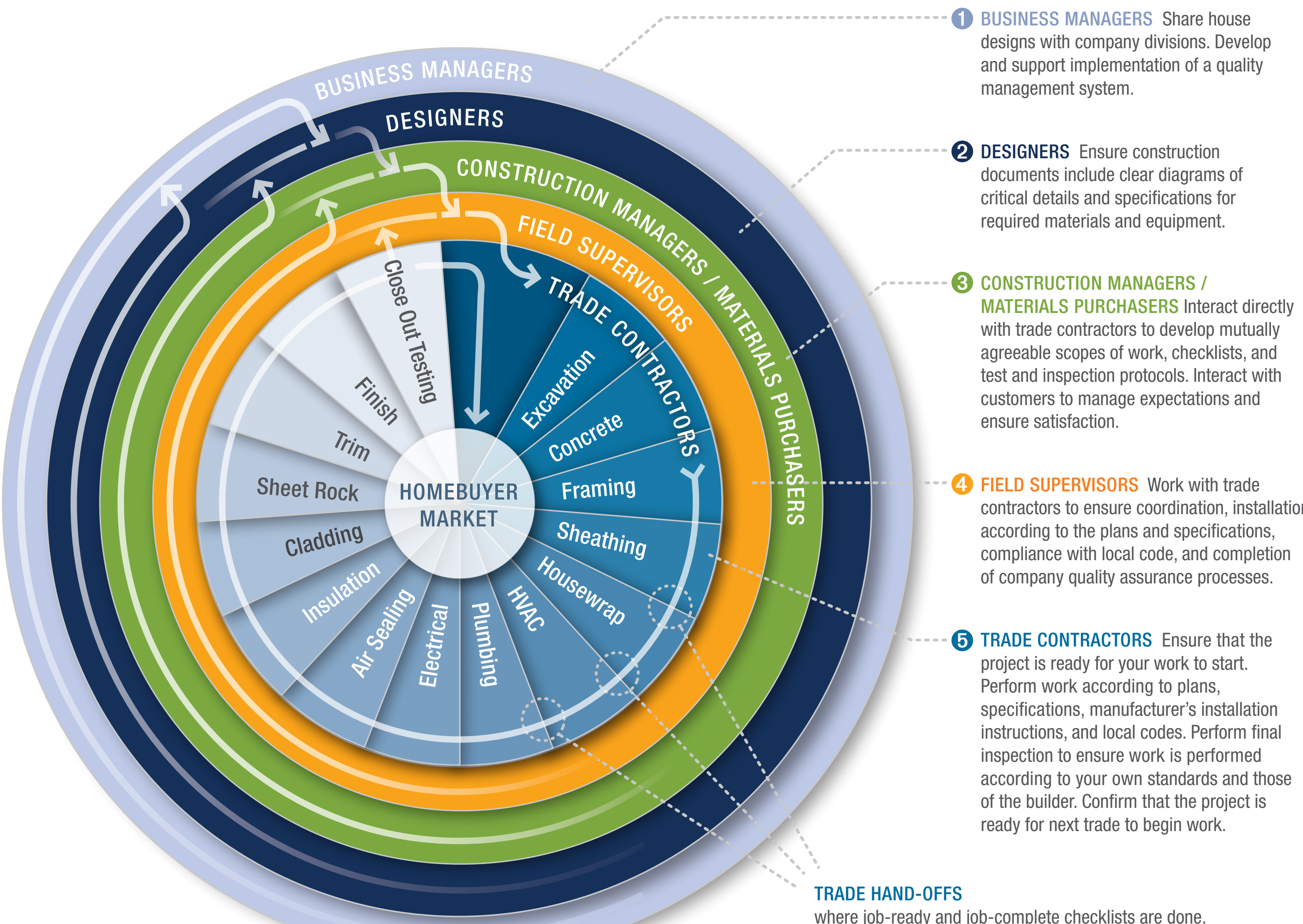
- **VERIFICATION/COMMISSIONING/FEEDBACK** – testing and inspections; see Chapter 11 for more details.

"While a quality home need not necessarily be a high-performance home, any high-performance home MUST be a quality home. The quality management approach is an essential element of the Building America approach to homebuilding because it is the main vehicle for moving from science to implementation."

Building Industry Research Alliance, a Building America research team lead

Quality Management Process Wheel

Information flows both to and from each part of the company including subcontractors.



The final judge of quality is the consumer. If a builder consistently meets consumer expectations, the rewards are tremendous. Consumer research organization J.D. Power found that truly delighted homebuyers (those rating their builders a 10 on a 10-point scale) recommend their builder to nearly twice as many people as the average new homebuyer (J.D. Power 2008).

"We have enjoyed our new Marsala townhome for about seven months. The integral concrete and insulation construction has made ours an extremely quiet, energy-efficient and comfortable home.... Devoted Builders has certainly lived up to their name by their devotion and committment to the total quality of the Mediterranean Villas townhome community. We are glad to be here."

Mr. and Mrs. Stewart, homeowners at Devoted Builders' Mediterranean Villas, Pasco, Washington, a Building America partner

For More Information on Quality Management

ASQ. 2008. *ISO 9001:2000 Interpretive Guide for the Design and Construction Project Team*. American Society for Quality Press, Milwaukee, WI. www.asq.org/quality-press.

2009 International Energy Conservation Code. Section 103.2, "Information on Construction Documents." International Code Council (ICC), Washington, D.C. www.iccsafe.org/Store/Pages.

Building Science Corp. 2008. *Quality Assurance Roadmap for High Performance Residential Buildings*. Building Science Corporation. www.buildingscience.com/documents/guides-and-manuals/gm-building-america-quality-assurance-roadmap/view?searchterm=quality.

DOE. 2006. *Building America Residential System Research Results: Achieving 30% Whole-House Energy Savings Level in Marine Climates, January 2006 – December 2006*, NREL/SR-550-39743, prepared by the Building America research teams BIRA, BSC, CARB, Davis Energy Group, FSEC, IBACOS, NAHBRC and NREL for the U.S. Department of Energy, http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/39743.pdf.

Haas Davenport, Linda. 2000. *The Scopes of Work Program: Procedures and Standard to Increase Quality*. NAHB BuilderBooks, Washington, D.C., http://store.builderbooks.com/cgi-bin/builderbooks.

ISO 9000. *Quality Management Systems*. International Organization for Standardization, www.iso.org.

NAHBRC. 2000. *Quality Assurance System for Wood Framing Contractors: National Quality Housing*. National Association of Home Builders Research Center. www.pathnet.org/si.asp?id=478.

NAHBRC. 2008. *Scopes of Work for High-Performance Homes*. Prepared for the National Renewable Energy Laboratory by the National Association of Home Builders Research Center, Upper Marlboro, MD.

Integrated Design

The integrated design process, including energy-efficiency modeling and appropriate HVAC system sizing, is at the heart of Building America recommendations. Integrated design is a process by which all the various building subsystems are evaluated for the local climate and their interrelationships are analyzed, planned, and optimized. The goal is to gain value at every step of the design process (value engineering) rather than relying solely on negotiation and procurement to manage costs.

Before World War II, a house was often designed and built under the watchful eye of a single person. As construction projects have become more complex and expertise has become more specialized, the decision-making, design, and construction processes have been divided among managers, designers, site superintendents, vendors, subcontractors, and the trades. Along with increasingly diverse teams, building materials and construction techniques have also multiplied and become more technical.

The integrated design process invites today's larger design and construction teams to share information and insights to achieve the kind of whole-house perspective and understanding that previously came with a single master builder.

Builders who use the integrated design approach focus on whole-house performance. They start by looking at how all the systems in the house (HVAC, insulation, walls, ceilings, and windows) work together to achieve a house that performs well in terms of energy efficiency, air quality, and moisture management. This investment in up-front planning is especially worthwhile for production builders because they reap the benefits with multiple applications of a house design.

In contrast, builders using typical design practices often start by emphasizing cost and size. With these external factors decided, they move through a linear process ending with house construction; building performance is considered as an afterthought or not at all.

Traditional Design Processes

Typically a design process includes the following steps.

1. PROGRAMMING:
In this conceptual development and planning stage, the price range, square footage, number of stories, lot sizes, general features, and styles are determined.

2. SCHEMATIC DESIGN:
Preliminary designs are developed including floor plan sketches, number of bedrooms, major options, basic circulation and function locations, as well as some elevation concepts.

3. DESIGN DEVELOPMENT:
Preliminary structural, mechanical, electrical, and plumbing plans are drawn.

4. CONSTRUCTION DOCUMENTS:
Final working drawings and specifications are ready for bidding and code approval.

The traditional design process tends to be linear, with input coming sequentially. Sometimes design decisions are made before the input is available. Sometimes the input is not part of the formal design process, but comes in the field where access to information is limited and decisions must be based on the materials, expertise, and conditions at hand. For example, HVAC equipment may not be sized until the installer shows up on the project site, and important decisions such as routes and sizes for ducts may not occur until installation work begins in the field.

When RDI designed its Solar Village in western Massachusetts, it used an expanded integrated design process and included architects, engineers, Building America staff, and trades (carpenters, plumbers, electricians, solar installers, etc.) in the initial planning meetings.

Related Standards & Procedures

- ISO 9000, Quality Management Systems
  www.iso.org
- 2009 International Energy Conservation Code, Section 103.2 “Information on construction documents,” International Code Council (ICC), Washington, DC. Available for purchase at www.iccsafe.org/Store/Pages

Building America team IBACOS encouraged S&A Homes to use an integrated design approach and to design the home around the HVAC system when it built its urban in-fill homes on narrow city lots.

"The idea is a whole-house system integration approach. We wanted to make sure the HVAC system and mechanicals were not an after-thought. A lot of builders put up the frame and don't really consider where duct lines and supply risers need to go or how the plumbing lines and drain lines may be routed. Before the HVAC guy gets in there and starts hacking up floor trusses, plates, and walls, let's put some thought into what needs to be routed where. The best approach is to start at the initial design of the building, making sure that all of these considerations are accounted for when you are planning."

Kevin Brozyna, a project manager for IBACOS, a Building America team lead

Integrated Design Process

A key idea behind integrated planning is that decisions about all building systems, including equipment selection, sizing, and placements, are made within the design process, not as afterthoughts in the field. The decisions are made with the help of analytical tools and the input of all relevant disciplines. Rather than a linear traditional process, the integrated process involves looping in ongoing input from relevant sources.

The following are steps within the integrated design process.

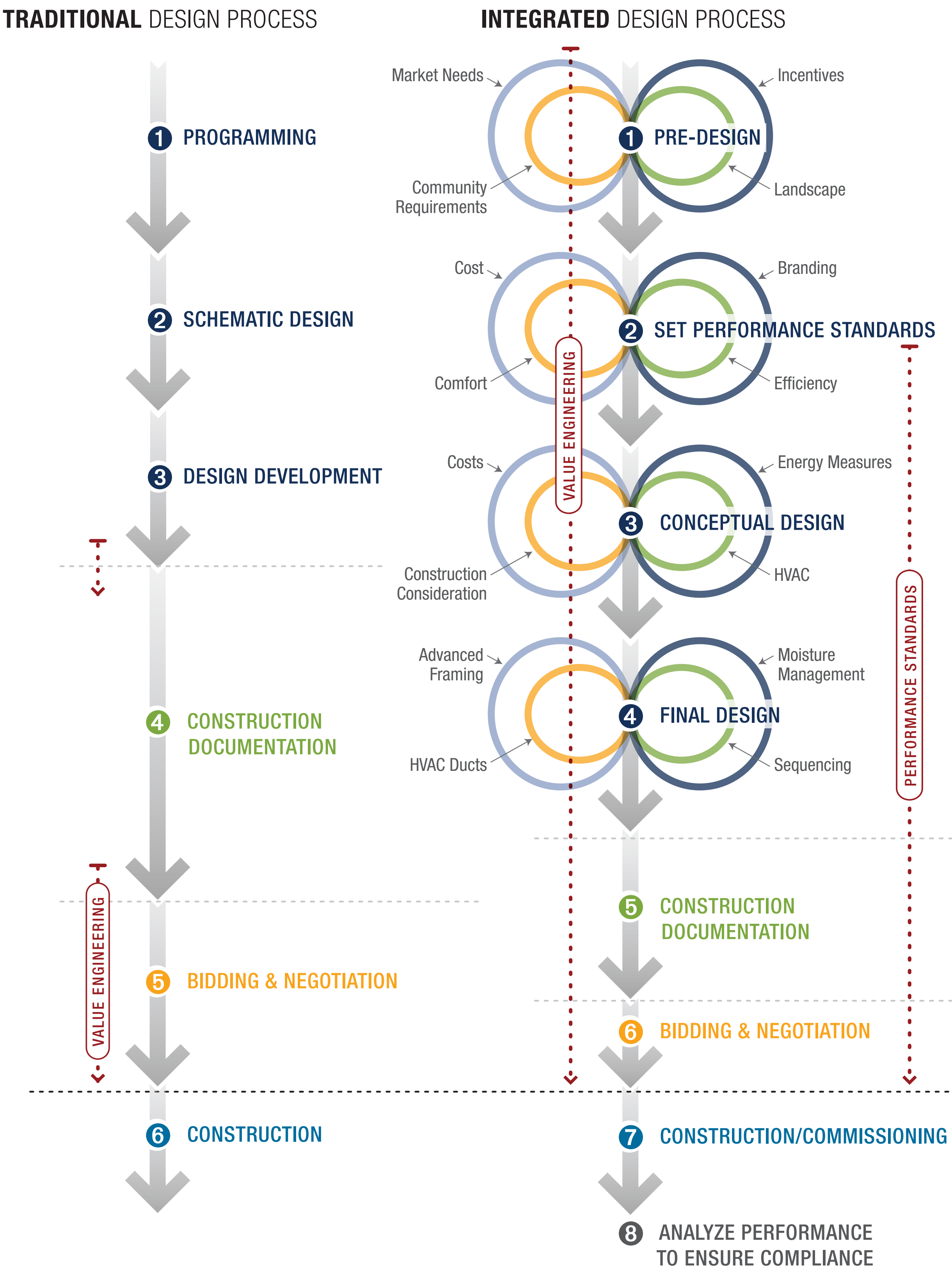
PRE-DESIGN – Bring together a diverse and knowledgeable team. The makeup of the team and members' roles will vary depending on the project or objective under consideration. Community design may benefit from ecologists, landscape architects, or solar planners. House designs may need input from architects or designers, structural engineers, framers, and HVAC contractors. Solving a particular installation challenge could involve the site supervisor and the relevant trades. For larger-scale efforts, select a facilitator to carry the process forward and set up a schedule of needed meetings.

SET PERFORMANCE STANDARDS – Early in the design process, establish standards that the house model will be expected to achieve. Measure progress against these standards at each step. Use market data to determine the level of quality, performance, size, and cost the houses will achieve. Performance areas may include moisture management, indoor air quality, energy efficiency, HVAC comfort, and any certification requirements (for example, achieving a Home Energy Rating Scale (HERS) index score to qualify for a tax credit).

CONCEPTUAL AND PRELIMINARY DESIGNS – Gain team feedback during all phases of design and construction. Use an energy specialist to test design assumptions and simulate possible solutions. It is important to work with framing and other contractors, especially HVAC contractors, to identify conflicts and develop solutions before houses go into production. You may want to consult with code officials for any nonstandard techniques or materials. By integrating design decision-making, all parties benefit. For example, the mechanical contractor can aggressively size the HVAC equipment knowing that the thermal envelope is well insulated, properly air sealed, and third-party inspected.

Traditional Versus Integrated Design Process

The Integrated Design Process loops in design input at every stage of development *(Adapted from IEA 2003).*



"The biggest challenge was getting the subcontractors up to speed. IBACOS was great in their quality assurance, they provided a triple check in the field."

Eric Jester, project manager, East Liberty Development, Inc., Pittsburgh

"We would do mock ups of some of the assemblies at our warehouse then have the contractors come to the mockup site so they could see what we were trying to achieve. If they had any questions or suggestions for how to improve the process, we could work those out before we got into the field."

Kevin Brozyna, a project manager for IBACOS, a Building America team lead, on the East Liberty project.

FINAL DESIGN – Create specific drawings and system designs. Generate architectural, framing, HVAC, electrical, and plumbing drawings that specify locations for equipment chases and runs. Develop framing plans showing the location of every stud, floor truss, and roof truss. HVAC drawings should specify duct sizes and locations, including chases designed to carry ducts inside conditioned space. Some builders create a single system design that can be approved, installed, and warranted by any installing contractor on most of their home models. This can apply for many systems including framing, electrical, plumbing, and HVAC.

CONSTRUCTION DOCUMENTATION – Base construction documents on the final design. Include statements of work for all subcontractors. Specify installation requirements. Use job-ready and job-complete checklists for self- and third-party verification.

CONSTRUCTION/COMMISSIONING – Build the houses to the designs. After ducts are in and sealed but before insulation and sheetrock are added, conduct duct leakage tests. After insulation is added, conduct visual inspections for compaction and voids. After sheetrock and wall surfaces are added, check whole-house air leakage, temperature evenness, room pressures, ventilation, and carbon monoxide levels. Confirm that specified appliances and lighting are installed. Use the NAHB-developed HotSpot tool to check and fix problem areas (see Chapter 11 for example).

ANALYZE PERFORMANCE TO ENSURE COMPLIANCE – Use computer models to simulate the energy consumption of your designs. As construction is completed, confirm performance with the quantitative measurements listed under commissioning above, including duct blaster and blower door testing using the SnapShot form developed by Building Science Corporation (BSC) (see Chapter 9 for form, see Chapter 11 for description of tests) or use verification forms for any labeling programs you are participating in.

For More Information on Integrated Design

AIA. 2007. *The Integrated Project Delivery Guide*, the American Institute of Architects, www.aia.org/contractdocs/AIAS077630

AIA. 2010. *Integrated Project Delivery: Case Studies*, the American Institute of Architects, www.aia.org/about/initiatives/AIAB082049

ANSI. 2007. ANSI/MTS 1.0. *Whole Systems Integrated Process Guide (WSIP) 2007 for Sustainable Buildings & Communities*. Institute for Market Transformation to Sustainability. American National Standards Institute, http://webstore.ansi.org/RecordDetail.aspx?sku=ANSI%2FMTS+1.0+WSIP+Guide-2007

BC Green Building Roundtable. 2007. *Roadmap for the Integrated Design Process, Part One: Summary Guide*. Prepared by Busby Perkins+Will and Stantec Consulting for Metro Canada. Vancouver, B.C. www.metrovancouver.org/buildsmart/design/Pages/Integrateddesignprocess.aspx

International Energy Agency. 2003. *Integrated Design Process Guideline*. Prepared by sol*id*ar planungswerkstatt architects and engineers and Architeckten B+S for the IEA. www.iea-shc.org/task23/design.htm

NIBS. 2010. *Engage the Integrated Design Process*. National Institute of Building Sciences. www.wbdg.org/design/engage_process.php

Value Engineering

Value engineering has its roots in World War II. While coming up with creative substitutions for building supplies in the face of wartime shortages, staff at General Electric developed a process that had the unintended consequences of reducing costs and improving products. Value engineering has evolved into a systematic method for improving the value of goods and services by examining approaches to meeting function. Value can be increased by either meeting function more efficiently or reducing cost. Value engineering within the construction design process was developed in the 1960s.

Optimum value engineering for framing, also referred to as advanced framing, is one example of how value engineering can reduce construction costs while maintaining or improving functionality. More information on advanced framing can be found in Chapter 7. Advanced framing can be an important design feature, but value engineering can be applied to all aspects of home design.

Much of Building America's research is aimed at helping builders choose more efficient construction materials and methods to make their buildings more efficient. Building America's research takes into account energy efficiency, as well as other important aspects of functionality, such as structural needs, durability, comfort, and health. Improved quality control also means fewer callbacks which leads to more customer referrals.

Value engineering is an important part of quality management and integrated design. Production builders are in a good position to take advantage of value engineering. The investment made up front in the design process pays off in the many homes where those improved designs are applied. Value engineering is not just about reducing cost, it is about selecting the systems with the best value and recognizing synergies within the integrated design process.

For More Information on Value Engineering

Moser, Cliff. 2007. "Using Active Value Engineering for Quality Management," *Practice Management Digest*, American Institute of Architects.

SAVE International. 2007. *Value Standard and Body of Knowledge*. www.value-eng.org/pdf_docs/monographs/vmstd.pdf

As part of its strong commitment to quality assurance, Devoted Builders in Kennewick, WA, has 100% of its homes third-party tested and inspected. All homes have met the federal tax credit level of 50% savings since 2007.

"Building America showed us a way to take a good system and make it a great system."

Eric Jester, project manager,
East Liberty Development, Inc.,
Pittsburgh, Pennsylvania

S&A Homes, who worked with Building America on six above-market-rate homes in Pittsburgh, decided to push the envelope by building a prototype zero-energy home with Building America team lead IBACOS providing technical support.

“The zero-energy lab house [which S&A Homes is constructing with IBACOS] is a great project. We skipped over 50% and 60% and went right to zero energy. The lab home pushes us even further into tomorrow so we understand now what we will need to do to stay ahead of the code even 10 or 15 years from now.”

Todd Winnor, project manager,
S&A Homes, Pittsburgh, Pennsylvania

“The next community I want to do totally BuiltGreen, including the street layout, infrastructure, etc., with all Building America-level ENERGY STAR and BuiltGreen homes. My goal is to build zero energy houses. Hopefully we can get closer and closer to that, and do it sensibly.”

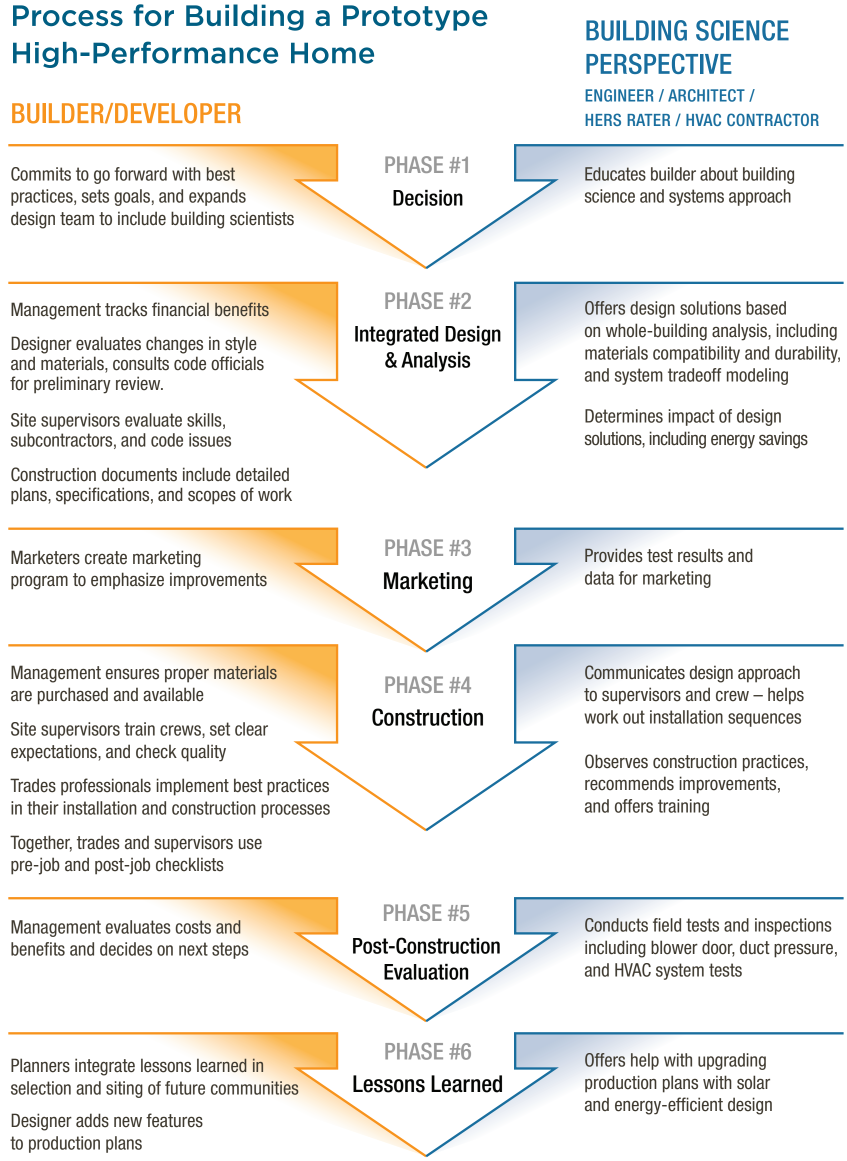
Fred Giacci, owner of Devoted Builders,
Kennewick, Washington

Managing Innovation with Prototypes

Many builders choose to try out Building America technical ideas in a prototype house. The prototype experience enables the builder to experiment with new materials, products, and construction practices with minimal costs and risks. After building one or a few prototypes, the builder decides which features to carry forward into standard construction. The chart below shows a process for working with building scientists, such as a Building America team, a HERS rater, engineer, architect, or trained staff member to build the prototype house.

Rural Development, Inc. (RDI) worked with Building America’s CARB team in 2006 on the development of a prototype home in Colrain, Massachusetts, that achieved a HERS score of 21. RDI used that experience to design 20 multi-family units in Turners Falls that achieved HERS scores of 8 to 18.

Process for Building a Prototype High-Performance Home



Chapter 4.
Selling Performance

Energy efficiency and low maintenance are a winning combination for Devoted Builders of Kennewick, Washington.

The number one reason builders give for building energy-efficient homes is to differentiate their product from their competitors, (NAHBRC 2007)—and it works. Building America has worked with hundreds of builders who have successfully used energy efficiency to sell houses. Consumers want the value and comfort high-performance homes offer. Builders want happy customers and the positive referrals they will give.

However, the sales do not happen by themselves. To recoup the investment builders make in energy efficiency and quality management, they should do the following:

- Brand and label their products for fast and easy differentiation.
- Train their sales staff to educate consumers.
- Market the sometimes hidden energy-efficient features of the home.
- Get their business name and products in front of the public.

Branding and Labeling

Branding and labeling offer two methods for gaining consumer attention and confidence. When consumers recognize a brand and associate that brand with positive attributes, they are more willing to consider purchasing that product.

Creating a recognizable brand that resonates with consumers is difficult. Large corporations that rely on consumer sales spend millions of dollars on campaigns to keep their brands fresh but familiar. This investment pays off best when products involve multiple, frequent purchases from many consumers. Most builders do not fit this equation very well—builders typically sell their products in limited markets, and homebuyers tend to hang onto their purchases for a long time.

"Real estate is perception. These homes gave a very strong perception that this was a good idea."

Eric Jester, project manager,
East Liberty Development, Inc.

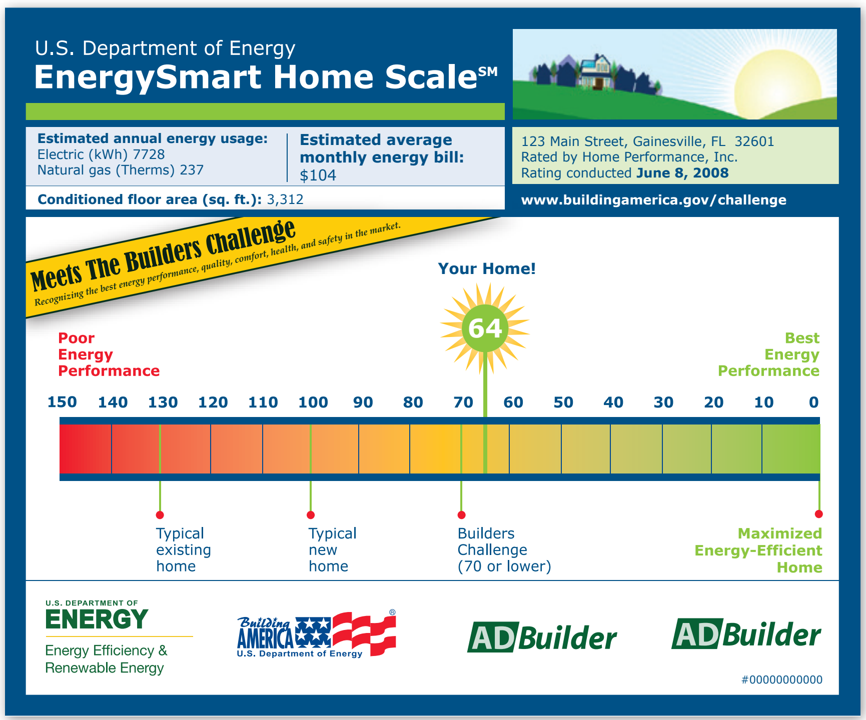
For S&A Homes and East Liberty Development Inc., energy efficiency has not only sold homes, it has helped sell the neighborhood. In a part of Pittsburgh where homes were typically selling for under $50,000, S&A's six highly efficient homes sold for $200,000 to $300,000.

Building AMERICA®
U.S. Department of Energy

CHAPTER TOPICS

Brands like Builders Challenge, ENERGY STAR, and other national and regional programs offer builders a recognizable label tied to known sets of standards. Qualifying for these nationally known programs will give your energy-efficiency efforts instant credibility, and they are excellent vehicles for leveraging your marketing dollars.

Homes that achieve a 70 or lower on the HERS Index and that meet specified quality criteria can qualify for DOE's Builders Challenge. The Builders Challenge label shown below is attached to qualifying homes. In addition to identifying the Builders Challenge brand, the label also provides useful information for consumers. The label incorporates the E-Scale, a ranking of energy efficiency based on the HERS index. Like a miles-per-gallon rating, this index gives consumers an easy way to compare and distinguish competing houses.



The ENERGY STAR logo is a label that most consumers recognize for products that are energy efficient and good for the environment. This label can be found on many consumer products ranging from computers and dishwashers to lights and homes. Homes that qualify for the ENERGY STAR for Homes label are generally about 15% more energy efficient than the 2006 IECC requirements. Whether or not builders choose to brand their homes as ENERGY STAR homes, many of the products that go into the home (or are on display in model homes) can carry the ENERGY STAR logo.

"Many builders out there have their own energy-efficiency programs, and each one is called something different. The U.S. Department of Energy is known and respected. It lends credibility if you can say you are meeting the DOE's Builders Challenge standard, as opposed to meeting a program criteria you came up with yourself."

Chris Kelly, vice president of operations, Pulte Phoenix Division

U.S. Department of Energy Builders Challenge

DOE has posed a challenge to the homebuilding industry—to make cost-effective, highly energy-efficient homes available to all Americans by 2030.

As of September 2010, 623 builders have participated in Builders Challenge, qualifying more than 3,700 homes. Homes are achieving average HERS scores of 63 and saving their homeowners on average $873 per home per year in energy cost savings.

Both the ENERGY STAR (www.energystar.gov) and the Builders Challenge (www.buildingamerica.gov/challenge) websites provide brochures and materials that builders can download for marketing.

DOE's Builders Challenge has formed national partnerships with other green building programs that provide marketing and labeling support, including the National Association of Home Builders' National Green Building Program™ (NAHB 2009), the U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED) for Homes program, and Masco's Environments for Living®.

Many Building America builders choose to offer their homeowners an energy-use guarantee. Some builders do this on their own; others work through Masco Home Service's Environments for Living program. Masco developed the program in 2001 with help from Advanced Energy Corporation and Building Science Corporation, a Building America team lead. Under Environments for Living, the home's heating and cooling energy use are estimated, and Masco guarantees the homeowner that Masco will pay them the difference if their energy bills are higher than the calculated estimate.

For homes at the Environments for Living gold and platinum level, Masco also offers a comfort guarantee promising the temperature at the thermostat will not vary more than three degrees from the temperature at the center of any conditioned room within that thermostat zone. The gold level requires that homes perform 15% above code (2006 IECC) and qualify for the U.S. EPA's ENERGY STAR® label. The platinum level requires that homes perform 30% above IECC and qualify for the U.S. DOE's Builders Challenge program.

Training Sales Staff

Having properly trained sales staff is key to helping buyers understand and appreciate the value of energy-efficiency features.

As the first builder to qualify homes for the Builders Challenge in California, the Grupe Company realized the importance of training. Grupe's approach to training involved the entire staff. Tools were developed for the sales team that included a technical sales resource binder, four hours of initial formal training, and ongoing training sessions. Training covered financial benefits for homeowners, solar power for homes, energy-efficiency features, and utility information.

Another Building America builder, Vern McKown, co-owner of Ideal Homes in Norman, Oklahoma, shared some of his tips for training and marketing at the Energy and Environmental Building Alliance (EEBA) National Conference in Denver, Colorado, in September 2009:

ENERGY STAR Update

In April 2010, the U.S. Environmental Protection Agency (EPA) announced new, more rigorous guidelines known as ENERGY STAR for New Homes Version 3.0. The updated requirements will ensure that the government's ENERGY STAR label continues to deliver a significant increase in energy efficiency over homes that are built to code and standard builder business practices. Homes that earn the ENERGY STAR label under Version 3.0 will show energy savings of 15% compared to homes built to the 2009 IECC. These guidelines are being phased in during 2011 and, on January 1, 2012, will become effective for all homes permitted on or after that date.

For more information about ENERGY STAR for Homes, see: www.energystar.gov

Builders who meet the DOE Builders Challenge criteria also qualify for the Environments for Living platinum level.

Field train sales staff every six months to keep them up to date on energy-efficiency techniques.

☑ TRAIN SALES STAFF.

- Field training of every sales person every six months, no matter how long they've been with the company.
- New hire sales training boot camp.

☑ GIVE SALES STAFF SIMPLE MESSAGES TO CONVEY, FOR EXAMPLE:

- Here's how we are different—show infrared camera photos.
- Blown-in insulation fills in nooks and crannies better than batt.
- Our duct leakage is 5%, the average is 27%.
- Our windows are high performance—less heat in, less energy loss out.
- Utilities are guaranteed.

☑ GET SALES STAFF TO WALK BUYERS THROUGH THE HOME.

- Identify four key exterior features and nine key interior features.
- Use mystery shoppers to find out what your sales folks are actually telling shoppers.
- Keep it simple—"We tell sales folks, if you aren't sure of the specifics just say 'we're better' and stop there."

☑ STAFF YOUR WEBSITE.

- Keep your website up to date.
- Make it active with a phone or email link to a live person.
- Respond to web inquiries within five minutes.
- When the typical customer looks at the website, they look at the location, street scene, elevation, and floor plan.
- Ideal Homes trains its sales staff to interrupt that typical thought process, to emphasize that "we are different and we are better," by pointing out energy savings and quality.

☑ FIND A NICHE.

- "We have a competitor 1.5 miles away who is a national builder. They sell at 78 cents/ft^2, we sell at \$1.12/ft^2. We have a different market niche," said McKown.
- All of Ideal's homes are Builders Challenge homes.

☑ DO YOUR OWN RESEARCH.

- Do exit interviews with customers, buyers, and lookers.
- Drill down for specifics in problem areas.
- Have every trade fill out job-ready and job-complete forms.
- Do NAHB quality certification audits of the whole company on a regular basis.

☑ ENSURE CULTURAL AND CORPORATE ALIGNMENT.

- Identify your company's core values and hire people who share those values.
- Ask your employees where the weak spots are and fix them.
- Ask your employees how you can help them do their jobs better.

"It's a matter of education. We sell a lot of homes to engineers, they are all over our product. But the general public needs more education on the value of energy efficiency. They need to understand, your home is worth more. It will be more comfortable and more easy to maintain. It's healthier. You'll save energy. Your utility bills are going to be lower."

Fred Giacci, owner, Devoted Builders, Kennewick, Washington

Marketing Energy Efficiency

A challenge for builders of energy-efficient homes is showing consumers the energy efficiency they are purchasing. Most energy-efficiency improvements are hidden away in walls and attics invisible to buying eyes. Making energy improvements "real" to the consumer is a multi-faceted, ongoing process that can include any of the following (NAHBRC 2010):

- Emphasize cost, comfort, health, and environmental benefits.
- Educate customers and sales professionals. Use duct blaster, blower door, and HERS scores to show differences.
- Use walk-throughs and model homes with display cutaways of energy features such as insulated attics and wall sections to help buyers and sales staff understand the energy-efficient construction process.
- Turn the model home's garage into an energy information center. Use side-by-side displays on walls, demo walls showing wall and window features, touch screen videos, and poster board displays.
- Organize tours for homebuyers, school groups, media, and realtors. Use slides, sample products, and energy bills as aids.
- Emphasize an energy-efficiency upgrade when signing the final papers. One builder has a wall of testimonials, photos, and examples of utility bills in his waiting room. Another builder has the buyer meet with the building site supervisor after the sale is made for one more chance to sign up for energy-efficiency upgrades.
- Provide take-home brochures that explain energy-saving features. Develop your own fact sheets or give away Building America and ENERGY STAR brochures, reprints of magazine articles, and vendor and trade association brochures. Also, give potential buyers a checklist so they can compare the energy-saving measures in your homes with those of other builders (see Appendix I).
- Use paid advertising with a simple slogan. One builder created an ad campaign based on "$60," a figure they guaranteed monthly electric bills would not exceed for the first year. They ran ads on billboards, the sides of buses, signs on their property, and in the newspaper.
- Use the Internet—websites, YouTube videos, Facebook, Twitter, etc.
- Seek out free publicity, send out press releases, hold media events.
- Participate in building-related charity events.
- Get involved in your local home builders association.
- Offer energy-efficiency guarantees.
- Make buyers aware of energy-efficient mortgages.

(top) Show potential buyers your energy-efficient features with cut-aways and side-by-side displays.

(bottom) Use signage to spell out your message.

Through 2009, Building America builders have won 93 Energy Value Housing Awards (EVHA) from the National Association of Home Builders Research Center. Beginning with the 2010 awards cycle, builders can earn points for participation in DOE's Builders Challenge program and can apply for Builders Challenge certification through the EVHA application process.

"Now we have a marketing advantage. We are looked at as one of the experts in the industry in terms of energy efficiency."

Chris Nelson, president of Nelson Construction, Farmington, Connecticut

East Liberty Development, Inc., promoted its new homes in a historic neighborhood of Pittsburgh with a ribbon-cutting ceremony attended by Pittsburgh's mayor, a congressional representative, the director of the Urban Renewal Authority, other elected officials, members of the press, and interested homebuyers in attendance. *The New York Times* and several regional news outlets picked up the story.

- Package energy efficiency features through a national or regional program or your company's own energy-efficiency "brand."

Reaching Out to the Media

Nothing is more cost effective than sending out a news release to local media to announce business news and other company activities. News related to energy efficiency can include partnering with the Builders Challenge, reaching a new best score for your area on the HERS Index, hitting milestones in numbers of energy-efficient houses built, winning awards for energy-efficient and green construction, trying out new technologies, offering tours of houses under construction, or cooperating with research organizations such as colleges or DOE. News releases can cover your company's involvement in educational and charitable activities, for example, teaching school children about energy efficiency or building homes with Habitat for Humanity.

Companies that try out new technologies or apply technologies on a big scale have earned much in the way of media exposure. For example, builders who have installed photovoltaic systems have been reported in *The New York Times*, on major televisions networks, and in the local press.

For More Information on Marketing

Builders Challenge www.buildingamerica.gov/challenge

ENERGY STAR www.energystar.gov

Environments for Living www.environmentsforliving.com

Farnsworth, Christina. 2003. "The Weakest Link." *Builder Magazine*, December 2003, http://www.builderonline.com/business/the-weakest-link.aspx?printerfriendly=true

NAHB. 2009. ICC 700-2008 *National Green Building Standard*, the National Association of Home Builders and the International Codes Council, www.nahb.org

NAHBRC. 2007. *Building America Challenge Survey of Builders and Consumers*. Proprietary survey commissioned by DOE and conducted by the NAHBRC as part of the Annual Consumer Practices Survey. National Association of Home Builders Research Center, Upper Marlboro, MD.

NAHBRC. 2009. Green Building Program. National Association of Home Builders Research Center, www.nahbgreen.org

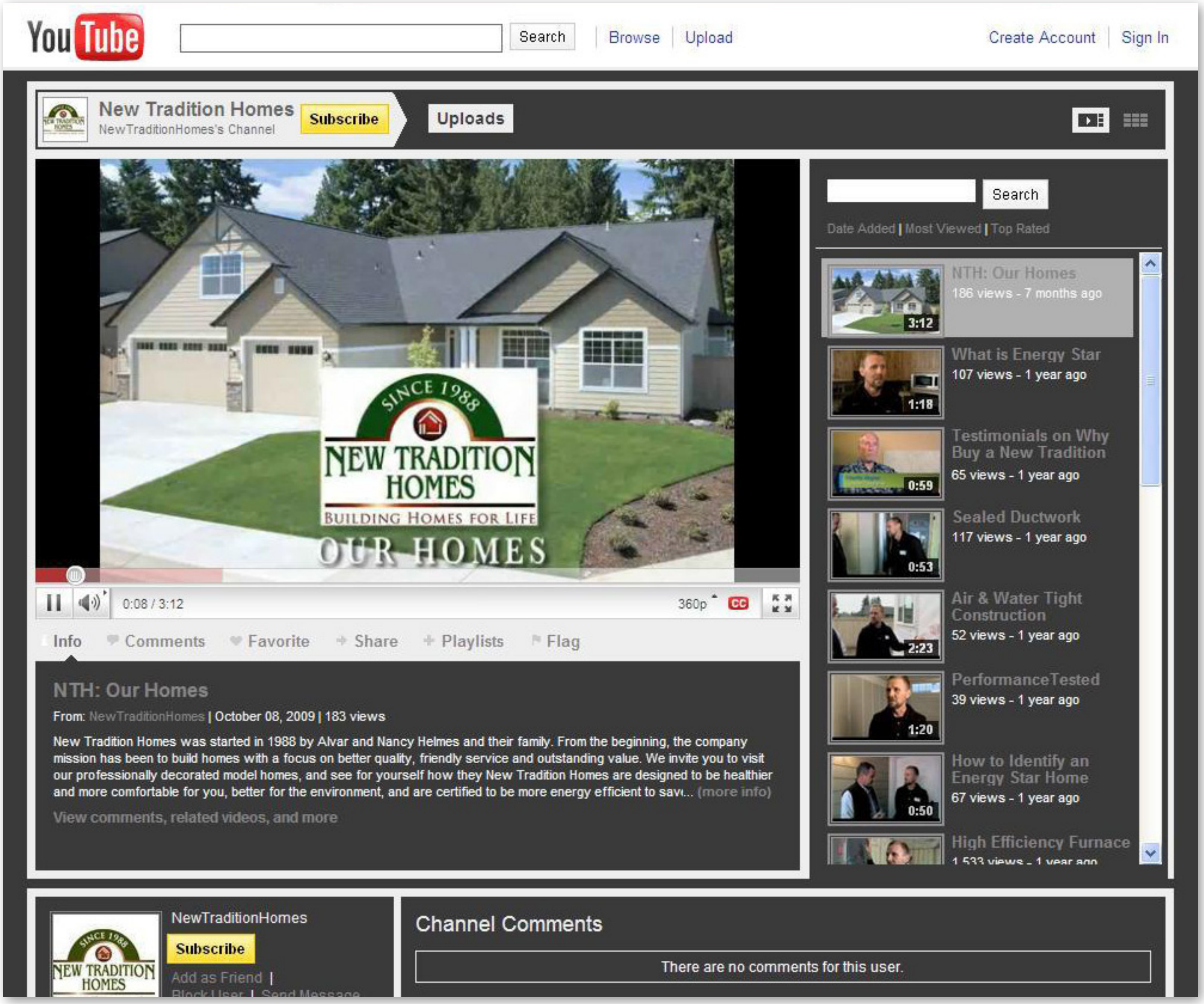
NAHBRC. 2010. Energy Value Housing Award Program. National Association of Home Builders Research Center, www.nahbrc.org/EVHA

Sikora, Jeannie. 2002. *Energy Value Housing Award Guide: How To Build and Profit with Energy Efficiency in New Home Construction*. National Association of Home Builders Research Center, Upper Marlboro, MD. www.nahbrc.org

U.S. Environmental Protection Agency. EPA Indoor airPLUS labeling program for new homes, www.epa.gov/indoorairplus/about.html

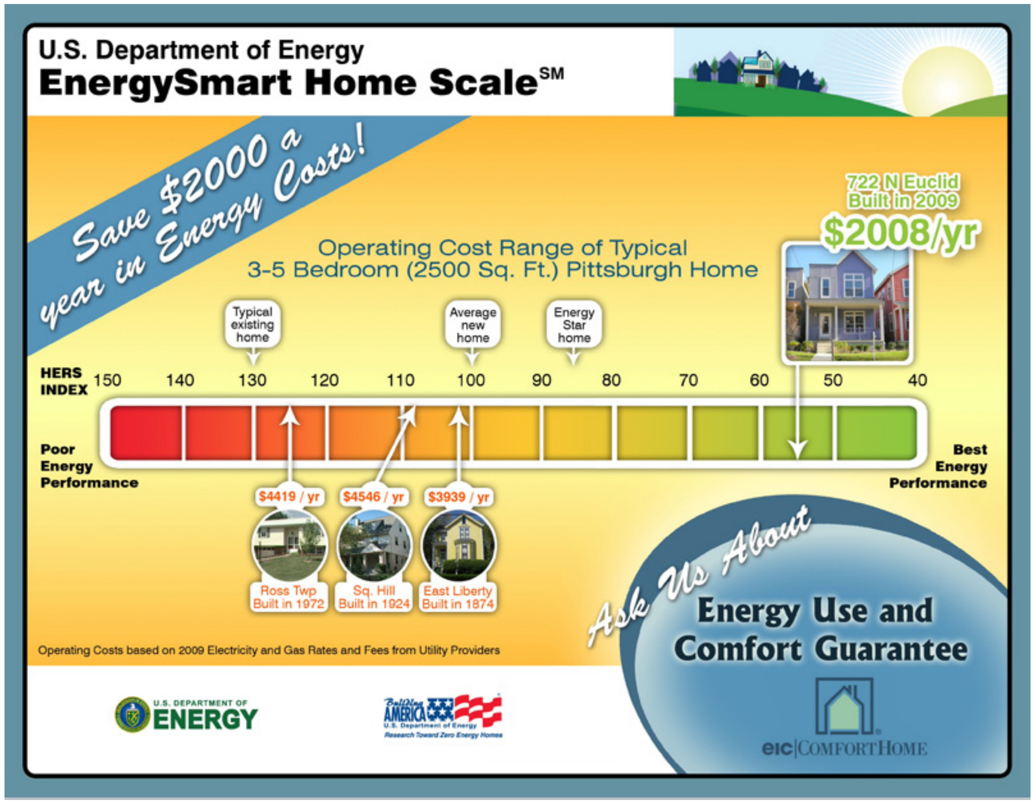
U.S. Environmental Protection Agency. WaterSense: An EPA Partnership Program, New Homes, "Saving Water—Inside and Out," www.epa.gov/watersense/pp/new_homes.htm

U.S. Green Building Council www.usgbc.org



Building America builder, New Tradition Homes of Washington State has its own channel on YouTube with over a dozen video clips advertising its energy-efficiency features. www.youtube.com/user/NewTraditionHomes

East Liberty Development, Inc., modified a Builders Challenge label to show the annual utility bills homebuyers can expect from one of its energy-efficient homes compared to utility bills from three typical existing local homes, a new code-built home, and an ENERGY STAR home.



Chapter 5.

The Cold and Very Cold Climates

There are 34 states that are wholly or partially in the cold or very cold Building America climates. Conditions vary widely across these climate zones, which stretch from Alaska to Arizona and California to Rhode Island.

Builders in the cold climate must be able to address solar gains in the summer and extreme, prolonged low temperatures and snow accumulation in the winter, along with torrential downpours, high winds, and, especially in areas east of the Mississippi, high humidity. The recommendations in this Best Practices guide apply to the cold and very cold climate regions. If you aren't sure that your project is within these climate regions, check the *Building America Best Practices Volume 7.1 Guide to Determining Climate Regions by County* (DOE 2010, www.buildingamerica.gov) for a list of counties and climate zones. The Building America cold/ very cold climate zones correspond to the International Energy Conservation Code (IECC) climate zones 5, 6, and 7 (Briggs et al. 2003; see maps page 5.3).

In addition to describing the cold and very cold climates, this chapter also provides information on building in the extreme weather conditions that can occur in these climates including heavy precipitation, high winds and tornadoes, flooding, earthquakes, and forest fires. Siting and design considerations with respect to solar gain are also included. See Chapters 7 and 8 for information on moisture management, air sealing, and thermal control techniques for foundations, walls, and roofs.

"Building America achieves superior performance by applying measures that work with the local climate. The principles that go into the design of Building America houses are sophisticated but not complicated. I would encourage any builder who is interested in near zero-energy construction to talk to us and give it a try."

George James, manager, new construction program, U.S. Department of Energy Building America

CHAPTER TOPICS

Design Considerations for Cold Climates

The extreme temperature variations, forces of driving wind and rain, snow accumulation and melting can take their toll on buildings and contribute to premature aging. Based on work with its cold climate case study builders, Building America makes the following recommendations for designing homes in the cold and very cold climate zones where high snow accumulation is likely:

- Don't put balconies, stairs, parking, or entrances under eaves.
- Design to avoid ice dams. Place any necessary roof penetrations high toward the ridge.
- Avoid electric snowmelt systems in roofs.
- Avoid use of gutters in high snow load locations.
- Orient buildings to allow for southern exposure to entrances, drives, and walks to encourage snow and ice melting and reduce the need for snow and ice removal and snow storage.
- Protect entrances and sidewalks by locating them under overhangs or at gable ends.
- Anticipate wind direction and drifting.
- Use low-maintenance, high-durability exterior products – for example cement fiber board siding, composite decking materials, and stained cedar railings.
- Keep furnaces and ducts out of attics and air seal ceiling lid well to lessen likelihood of ice dam formation.
- Heat and insulate basements and crawlspaces.
- Place footings below frost depth.

Climate Description

Cold

A cold climate is defined as a region with between 5,400 and 9,000 heating degree days (65°F basis). The Building America cold climate corresponds to the IECC climate zones 5 and 6.

Very Cold

A very cold climate is defined as a region with between 9,000 and 12,600 heating degree days (65°F basis). The Building America very cold climate corresponds to IECC climate zone 7.

For More Information on Climate Description

Briggs, RS; RG Lucas; and ZT Taylor. 2003. "Climate Classification for Building Energy Codes and Standards: Part 2 - Zone Definitions, Maps and Comparisons," *Technical and Symposium Papers, ASHRAE Winter Meeting*, Chicago, January 2003.

DOE. 2010. *Vol. 7.1: Guide to Determining Climate Regions by County*. PNNL-19517, Building America Best Practices Series, Prepared for the U.S. Department of Energy by Pacific Northwest National Laboratory, www.buildingamerica.gov

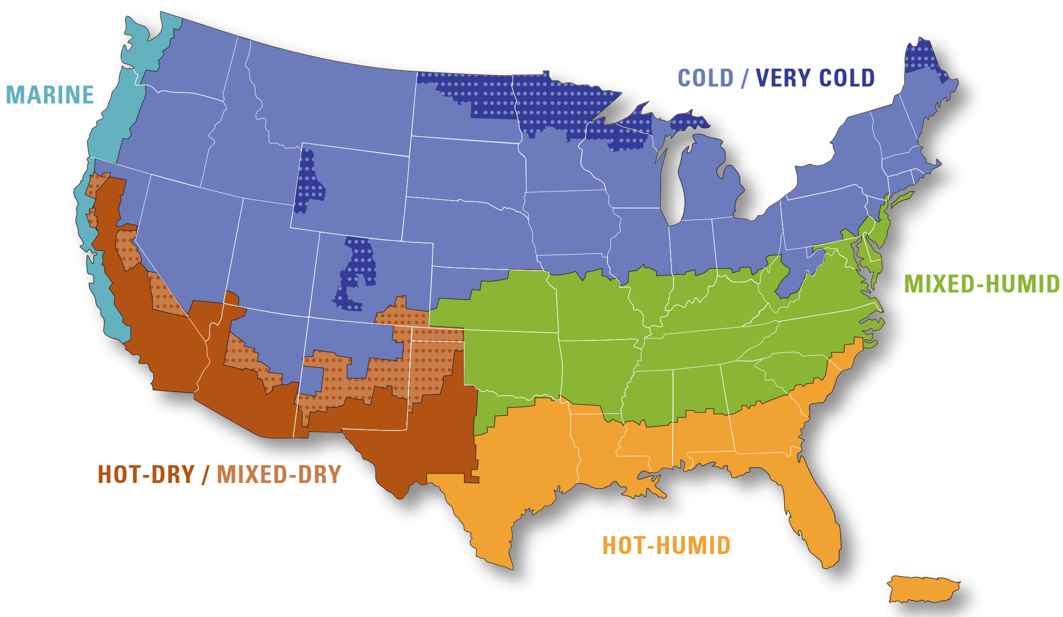
NOAA. 2010. National Climatic Data Center. www.climate.gov/#dataServices/pastPresent

FEMA Fact Sheets

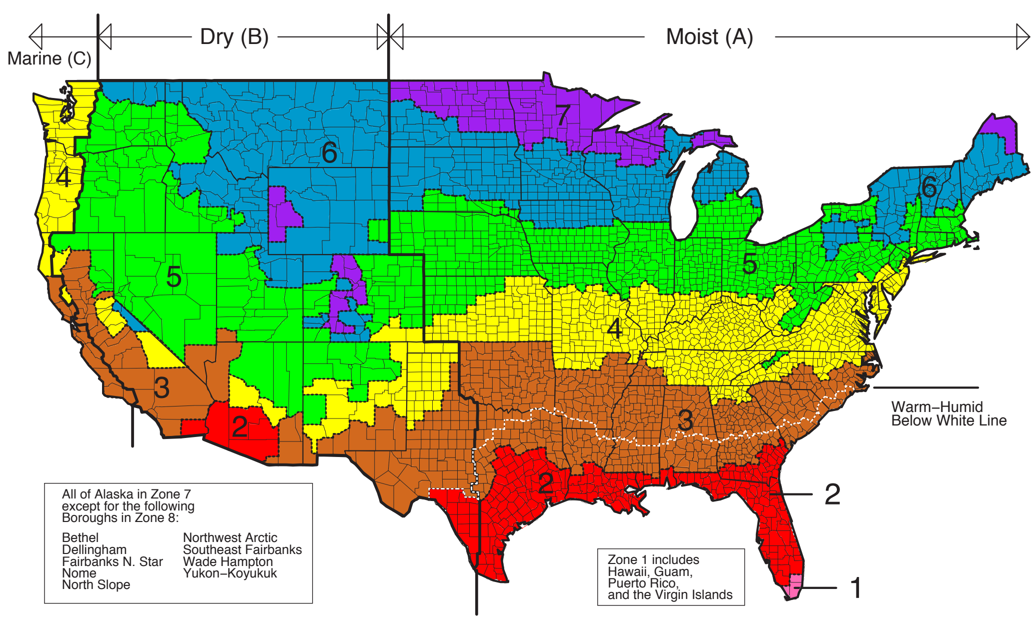
The Federal Emergency Management Agency (FEMA) has produced a series of 31 fact sheets providing recommendations for building homes in high wind and rain areas. The guides cover siting recommendations; moisture barrier systems; housewrap, masonry, roof sheathing, and other building materials; door and window installation; roof and deck-to-wall flashing; tile and asphalt roofing techniques for high wind areas; foundations; and construction techniques in flood-prone areas. See www.fema.gov/library/viewRecord.do?id=1570.

Subarctic

A subarctic climate is defined as a region with 12,600 heating degree days (65° basis) or more. The only subarctic regions in the United States are found in Alaska, which is not shown on the climate maps below. The Building America subarctic climate zone corresponds to IECC climate zone 8. While some of the guidelines in this document would apply to construction in the subarctic, the subarctic climate has its own unique considerations, which are not addressed in this guide.



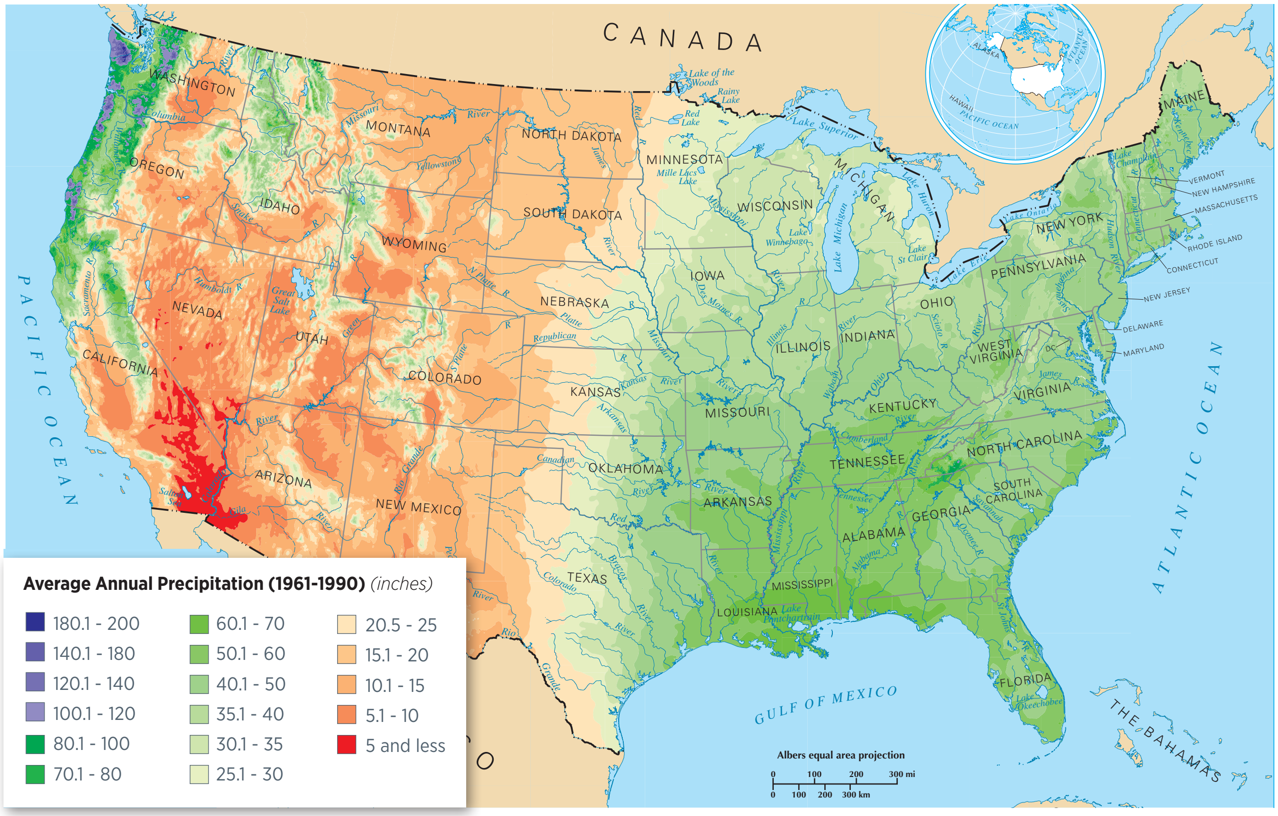
Building America U.S. Climate Regions



International Energy Conservation Code Map

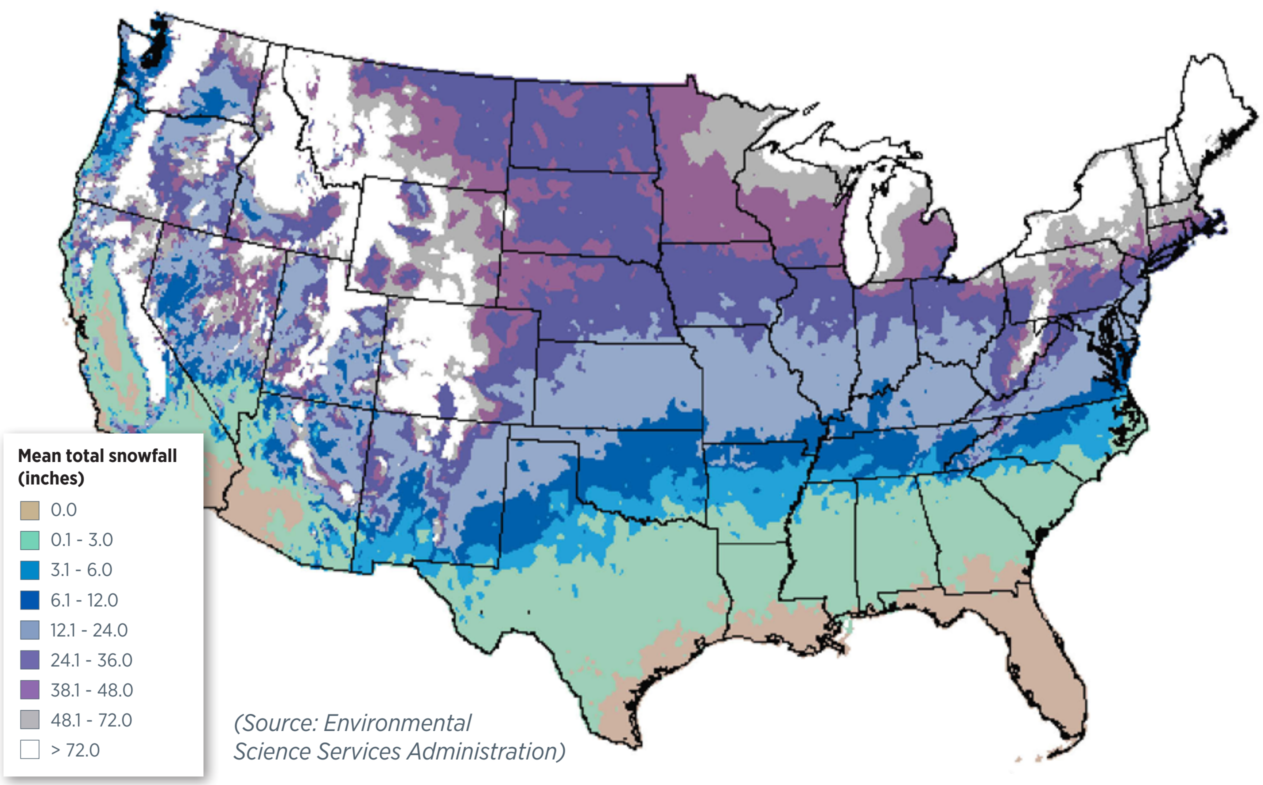
The Building America cold and very cold climate regions correspond to zones designated 5, 6, and 7 on the International Energy Conservation Code map. The Building America subarctic climate corresponds to IECC climate zone 8, which occurs only in Alaska and does not appear on this map.

Average Annual Precipitation



(Source: U.S. Geological Survey)

Mean Annual U.S. Snowfall



(Source: Environmental Science Services Administration)

Weather

Portions of the cold climate are subject to frequent and intense rain and snow storms, severe thunderstorms, and hail. Some areas are at high risk for tornadoes and high winds. Large portions of the Midwest and Northeast have been subject to flooding, with most of the counties of these areas experiencing four or more presidential disaster declarations due to flooding since 1965.

The region is at low risk of earthquakes except for localized areas in Idaho, Wyoming, and Utah and at the border of Tennessee and Missouri. The cold and very cold climate zones are at low risk of volcanic eruption except in Alaska, Washington, and Oregon. Portions of the cold climate are prone to landslides, especially in the Rocky Mountains and Appalachian Mountains. The region is at low risk for hurricanes except along the Eastern seaboard (USGS 2010).

Precipitation

Cold climate states in the southwest and Great Plains are the driest in the United States, experiencing less than 20 inches of precipitation per year, while cold states in the Northwest, Midwest, and Northeast commonly experience annual precipitation levels of 40 inches or more. Construction techniques for snow and moisture management are described in Chapter 8.

For More Information on Weather and Precipitation

National Climatic Data Center. 2005. Climate Maps of the United States. National Oceanic and Atmospheric Administration (NOAA) http://hurricane.ncdc.noaa.gov/cgi-bin/climaps/climaps.pl

U.S. Geological Survey. 2005. "The National Atlas of the United States of America: Precipitation," U.S. Department of the Interior, www.nationalatlas.gov.

U.S. Geological Survey. 2010. "Natural Disasters," www.usgs.gov/hazards/

Flooding

Flooding is a concern along inland waterways of the cold climate. Large portions of the Midwest and Northeast have been subject to flooding, with most of the counties of these areas experiencing four or more presidential disaster declarations due to flooding since 1965. Builders should check state building codes and contact the local community floodplain administrator for information on local floodplain management regulations. Location-specific Flood Insurance Rate Maps (FIRMs) can be obtained at www.fema.gov/hazard/map/firm.shtm.

If a community adopts and enforces adequate floodplain management regulations, FEMA will make flood insurance available within the community. Title 44 of the U.S. Code of Federal Regulations (CFR) contains the National Flood Insurance Program

(top) Large-scale floods have hit the midwest repeatedly in recent decades *(Photo source: USGS)*

(middle) S&A Homes practices good water runoff management to control sediment during construction and to ensure that stormwater drains away from the house after construction.

(bottom) Vegetated swales, pervious pavers, pocket parks, and retention of existing trees all help to minimize runoff and lessen impacts on municipal sewer systems.

Extreme Climate

The cold and very cold climates include some of the driest states (New Mexico, Utah, Nevada) and some of the wettest (Michigan, New York, West Virginia) as well as some of the most tornado-prone (Iowa, Illinois, Indiana); hail-prone (Colorado, Kansas), and windiest states (Massachusetts, Minnesota, Wyoming). And, of course, the top ten snowiest and top 10 coldest U.S. cities are located in the cold and very cold climates. Conditions can vary significantly from season to season within these states. The ten U.S. cities with the largest variation in average seasonal temperature from summer to winter are all cold climate cities, with variations of up to 91 degrees between average summer and average winter temperatures. Some locations experience dramatic temperatures swings even within a single day – swings of 60, 80, and even 100 degrees have been known to occur. (NOAA 2010).

(NFIP) criteria for floodplain management, including design and construction standards for new and substantially improved buildings located in special flood hazard areas (SFHAs) identified on the NFIP's Flood Insurance Rate Maps (FIRMs). An SFHA is an area that has 1% chance of being flooded in a given year. **[CFR Title 44, Section 60.3(a)(3) requires that all new construction in a flood-prone area be constructed with materials resistant to flood damage.]** The lowest floor of a residential building must be elevated to or above the base flood elevation (BFE). All construction below the BFE is susceptible to flooding and must consist of flood damage-resistant building materials, for example brick; cement board; concrete; non-paper faced gypsum; steel or solid-wood preservative-treated studs, trusses, and joists; and ceramic tile. Flood-resistant materials are described in *"Flood Damage-Resistant Materials Requirements,"* one of a series of Technical Bulletins that FEMA has produced to provide guidance concerning the building performance requirements of the NFIP (available at www.fema.gov/plan/prevent/floodplain/techbul.shtm). **[Code requirements for flood-resistant construction are detailed in the 2009 IRC R322.]**

"FEMA reports that up to 25% of NFIP flood insurance claims are paid on buildings that are outside of the mapped SFHA. This occurs for many reasons, including out-of-date maps and local drainage problems" (FEMA 2008); therefore, all builders should be aware of flood-safe construction practices, regardless of location designation.

Joseph Lstiburek of Building Science Corporation, a Building America team lead, recommends three basic strategies for building in flood-prone areas: elevate structures, build with materials that can get wet, and design assemblies to easily dry when they get wet. Specific recommendations include building the first floor using non-water-sensitive materials such as masonry, using an elevated slab or raising the crawlspace floor above grade, and using rigid foam exterior insulation such as rigid fiberglass rather than batt cavity insulation (especially on basement and first-floor walls).

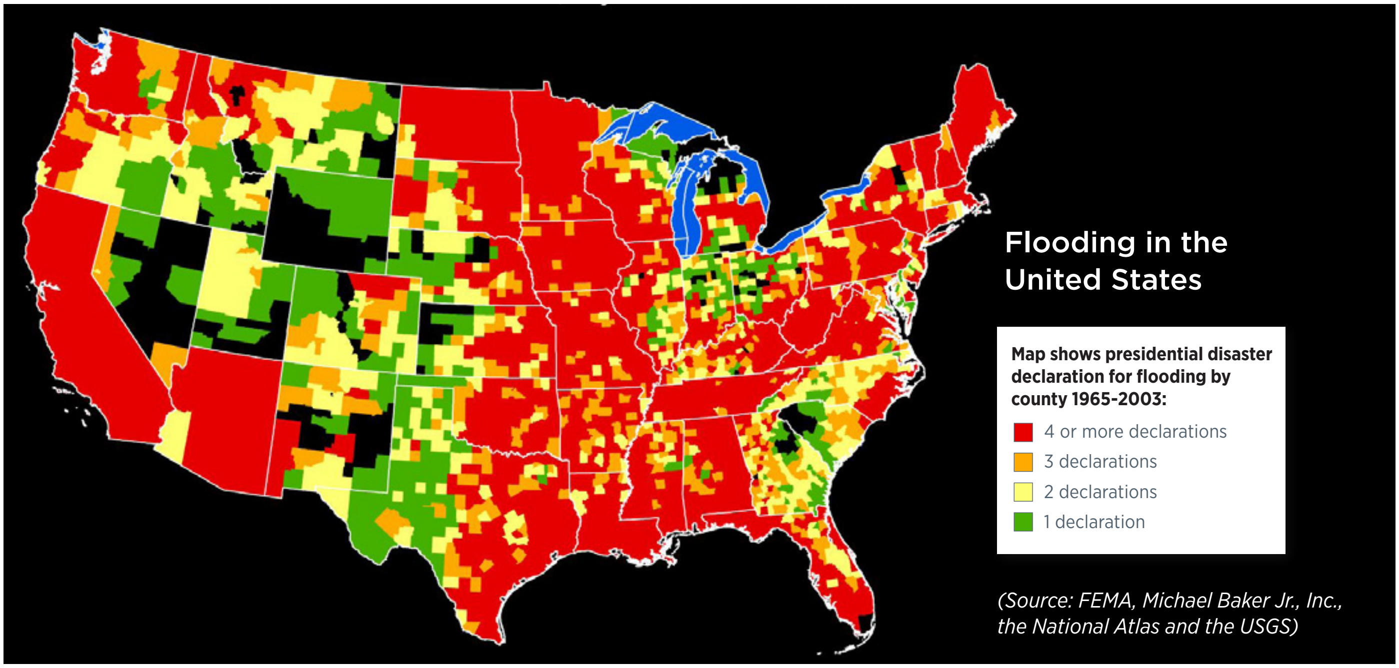
For More Information on Construction in Flood Zones

Algan, H. and Wendt, R. 2005. *Pre-Standard Development for the Testing of Flood-Damage-Resistant Residential Envelope Systems, Comparison of Field and Laboratory Results - Summary Report*, Oak Ridge National Laboratory.

FEMA. 2000. *Coastal Construction Manual*, Third Edition, FEMA-55, Federal Emergency Management Agency, Washington, D.C., www.fema.gov

FEMA. 2008. *Flood Damage-Resistant Materials Requirements for buildings located in special flood hazard areas in accordance with the National Flood Insurance Program*, August 2008, FEMA Technical Bulletin, Federal Emergency Management Agency, www.fema.gov/library/viewRecord.do?id=1580

Lstiburek, Joseph. 2006. *Flood and Hurricane Resistant Buildings*, Building Science Digest 111, Building Science Press, www.buildingscience.com



Stormwater Management

Builders are increasingly being called upon to manage surface runoff water onsite during and after construction because stormwater runoff carries with it sediment and pollutants that negatively impact water quality and high levels of runoff tax municipal sewer systems. Builders should check local requirements and guidelines regarding site water runoff control during and after construction. For long-term stormwater management, builders can minimize impervious surface areas by designing smaller building footprints, clustering developments, and adding green space areas; installing onsite rain-water harvesting systems; and using pervious paver materials. Other recommendations include planting vegetated buffers around parking areas; planting new trees and shrubs and retaining existing trees to minimize erosion; constructing swales, drywells, soakage trenches, planter boxes, vegetated infiltration basins, and flow-through planters; and installing drywells under streets to handle overflow from large storm events.

Tornadoes and High Winds

The cold climate includes areas in wind zone 4 (the highest risk zone) on FEMA's scale of four U.S. wind zones, as well as areas designated special wind regions and hurricane-susceptible regions. FEMA, the NAHBRC, and the U.S. Department of Housing and Urban Development (HUD) have put together guidelines for constructing asphalt and tile roofs in high-wind coastal areas www.fema.gov/library/viewRecord.do?id=1570. The Institute for Business and Home Safety provides structural details and guidance and a list of building materials acceptable for high-wind areas at www.disastersafety.org.

For More Information About Stormwater Management

EPA. 2010. Stormwater Program. U.S. Environmental Protection Agency. http://cfpub.epa.gov/npdes/home.cfm?program_id=6

Shaw, Daniel, Rusty Schmidt, Brian Ashman, Hugh Johnson, and Tony Randazzo. *Plants for Stormwater Design, Volume II, Species Selection for the Upper Midwest*, Great River Greening, St. Paul, Minnesota.

City of Portland. 2010. *Stormwater Solutions Handbook*, Bureau of Environmental Services, www.portlandonline.com/bes/index.cfm?c=43110

City of Cleveland. 2004. *Guidance Document: Erosion and Sediment Control Best Management Practices for Home Builders*, Cleveland, Tennessee.

NAHB. 2010. "Citing Flawed Analysis, Feds Send EPA Storm Water Rules Back to the Drawing Board," National Association of Home Builders press release, August 13, 2010 www.nahb.com/news_details.aspx?sectionID=479&newsID=11185

For More Information on Construction in Tornado and High Wind Areas

FEMA. *Home Builder's Guide to Coastal Construction*. Federal Energy Management Association. www.fema.gov/library/viewRecord.do?id=1570

FEMA. 2008. *Taking Shelter from the Storm: Building a Safe Room for Your Home or Small Business*, FEMA 320, Third Edition, Federal Emergency Management Agency, www.fema.gov/library/viewRecord.do?id=1536

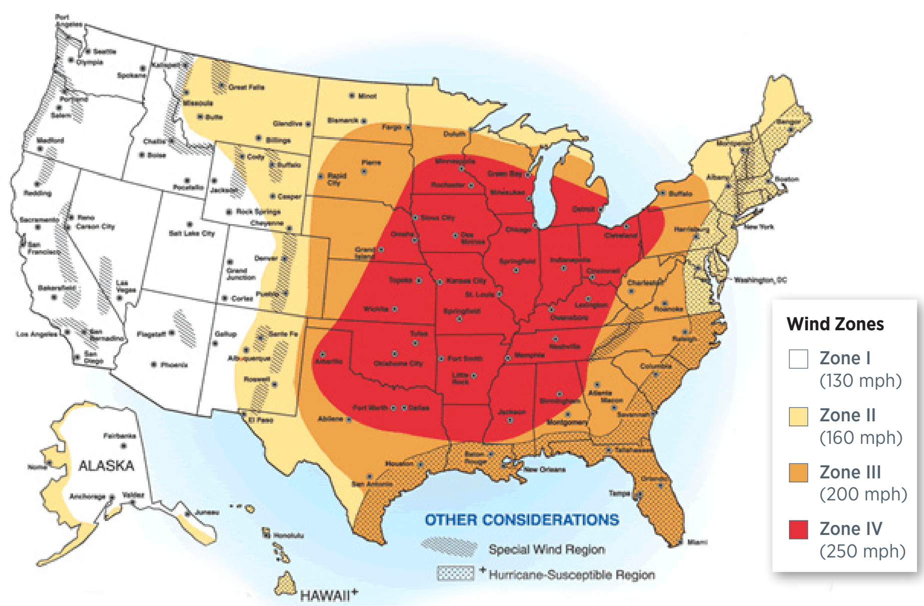
Institute for Business and Home Safety. 2008. *Fortified for Safer Living Builders Guide*, 2008 Edition. www.ibhs.org.

NAHB. 2008. "Fire Official Surge Sweeps Sprinkler Mandate to Victory," *Nation's Building News,* September 22, 2008. www.nbnnews.com/NBN/issues/2008-09-22/

New requirements in the **2009 IRC R301** address some of these high-wind concerns with increased wall bracing requirements for homes built in high-wind and high-seismic actvity areas. The new code increases the amount of wall bracing needed to resist wind loads for three-story homes, homes with large open plans, and homes in high-wind regions. In addition, the new code requires blocking between the roof framing members at braced wall panels for homes with deep truss members or roof joists, or homes in high-wind and high-seismic areas. The new requirements include prescriptive blocking details for these conditions. These changes may require revisions to stock plans and standard detailing practices.

For builders and homeowners in tornado-prone areas, FEMA has prepared a guide for building safe rooms—rooms with reinforced walls where occupants can safely take shelter during a tornado or hurricane.

Wind Zones in the United States



(Figure Source: FEMA 2008)

Seismic Events

Portions of the cold climate region, including areas in and around Idaho, Wyoming, Illinois, New York, and Alaska, are in seismic design categories C, D, and E. **Construction in these areas must follow the requirements of the 2009 IRC, which addresses seismic provisions in R301.2.2.** Information on design and construction in earthquake-prone areas—including above-code recommendations; detailed figures for foundations and foundation walls, floor construction, walls, roof-ceiling systems, chimneys, fireplaces, balconies and decks; and checklists for builders, designers, and plan checkers—can be found in FEMA's *Homebuilder's Guide to Earthquake Resistant Design and Construction* (FEMA 2006).

For More Information on Seismic Events

FEMA. 2006. *Homebuilder's Guide to Earthquake Resistant Design and Construction*. Federal Emergency Management Agency www.fema.gov/library/viewRecord.do?id=2103

2009 IRC. 2009. *International Residential Code - One and Two-Family Dwellings*, Section R301.2.2. International Code Council, Washington, DC. www.iccsafe.org/Store/Pages

USGS. Earthquake Hazards Program. http://earthquake.usgs.gov/research/hazmaps/

Forest Fires

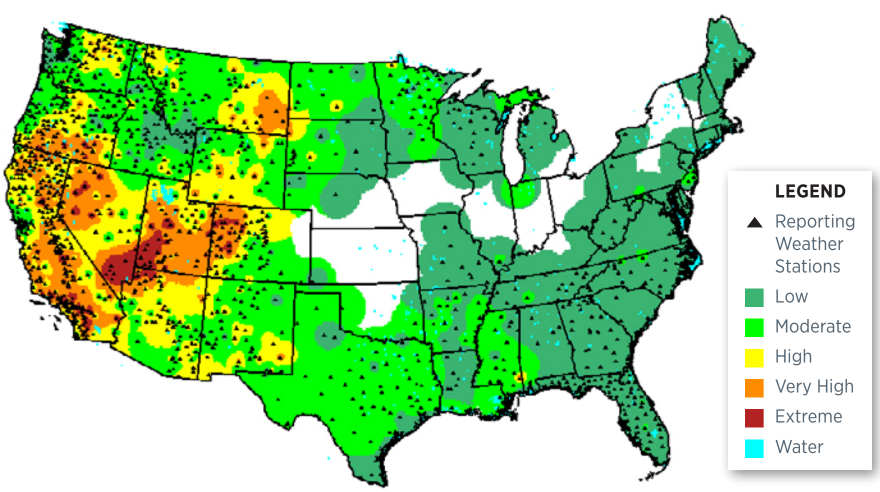
Each year the United States experiences approximately 10,600 forest fires, burning an average of 960,000 acres. Most of these fires occur in the heavily forested western states. Western parts of the cold climate are susceptible to forest fires, particularly during the hot, dry summers and early fall.

The Institute for Business and Home Safety provides several recommendations for building in areas of high forest fire danger:

- Locate the building away from ridge tops, canyons, and areas between high points on a ridge.
- Use roofing material with Underwriters Laboratories Class A or least-combustible fire ratings (e.g., asphalt-fiberglass shingles, steel, clay or concrete tiles). With tile and shingle roofs, any gaps at ends must be blocked to prevent embers from entering underlayment. Complex roof designs are more hazardous in a fire than simple roof designs.
- Cover eave vents with a minimum 18-inch metal mesh screen.
- Use non-combustible siding, including fiber cement, traditional "three-coat" stucco, and brick, rather than vinyl or untreated wood siding.
- Install ½-inch mesh spark arrestors in fireplace chimneys.
- Use non-combustible materials like metal and stone for fences that attach to the house. Use metal rather than vinyl gutters.
- Keep plantings away from walls; plant trees far enough away so that trees will not overhang the roof; thin plants and trees within 30 feet of the structure.
- Use fire-retardant-treated wood or wood-plastic composite decking or consider stone or concrete patios rather than wood decks.

Forest Fires

Forest fire danger in the United States for a typical late summer day (observed August 31, 2009)



Forest fire danger is high in the west in late summer, even in the marine climate, due to low precipitation levels July through September.

For More Information on Construction in Wildfire-Prone Areas

FEMA. *Prepare for a Wildfire*. www.fema.gov/hazard/wildfire/wf_prepare.shtm

Institute for Business and Home Safety. 2008. *Protect Your Property from Wildfire, Pacific Northwest Edition*, www.disastersafety.org/text.asp?id=wildfire_main

Institute for Business and Home Safety. "Quick Tips for Creating a Wildfire-Resistant Exterior" http://disastersafety.org/projects/?id=1425&category=1136

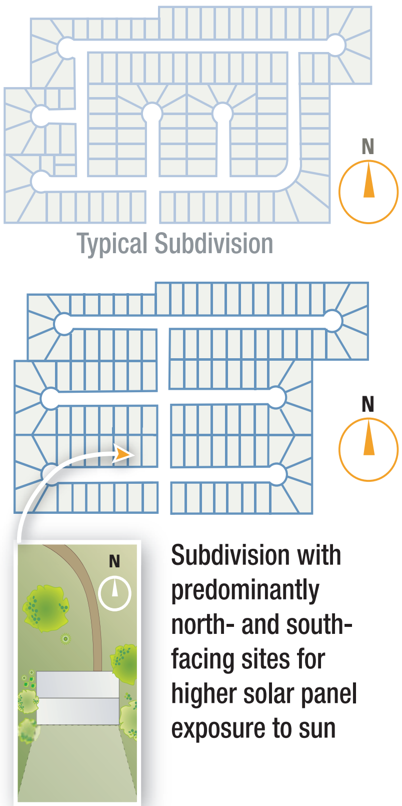
International Code Council. 2006. 2006 ICC: International Wildland Urban Interface Code, www.iccsafe.org/Store

NFPA. *Safer from the Start – A Guide to Firewise-Friendly Developments*, National Fire Protection Association, http://catalog.cmsassociates.com/firewise/index.php?page=item&id=469&icn=18156

University of California. "Builders' Wildfire Mitigation Guide," http://firecenter.berkeley.edu/bwmg/

(Figure source: WFAS-MAPS Graphics, Fire Behavior Research Center, Missoula, Montana, U.S. Forest Service)

Plan subdivision lot lines and roads for predominantly north and south orientation



Subdivision with predominantly north- and south-facing sites for higher solar panel exposure to sun

Considering Solar Gain in Siting & Design

Passive and active solar design elements can be incorporated into homes throughout the cold climate, especially in the West and Southwest. Design considerations include lot orientation, roof tilt, overhangs, windows, and shading.

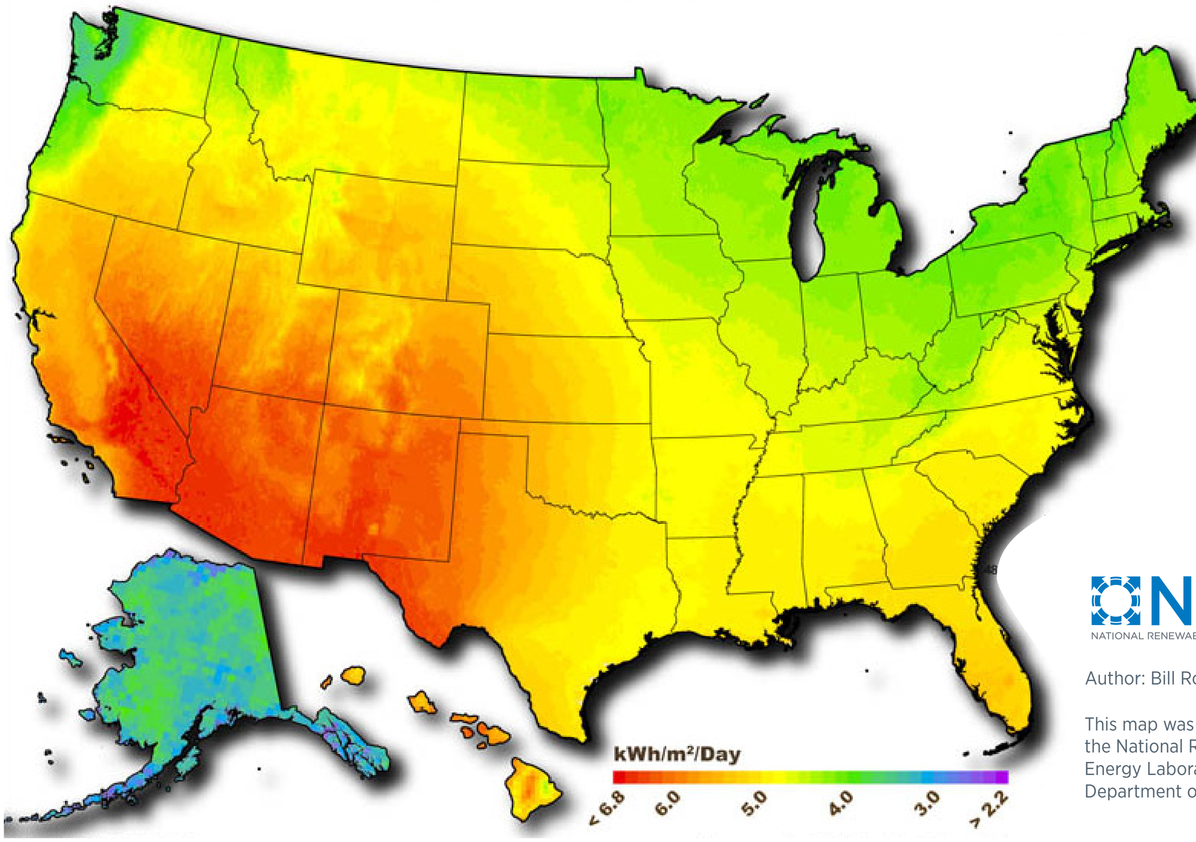
Lot Orientation and Home Siting

One virtually no-cost option for improving energy performance is to subdivide for solar orientation (see subdivision layout figure).

In the heating-dominated cold climate regions, builders can use passive solar orientation to take full advantage of the sun's natural heat. By facing the long side of a home to the south and the short sides to the east and west, the building will capture solar heat in the winter and block solar gain in the summer. While the ideal orientation would be to face the home's long side directly into the sun, it can be oriented up to 30 degrees away from due south and lose only 5% of the potential heating savings. Locating windows on the home's south side will enhance its passive solar performance. If the south-facing window area reaches 8% to 10% of floor area, the home can be called "sun tempered." A home with south-facing glass area of 15% to 20% of floor area would be called a true passive solar home; this much south-facing glass requires thermal storage mass and summer shading to mitigate summer heat gains.

A study done in the Pacific Northwest by the Bonneville Power Administration placed passive solar home space-heating savings between 10% and 20%, and a study by the City of San Jose, California, estimated savings for cooling costs between 10% and 40% (Iris Communications, Inc. 1995). The homes in both of these studies were oriented to the sun but did not include any special solar design features. East- and west-facing walls receive a large amount of solar heat from the low-angle sun as it rises and sets. To minimize overheating during spring and fall, builders should limit the amount of west-facing glass.

Home siting for roof-mounted solar photovoltaics benefits from an orientation that provides significant south-facing roof area but due south is not necessary. In the cold climate, where the optimal tilt angle varies from 30° in the south to 48° in Alaska, at an azimuth of 0° (due south) the tilt can run from flat (0°) all the way to a roof pitch of 70° and still receive 90% to 100% of available energy. If the tilt is at the optimum of 30°, the azimuth could vary to about 65° either east or west in the south or 50° in the north and still receive 90% to 100% of the available energy (Christensen and Barker 2001).



NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Author: Bill Roberts - October 20, 2008

This map was produced by the National Renewable Energy Laboratory for the U.S. Department of Energy.

U.S. Solar Resource

This map shows an annual average of the kilowatt hours per day of solar energy available per square meter across the United States. As shown on the map, the cold climate has 5 or more kWh/m^2/day of solar resource available.

(Annual average solar resource data are shown for a tilt-latitude collector. The data for Hawaii and the 48 contiguous states are a 10-km satellite modeled dataset [SUNY/NREL 2007] representing data from 1998-2005. The data for Alaska are a 40-km dataset produced by the Climatological Solar Radiation Model [NREL, 2003].)

(Map source: National Renewable Energy Laboratory, www.nrel.gov/gis/solar.html)

For More Information on Solar Orientation

Christensen, C.B., and G.M. Barker. 2001. "Effects of Tilt and Azimuth on Annual Incident Solar Radiation for United States Locations," NREL Report No. CP-550-32966, In *Solar Engineering 2001: Proceedings of the International Solar Energy Conference*, S.J. Kleis and C.E. Bingham (eds.), Presented at FORUM 2001, April 21–25, 2001, Washington, DC, The American Society of Mechanical Engineers (ASME), New York.

DOE. 2007. Building America Best Practices Series for High-Performance Technologies: Volume 6, Solar Thermal & Photovoltaic Systems. U.S. Department of Energy Building America Program, www.buildingamerica.gov

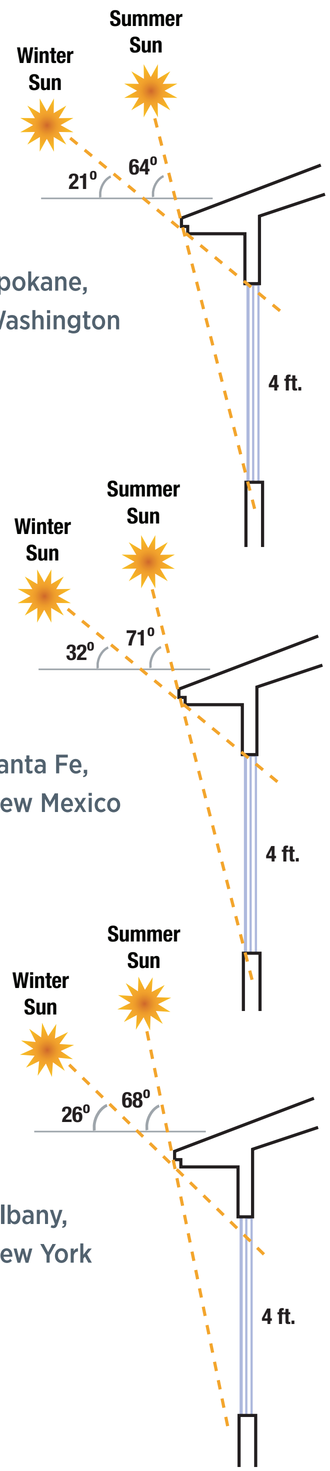
Iris Communications, Inc. 1995. "Turn to Solar for Lower Heating Costs" *Energy Source Builder* #42, December 1995, www.oikos.com/esb/42/solar.html

National Renewable Energy Laboratory. Solar Maps, www.nrel.gov/gis/solar.html

University of Oregon. Sun charts available free at http://solardat.uoregon.edu/SunChartProgram.html

Viera, R.K., K.G. Sheinkopf, and J.K. Stone. 1992. *Energy-Efficient Florida Home Building*. 3rd printing. Florida Solar Energy Center. FSEC-GP-33-88. Cocoa Beach, Florida.

Sun angles vary by latitude



Sun angles vary by latitude, season, and time of day. Sun angles shown here are calculated for noon on June 21 and December 21. *(Source: Sustainable by Design, www.susdesugn.com/sunangle)*

Overhangs

When positioning buildings to get the maximum passive solar benefit, overhangs can help manage heat gain and glare. Roofs should be designed with overhangs and porches to shade windows and doors. Overhangs also provide protection from rain, hail, and the effects of overheating and ultraviolet radiation on siding and windows. Overhangs may take the form of eaves, porches, awnings, pergolas, or trellises. Overhangs should be sized to account for differences in sun angles, elevation, window height and width, wall height above the window, and amount of shading desired based on time of day and time of year.

Free and low-cost computer programs are available for sizing overhangs based on location. A free program telling you the angle of the sun for any point in the country is available at www.susdesign.com/sunangle/. Latitude, longitude, and elevation data can be obtained at www.wunderground.com/calculators/solar.html. Optimal overhang dimensions can be calculated at www.susdesign.com/overhang/index.php. For example in Santa Fe, New Mexico, a 3-ft high by 4-ft wide window positioned 2 feet below the overhang would need an overhang extending 1.5 feet to provide full shade at mid-summer at 2 pm. For a list of free and available-for-purchase energy models, including solar design tools, see DOE's Building Technologies Program website at http://apps1.eere.energy.gov/buildings/tools_directory/subjects.cfm/pagename=subjects/pagename_menu=other_applications/pagename_submenu=solar_climate_analysis. A low-cost sun angle calculator is available from the Society of Building Science Educators at www.sbse.org/resources/sac/index.htm.

Windows

Windows should be selected to manage the quantity of heat loss and solar gain. In the heating-dominated cold climate, it is preferable to use windows with a lower U-value and a higher solar heat gain coefficient (SHGC). The U-value is a measure of heat transfer. The lower the U-value the better the window performs at stopping heat flow. The SHGC measures how well the window blocks heat caused by sunlight. The lower the rating the less solar heat the window transmits. The IECC requires a window U-value of 0.35 or lower in the cold climate; no SHGC is specified. For more information about windows, see Chapter 8 of this guide and also see the Efficient Windows Collaborative website at www.efficientwindows.org.

Shading

Shade can be provided by intentional planting or preservation of existing trees on the site. Tree preservation increases salability. Native trees are the most beneficial to the environment. The NAHB reports in its survey of buyers, *What 21st Century Home Buyers Want*, that over 80% of respondents in the West rated trees as essential or desirable (NAHB 2002). American Forests and the NAHB (1995) found that mature trees may add from $3,000 to $15,000 to the value of a residential lot.

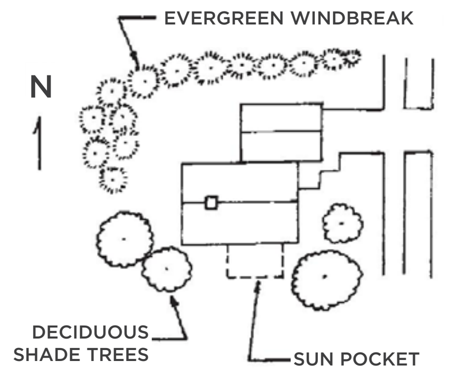
Truly cool neighborhoods have trees. A study in Florida has shown that a subdivision with mature trees had cooler outside air with less wind velocity than a nearby development without trees (Sonne and Viera 2000). The development with a tree canopy had peak afternoon temperatures during July that were 1.1°F to 3.1°F (± 0.7°F) cooler than the site without trees. The total effect of shading—lower summer air temperature and reduced wind speed—can reduce cooling costs by 5% to 10% (McPherson et al. 1994).

While evergreen trees may provide better wind protection, deciduous trees are ideal for summer shading in the cold climate because their lack of leaves in the winter will not block desirable solar gain during the heating season. Trees reduce cooling requirements, particularly when located on the south and west side of the home to block low-angle, late-afternoon, peak solar-gain sun. Trees more than 35 feet from the structure are too far away for shade.

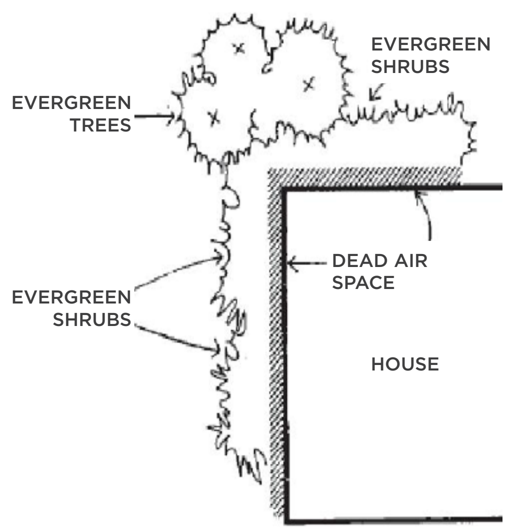
The Colorado State University Extension reported that proper use of deciduous shade trees could cut cooling bills more than 20%. They also noted that research into windbreaks conducted on the Great Plains showed winter heating energy savings of up to 25% were possible when evergreen trees and shrubs were properly placed on the north and east sides of homes (Walker and Newman 2009). One or more rows of evergreens placed along the corner of the home that faces prevailing winds provides an effective windbreak. The optimal distance of the windbreak from the home for reducing wind velocity is one to three times tree height. A thick hedge of evergreen shrubs planted 4 to 8 feet from the foundation along the northwest corner of the home can create a trapped dead air space that helps to insulate the home.

Care should be taken not to shade roof-mounted solar equipment (e.g., photovoltaic panels and solar thermal water heating panels) or areas of the roof that could be reserved for future solar installations. A simple rule of thumb is that any potential shading

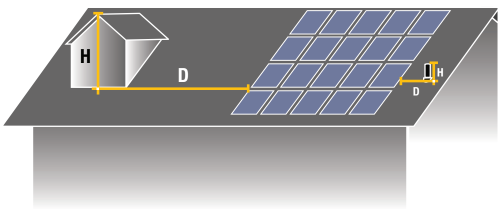
Careful landscaping can preserve roof-top solar exposure and provide shading to help control solar gain through windows.



Large deciduous shade trees on the south-west corner of the home provide welcome relief from summer afternoon sun while allowing desirable winter sun to warm the house. *(Source: Colorado State University Extension, Walker and Newman 2009).*



A thick hedge of evergreen trees planted on the corner facing prevailing winds provides a windbreak. *(Source: Colorado State University Extension, Walker and Newman 2009).*



For houses with solar photovoltaic roof panels, any potential shading structure should be twice as far away from the photovoltaic array as it is tall (D = 2 * H)

structure should be twice as far away from the solar equipment as the structure is tall. Sun charts and digital tools are available to assess how obstructions such as trees, buildings, or chimneys will fall between the solar panel and the sun at various times of the year.

Established trees can also provide a ground-stabilizing force in areas with sloped lots that may be at higher risk of erosion and mud slides.

For More Information on Shade

American Forests and the National Association of Homebuilders. 1995. *Building Greener Neighborhoods: Trees as Part of the Plan*. NAHB, Washington, D.C. www.nahb.org/product_details.aspx?forsaleID=26

McPherson, G.E., D.J. Nowak, and R.A. Rowntree (eds). 1994. *Chicago's Urban Forest Ecosystem: Results of the Chicago Urban Forest Climate Project*. U.S. Department of Agriculture, Forest Service, Northeastern Research Station, www.treesearch.fs.fed.us/pubs/4285

National Association of Home Builders. 2002. *What 21st Century Homebuyers Want: A Survey of Customer Preferences*, National Association of Home Builders, www.BuilderBooks.com

Walker, L. and S. Newman. 2009. *Landscaping for Energy Conservation*. No 7.225, Colorado State University Extension. www.ext.colostate.edu/pubs/garden/07225.html

Moss

In climates with high humidity, unwanted moss and algae can grow on roofs—especially on north- and east-facing surfaces where they can stain and damage most roofing types. To inhibit moss and algae growth, roofs must have sunlight and airflow, allowing them to dry properly. Options for inhibiting moss growth in heavily treed areas include using metal roofs, installing metallic zinc or copper strips along the roof just beneath the peak, or using copper-treated asphalt shingles. The better option from an environmental (and cost) standpoint is to allow adequate air and light to reach the roof by planting and trimming trees so that branches do not overhang the roof.

New roofs are not immune to moss, which can spread quickly under favorable conditions like constant shade and low roof pitch.

For More Information on Moss

City of Portland. "Safe Roof Moss Control," Portland Bureau of Environmental Services, City of Portland, Oregon, www.portlandonline.com/BES/index.cfm?c=50367

Chapter 6.

Building Science and the Systems Approach

When builders design houses to work well as a system, not only do the houses save energy, they also are better able to withstand the elements. *(Photo source: Leif Juell, Alternative Power Enterprises, Inc.)*

This chapter introduces fundamental principles of building science, including the systems approach to house design. The dynamic forces that drive the movement of moisture, air flow, and heat in homes are described. This background information helps to explain the underpinnings of the best practices described in later chapters. In applying building science, the goal is to design and build houses that work within the bounds of natural forces, and in some cases to put these forces to work for occupant comfort and building efficiency.

"Most builders view each aspect of the house—the electrical work, the plumbing, the framework—as separate jobs, but the Building America approach views each area as part of the whole...If you view the whole house as the system...it's not only easier, you end up with a better product."

Lee Rayburn, developer of Centennial Terrace in Tucson, Arizona

CHAPTER TOPICS

The Systems Approach

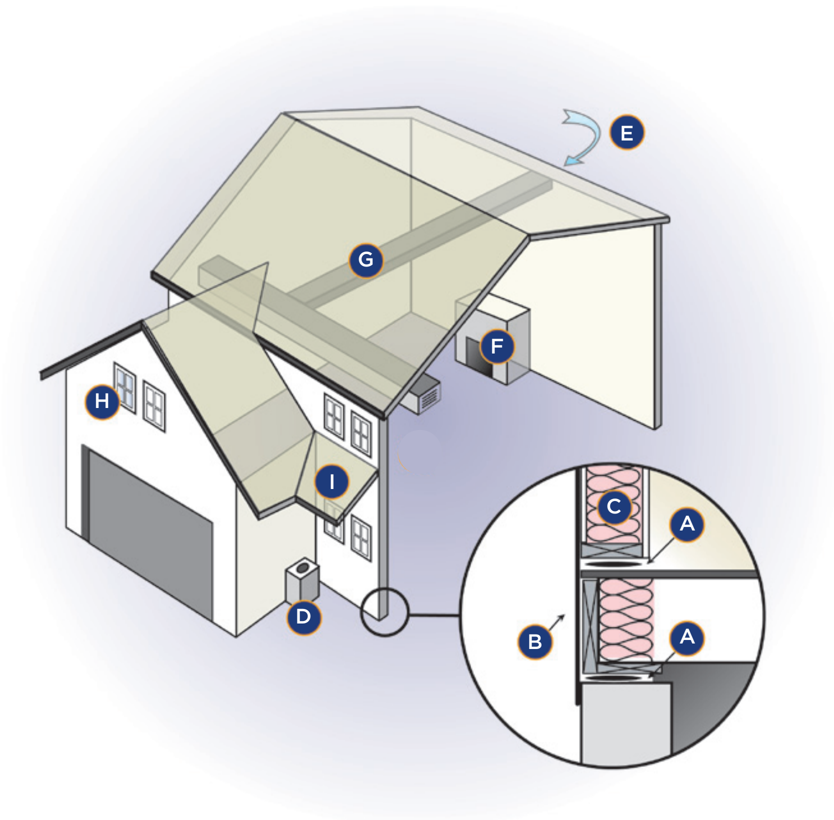
Building America takes a systems approach to home design recognizing that, as buildings become increasingly efficient, one must take into account the interactions of all of the home's components and subassemblies, both to maximize performance and to avoid catastrophe. This "whole-house" approach recognizes that changes in one or a few components can dramatically change how other components perform, affecting overall building energy use, comfort, and durability.

Building Science Basics

The successful builder needs to understand all of the forces that affect a house and how these forces interact with each other and the home's components. These forces include water, vapor, air flow, heat transfer, and occupants.

The Systems Approach to House Design

In a system-designed house all the parts are designed to work together for a healthy, durable home that minimizes builder callbacks while cutting energy, maintenance, and repair costs down the road.



A. **Air Sealing:** Helps maintain proper pressure balance in the home and stops stack effect, limiting drafts and keeping humidity, soil gases, and garage contaminants out of the house. It also creates a barrier to rodents and insects.

B. **Well-Designed Moisture Barriers and Drainage:** Avoids expensive structural damage and helps stop humidity, mold, and mildew.

C. **Insulation:** Holds comfortable temperatures in conditioned spaces and helps control noise. For insulation level recommendations, visit www.ornl.gov/sci/roofs+walls/insulation/ins_16.html

D. **Right-Sized and High-Efficiency HVAC Equipment:** Costs less to install than bigger equipment, saves energy, and is designed to comfortably handle heating and cooling loads.

E. **Ventilation:** Exhaust fans remove moisture and pollutants. A controlled, filtered air intake ensures plenty of fresh air.

F. **Sealed Combustion Appliances:** Reduce moisture buildup and ensure the safe removal of combustion gases with sealed combustion appliances.

G. **Compact and Tightly Sealed Duct Runs:** Short, straight duct runs in conditioned space yield better airflow with less chance for leaks and fewer contaminants like humidity and dust from attics or crawlspaces. Leaky ducts are a major contributor to mold problems. Multiple return air paths ensure balanced air pressure for less drafts and more balanced temperatures throughout the house. Ducts are in conditioned space.

H. **Efficient Windows:** Help to reduce heating and cooling loads. Window flashing protects against water leaks.

I. **Overhangs:** Provide shade, reduce cooling load, and direct water away from the house.

Water

Rainwater wants to flow down and will take the path of least resistance. To minimize mold and moisture damage in homes, builders must become experts in moisture-management techniques, learning how to guide rainwater off or out of the structure and how to incorporate redundant levels of moisture protection into the home's building shell.

Liquid moisture can also originate in the ground and flow upwards. This uptake is due to capillary action that is related to the adhesive properties of water. Water is attracted to other water. This is called cohesion. Water is also attracted to other materials. This is called adhesion. Capillary action allows water to climb up into seemingly solid materials through pores in the material. A capillary break is a non-permeable material that blocks the capillary flow of water from the ground. See Chapter 8 for more details.

Vapor

Water in its liquid state is not the only problem; water vapor can also be a source of damage. Water vapor causes problems when it is trapped within a building assembly, such as a wall cavity. When warm air touches a cold surface, the water vapor it carries can condense, turning into its liquid form, where it can cause damage to structural components. 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 a vented attic or crawlspace.

Unlike moisture in its liquid form, water vapor travels wherever air flows. Air is vapor's heavy lifter. Where there are air leaks, there are vapor leaks. Stopping air leaks by thoroughly air sealing the building envelope is an important step in limiting damage from water vapor.

Water vapor also can be carried by diffusion, which can force vapor through materials and into places it shouldn't be, such as wall cavities. Differences in vapor pressure and temperature are the forces that drive diffusion. Vapor diffusion moves moisture from areas of higher vapor pressure to areas of lower vapor pressure, and from areas of higher temperature to areas of lower temperature.

Vapor movement through a building component can be impeded by use of a vapor diffusion retarder. Vapor retarders are sometimes called vapor barriers but vapor barrier is a misnomer because all materials will allow some transmission of vapor, even if only a small amount. The ability of a material to retard the diffusion of water vapor is measured by units known as "perms" referring to the material's permeability. A perm is a measure of the amount of water vapor that passes through a material over a fixed period of time; the higher the number, the more easily water vapor can pass through. Code defines

(top) When moisture is trapped inside walls, mold can grow unchecked, causing damage to the walls and health impacts for the occupants. *(Photo source: EPA; photo by Terry Brennan)*

(middle and bottom) This sprinkler was placed too close to the house's foundation wall. Moisture seeped through the concrete block causing water stains and mold inside. *(Photo source: EPA; photo by Terry Brennan)*

Class III Vapor Retarders Permitted in Cold Climate under Following Conditions

(source: 2009 IRC Table R601.3.1)

Zone	Class III vapor retarders permitted for:
5	• Vented cladding over OSB • Vented cladding over plywood • Vented cladding over fiberboard • Vented cladding over gypsum • Insulated sheathing with R-value ≥ R-5 over 2x4 wall • Insulated sheathing with R-value ≥ R-7.5 over 2x6 wall
6	• Vented cladding over fiberboard • Vented cladding over gypsum • Insulated sheathing with R-value ≥ R-7.5 over 2x4 wall • Insulated sheathing with R-value ≥ R-11.25 over 2x6 wall
7 & 8	• Insulated sheathing with R-value ≥ R-10 over 2x4 wall • Insulated sheathing with R-value ≥ R-15 over 2x6 wall

Perm Ratings of Common Sheathing Materials

Plywood sheathing	More than 1.0 perm
OSB	More than 1.0 perm
Exterior gypsum	More than 1.0 perm
Fiberboard sheathing	More than 1.0 perm
Extruded polystyrene foam sheathing 1 inch	1.0 perm or less
Film-faced extruded polystyrene 0.5 inch thick with perforated facing	More than 1.0 perm
Nonperforeated foil-faced rigid insulation	Less than 0.1 perm
Polypropylene-faced rigid insulation	Less than 0.1 perm
Three-coat, hard-coat stucco over 2 layers of Type D asphalt-saturated Kraft paper and OSB	Less than 1.0 perm

Source: Lstiburek 2006. See Building Science Corporation 2006 for an extensive list of building material perm ratings.

classes of vapor retarders based on their perm ratings (see table below). Vapor retarder requirements were removed in the 2009 IECC; however, vapor retarder requirements are addressed in the 2009 IRC.

How, where, and whether a vapor diffusion retarder should be used depends on the climate. Typically, the number of Heating Degree Days (HDD) in an area is used to help make these determinations. (See Chapter 5 for a comparison of Building America climate zones and IECC climate zones.) In the cold and very cold climates (equivalent to IECC climate zones 5, 6, and 7), the vapor retarder should be located on the warm side of the wall, i.e., on the interior side of the insulation.

A Heating Degree Day

is a unit that measures how often outdoor daily dry-bulb temperatures fall below an assumed base, normally 65°F (18°C)

2009 IRC R601.3 specifies the use of Class I or II vapor retarders on the *interior* side of framed walls in IECC climate zones 4c, 5, 6, 7, and 8; however, per a change in the 2009 IRC from the 2006 IRC, Class III vapor retarders are now permitted in all of these climate zones under certain conditions. The 2009 IRC R601.3.1 allows the use of Class III vapor retarders (such as latex paint) instead of Class 1 or Class II vapor retarders when the wall assembly allows drying through the use of ventilated claddings or reduces closed-cavity condensation potential through the use of exterior insulating sheathings. See the table on Class III vapor retarders for a listing of specific requirements in each IECC climate zone under which Class III vapor retarders are permitted in IECC zones 5, 6, 7, and 8.

Vapor Retarder Definitions

The 2009 IRC R601.3 gives the following definitions and examples for vapor retarder classes:

Class	Definition	Examples
I	0.1 perm or less	Sheet polyethylene, sheet metal, non-perforated aluminum foil
II	Greater than 0.1 perm to less than 1.0 perm	Kraft-faced fiberglass batts or low-perm paint
III	Greater than 1.0 perm to less than 10 perm	Latex or enamel paint

The 2009 IRC 601.3 also specifies that Class I or Class II vapor retarders are not required in IECC zones 5, 6, 7, and 8 under the following conditions: basement walls, in the below-grade portion of any wall, or in construction where moisture or frozen moisture will not damage the materials used in the assembly. (See the sidebar on the following page for a discussion of this exception).

While Class 1 vapor retarders are not required in any climate zone, their use is most applicable in the very cold and subarctic climates. (See sidebar and see Building Science Corporation 2008 and Lstiburek 2006 for more information and wall construction examples).

Air Flow

Air enters a home through openings in walls, cracks around doors and windows, and at intersections of building assemblies. Key points of air entry include rim joists where foundations meet floors and walls, where walls and floors for upper stories join together, and where walls intersect the roof. The pressure difference between indoor and outdoor air (or between indoor air and soil gas), temperature differences, and wind are the driving forces of air infiltration. Plugging air leaks is one way to slow down infiltration.

Air movement can affect how well insulation works. When outside air is pushed through insulation in places such as attics, walls, or crawlspaces, it robs the insulation's ability to slow down heat loss. This process is called wind wash or air intrusion. Using baffles, dams, and wind blocks in attics keeps ventilation ports open and directs air away from the insulation.

Controlled air movement in the right place is beneficial. Providing a ventilation space behind exterior wall cladding allows the material to dry out and prevents the moisture from contaminating housewraps, sheathing, or other wall components. Wall venting behind brick veneers is especially important. Under the right conditions, energy from the sun can push vapor through wet brick with the force of a steam boiler. Ventilation cavities behind brick help to dissipate this vapor before it is injected into the framed cavity.

Crawlspaces and attics are other areas in homes that have traditionally used passive ventilation to dissipate moisture.

Researchers and builders have developed methods of building unvented, conditioned attics and crawlspaces, and sealing these areas may be recommended if they are to provide conditioned space to house HVAC equipment and ducts. (See Chapter 8 for more on crawlspaces.)

Planned ventilation is needed to provide a healthy and comfortable indoor environment. Relying on air leakage to provide ventilation and combustion air is unreliable. By its nature, infiltration is not a reliable form of ventilation. It depends on pressure and temperature differentials that change constantly. Air leaks may also carry with them moisture that can cause structural or mold problems. Combustion in furnaces, fireplaces, dryers, and cooking appliances requires air. If multiple combustion or exhaust systems are drawing air at the same time and if these appliances are not all direct vented to the outdoors, there is a chance that combustion appliances can backdraft, drawing flue gases into a home rather than expelling them outdoors. Mechanical ventilation and sealed combustion systems are described in Chapter 9.

Nelson Construction of Farmington, Connecticut, uses two inches of foil-faced polyisocyanurate insulating sheathing taped at the seams for an insulated air sealed exterior that is finished with Tyvek house wrap and vinyl siding.

Use of Class I or Class II Vapor Retarders in Basements in Cold Climates

The 2009 IRC 601.3 specifies Class I or Class II vapor retarder in zones 4c, 5, 6, 7, or 8 "except on the following: basement walls, in the below-grade portion of any wall, or in construction where moisture or frozen moisture will not damage the materials used in the assembly." This exception is explained in Building Science Corporation 2008 as follows: "Below grade spaces such as basements are of particular concern with respect to Class I vapor control layers. Because the moisture drive in below grade walls is always to the interior, installing a high level of vapor control on the interior of the wall will cause moisture related durability issues by trapping moisture in the enclosure (see *BSD-103: Understanding Basements*). However, a Class I vapor control layer could be used in a below grade assembly under the following conditions: (a) no moisture-sensitive material is trapped between the concrete and the Class I vapor control layer, (b) this space is completely isolated from air communication with the interior, and (c) the Class I vapor control layer is protected from interior-sourced condensation. An example of this assembly would be foil-faced polyisocyanurate applied to the basement wall, with a gap between the insulation and the concrete isolated and air sealed from the interior."

Water-Carrying Capacity of Diffusion vs. Air Flow

Research shows 30 times more water vapor is carried through walls by air flow than by diffusion.

Unintentional air leaks can allow leakage of significant amounts of air into and out of a home in an uncontrolled manner through unsealed seams and unplugged holes in the walls, ceiling, and floors. *(Figure source: EPA)*

Heat Transfer

Heat travels via three mechanisms: conduction, convection, and radiation.

Conduction

Conduction is the movement of heat through a material. It is the cause of a hot handle on a sauce pan simmering away on a range top. Heat flows from warm areas to cold areas. The larger the temperature difference between the areas the faster heat will flow.

The ability of materials to resist heat flow influences conduction. Insulation is very good at resisting conducted heat flow. Dimensional lumber is not very good at resisting heat flow. The best way to slow down conduction is to add insulation to building envelope assemblies. It is important that insulation be installed to fill all voids in the building envelope. It is easier to fill voids using blown-in or sprayfoam insulation than with batt insulation. Blown cellulose or fiberglass insulation for example flows almost like a liquid, filling in areas behind wiring and framing where batt insulation might be compressed or blocked. Spray foam is applied as a liquid and also fills voids that may be difficult to reach with batts. Batts work well in large, uninterrupted areas if installed properly.

The rate at which heat flows through a material is described using two terms: R-value and U-value. Resistance to heat flow is called R-value, the higher the R-value the more resistant a material is to heat conduction. R-values can be added together to calculate how well an entire assembly will resist heat flow.

Conductivity is described using U-value. Conductivity refers to how well a material or assembly conducts heat. It is inversely proportional to R-value. If the U-value is high, then the R-value is low. From an energy-efficiency perspective, high R-values and low U-values are good. U-values may be calculated for an entire assembly or for an individual component. However, U-values for a number of components cannot be added together to calculate the overall U-value for an assembly such as a wall.

Convection

Convection is the movement of heat via a gas or liquid. Warm air becomes buoyant, while cold air tends to sink. Convection is the force that draws hot air up a chimney. This force is sometimes called the stack effect.

Designers and builders can use convection as a natural way to cool and ventilate a home, but it can cause problems in the wrong places and circumstances.

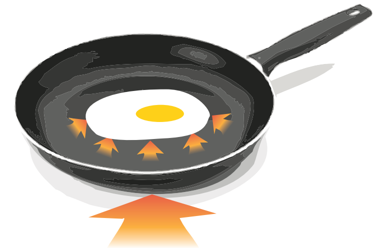
In cooler climates, heated air tends to rise to the top of tall structures. Warmer air becomes buoyant and can carry more moisture than cool air. Near cold surfaces, such as inefficient windows, cooler air drops. As the air cools below the dew point, it must give up some of its moisture, which then condenses on the cold surface. This is why windows sometimes have condensation in wintertime.

In the summer, air-conditioned structures, colder air sinks, drawing in warmer air through leaks in the building envelope. Warmer air carries more moisture than cold air; as it cools, this moisture may condense inside structural assemblies. This outside air can also increase indoor humidity levels, causing occupants to turn up the air conditioner, which exacerbates the problem.

Convective air currents can set up wherever differences in air pressure drive air movement. This applies to the house as a whole, and to smaller spaces. Convective loops can occur in cavities inside walls

Conduction

Heat transferred by contact, like the hot pan that fries an egg or the hot asphalt that burns bare feet.



Convection

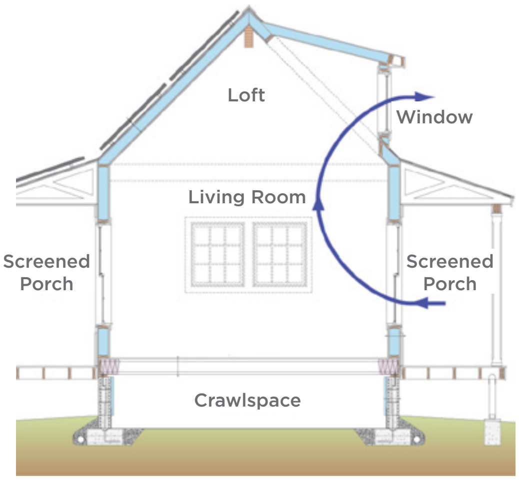
Heat transferred via air or liquid movement in a pattern of cooling/ falling and warming/ rising like hot water that rises and falls in a percolating coffee pot.

Radiation

Heat transferred through space by rays, like rays of sun that warm your skin if the rays are not blocked by a building or tree.

Stack Effect

The stack effect is the flow of air that results from warm air rising, creating a positive pressure area at the top of a building and a negative pressure area at the bottom of a building. The stack effect can overpower the mechanical system and disrupt ventilation and circulation in a building. It pulls unfiltered air and soil gases into a home through cracks in the foundation and around doors and windows and it draws conditioned air up and out through air leaks around ceilings, chimneys, flue, and pipe chases.



Building America's research team lead Building Science Corporation used convection to help cool this structural insulated panel (SIP) cottage in Georgia. Cool air from the screened porches is drawn into the building's interior where it heats up and is pulled up and out the second-story windows, drawing more air in through the shaded first-story windows.

where there are voids in insulation, in attics, and even between tight-fitting blinds and inefficient windows. Differences in temperature between the conditioned space and outdoors can create enough of a pressure difference inside a wall cavity to form a convective loop.

The most effective strategies for stemming convective heat losses are to avoid air temperature differentials inside structures, to fully fill insulated cavities with insulation (no voids), and to seal air leaks. Properly installing adequate insulation eliminates cold spots in walls and structural cavities. Sealing air leaks blocks air movement and minimizes the temperature differentials that occur when conditioned and unconditioned air mix.

Radiation

Radiation is the movement of heat by solar or infrared rays. For example, much of the heat from a woodstove is in the form of radiation. The key to radiation is that, unlike conduction or convection, this process does not involve a molecular connection between the source and the recipient of the heat. That is one reason a person sitting across the room feels toasty from a radiant heater, such as a woodstove. Heat can be transferred through a vacuum via radiation; this is how heat from the sun is transferred to Earth through the vacuum of space.

Radiant heat can influence comfort. In a house with a reasonable indoor temperature, radiant heat from a hot window or wall can influence the comfort level of building occupants. In cold climates, heat radiating from occupants to a cold window or wall can make them feel colder. On the other hand, when indoor warming is needed, an occupant exposed to radiant floor heating may feel warmer than the air temperature suggests.

Techniques for controlling solar radiation heat gain include tree shading and window awnings or overhangs. Radiant barriers installed in the attic and light-colored roofing material are used to minimize solar heat gain in the hot dry and hot humid climates but are not recommended in the heating-dominated areas of the cold climate.

At night, a house can radiate heat to a clear night sky. The resulting cooling can lead to condensation in attics and roof wetting. Researchers are exploring ways to use radiation to the night sky as a passive way to cool homes.

Occupants

Occupants are a force unto themselves, not tied directly to climate or building dynamics but able to strongly influence building performance.

Occupant comfort and costs are at the center of design considerations. However, as the building operators and maintainers, occupants can do much to correct or unbalance a system. Providing correct information in the form of owners manuals, homeowner education, and accurate marketing materials can help occupants make decisions that will contribute to their home's longevity, comfort, and efficiency.

Occupants can have an enormous impact on the energy performance of their homes by the selections they make in appliances, entertainment systems, computers, tools, and other electric equipment. These plug loads make up about 40% of energy loads in homes. As builders and researchers figure out how to make thermal, lighting, and ventilation equipment more efficient, these miscellaneous plug loads will become more and more important in how energy is managed in homes.

Occupant choices in appliances and home electronics have a big impact on plug load.

More Information on Water, Vapor, Air Flow, and Heat Transfer

2009 IECC. 2009. *International Energy Conservation Code*, International Code Council (ICC), Washington, DC. www.iccsafe.org/Store/Pages

2009 IRC. 2009. *International Residential Code - One and Two-Family Dwellings*, Section 408.3, "Unvented Crawl Spaces," International Code Council (ICC), Washington, D.C. www.iccsafe.org/Store/Pages

ASTM E-2112-07. "Standard Practice for Installation of Exterior Windows, Doors and Skylights." American Society for Testing and Materials (ASTM), www.astm.org/Standards/E2112.htm

ASTM E 2266. "Standard Guide for Design and Construction of Low-Rise Frame Building Wall Systems to Resist Water Intrusion." American Society for Testing and Materials (ASTM), www.astm.org/Standards/E2266.htm

Buildernews Magazine. May 2004. "Housewrap Felt or Paper: Comparing specs on weather barriers," www.buildernewsmag.com/index.php?option=com_content&view=article&id=1168%3AHousewrap+Felt+or+Paper%3A&Itemid=107

Building Science Corporation. Homeowner Information Resources. www.buildingscience.com/resources/more-topics/homeowner_resources

Building Science Corporation. 2006. Info-500: Building Materials Property Table, Building Science Corporation , Created: 2010/04/16, Info-500: Building Materials Property Table

Building Science Corporation. 2008. Info-310: Vapor Control Layer Recommendations, By Building Science Corporation, Sept. 8, 2009, www.buildingscience.com/documents/information-sheets/3-water-management-and-vapor-control/info-sheet-310-vapor-control-layer-recommendations?topic=resources/more-topics/vapor_barrier_code_changes

Fenestration Manufacturers Association (FMA)/American Architectural Manufacturers Association (AAMA) 100-07. "Standard Practice for the Installation of Windows with Flanges or Mounting Fins in Wood Frame Construction." Available from AAMA's online store at www.aamanetstore.org/pubstore/ProductResults.asp?cat=0&src=100

HGTVpro.com. "Improved Stucco Systems." Article available at www.hgtvpro.com/hpro/bp_exterior_finishes/article/0,2617,HPRO_20149_4243887,00.html

IBACOS. 2002. "Moisture Issues in Homes with Brick Veneer." IBACOS article available at www.eere.energy.gov/buildings/building_america/pdfs/db/36397.pdf

Lstiburek, Joseph W. 2001. "Brick, Stucco, Housewrap and Building Papers," RR-0105, Building Science.com, www.buildingscience.com/documents/reports/rr-0105-brick-stucco-housewrap-and-building-paper/

Lstiburek, Joseph W. 2003. *EEBA Water Management Guide.* Energy and Environmental Building Association. Minneapolis, Minnesota. www.eeba.org/bookstore/prod-Water_Management_Guide-9.aspx

Lstiburek, Joseph W. 2004. "Understanding Vapor Barriers," ASHRAE Journal, August 2004. www.renewable-resource.net/resources/Understanding_Vapor_Barriers

Lstiburek, Joseph W. 2006. *Building Science Digest 106: Understanding Vapor Barriers*. Building Science Press. Waterford, Massachusetts. www.buildingscience.com/documents/digests/bsd-106-understanding-vapor-barriers

Lstiburek, Joseph W. 2008. "Concrete Floor Problems," BSI-003, Building Science Corporation, www.buildingscience.com/documents/insights/bsi-003-concrete-floor-problems.

Parker, D., J. Sherwin, J. Sonne, N. Moyer. 2002. *Comparative Evaluation of the Impact of Roofing Systems on Residential Cooling Energy Demand in Florida*. Florida Solar Energy Center, FSEC-CR-1220-00, http://securedb.fsec.ucf.edu/pub/pub_show_detail?v_pub_id=4120

Straube, John. 2001. "Wrapping it Up," *Canadian Architect*, May 2001. www.cdnarchitect.com/issues/ISarticle.asp?aid=1000115982

U.S. Department of Energy. 2000. "Technology Fact Sheet on Weather-Resistive Barriers." Available on the Web at www.toolbase.org/PDF/DesignGuides/weatherresistantbarriers.pdf

U.S. Department of Energy. 2009. "Residential Requirements of the 2009 International Energy Conservation Code," DOE Building Energy Codes Program, PNNL-SA-65859, www.energycodes.gov/training/pdfs/2009_iecc_residential.pdf

U.S. Environmental Protection Agency. Mold Course - *Introduction to Mold and Mold Remediation for Environmental and Public Health Professionals*. Accessed 6/18/2009, www.epa.gov/mold/index.html

Chapter 7.

The Overall Building Envelope

The building envelope is the boundary that separates interior comfort from exterior conditions. The envelope encompasses three boundaries: the thermal boundary, the pressure boundary, and the weather barrier.

- The thermal boundary consists of the building assemblies surrounding the space that is purposefully cooled or heated. The insulation plus the air barrier form the thermal boundary.
- The pressure boundary is the point at which inside air and outside air are separated. The line where the pressure difference across the building shell is greatest between the inside and outside of the house is the pressure boundary. This boundary is where air sealing should occur. Thermal and pressure boundaries should be aligned.
- The weather barrier includes screens to shed rain.

This chapter describes three strategies that apply to the overall building envelope: advanced framing, insulating, and air sealing. These strategies involve the entire house envelope and directly address the thermal and pressure boundaries. Specific practices that apply to particular assemblies, such as foundations, walls, and roofs, are described in the next chapter.

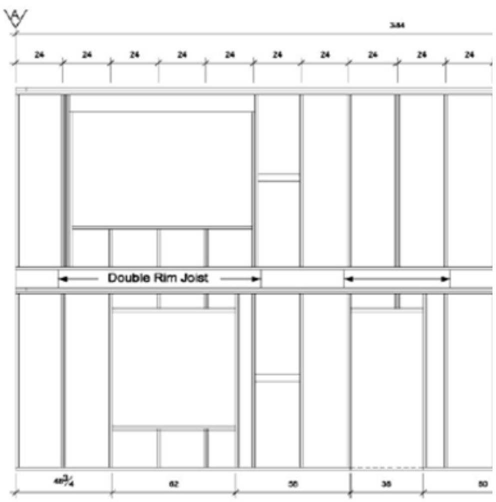
Advanced Framing

Optimal value engineering or advanced framing refers to framing techniques that require less lumber than standard framing practices but provide all the needed structural strength. Using less lumber leaves more room for insulation while saving resources and reducing waste. The recommendations below apply to standard framing using dimensional lumber. Other energy-efficient framing materials not described here include structural insulated panels, insulated concrete forms, and steel framing.

"Advanced framing is such a simple thing but very few builders are doing it. It is a selling point with customers. The performance characteristics are easy to point out to the customer and it's easy to carry the energy-saving concepts through to other items like high-performance windows, more insulation, and air sealing."

Builder Barrett Burr, Olympia, Washington

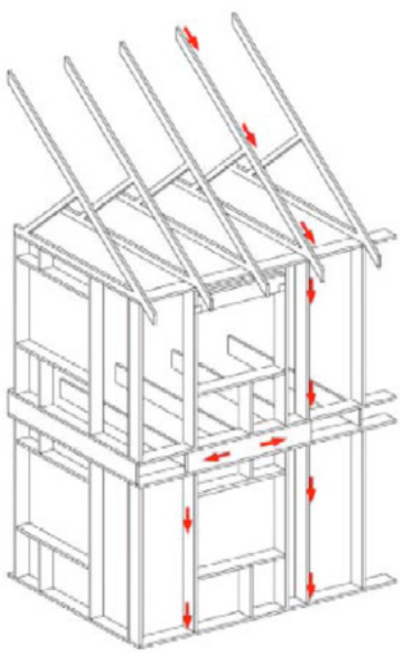
CHAPTER TOPICS



(left) Sheet goods come in 4x8-foot dimensions. Designing and building on a 2-foot grid saves cutting time and reduces lumber and sheet good waste.

(right) Framing details include ladder blocking and two-stud corners. *(Photo source: Tommy Williams Homes)*

In a Building America study (described in the Partnership for Advancing Technology in Housing [PATH] Toolbase) advanced framing resulted in 50% reductions in installation and materials costs along with a 7% increase in the amount of wall cavity area that could be insulated. The simple measures taken in this project included single top plates, 24-inch on-center 2x6 wall studs, and standardization of window and door openings to match the 24-inch layout. A production builder in California who switched to advanced framing methods realized a 40% reduction in wall framing costs, for a materials-purchasing savings of over $1,100 per house.

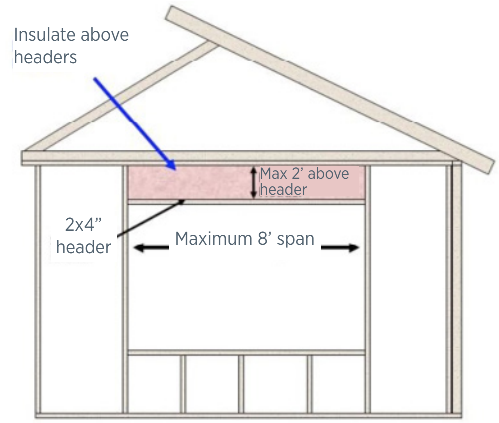


Advanced framing techniques include aligning wall studs with trusses and using single top plates.

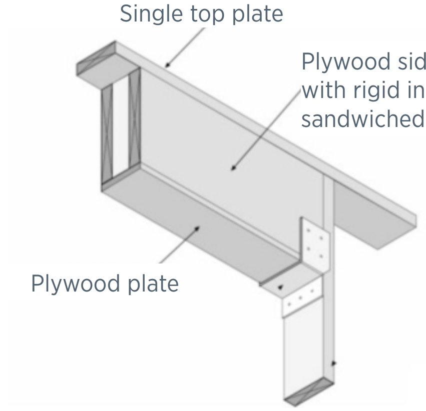
A sample of advanced framing techniques includes the following:

- **TWO-FOOT MODULE DESIGN.** Starting with the foundation, the house exterior dimension footprint should be based on 2-foot increments. Because sheet goods come in 4-foot by 8-foot dimensions, this reduces waste and cuts material costs.
- **FRAME 24-INCH ON-CENTER.** Typical practice is to frame walls, floors, and often roofs at 16 inches on center. However, 24-inch on-center walls are structurally adequate for most residential applications. Even though the stud size is increased from 2x4 to 2x6 on load-bearing walls, changing stud-spacing from 16 to 24 inches can reduce framing lumber needs significantly. Confirm with local building officials because some jurisdictions in high-wind areas may not allow 24-inch on-center (PATH).
- **ALIGN FRAMING MEMBERS AND USE A SINGLE TOP PLATE.** Double top plates are used to distribute loads from framing members that are not aligned above studs and joists. By aligning framing members vertically throughout the structure, the second plate can be eliminated. Plate sections are cleated together using flat plate connectors [2009 IRC R602.3.2].

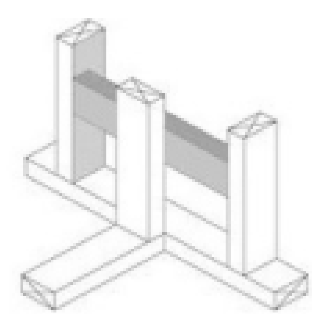
- **SIZE HEADERS FOR ACTUAL LOADING CONDITIONS.** Headers are often oversized for the structural work that they do. Doubled-up 2x6 headers end up in non-load-bearing walls. Doubled-up 2x12 headers end up in load-bearing walls, regardless of specific loading conditions. Nonbearing walls do not need structural headers [2009 IRC R602.7.2]. Proper sizing may allow for the use of insulated headers in which foam insulation is sandwiched between lumber.
- **LADDER-BLOCK EXTERIOR WALL INTERSECTIONS.** Where interior partitions intersect exterior walls, three-stud "partition post" or stud-block-stud configurations are typically inserted. Except where expressly engineered, these are unnecessary. Partitions can be nailed either directly to a single exterior wall stud or to flat blocks inserted between studs. This technique, called "ladder blocking" or "ladder framing," creates room for more insulation.
- **USE TWO-STUD CORNERS.** Exterior wall corners are typically framed with three studs. The third stud generally only provides a nailing edge for interior gypsum board and can be eliminated. Drywall clips, a 1x nailing strip, or a recycled plastic nailing strip can be used instead. Using drywall clips also reduces opportunities for drywall cracking and nail popping, frequent causes of builder callbacks.
- **ELIMINATE REDUNDANT FLOOR JOISTS.** Double floor joists are often installed unnecessarily below non-load-bearing partitions. Nailing directly to the subfloor provides adequate attachment and support. Partitions parallel to overhead floor or roof framing can be attached to 2x3 or 2x4 flat blocking.
- **USE 2X3s FOR PARTITIONS.** Interior, non-load-bearing partition walls can be framed with 2x3s at 24 inches on center or 2x4 "flat studs" at 16 inches on center [2009 IRC R602.5].



Using single 2x4 headers instead of double 2x6 headers in non-load-bearing walls allows space for insulation.



Closed, insulated headers are one advanced framing technique. *(Figure source: CARB)*



Ladder blocking where exterior walls intersect interior walls provides space for insulation and cuts back on thermal bridging.

For More Information on Advanced Framing

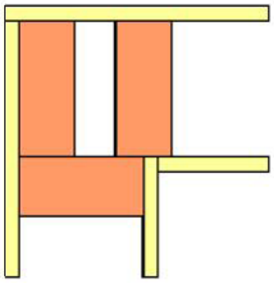
IBACOS. 2003. *Best Practices: Optimum Value Engineering*. Available on the Building America website at www.eere.energy.gov/buildings/building_america/pdfs/db/35380.pdf

Lstiburek, Joseph. 2005. "The Future of Framing Is Here," *Fine Homebuilding*, November 2005, No. 174, p. 50-55.

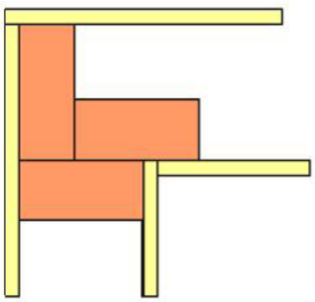
NAHB Research Center. "Advanced Framing Techniques: Optimum Value Engineering (OVE)," Available at www.toolbase.org/Construction-Methods/Wood-Framing/advance-framing-techniques accessed 6-4-08

NRDC. 1998. *Efficient Use of Wood in Residential Construction*. Natural Resources Defense Council, Washington, D.C. www.nrdc.org/cities/building/rwoodus.asp

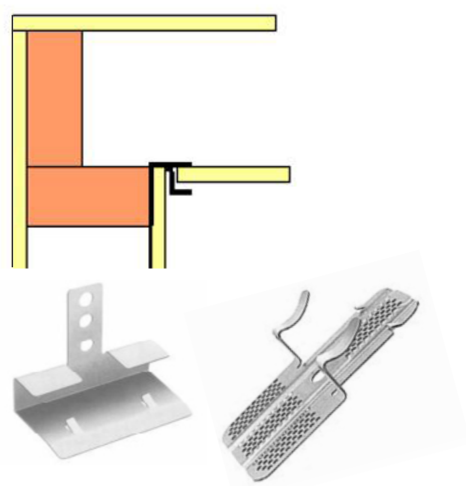
PATH. ToolBase Techspecs: Advanced Framing Techniques. www.toolbase.org/pdf/techinv/oveadvancedframingtechniques_techspec.pdf



Conventional three-stud corner leaves a cavity that must be insulated by the framers—not good.



Improved three-stud corner allows insulation to be installed later, in sequence.



Two-stud corners with drywall clips use the least wood and give the best thermal performance.

Rural Development, Inc., achieved an R-42 wall insulation value on homes in western Massachusetts by creating a double wall of two 2x4 16-inch on-center walls and stuffing the 11-inch cavity between the walls with dense-pack, dry-blown cellulose.

DOE. 2002. Advanced Wall Framing. 6-page fact sheet by the U.S. Department of Energy www.nrel.gov/docs/fy01osti/26449.pdf

DOE. 2009. Advanced Framing, Article 1399, U.S. Department of Energy Building Energy Codes Resource Center, http://resourcecenter.pnl.gov/cocoon/morf/ResourceCenter/article//1399

Insulation

Insulation is usually hidden away behind finished surfaces, but insulation is the material that does the most to block heat loss through conduction. Insulation comes in a variety of forms; some of the common options are described below. Average R-values are provided in the table.

Common Insulating Materials (R-values per inch of insulation)

INSULATING MATERIAL		Avg. R-Value per Inch
Fiberglass	• Unfaced batt, standard density	R-2.9 to R-3.8
	• Unfaced batt, high density	R-3.7 to R-4.3
	• Blown fiberglass	R-2.2 to R-2.7
Expanded Polystyrene (EPS)	• Rigid foam board	R-3 to R-4
	• Beads	R-2.3
Extruded Polystyrene (XPS)	• Rigid foam board	R-5
Polyisocyanurate	• Rigid board	R-5.6 to R-8
	• With foil facing	R-7.1 to R-8.7
Polyurethane	• Spray foam or foam board	R-7 to R-9
	• Foam board with foil facing	R-7.1 to R-8.7
	• Soy-based polyurethane spray foam	R-3.7
Other	• Cellulose, blown	R-3.6 to 3.8
	• Mineral wool, rock or slag, batt or loose	R-3.7
	• Cotton batt	R-3.4
	• Sheep's wool batt	R-3.5
	• Strawbale	R-2.4
	• Plastic PET	R-3.8 to R-4.3

Source: DOE Energy Savers website: www.energysavers.gov/your_home/insulation_airsealing/index.cfm/mytopic=11510

BLANKETS OR BATTS: Blanket insulation in the form of batts or rolls is a flexible product made from mineral fibers, fiberglass, or textile fibers. Batts 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. Standard fiberglass batt insulation features R-values between R-11 (3.5-inch thick) and R-38 (12-inch thick). High-performance (medium- and high-density) fiberglass batts with greater R-values per inch of thickness are also available. If you choose to use other types of insulation, such as blown-in, batts can be installed in areas that may become inaccessible as construction unfolds; for example behind shower inserts, beneath stairs, or in rim joists. Batts also make good dams in attics around access points or other areas where blown-in insulation should be held back. Batts are not air barriers. Kraft facing forms a Class II vapor retarder. See Chapter 6 for more about vapor retarder code requirements in the cold climate.

BLOWN-IN: Blown-in, loose-fill insulation includes loose fibers or beads that are blown into building cavities or attics using special pneumatic equipment. Netting may be stapled to studs to hold blown-in insulation in place before gypsum board is installed. Another form of blown-in insulation is fibers, such as cellulose made from recycled newspaper, that is mixed with a wet adhesive and sprayed into the wall cavity, then allowed to set in the walls making it resistant to settling. An advantage of blown-in insulation is that it easily takes the form of the cavity into which it is blown. Blown-in insulation will also fill spaces behind and around potential obstacles, such as electrical boxes, wiring, and plumbing. The blown-in material can provide some resistance to air infiltration if the insulation is sufficiently dense, but blown-in insulation should not be considered an air barrier.

SPRAY POLYURETHANE FOAM (SPF): Foamed-in-place polyurethane foam insulation can be applied by a professional applicator using special equipment to meter, mix, and spray the insulation into cavities where the foam hardens in place. Some polyurethane foams are made with up to 20% soy-based oil stock rather than 100% hydrocarbon-based oil. Sprayed foam makes an excellent air seal and can be used to reach hard-to-get-at places. Critical points where this type of foam is especially useful include complicated intersections of building elements with odd shapes and many joints. Other common areas include the rim joists at the intersection of the foundation and floor and between floors.

Spray foam comes with either an open-cell (OC SPF) or closed-cell (CC SPF) structure. An open-cell structure allows air to move between the cells within the insulation; water may be used as the blowing agent.

(1) Batt insulation in ceiling. *(2)* Blown-in insulation. *(3)* Spray foam. *(Photo source: Sam Garst).* *(4)* Spray foam applied along the underside of the roof deck to provide a conditioned and non-vented attic space for ducts and air handlers.

(top) Masonry walls are insulated with interior rigid insulation.

(bottom) Sealing gaps between floor joists with spray foam provides a good air seal that prevents the flow of heat, cold, and pollutants from unconditioned space to conditioned space.

"You really can't overdo insulation. It is relatively cheap compared to other components of the house and you will pay for under-insulating for the life of the house."

Homebuilder Sam Garst

Closed-cell foam is more rigid and dense with each cell forming a bubble that captures the gas inside of it. Closed-cell foam contains special gases that make it expand and give it greater R-values. Open-cell foam is less dense, has a lower R-value rating, and is generally less expensive. Both types of foam are excellent air sealers. High-density, closed-cell foams have greater resistance to bulk liquid and vapor and may serve as both air and vapor barriers. Spray foam companies have converted to using a non-ozone-depleting blowing agent, but these agents may still have global warming potential.

RIGID FOAM INSULATION: Rigid insulation is made from fibrous materials or plastic foams that are pressed or extruded into sheets and molded pipe coverings. Rigid insulation provides thermal and acoustical insulation, strength with low weight, and coverage with few heat loss paths. Rigid foam insulating sheathing has other significant benefits, particularly in the areas of moisture control. Inwardly driven moisture from reservoir claddings such as brick and stucco can be controlled by rigid foam insulating sheathing. Code permits the use of rigid foam insulating sheathing of sufficient thickness in place of interior vapor barriers and vapor retarders, thereby enhancing the inward drying of the wall assembly; so that "double vapor barriers" can be avoided [2009 IRC 601.3, see IRC for R-values by IECC climate zone]. If sufficiently braced, walls can use rigid foam as an insulating sheathing in place of oriented strand board (OSB) and plywood sheathings for cost savings.

Rigid foam insulation sheets may be faced with a reflective foil that reduces radiant heat transfer when facing an air space. Foil facing also makes the board nearly impervious to water and vapor, so it should be used with caution. Rigid foam insulation may be used in combination with other insulation types, such as on the exterior of walls whose cavities are filled with cellulose or fiberglass. Foam sheets that may be in contact with the ground should be borate-treated for termite resistance. Rigid fiberglass insulation is used on the exterior of basement or foundation walls and can form a moisture screen.

Rigid insulation sheets may be applied to the exterior of wall assemblies as insulating sheathing. This approach helps to seal air leaks, block thermal bridges where framing lumber spans the wall, provide a drainage plane or rain screen, and create additional R-value near the exterior surface of the wall. Insulation on the outside of the wall helps to temper the wall's interior temperature and avoid condensation. Here is a summary of rigid insulation materials:

- **Polyisocyanurate – 5.6 to 8.7 R-value per inch**
  Typically foil-faced rigid sheet; it should not be used in contact with soil because it absorbs moisture; foil facing is a vapor barrier

and should be used with caution; a non-ozone-depleting blowing agent is used (pentane).

- **Extruded Polystyrene (XPS) – 5 R-value per inch**
  More consistent density and greater compressive strength than EPS; preferred material for soil contact or as rain barrier because it is resistant to liquid moisture penetration. The EPA deadline to switch to a non-ozone-depleting, VOC-free blowing agent was January 1, 2010.

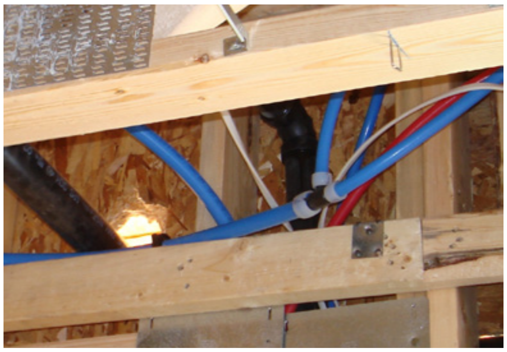
- **Expanded Polystyrene (EPS) – 2.3 to 4 R-value per inch**
  EPS foam beadboard uses a non-ozone-depleting blowing agent (pentane). Spaces between beads can absorb water. It is not a vapor retarder. It is often used in structural insulated panels and insulating concrete forms; comes with borate treatment making it resistant to insects; requires a capillary break between soil and insulation; and comes in many densities and grades.

- **Fiberglass – 2.2 to 4.3 R-value per inch**
  Drainable and resistant to insect degradation; excellent for soil contact.

REFLECTIVE INSULATION SYSTEMS: Reflective insulation systems are fabricated from aluminum foils with a variety of backings such as roof sheathing, kraft 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. There are no R-values for reflective insulation because R-values apply to conduction and reflective barriers reflect radiant heat. 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. As a general rule, the reflective surface of a radiant barrier should face downward so that dust cannot collect on the surface. As the level of ceiling insulation increases, the value of a radiant barrier is diminished. In the cold and very cold climates where solar heat gain is less of an issue, reflective insulation is not necessary and installation of higher levels of attic insulation would be a more cost-effective way to get higher R-values. Radiant barriers should not be installed directly on top of attic floor insulation. In cold weather, a radiant barrier installed on the cold side of the insulation can act as a vapor barrier in the wrong location. When warm moisture carrying house air leaks into the attic in the winter, it may condense on the underside of the barrier. Even a perforated radiant barrier can trap moisture in cold climates since the water can freeze in the small holes and seal them. Because of these hazards, it is strongly recommended that you NOT apply

(top) Bob Ward Companies used an exterior wall sheathing consisting of a 1/8-inch layer of laminated fiberboard covered with 1/8-inch of extruded polystyrene foam board. This layer goes on the exterior side of the studs under the stone or wood siding. Joints are taped so the foam board serves as an air barrier as well, eliminating the need for housewrap. This exterior insulation layer moves the dew-point surface to the outside of the framing member, reducing the potential for condensation and moisture damage within the wall cavity. *(Photo source: Bob Ward Companies)*



(top) Holes in the top plate for wiring are sealed with foam.

(middle) Unsealed holes for pipes can leave large gaps for air and bugs to pass through.

(bottom) Thorough air sealing and locating ducts in conditioned space are two ways the Loudon County Habitat for Humanity affiliate improves the efficiency of its homes. *(Source: Loudon County Habitat for Humanity)*

radiant barriers directly on top of the attic floor insulation. Installing them at all in a cold climate is not generally cost effective (DOE 2009).

For More Information on Insulation

ASHRAE. 2009. *ASHRAE Handbook of Fundamentals*. American Society of Heating, Refrigerating, and Air-Conditioning Engineers. www.ashrae.org/publications/page/158

Consortium for Advanced Residential Buildings. Steven Winter Associates (CARB-SWA). 2009. *Open-Cell vs Closed-Cell Foam Guide*. www.carb-swa.com

ENERGY STAR. Builder Option Packages (BOPS) with recommended insulation levels by county. www.energystar.gov/index.cfm?c=bop.pt_bop_index

Florida Solar Energy Center (FSEC). 1988. *Consumer Facts about Radiant Barriers*. FSEC-FS-37-88. FSEC, Cocoa, FL. www.fsec.ucf.edu/en/publications/pdf/FSEC-FS-37-88.pdf

Krigger, John and Chris Dorsi. 2009. *Resident Energy: Cost Savings and Comfort in Existing Buildings*, 5th Edition, Prentice Hall (previous editions published by Saturn Resource Management).

Mathis, R.C. 2007. *Insulating Guide*. Building Science Press. Westford, MA. Available for purchase at www.eeba.org/bookstore/prod-Insulating-Guide-8.aspx

Parker, Danny and John Sherwin. 1998. "Comparative Summer Attic Thermal Performance of Six Roof Constructions." TO-98-17-3. *1998 ASHRAE Annual Meeting*, Toronto, Canada. www.fsec.ucf.edu/en/publications/pdf/FSEC-PF-337-98.pdf

Parker, Danny. 2001. *FPC Residential Monitoring Project: New Technology Development Radiant Barrier Pilot Project*. FSEC-CR-1231-01. Florida Solar Energy Center, Cocoa, FL. www.radiantbarrierdoneright.com/FSEC.pdf

Roos, Carolyn. 2008. *Principles of Heat Transfer*. WSUEEP07-004. Washington State University, Extension Energy Program, Olympia, WA. www.energy.wsu.edu/pubs/

U.S Department of Energy (DOE). 2009. "Cool Down with 'Reflective Insulation' Materials." *Setting the Standard*. January 2009. DOE Building Energy Codes Program, www.energycodes.gov/publications/STS/2009/standard_january09.pdf

U.S. Department of Energy. 2009. "Radiant Barriers," updated May 28, 2009, www.energysavers.gov.

U.S. Department of Energy (DOE). 2008. *Insulation Fact Sheet*. DOE/CE-0180. DOE's insulation calculator for recommended insulation levels. www.ornl.gov/sci/roofs+walls/insulation/ins_16.html

U.S. Department of Energy (DOE). 1991. *Radiant Barrier Attic Fact Sheet*. DOE/CE-0335P. www.ornl.gov/sci/roofs+walls/radiant/rb_01.html

U.S. Department of Energy (DOE). "Recommended insulation levels by zip code." www1.eere.energy.gov/consumer/tips/insulation.html

Air Sealing

Unintentional air flow (through-wall penetrations, leaks around doors and windows, and cracks in the roof) robs a home of warm or cool air, serves as a pathway for moisture flow, and decreases comfort levels. Controlling air infiltration is one of the most cost-effective and simplest energy-efficiency measures in modern construction practices. Extensive air sealing is one of the primary 40% improvement strategies. Air sealing is required by the 2009 IECC 402.4, which identifies several areas for air sealing and requires verification with a blower-door test or visual inspection.

Good caulking and sealing will reduce the infiltration of dust and dirt (and even bugs) that can enter homes through cracks and holes. The materials and approaches recommended here are common and time tested. However, these measures must be carefully installed to be effective and must be installed in the proper construction sequence before cavity areas are covered up by fixtures or walls. Health and safety are essential factors to consider when air sealing, especially if the home contains combustion appliances. See Building America's Air Sealing guide for more information (www.buildingamerica.gov).

Sealing against air leakage is primarily done for thermal reasons, but when coupled with appropriate mechanical ventilation, this procedure also assists in maintaining good indoor air quality for the occupant. This combination helps to provide controlled air rather than relying on pressure and temperature differences to supply air. Air leaks also carry water vapor; if this water vapor condenses, it can cause mold and other moisture problems. An important job for air barrier systems is separating garages from conditioned spaces to keep pollutants out of the house.

The key to the control of airflow is the use of a continuous air barrier. This barrier may be made up of several types of materials as long as it provides an unbroken barrier between conditioned space (indoors) and unconditioned space (outdoors, attic, crawlspace, and garage).

Typically mudded and taped gypsum board serves as an air barrier on the home's interior. Alternatively, stucco or taped and caulked rigid foam may serve as an air barrier on the home's exterior.

Building America researchers have worked with three building approaches that push the air and thermal barriers toward the exterior of the building shell: 1) conditioning crawlspaces and basements or using slabs, 2) installing insulated exterior sheathing, with sealed seams, and 3) conditioning attics. These approaches make it easier to provide an uninterrupted air barrier (see Chapter 14).

The installation of high-efficiency furnaces and water heaters can also help control air leakage. Natural gas-fired condensing furnaces achieve combustion efficiency levels greater than 90%. These direct-vent furnaces and water heaters are sealed combustion systems that intake and exhaust air through plastic pipes that do not require a vertical chimney. Chimneys and flue chases are notorious for air and thermal leaks. A direct-vent fireplace can also eliminate the need for a chimney entirely. Ducts located in conditioned space eliminate penetrations through the building shell and avoid the intake of unconditioned air that can occur through duct leaks. More information on these systems is included in Chapter 9.

(top) Seams are caulked to provide a good air seal before installing insulation and dry wall.

(middle) Air sealing the wall between the garage and the home is vital for occupant health and safety.

(bottom) Framing is sequenced to install an air barrier of OSB, plywood, or rigid foam between the porch and the attic.

"There are plenty of ways to create a more energy-efficient home; solar power is one way, but insulation and a tight seal can go a long way to achieve this as well."

Bob Walter, Morrison Homes,
Elk Grove, California

Builder David Sullivan and the South Chicago Workforce worked with Building America on the first structural insulated panel (SIP) home project ever permitted in the City of Chicago. SIPS provide excellent air sealing and insulating properties with fewer seams to caulk and much less thermal bridging than typical stud construction.

The Thermal Bypass Checklist

The ENERGY STAR for Homes program has compiled the Thermal Bypass Checklist, a comprehensive list of potentially vulnerable spots in the building envelope. The checklist identifies 25 points to inspect throughout the home, covering all major components of the building envelope including exterior walls, floors, ceilings, attics, and shafts. Builders can use the checklist to verify the integrity of the air barriers in the building envelope. The ENERGY STAR website contains the thermal bypass checklist and additional guidelines for installing insulation and air sealing.

See the *ENERGY STAR Qualified Homes Thermal Bypass Inspection Checklist* on the previous page.

For More Information on Air Sealing

2009 IECC. 2009. *International Energy Conservation Code*, Section 402.4 "Air Leakage," International Code Council (ICC), Washington, DC. www.iccsafe.org/Store/Pages

DOE. 2010. *Retrofit Techniques and Technologies: Air Sealing*, PNNL-19284, U.S. Department of Energy, http://www1.eere.energy.gov/buildings/building_america/

ENERGY STAR. 2008. "Thermal Bypass Checklist" www.energystar.gov/ia/partners/bldrs_lenders_raters/downloads/Thermal_Bypass_Inspection_Checklist.pdf

ENERGY STAR. 2008. "ENERGY STAR Qualified Homes: Thermal Bypass Checklist Guide," ENERGY STAR. www.energystar.gov/ia/partners/bldrs_lenders_raters/downloads/TBC_Guide_062507.pdf

Lstiburek, Joseph. 2006. *Building Science Digest 104: Understanding Air Barriers*. Building Science Press, Waterford, MA. Available at www.buildingscience.com/documents/digests/bsd-104-understanding-air-barriers

Lstiburek, Joseph. 2010. *Guide to Attic Air Sealing*, prepared by Building Science Corporation for the U.S. Department of Energy Building America Program. www.buildingscience.com/documents/primers/Attic%20Airsealing%20Guide%20-%20BSC%20Draft%20-%202010-02-12.pdf/view

ENERGY STAR Qualified Homes Thermal Bypass Inspection Checklist

Home Address:______________________________City:________________State:_______

Thermal Bypass	Inspection Guidelines	Corrections Needed	Builder Verified	Rater Verified	N/A
1. Overall Air Barrier and Thermal Barrier Alignment	**Requirements:** Insulation shall be installed in full contact with sealed interior and exterior air barrier except for alternate to interior air barrier under item no. 2 *(Walls Adjoining Exterior Walls or Unconditioned Spaces)*				
	All Climate Zones:				
	1.1 Overall Alignment Throughout Home	☐	☐	☐	☐
	1.2 Garage Band Joist Air Barrier (at bays adjoining conditioned space)	☐	☐	☐	☐
	1.3 Attic Eave Baffles Where Vents/Leakage Exist	☐	☐	☐	☐
	Only at Climate Zones 4 and Higher:				
	1.4 Slab-edge Insulation (A maximum of 25% of the slab edge may be uninsulated in Climate Zones 4 and 5.)	☐	☐	☐	☐
	Best Practices Encouraged, Not Req'd.:				
	1.5 Air Barrier At All Band Joists (Climate Zones 4 and higher)	☐	☐	☐	☐
	1.6 Minimize Thermal Bridging (e.g., OVE framing, SIPs, ICFs)	☐	☐	☐	☐
2. Walls Adjoining Exterior Walls or Unconditioned Spaces	**Requirements:** • Fully insulated wall aligned with air barrier at both interior and exterior, **OR** • Alternate for **Climate Zones 1 thru 3**, sealed exterior air barrier aligned with RESNET Grade 1 insulation fully supported • Continuous top and bottom plates or sealed blocking				
	2.1 Wall Behind Shower/Tub	☐	☐	☐	☐
	2.2 Wall Behind Fireplace	☐	☐	☐	☐
	2.3 Insulated Attic Slopes/Walls	☐	☐	☐	☐
	2.4 Attic Knee Walls	☐	☐	☐	☐
	2.5 Skylight Shaft Walls	☐	☐	☐	☐
	2.6 Wall Adjoining Porch Roof	☐	☐	☐	☐
	2.7 Staircase Walls	☐	☐	☐	☐
	2.8 Double Walls	☐	☐	☐	☐
3. Floors between Conditioned and Exterior Spaces	**Requirements:** • Air barrier is installed at any exposed fibrous insulation edges • Insulation is installed to maintain permanent contact with sub-floor above including necessary supports (e.g., staves for blankets, netting for blown-in) • Blanket insulation is verified to have no gaps, voids or compression. • Blown-in insulation is verified to have proper density with firm packing				
	3.1 Insulated Floor Above Garage	☐	☐	☐	☐
	3.2 Cantilevered Floor	☐	☐	☐	☐
4. Shafts	**Requirements:** Openings to unconditioned space are fully sealed with solid blocking or flashing and any remaining gaps are sealed with caulk or foam (provide fire-rated collars and caulking where required)				
	4.1 Duct Shaft	☐	☐	☐	☐
	4.2 Piping Shaft/Penetrations	☐	☐	☐	☐
	4.3 Flue Shaft	☐	☐	☐	☐
5. Attic/ Ceiling Interface	**Requirements:** • All attic penetrations and dropped ceilings include a full interior air barrier aligned with insulation with any gaps fully sealed with caulk, foam or tape • Movable insulation fits snugly in opening and air barrier is fully gasketed				
	5.1 Attic Access Panel (fully gasketed and insulated)	☐	☐	☐	☐
	5.2 Attic Drop-down Stair (fully gasketed and insulated)	☐	☐	☐	☐
	5.3 Dropped Ceiling/Soffit (full air barrier aligned with insulation)	☐	☐	☐	☐
	5.4 Recessed Lighting Fixtures (ICAT labeled and sealed to drywall)	☐	☐	☐	☐
	5.5 Whole-house Fan (insulated cover gasketed to the opening)	☐	☐	☐	☐
6. Common Walls Between Dwelling Units	**Requirements:** Gap between drywall shaft wall (i.e., common wall) and the structural framing between units is fully sealed at all exterior boundary conditions				
	6.1 Common Wall Between Dwelling Units	☐	☐	☐	☐

Home Energy Rating Provider: ____________________ Rater Inspection Date: _____________ Builder Inspection Date: _____________

Home Energy Rater Company Name: _______________________ Builder Company Name: ________________________________

Home Energy Rater Signature: ___________________________ Builder Employee Signature:______________________________

Posted 06/02/08

Chapter 8.

Building Envelope Sub-Assemblies

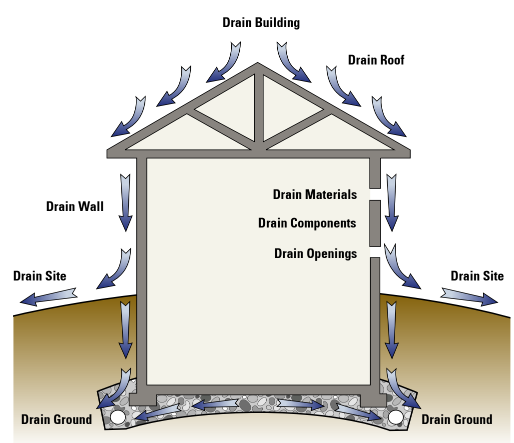
In its simplest form, building envelopes are cubes that incorporate three parts: the floor, four walls, and a roof. In actuality, these assemblies are complicated combinations of rectangles, triangles, and even domes. Building homes that deliver comfort, durability, and energy performance requires paying attention to the details of each assembly. This chapter provides guidance on controlling liquid and water vapor, air flow, and heat flow in the foundation, wall, and roof assemblies.

CHAPTER TOPICS

Foundation Assemblies

Slab, crawlspace, and basement foundation types are all common in the cold climate. The foundation forms the solid underpinning for a house's structural integrity. It also provides the boundary between the house and the ground, preventing the unwanted transfer of moisture, air, heat, and soil gases from the ground to occupied living spaces. It plays an important role in building durability and occupant health as well as in building energy efficiency. See Chapter 14 for detailed foundation drawings that show measures for controlling moisture, air, and heat flow.

Drain all water away from the structure



(Figure adapted from Building Science Corporation)

Controlling Liquid Water in Foundations

Proper site grading directs surface water away from building foundations and walls. The steeper the slope away from the building, the better the water will drain. All building foundations should be designed and constructed to prevent the entry of moisture.

Most foundation water leakage or intrusion is due to either bulk moisture leaks or capillary action. Bulk moisture is the flow of liquid water. Capillary action occurs when water wicks or is absorbed into

(top) Make sure the downspouts are continuous to the ground and extend to at least 3 feet from the house. Install flashing at the roof valleys and edges and install rain gutters to guide water off the roof and away from the house. *(Photo Source: EPA, photo by Terry Brennan)*

(middle) This foundation moisture management approach uses a dimpled-plastic drainage plane and damp proofing on the exterior side of the foundation wall. Landscape filter fabric keeps soil from clogging the gravel around a perforated drainage pipe that runs along the outside of the footing. A gasket keeps moisture from migrating up through the footing into the treated sill plate.

(bottom) Here, a damp proof coating and exterior rigid fiberglass insulation are applied to the foundation wall below grade.

small cracks and pores in building materials, such as masonry block, concrete, or wood. Moisture can also be carried by soil gas into the home. Moisture may cause structural decay and can contribute to human health problems.

The following practices apply to all foundation systems.

- Design the house structure with overhangs, gutters, drainage planes, and flashing to shed rainwater and conduct it away from the house **[as required in 2009 IRC R703.1 and R703.8]**.
- Slope top soil to drain away from the house. **[2009 IRC R401.3 requires that the lot be graded to fall at least 6 inches in the first 10 feet from the foundation.]** Building America recommends a surface grade of at least 5% for at least 10 feet around and away from the entire structure.
- Drain driveways, garage slabs, patios, stoops, and walkways away from the structure. **[IRC 2009 R401.3 requires that impervious surfaces within 10 feet of the building foundation be sloped at least 2% away from the building.]**
- Keep all untreated wood away from contact with earth and concrete. Keep wood and fiber cement siding at least 8 inches from the soil surface to minimize damage from rain splashing up from ground surface.
- Install a protective shield such as a plastic L bracket, gasket, or water-proof membrane between foundation wall stem and sill plate to keep capillary water from wicking into the wall from the foundation. Metal flashing can also serve this function and serve as a termite shield **[2009 IRC R318.3]**.
- Damp-proof all below-grade portions of the exterior concrete foundation walls **[2009 IRC R406]**.
- Cover exposed earth in crawlspace floors with 6-mil polyethylene sheeting. All joints of the vapor retarder shall overlap by 6 inches and be sealed or taped. The edges of the vapor retarder shall extend at least 6 inches up the stem wall and shall be attached to the stem wall. **[2009 IECC 402.2.9 and 2009 IRC 408.3 require vapor retarder over exposed earth in unvented crawlspaces only.]**

In addition to these code requirements, Building America makes the following recommendations for foundation moisture management:

- Damp proof the exposed portion of the foundation with latex paint or other sealants.

- Apply a protective coating over rigid foam exterior foundation wall insulation at above-grade applications. Examples of protective coverings include flashing, fiber-cement board, parging, treated plywood, or EPDM membrane.

- Place a continuous drainage plane or free-draining materials over the damp proofing or exterior insulation on foundation walls to channel water to the foundation drain and relieve hydrostatic pressure. Drainage plane materials include impervious plastic mats, high-density fiberglass foam insulation boards, and uniformly graded gravel.

- Place slabs and crawlspace floors above the surrounding grade.

- Treat footings poured independent of slabs or foundation walls with a bituminous damp-proof coating, masonry capillary-break paint, or a layer of 6-mil polyethylene plastic to isolate the footing from the remainder of the assembly.

- Place 6-mil polyethylene sheeting or rigid foam insulation directly beneath the slab or basement floor. Wrap sheeting continuously over the slab and footings up to grade [per 2009 IRC R406.3.2].

- Do not place a sand layer between the vapor retarder and the concrete slab or basement floor. Differential drying and cracking is better handled with a low water-to-concrete ratio and wetted burlap covering during initial curing.

- Place a 4-inch-deep, ¾-inch gravel bed directly beneath the polyethylene sheeting to act as a capillary break and drainage pad.

- Install a perimeter drain below the drainage plane along the side (not on top of) footings for all basements and crawlspaces where the floor is below grade.

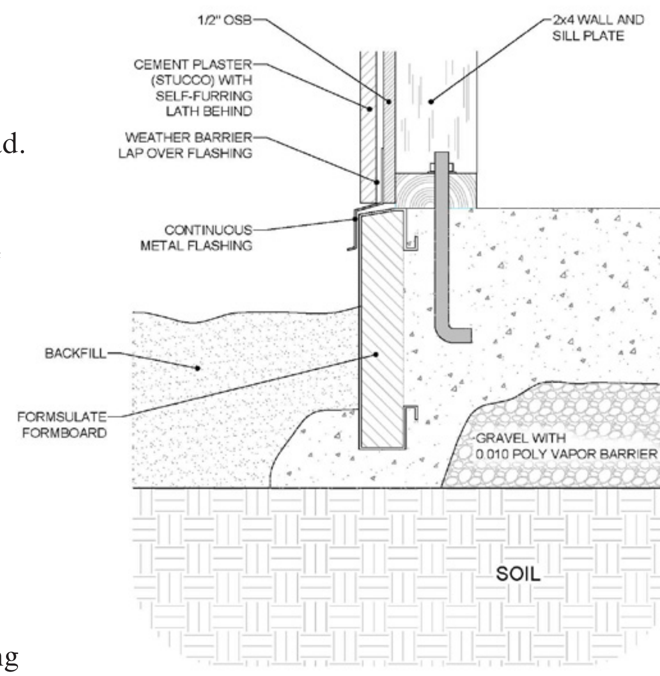
- Ensure that the lowest excavated site foundation level is above the local groundwater table at its maximum elevation [per 2009 IRC R408.6].

- Place drainage systems below basement floors.

Frost Heave and Adfreeze

Frost heave occurs when ice crystals form from water at the freezing plane of soil that is saturated. As the water is pulled up into ice crystals, the ground below dries drawing in more water from the surrounding soil, which is in turn drawn up into ice crystals, thus creating an upward thrust of soil and ice. The concern is that this

Davis Energy Group of the CARB Building America team developed a method for insulating slab perimeters. The method, which is commercially available, uses termiticide-treated rigid foam insulation encased in PVC as the form for the concrete foundation. In cold climate locations, the forms can be stacked to provide deeper protection against frost (Personal communication with David Springer, Davis Energy Group, 11/10/10).



Detail of insulating form for slab perimeters. *(Source: Davis Energy Group)*

Unvented, insulated crawlspaces are recommended in the cold climate in the eastern and midwestern United States, where high humidity levels can cause moisture problems in vented crawlspaces.

expanding soil and ice, or frost heave, will push against building foundations causing them to crack and buckle. However, frost expansion always follows the direction of heat loss. So expansion will be up and away from the building foundation if the basement is heated. According to Joseph Lstiburek at Building Science Corporation, several years of investigative work by the Canadian Department of Energy, Mines, and Resources found no evidence of frost-damaged foundations in homes with heated basements, regardless of whether the walls were insulated or uninsulated, and regardless of whether the insulation is on the interior or exterior of the wall (Lstiburek 2011). In insulated basements heat loss is greatly reduced but the direction of heat loss remains outward, and frost direction will follow the direction of heat loss. Another concern is adfreeze, or adhesion freezing, where saturated soil freezes against a foundation wall, adhering to it and lifting the wall when it heaves upward. Fortunately water molecules also migrate in the direction of heat loss so, in cold soil, water will migrate away from the foundation wall of a heated basement, reducing the strength of adhesion bonds and the likelihood of damage. Lstiburek notes that this is again true in insulated as well as uninsulated basements as long as they are heated (Lstiburek 2011).

If you don't want to heat the basement, you can lay a skirt of R-10 rigid insulation around the perimeter of the building laid several inches below ground that extends horizontally a distance equal to the average frost depth. A better option is to avoid frost-susceptible soils and water saturation at the foundation. Use granular soil, not fine or silty soil for backfill along the foundation and provide good site grading and perimeter drainage as described above (Lstiburek 2011).

- Place footings below frost depth.
- Use gravel with no more than 3% grains finer than 0.02 mm. Don't use clays, silts, tills, or very fine-grained sand as a backfill because they are susceptible to frost action.
- Prevent saturation of soil at foundation by grading site and providing perimeter drainage at footing.

Controlling Water Vapor in Foundations

Water vapor from basement and slab foundations can be controlled using the techniques described above. In vented crawlspaces the dominant source of moisture is bulk water, not water vapor from indoor or outdoor air condensing in the crawlspace. Water enters the crawlspace because of improper irrigation practices, ground slope, rain runoff, high groundwater tables, rain and snow during the construction process, and leaks in plumbing (Baker and Murray 2006). These sources can be controlled by careful site grading, installation of drainage systems, proper foundation design and water-proofing measures, appropriate landscaping, and other measures listed above.

Some moisture in crawlspaces occurs from soil vapor. To control water vapor from soil in crawlspaces, do the following:

- Install 6-mil polyethylene across the entire ground surface.
- Overlap all seams by 12 inches and tape.
- Seal the polyethylene to the walls with pressure-treated wood strapping nailed at least 6 inches up the walls or to a height equal to ground level [2009 IECC 402.2.9].

Some Building America teams recommend installing one polyethylene groundcover at the beginning of construction; then, when construction is completed, installing a second sheet to cover any rips in the first one and sealing it to the walls. To improve durability, a minimum 2-inch concrete slab can be poured over the polyethylene.

In some parts of the country, the condensation of water vapor due to temperature differences in vented crawlspaces can be a significant source of crawlspace moisture. In the Midwest and eastern half of the country, where summers are humid, moisture can be carried into the crawlspace in the air drawn through open foundation wall vents. When this warm, moist air reaches cooler structural framing, the moisture condenses onto the framing and can cause mold and structural problems. In winter, cold air is drawn into the crawlspace and does little to dry out crawlspaces, but can lower temperatures, cause condensation on warm floor joists, and freeze exposed waterpipes. In these climate conditions, which are common east of the Mississippi, Building America research teams recommend sealing, insulating, and conditioning the crawlspaces.

In the west, summers are dry and winters north of the hot-dry climate zone are heating-dominated so relative humidity in vented crawlspaces is likely to stay low enough throughout the year to avoid condensation-related moisture problems. Building America research done in a cold, dry location in eastern Washington State regarding the value of vented versus unvented crawlspaces seemed to indicate either method could be acceptable depending on the specific location of the house being built (in a high radon area or not) and specific circumstances of the home (ducts in the crawlspace or not). High radon levels were found in the crawlspaces of two homes in the study with unvented crawlspaces but power venting of the crawlspace with a fan kept radon levels inside the home below the EPA threshold of 4 pCi/L (Nordeen 2008; Dave Hales, WSU Energy Extension Program, personal communication October 2009).

Sealed, conditioned crawlspaces offer non-energy advantages over vented crawlspaces that are worth considering such as minimizing the risk of freezing pipes, cold floor complaints, bulk water intrusion, and pest intrusion. While unvented crawlspaces can provide a better environment for HVAC equipment than a vented crawlspace, the best practice is to locate the furnaces and ducts in conditioned space. Ducts that are located in the crawlspace must be mastic sealed. In areas with high radon levels, mitigation measures should be installed in unvented crawlspaces, including gravel under the slab and installation of a radon/soil gas vent stack, with an electric fan for power venting if necessary.

Unvented crawlspaces are allowed in the 2009 IRC R408.3 as long as the exposed earth is covered with a Class 1 vapor retarder that is overlapped at edges, taped, and sealed to walls; the walls are insulated; and the crawlspace is mechanically vented with an exhaust fan or supplied with conditioned air and a return duct. Check for any state restrictions

Prepare Your Site for Good Drainage

New Tradition Homes of Vancouver, Washington, does extensive site preparation to ensure good drainage. For homes with crawlspaces, they will raise and grade building sites so that all crawlspaces can drain to daylight. Excavators dig out the crawlspace, grade it flat, then dig out a sloped trench diagonally across the crawlspace that exits to a low-point drain sleeve with a one-way valve to let water out but not in. This drain sleeve directs the water to an infiltration system (a drywell) or out to the street via a curb cut.

Once the sloped trench is dug, 4 to 6 inches of crushed rock are laid over the entire crawlspace and foundation area. Next, the concrete footing, stem, and foundation are poured on top of the rock. When the house is complete, 6-mil visquene is laid over the crawlspace ground. This can be covered with a concrete slab that is sloped to drain to the low point drain where water can exit to daylight.

"When water finds its way into the crawlspace because of our persistent rains, it has a natural channel to flow out via the low-point drain," said Steve Tapio, head of New Tradition's in-house building science team. On foundation walls, the builder adds damp proofing, dimpled plastic drainage sheets, and a perimeter drainage pipe if there is living space below grade.

For More Information on Foundation Moisture Control

Baker, Ken, and Chuck Murray. 2006. *Crawlspace Issues in the Northwest.* Washington State University Extension Energy Program. www.kenergy.us/pdf/Regional%20Crawlspace_final.pdf

Building Science Corporation, *Crawlspace Insulation*, Information Sheet 512. www.buildingscience.com/documents/information-sheets/5-thermal-control/crawlspace-insulation/?searchterm=512

Burn, K.N. 1976. *Frost Action and Foundations*, CBD-182, Canadian Building Digests, National Research Council Canada, www.nrc-cnrc.gc.ca/eng/ibp/irc/cbd/building-digest-182.html.

EPA. *Consumer's Guide to Radon Reduction*. U.S. Environmental Protection Agency www.epa.gov/radon/pubs/consguid.html

EPA. 2010. "Technical Guidance to the Indoor airPLUS Construction Specification: 1. Moisture Control - Water-Managed Roof Assemblies," www.epa.gov/indoorairplus/technical/moisture/1_7.html

Journal of Light Construction. 1997. "Troubleshooting Guide to Residential Construction." *The Journal of Light Construction*, Ed. Steven Bliss, Williston, Vermont.

Lstiburek, Joseph. 2004. *Builders Guides*. Guides to mixed humid, hot-dry, mixed-dry, and cold climates, available for purchase at www.eeba.org/bookstore.

Lstiburek, Joseph. 2006. *EEBA Water Management Guide*, available for purchase at www.eeba.org/bookstore/prod-Water_Management_Guide-9.aspx

Lstiburek, Joseph. 2008. *Concrete Floor Problems*, BSI-003, Building Science.com. www.buildingscience.com/documents/insights/bsi-003-concrete-floor-problems

Lstiburek, Joseph. 2011. Double Rubble Toil and Trouble, Insight 045, Feb. 2011, Building Science Corporation, www.buildingscience.com/documents/insights/bsi-045-double-rubble-toil-trouble/

Lubliner, Michael, Larry Palmiter, David Hales, and Andrew Gordon. 2007. "Crawlspace Design in Marine and Cold Climates," in *Thermal Performance of the Exterior Envelopes of Buildings X, Proceedings of ASHRAE THERM X*, Clearwater, FL, Dec. 2007. www.ornl.gov/sci/buildings/2010/Session%20PDFs/96_New.pdf

Nordeen, Gary. 2008. *Unvented Crawl Spaces,* Washington State University Extension Energy Program, www.energy.wsu.edu/pubs/

Robinsky, I., and K. E. Bespflug, 1973. "Design of Insulated Foundations." J. Soil Mech. Found. Eng., A.S.C.E., Vol. 99, SM9, p. 649-667.

Controlling Air Infiltration in Foundations

The greatest challenges for air sealing are at the intersections of different building assemblies. **[The 2009 IECC 402.4 requires air sealing of the building thermal envelope at rim joists, utility penetrations, and other areas.]** Building America recommends the following foundation air sealing techniques:

- Install a sill gasket between the concrete foundation wall and the bottom plate to control air infiltration and to serve as a capillary break.
- Seal all panel joints to stop air leakage through subfloor sheathing installed over unconditioned spaces such as vented crawlspaces, unconditioned garages, or cantilevered floors over exterior walls.
- Use two-part spray foam to air seal and insulate at the sill plate, forming a continuous seal at the subfloor-rim joist-sill plate interface.

Controlling Heat Flow in Foundations

Insulation techniques for slab, crawlspace, and basement foundations are described below.

Slab Foundation Insulation

Slabs in the cold climate should be insulated at the perimeter with borate-treated foam board or rigid fiberglass insulation approved for below-grade use. **[The 2009 IECC 402 requires a slab R value of R-10 on the interior or exterior side of the foundation wall, plus an additional R-5 if the slab is heated (i.e., contains radiant heating coils) in the cold climate. This insulation must extend down vertically and out from the exterior or in from the interior a total of 2 feet in IECC climate zone 5 or 4 feet in IECC climate zones 6 or 7.]** Building America recommends that rigid insulation be placed on the interior side of the stem wall from the slab to the top of the footing. Building America recommends that an R-10 layer of rigid foam insulation extend underneath the entire slab, whether or not the slab is heated, in the cold climate. This provides additional moisture control and minimizes the likelihood of condensation and mold in carpeting and floor coverings over an uninsulated floor.

Some code officials may require a gap between exterior insulation and wood foundation elements to provide a termite inspection area. Exterior insulation should be applied from the top of the foundation wall to the bottom of the frost line. The exterior face of the insulation exposed to outside air should be covered with flashing, fiber cement board, parging (stucco type material), treated plywood, or EPDM membrane material.

Code/Above Code

Insulation for Slab on Grade

A comparison of the 2009 IECC climate zones 5–8, and Building America recommendations

Code	
2009 IECC	Slab Edge Insulation, Vertical Extension
IECC 5	Unheated R-10, 2 ft Heated* R-15
IECC 6	Unheated R-10, 4 ft Heated* R-15, 4 ft
IECC 7&8	Unheated R-10, 4 ft Heated* R-15, 4 ft
Above Code	
Building America Recommendations	Unheated R-15 rigid foam at perimeter, exterior or interior Heated* R-15 perimeter plus R-10 underneath entire slab

** Heated slab refers to a slab floor containing radiant floor heating coils. Location of insulation is between the heated slab and the foundation wall. Vertical insulation extends down from top of slab and can extend down, down and in under the slab, or down and out from the building the number of feet designated.*

Code/Above Code

Floor Insulation for Vented Crawlspaces and Unconditioned Basements

A comparison of the 2009 IECC climate zones 5–8 and Building America recommendations

Code	
2009 IECC	Floor insulation shall maintain permanent contact with underside of subfloor decking
IECC 5	R-30*
IECC 6	R-30*
IECC 7&8	R-38*
Above Code	
Building America Recommendations	R-30* under floor deck, recommend full spray foam or flash spray foam to air seal and insulate, especially at rim joists.

**Or insulation sufficient to fill the framing cavity, R-19 minimum.*

In cold climates, the primary slab-on-grade approach involves stem wall and footing construction to locate the bottom portion of the foundation below the frost depth. Shallow, frost-protected foundation insulation approaches are not recommended for production builders due to the likelihood of damage to pieces of rigid insulation laid horizontally out from the building.

For More Information on Slab Foundations

Building Science Corporation. 2004. *Houses that Work*. www.nrel.gov/docs/fy04osti/34585.pdf

The American Society of Civil Engineers. Standard 32-01: *Design and Construction of Frost-Protected Shallow Foundations*.

University of Minnesota, Building Foundations Research Program, *Frost Protected Shallow Foundations Design Specifications*. www.buildingfoundation.umn.edu/MHFAfrostFoundation.htm

Building Science Corporation. 2009. *Slab Edge Insulation*, Information Sheet 513, www.buildingscience.com/documents/information-sheets/5-thermal-control/slab-edge-insulation/

Crawlspace Insulation

Two methods are in use for insulating crawlspaces. The first, in common use over the last several decades, is to insulate the underside of the building floor and locate screened vents above grade in the foundation walls to provide the unconditioned crawlspace with ventilation. With ventilated crawlspaces, it is essential to air seal and properly insulate the underside of the first floor and tightly seal and insulate any ducts located in the crawlspace. **[2009 IECC 402 requires R-30 floor insulation in IECC climate zones 5 and 6 and R-38 insulation in climate zones 7 and 8, or at least enough to fill the framing cavity to a minimum of R-19.]** Research has shown that vented crawlspaces can have moisture problems, especially in areas with frigid winter air or warm, humid summer air (Building Science Corporation 2009).

Another approach **[permitted by 2009 IECC 402.2.9]** is referred to as conditioned crawlspaces, or mechanically vented crawlspaces. With this type of system, foundation side walls are insulated on either the interior or exterior (or both) and no passive outside air vents tunnel through the foundation wall. **[2009 IECC 402 requires R-10 rigid foam on interior or exterior or R-13 cavity insulation on interior in IECC climate zones 5, 6, 7, and 8.]** Unvented, conditioned crawlspaces can provide a conditioned space for ducts and air handlers, although best practice is not to place HVAC equipment in the crawlspace.

When insulating a conditioned crawlspace, some Building America researchers recommend installing insulation on the exterior side of the foundation wall. Exterior insulation will help to protect the foundation from the freeze-thaw cycle and a warmer wall is less likely to condense moisture. Products such as borate-treated foam board or rigid fiberglass insulation work well. Extruded polystyrene (R-5 per inch) is durable and moisture resistant. Expanded polystyrene (R-4 per inch) is less expensive, but it has a lower insulating value. Rigid fiberglass insulation does not insulate as well as foam but provides a drainage plane. Some code officials may require a gap between exterior insulation and wood foundation elements to provide a termite inspection area. Insulation that is exposed above grade must be covered with a protective coating such as flashing, fiber cement board, parging (stucco type material), treated plywood, or EPDM membrane material. **[The 2009 IRC 406 requires damp proofing of the foundation wall below grade.]**

If placed on the interior of a conditioned crawlspace, wall insulation must extend down the wall to a depth at least 2 feet below grade level **[2009 IECC 402.2.9]** and be rated for crawlspace and basement exposure. Polyisocyanurate rigid foam insulation with an aluminum facing is a good interior insulation choice and has an R value of R-7.1 to R-8.7 per inch. If the crawlspace wall extends less than 2 feet below grade level, then the remaining insulation must be placed horizontally along the ground at the base of the wall.

For more information on Crawlspace Insulation:

Broniek, John. *Builder System Performance Packages Technical Report*. Prepared by IBACOS for the Building America Program. www.buildingamerica.gov

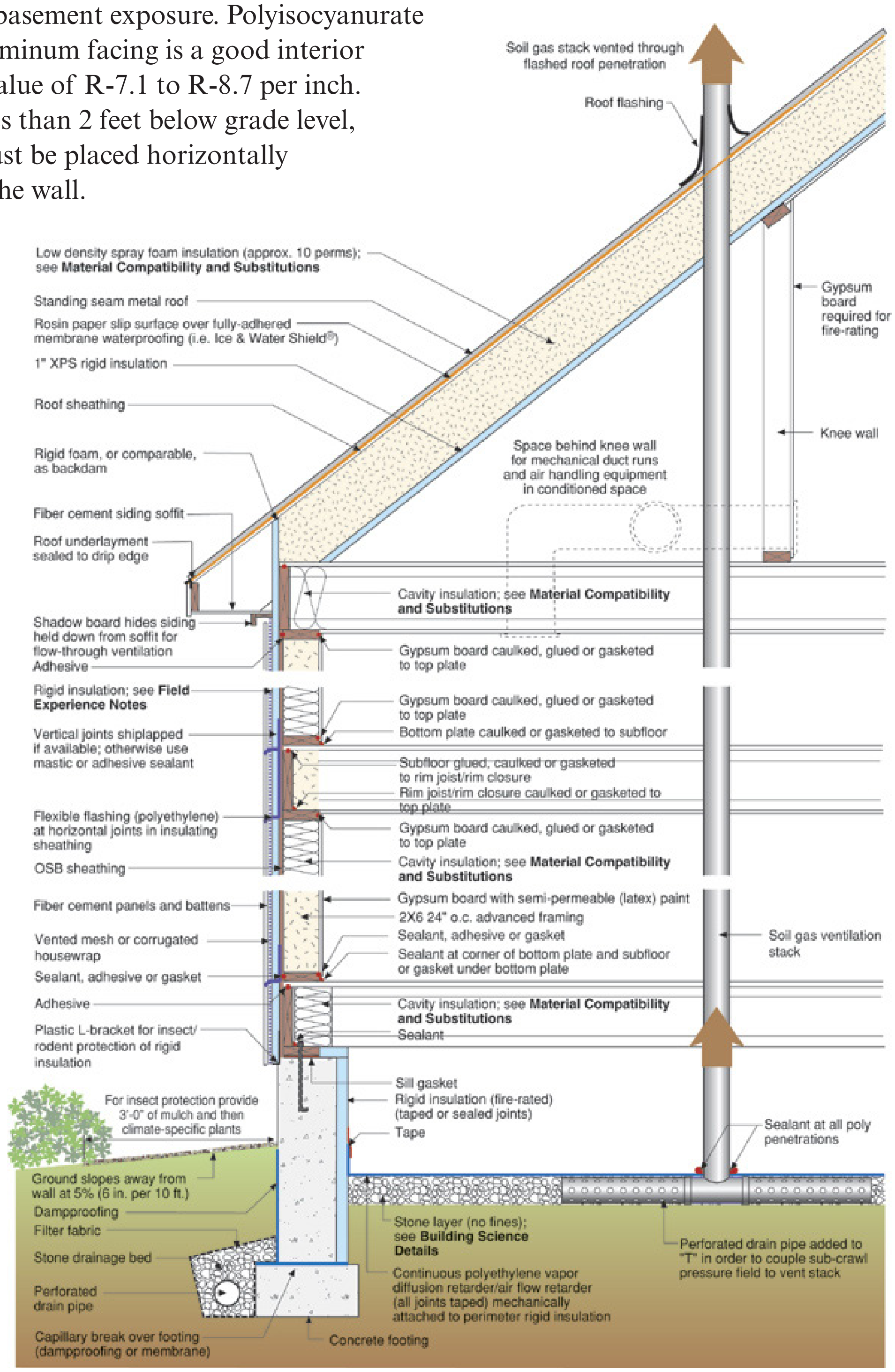
Building Energy Codes Resource Center, *Details for Mechanically Vented Crawlspaces - Code Notes*, http://resourcecenter.pnl.gov/cocoon/morf/ResourceCenter/article//131 (includes information on sizing the mechanical ventilation).

Building Science Corporation. 2009. *Crawlspace Insulation*, Information Sheet 512. www.buildingscience.com/documents/information-sheets/5-thermal-control/crawlspace-insulation

U.S. EPA. 1995. *Passive Radon Control System for New Construction*, EPA 402-95-012, U.S. Environmental Protection Agency, www.epa.gov/radon/rrnc/moreinfo.html

Yost, Nathan. May 2003. "The Case for Conditioned, Unvented Crawlspaces." *Building Safety Journal*. www.buildingamerica.gov

www.crawlspaces.org



Building Science Corporation recommended this wall detail for this home in Aspen, Colorado, that has a sealed, insulated crawlspace. Additional wall schematics for other cold climate locations are shown in Chapter 14. *(Source: Building Science Corporation).*

Code/Above Code

Wall Insulation for Conditioned Crawlspaces and Conditioned Basements

A comparison of the 2009 IECC climate zones 5–8, and Building America recommendations

Code	
2009 IECC	
IECC 5	R-10/13*
IECC 6	R-15/19*
IECC 7&8	R-15/19*
Above Code	
Building America Recommendations	Exterior Exterior of foundation wall insulated with R-21 of rigid fiberglass or borate treated XPS Interior Interior of foundation wall insulated with R-21 of rigid fiberglass, rigid EPS or XPS foam, or poly-iso spray foam

** For a conditioned crawlspace, mechanical ventilation to the outside is recommended where there are high radon or soil gas concentrations.*

Per 2009 IECC, 15/19 means R-15 continuous insulated sheathing on the interior or exterior of the home or R-19 cavity insulation at the interior of the basement wall. "15/19" can be met with R-13 cavity insulation on the interior of the basement wall plus R-5 continuous insulated sheathing on the interior or exterior of the home. 10/13 means R-10 continuous insulated sheathing on the interior or exterior of the home or R-13 cavity insulation at the interior of the basement wall.

Basement Insulation

Basements are a common foundation system in the cold climate. Wall insulation in basements is similar to that described for crawlspaces. Basement floors are insulated in the same way as slabs. **[2009 IECC 402 requires R-10 rigid foam on the interior or exterior surface of the walls or R-13 cavity insulation on interior basement walls in IECC climate zone 5. In IECC climate zones 6, 7, and 8, the requirement is R-15 continuous rigid foam insulated sheathing on the interior or exterior, or R-19 interior cavity, or R-5 exterior plus R-13 cavity insulation. In IECC climate zone 5, R-10 slab floor edge insulation is required extending 2 feet horizontally under the slab or out from the building. In IECC zones 6, 7, and 8, this increases to R-15 and 4 feet.]**

Insulating basement walls, whether on the interior or exterior, does not make the walls more likely than uninsulated walls to be damaged by frost heave or adfreezing (Lstiburek 2011). Placing rigid insulation on the exterior sides of basement walls is one method for insulating the basement (Broniek 2003; Yost and Lstiburek 2002). Exterior insulation will help to protect the basement wall from freeze-thaw cycles and will help make the wall warmer, giving condensation less chance of forming and improving thermal comfort. Exterior wall insulation must be approved for below-grade use. Products such as borate-treated foam board or rigid fiberglass insulation work well. Extruded polystyrene (R-5 per inch) is durable and moisture resistant. Expanded polystyrene (R-4 per inch) is less expensive, but it has a lower insulating value. Rigid fiberglass insulation does not insulate as well as foam but it is the only insulation option that provides a drainage plane for foundation walls. Some code officials may require a gap between exterior insulation and wood foundation elements to provide a termite inspection area. Insulation that is exposed above grade must be covered with a protective coating such as flashing, fiber cement board, parging (stucco type material), treated plywood, or membrane material. Exterior insulation is an especially good choice in areas with high water tables or poorly draining soils.

One builder in Aspen, Coloroado, Shaw Construction, who worked on a Building America project described in this report, insulated basement floors with high-density, closed-cell spray foam that was sprayed directly onto the 4-inch layer of gravel under the foundation slab. The foam layer was about 4 inches thick, providing approximately R-28 of insulation. Because the foam was closed cell, it served as a vapor barrier as well. If the basement space was to be unheated, the slab was fully insulated with spray foam underneath. All heated basements were insulated from the perimeter to about 2 to 3 feet in under the slab. Interior basement walls were insulated with R-13 (2 inches) of polyisocyanurate on the interior of the basement walls.

If interior insulation is used, the insulation should be permeable enough to allow drying to the inside. Building Science Corporation (2009) recommends using up to two inches of unfaced extruded polystyrene (R-10), four inches of unfaced expanded polystyrene (R-15), three inches of closed-cell medium-density spray polyurethane foam (R-18), or up to ten inches of open-cell low-density spray foam (R-35) on the interior walls. The foam should be installed in a manner that forms an air barrier to prevent interior conditioned air from meeting the cold concrete basement wall, where condensation could form. The foam should be covered with a fire/ignition barrier such as gypsum board per local building code. If a stud frame wall is used, additional insulation can be added to fill the stud cavities. Building Science Corporation notes that regardless of the insulation type used, a capillary break should be installed on the top of the footing between the footing and the perimeter foundation wall to control "rising damp" and a second capillary break should be installed between the foundation wall and framing.

For More Information on Basement Insulation

BIRA, BSC, CARB, FSEC, IBACOS, and NREL. 2005. *Building America Residential System Research Results: Achieving 30% Whole House Energy Savings Level in the Cold Climate.* NREL/TP-550-38783, U.S. Department of Energy.

Broniek, John. 2003. *Builder System Performance Packages Technical Report*. Prepared by IBACOS for the Building America Program. Available at www.buildingamerica.gov in the publications section.

Building Science Corporation. 2006. *Read this Before You Design, Build or Renovate*, Building Science Primer 040, www.buildingscience.com/documents/primers/plonearticlemultipage.2006-12-05.5229931729/

Building Science Corporation. 2009. Basement Insulation, Info-511, May 14, 2009, www.buildingscience.com/documents/information-sheets/5-thermal-control/basement-insulation

DOE. 2009. *Basement Insulation.* U.S. Department of Energy, Energy Savers, www.energysavers.gov/your_home/insulation_airsealing/index.cfm/mytopic=11470

Lstiburek, Joseph. 2006. Builder's Guide to Cold Climates. Building Science Press. Energy and Environmental Building Association.Westford, MA.

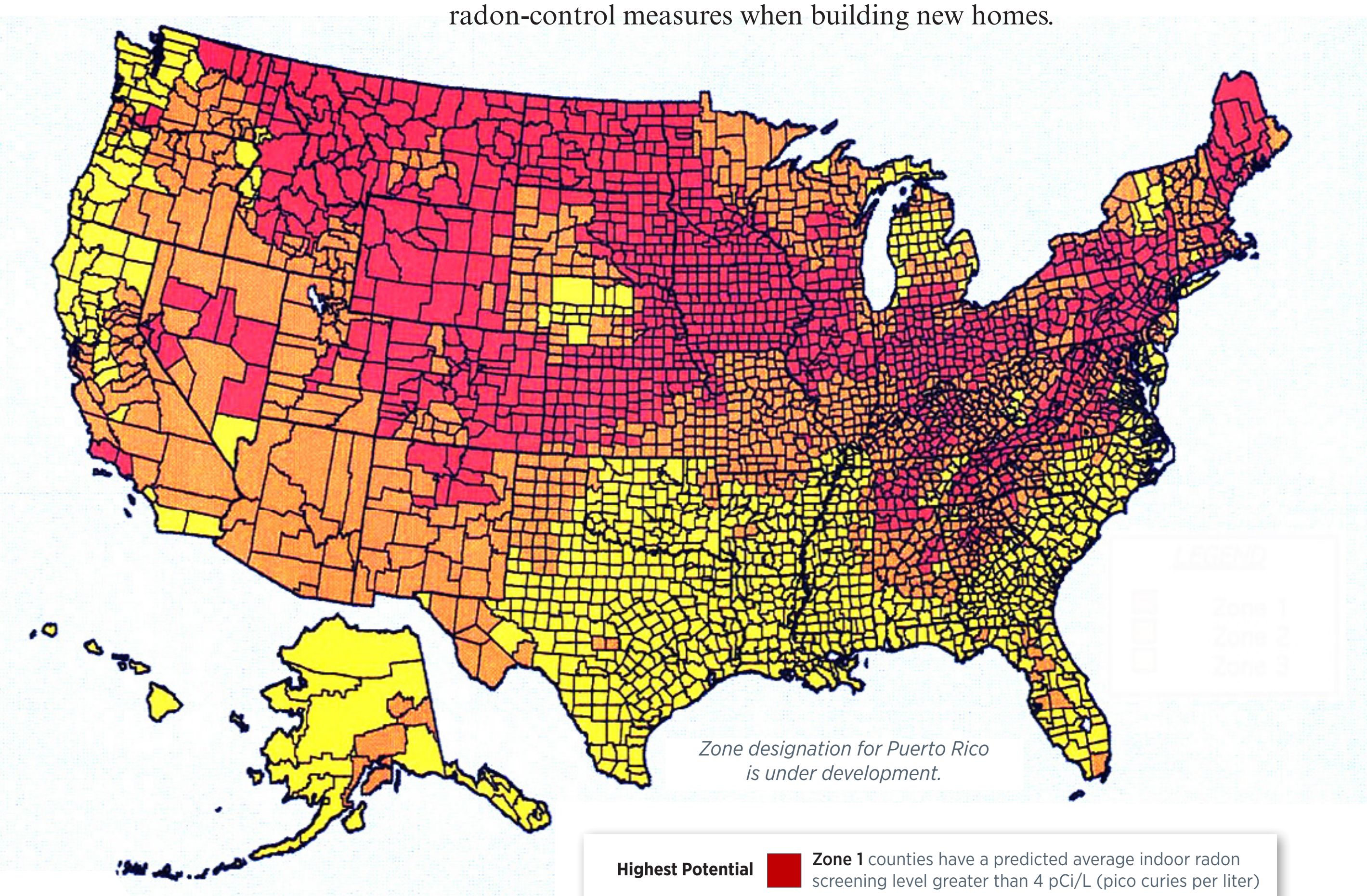
Lstiburek, Joseph. 2011. Double Rubble Toil and Trouble, Insight 045, Feb. 2011, Building Science Corporation, www.buildingscience.com/documents/insights/bsi-045-double-rubble-toil-trouble/

Yost, Nathan, and Joseph Lstiburek. 2002. *Basement Insulation Systems.* Prepared by Building Science Corporation for the Building America Program. www.eere.energy.gov/buildings/building_america/pdfs/db/35017.pdf

Controlling Other Foundation Issues

Radon Control

The EPA divides counties into one of three zones based on radon-level potential. The EPA radon map on this page shows radon potential in the cold climate states by county. The EPA recommends that all homes built in zone 1 areas (high radon potential) have radon-reduction systems. The EPA cautions that local levels may vary and recommends that all homes be tested regardless of geographic location. 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 when building new homes.



Highest Potential	**Zone 1** counties have a predicted average indoor radon screening level greater than 4 pCi/L (pico curies per liter)
Moderate Potential	**Zone 2** counties have a predicted average indoor radon screening level between 2 and 4 pCi/L
Low Potential	**Zone 3** counties have a predicted average indoor radon screening level less than 2 pCi/L

EPA Radon Zone Map
(Source: www.epa.gov/radon/zonemap.html)

The purpose of this map is to assist National, State, and local organizations to target their resources and to implement radon-resistant building codes. This map is not intended to be used to determine if a home in a given zone should be tested for radon. Homes with elevated levels of radon have been found in all three zones. All homes should be tested regardless of geographic location.

IMPORTANT: Consult the EPA Map of Radon Zones document (EPA-402-R-03-071) before using this map. This document contains information on radon potential variations within counties. EPA also recommends that this map be supplemented with available local data in order to further understand and predict the radon potential of a specific area.

Measures taken to control foundation moisture are also important first steps in controlling radon. A layer of gravel (4-inch minimum) under the slab provides a path for radon and other soil gas to escape to the atmosphere rather than being drawn into the house. A sealed vapor retarder helps to block soil gas entry into the house.

EPA's "Model Standards and Techniques for Control of Radon in New Residential Buildings" discusses techniques for controlling radon with various foundation types. One measure recommended by the EPA to control radon and other soil gases is a passive soil gas stack that vents to the roof and is connected to a horizontal perforated drain pipe embedded in the gravel under the slab, basement floor, or crawlspace ground cover. The stack may also be attached to a strip of geotextile drainage matting. This system is often installed as a precaution even when no evidence of radon has been shown, because it is far easier to install during construction than to come back later and retrofit an under-slab venting system. The pipe can act as a passive vent. 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. An electrical outlet should be installed in the attic for possible future fan installation.

To determine potential radon levels in the county in which you are building, see the EPA radon potential map shown on the previous page and at www.epa.gov/radon/zonemap.html.

[Many of these radon control recommendations can be found in the 2009 IRC, Appendix F, which has recommended methods that are not required unless specifically referenced in the adopting ordinances.]

For More Information on Radon Control

U.S. Environmental Protection Agency. *Model Standards and Techniques for Control of Radon in New Residential Buildings*. Cited 6/18/09. www.epa.gov/radon/pubs/newconst.html#Principles.

U.S. Environmental Protection Agency. 2009. *EPA Map of Radon Zones*, www.epa.gov/radon/zonemap.html

U.S. Environmental Protection Agency. 1995. *Passive Radon Control System for New Construction*, EPA 402-95-012. www.epa.gov/radon/rrnc/moreinfo.html

Landscaping

Landscaping is a critical element in the marketability of a house. Plants also can be used to shade foundations and reduce cooling loads. Choosing native plants results in the need for less irrigation and, thus, less chance for irrigation water to create a moisture problem in the house.

(top) Place plants at least 18 inches from finished structure and direct irrigation away from the foundation.

(bottom) Carpenter ants are attracted to wet wood and can be very destructive. *(Photo source: Michigan State University Extension)*

Building America recommends plants be kept at least 18 inches from the finished structure, with any supporting irrigation directed away from the finished structure. Decorative ground cover, such as mulch or pea stone, should be no more than 2 inches deep for the first 18 inches from the finished structure to assist drainage.

Pest Control

The following pest control notes should be included on construction documents and details:

- Use local code and Termite Infestation Probability (TIP) maps to determine environmentally appropriate termite treatments, bait systems, and treated building materials for assemblies that are near soil or have ground contact. **[The Termite Infestation Probability Map, Figure R301.2(6) in the 2009 IRC, shows slight to heavy probability of termite infestation across the cold climate.]**

The 2009 IRC R318.1 dictates one or more of the following termite treatments: chemical termiticides; termite baiting; pressure/preservative treated wood; naturally termite-resistant wood; physical barriers, and steel framing.

In addition Building America recommends:

- Keep all wood (including siding, decking, and fencing that attaches to the house) from soil contact to minimize the presence of wet wood, which attracts carpenter ants.
- Use termite flashing and insulation products with termiticides or use fiberglass rigid insulation when insulating slab edge or exterior foundation walls.

Wall Assemblies

Controlling the intrusion of water and the movement of water vapor, air, and heat through the building envelope by proper design and construction of wall assemblies are major goals in the cold climate zone.

Controlling Liquid Water in Walls

Experience with buildings in most regions of North America has shown that drained and screened cladding systems are the preferred approach to reliably provide rain control. Drainage within the wall complements the shedding on the exterior surface.

Builders must assume some rainwater will penetrate the outer surface of the wall. This water is removed or drained via a drainage screen within the wall. Some examples of drainage screened walls include stud cavity walls with lap siding, brick veneer, stone veneer, or vinyl siding.

Walls in all climates should be constructed with flashing and drainage planes to direct water away from the structure and to the exterior. All drained enclosure systems must have a screen or cladding, a drainage gap (a clear air space), a drainage plane (a water-repellent plane), flashing at the base to direct water outwards, and drain holes (weep holes) to allow water out of the drainage gap. Although drainage-screened walls provide excellent rain penetration control, problems can still develop at interruptions in the plane of the wall.

Care should be taken to overlap all wall layers to provide an exit pathway for all precipitation down and out of the building assembly as follows:

- Lap all materials in shingle fashion to direct water down and out, away from the wall assembly.
- Flash all wall penetrations and interruptions (windows, decks, and the termination of walls at grade).
- Incorporate extended overhangs in the design to keep water away from walls and windows and to provide shade. Sizing of overhangs for shade is described in Chapter 5.
- Install gutters.
- Back prime and back vent siding.
- Use housewrap.
- Elevate the bottom of the wall enough to prevent rain from splashing up on the siding.

Drainage Planes

Elevation drawings should specify building paper, housewrap, or taped insulating sheathing (rigid foam insulation) behind the exterior cladding to serve as a drainage plane or water-resistive barrier [2009 IRC R703.2] (also called a house membrane or rain barrier). This drainage plane can sometimes also serve as the exterior air barrier.

None of these materials is waterproof, but they will shed rainwater that penetrates exterior cladding. They can prevent liquid water from wicking through, while remaining sufficiently vapor permeable ("breathable") for outward drying (Straube 2001).

Drainage Plane Choices (House Membrane or Rain Barrier)

None of these is waterproof but they serve to shed rainwater that penetrates exterior cladding while remaining vapor permeable.
(Adapted from Straube 2001)

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 for over 100 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.

Taped rigid foam insulation can serve as a drainage plane, air barrier, and vapor barrier as well as a thermal boundary behind a stucco cladding. If using housewrap instead, never apply stucco directly to plastic housewrap. Provide a drainage space to prevent wetting of the housewap or use two layers of textured building paper.

(top) This pipe is flashed with flexible flashing. Housewrap is layered shingle style over the top edge of the flashing.

(bottom) New Tradition Homes of Washington State flashes the bottom edge of its wall sheathing, then layers housewrap over the top edge of the flashing, as shown in this display.

Most building paper is UV-resistant, whereas housewrap UV-exposure limits vary. If building paper is used as a drainage plane in areas prone to severe storms, use two layers to increase resistance to leakage at fasteners and allow for more flexible installation. If felt is used, install it half-lapped to create two layers.

Installation is key for all types of housewraps. See the Installers Guide on installing housewraps in Chapter 14. During construction and operation, it is important that housewraps remain clean. Surface contaminants interfere with the wrap's ability to hold out water. Some cladding can contaminate wraps if the two are in direct contact. For example, water-soluble extractives in wood, such as tannins and wood sugars in redwood and cedar, can contaminate the surface of housewraps and building papers. Back-priming or back-coating wood clapboards and trim helps to isolate the surfactants in the wood from the housewrap or building paper surface. Back priming is also recommended on all wood and cementitious cladding systems to avoid water saturation, migration, and potential warping and rot. Stucco should never be installed in direct contact with any of the plastic-based housewraps.

Installation is key for all types of housewraps. See the Installers Guide on installing housewraps in Chapter 14. During construction and operation, it is important that housewraps remain clean. Surface contaminants interfere with the wrap's ability to hold out water. Some cladding can contaminate wraps if the two are in direct contact. For example, water-soluble extractives in wood, such as tannins and wood sugars in redwood and cedar, can contaminate the surface of housewraps and building papers. Back-priming or back-coating wood clapboards and trim helps to isolate the surfactants in the wood from the housewrap or building paper surface. Back priming is also recommended on all wood and cementitious cladding systems to avoid water saturation, migration, and potential warping. Provide a drainage space to prevent wetting of the housewap or use two layers of textured building paper. Apply shingle fashion and install a weep screed at the bottom of the wall sheathing beneath the first layer of housewrap (Lstiburek 2008).

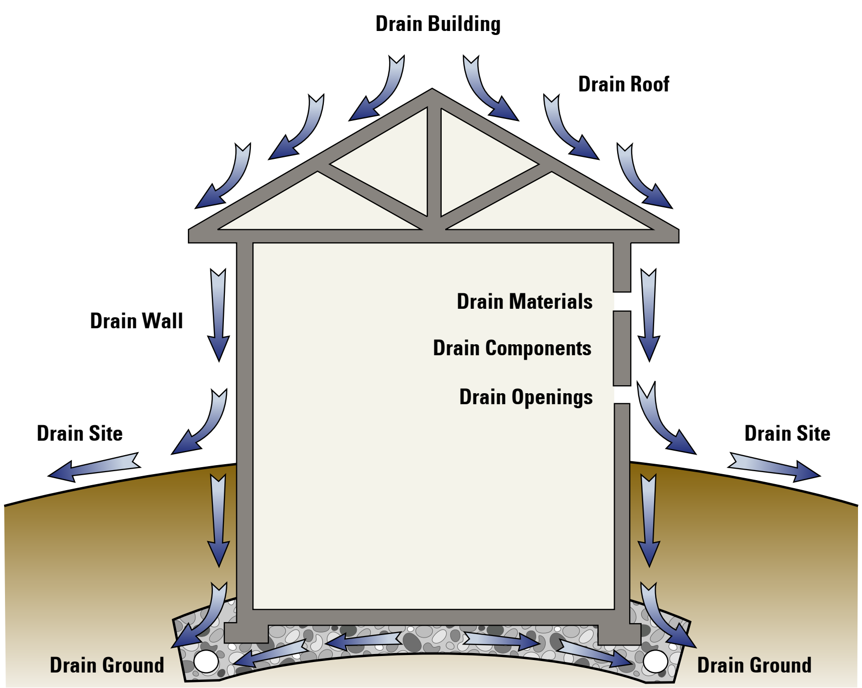
Drainage Gaps

It is essential to provide an air gap or air space between cladding and housewraps to reduce the time liquid phase water is trapped in the exterior of the wall assembly. A drainage gap between wood or fiber cement cladding and housewraps can be provided by 1x4 furring strips ("cedar-breather"), contoured housewrap, or some other spacer. Building America recommends a gap of at least 1/6-inch behind lap siding and a drainage space of ¾ inch between stucco and plastic housewraps to control liquid phase water penetration. A 1-inch air gap is needed behind brick veneer **[as required by 2009 IRC R703.7.4.2]**.

Flashing

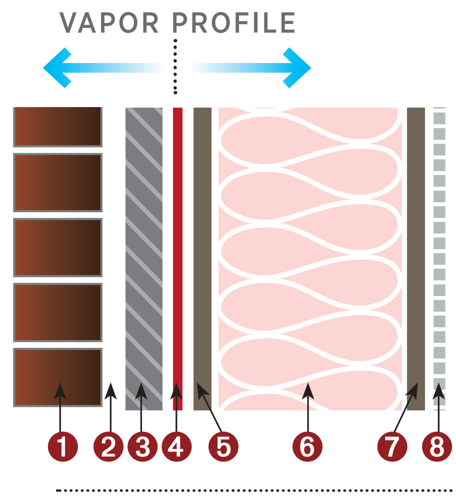
Details should be provided for flashing for all windows and doors; wall-roof junctions; attachments (such as porches and decks); projections and offsets (such as bay windows); and pipes, vents, wiring, exterior light fixtures, and other penetrations through the wall. See Chapter 14 for instructions on installing window flashing. **[Flashing should be specified in accordance with the 2009 IRC R703.8.]** Additional guidance can be found in the *EEBA Water Management Guide* (Lstiburek 2006a) and DOE's *Technology Fact Sheet on Weather-Resistive Barriers* (DOE 2000), available on the Web at www.eere.energy.gov/buildings/info/documents/pdfs/28600.pdf.

Drain all water away from the structure



Controlling Water Vapor in Walls

As discussed in Chapter 6, most vapor transmission through building assemblies is via air flow so stopping air leaks is an important way to prevent water vapor from getting into walls. Water vapor can also move via diffusion. Vapor pressure moves water vapor from indoors to outdoors during cold-dry weather and from outdoors to indoors during hot-humid weather. Water vapor that is trapped in walls or condenses in walls due to temperature differences can cause moisture problems like mold. Vapor retarders will stop this vapor diffusion.



1. Brick veneer/stone veneer/ship-lapped siding
2. Drainage cavity
3. Exterior rigid insulation – extruded polystyrene, expanded polystyrene, rigid fiberglass
4. Housewrap
5. Non-paper-faced exterior gypsum sheathing, plywood, or oriented strand board (OSB)
6. Insulated wood stud cavity
7. Gypsum board
8. Latex paint or vapor semi-permeable textured wall finish. No vapor barrier on inside (no polyethelene sheeting, no vinyl wallpaper on exterior walls)

Vapor Retarder Recommendations:

- Allow building assemblies to dry to either the exterior or the interior or both.
- Avoid use of a less permeable vapor retarder where a more permeable retarder will provide satisfactory performance, to encourage drying.
- Avoid installing vapor barriers on both sides of assemblies, i.e., double vapor barriers, to facilitate assembly drying in at least one direction.
- Avoid installing Class I vapor barriers (polyethylene sheet, foil-faced batt) on the interior of air conditioned assemblies.
- Avoid vinyl wall coverings on the inside of air conditioned assemblies.
- Ventilate to ASHRAE 62.2.

(Source: Lstiburek 2006c)

Windows

One critical point of concern is water leakage around windows. The *EEBA Water Management Guide* (Lstiburek 2006) offers examples of many window flashing applications. See Chapter 14 for detailed examples of window flashing for homes with housewrap and plywood or OSB sheathing. Window and door flashing details should be designed to match specific wall assemblies and claddings. Flashing systems should be designed in accordance with ASTM Standard E2112-07, "Standard Practice for Installation of Exterior Windows, Doors, and Skylights" (ASTM 2007).

Water should not be directed to flow into the wall. This could soon lead to water intrusion in the wall.

Vapor Retarders

[According to the 2009 IRC R601.3], in the cold climate Class 1 or 2 vapor retarders are required (except as described in the following paragraphs) on the interior side of unvented, framed walls, except for basement walls, the below-grade portion of any wall, or construction where moisture or its freezing will not damage the materials. Examples of Class 1 vapor retarders include sheet polyethylene and unperforated aluminum foil. An example of a Class 2 vapor retarder is kraft-faced fiberglass batt insulation.

[According to the 2009 IRC R601.3], in the cold climate (IRC/IECC climate zones 5, 6, and 7), Class 3 vapor retarders (e.g., latex paint) can be used instead of Class 1 or Class 2 vapor retarders when walls are vented as described in the table in Chapter 6.

Vapor retarders can block the entry of vapor. However, vapor retarders can also block vapor's exit. It is important that moisture not get trapped inside of walls. Walls need to dry to the interior, the exterior, or both. To avoid trapping moisture in walls, Building America recommends that Class 1 or 2 vapor retarders not be placed on the interior side of the building envelope between gypsum board and framing; Class 3 vapor retarders, such as latex paint, should be used instead. Vinyl-coated wallpaper is not recommended on the walls or ceilings that form the building envelope of homes in the cold climate.

Use of rigid foam exterior sheathing reduces the need for a Class I or II interior vapor retarder. This insulated sheathing reduces the probability of condensation inside the wall. In hot, humid weather, insulating sheathing acts as a vapor retarder and helps prevent moist outdoor air from entering the wall, reducing the potential for condensation to form on the back side of the interior gypsum board of air-conditioned homes. In cold weather, the exterior foam layer minimizes thermal bridging from the studs to the outside and keeps the wall cavity temperature above dew point, reducing the likelihood of condensation forming on the interior surface of the sheeting. If the foam is taped at the seams and caulked at the edges, it serves as an air barrier and rain screen.

Drainage Spaces

Cladding should have a drainage space behind it of 1 or 2 inches for brick and stone veneer, 3/4 inch for stucco, and 1/16 inch for siding. Bricks and other masonry absorb water in the form of precipitation and irrigation. Solar energy will then drive this moisture in the form of vapor into the wall assembly. The 1-inch gap **[as required by 2009 IRC R703.7.4.2]** allows the vapor to dissipate before entering wall cavities. An air space stops capillary movement of moisture, discourages vapor diffusion, stops the contamination of the drainage plane via contact with the cladding, and allows air circulation for better drying. In some wall assemblies, ventilation openings to the exterior at both the top and bottom further encourage drying. See Straube (2009) for information about the performance of drainage spaces with different wall types.

Dry Building Materials

Building with wet or green materials can be a source of vapor in walls. Damp lumber should be allowed to dry before use to 12% moisture content (FPL 2010) or as required by local code; heaters may be required for adequate drying in cold weather. Interior relative humidity should be kept to less than 35% during the coldest part of the heating season.

Air Sealing

Water vapor is far more likely to be transported into walls by air movement than by diffusion. Therefore, air sealing is an important method for preventing water vapor movement into walls. Air sealing is further described in the next section.

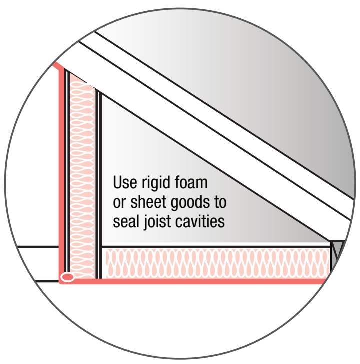
Controlling Air Infiltration in Wall Assemblies

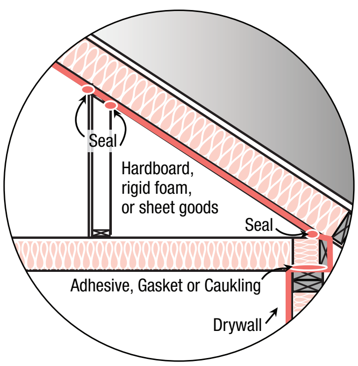
[The 2009 IECC 402.4 requires that the building thermal envelope be durably sealed to limit infiltration and specifies that the following areas should be caulked, gasketed, weather-stripped or otherwise air sealed: all joints, seams, and penetrations; site-built windows, doors, and skylights; window and door openings; utility penetrations; dropped ceilings or chases on exterior walls; knee walls; walls and ceilings separating a garage from the conditioned space; behind tubs and showers on exterior walls; common walls between dwelling units; attic access openings; rim joist junctions; and other sources of infiltration. Air leakage is to be tested with a blower door or visual inspection.] To be effective the air barrier must be continuous, meaning that it extends over the entire envelope of the structure, although it may be made up of many materials. Indicate on plans the methods, materials, and locations where sealing is needed to form the house air-pressure barrier.

(top) When rigid foam insulation is applied to the exterior side of the wall cavity under the cladding, with seams taped and glued down, it acts as a vapor barrier, preventing moisture in brick and stucco finishes from being driven inward during drying. It also serves as an air barrier and rain screen, and during the heating season, it maintains the temperature of the wall cavity above dew point, to prevent condensation. *(Photo Source: S+A Homes)*

(bottom) Window flashing on outside is overlapped to provide a continuous drainage plane.

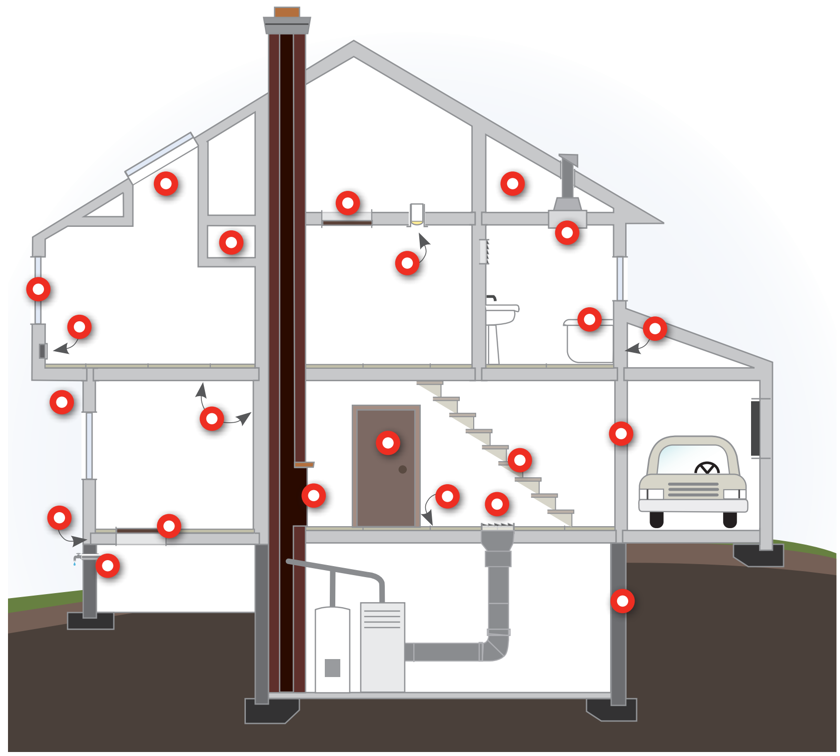
(see house figures at right) Air sealing is needed throughout the house to ensure an airtight shell. The house on top uses conventional approaches. The house on the bottom uses external rigid foam sheathing, which provides a continuous air barrier so fewer air sealing steps are required. Foam sheathing can also serve as a drainage plane, vapor barrier, and thermal barrier. (Detailed drawings are in Chapter 14.)



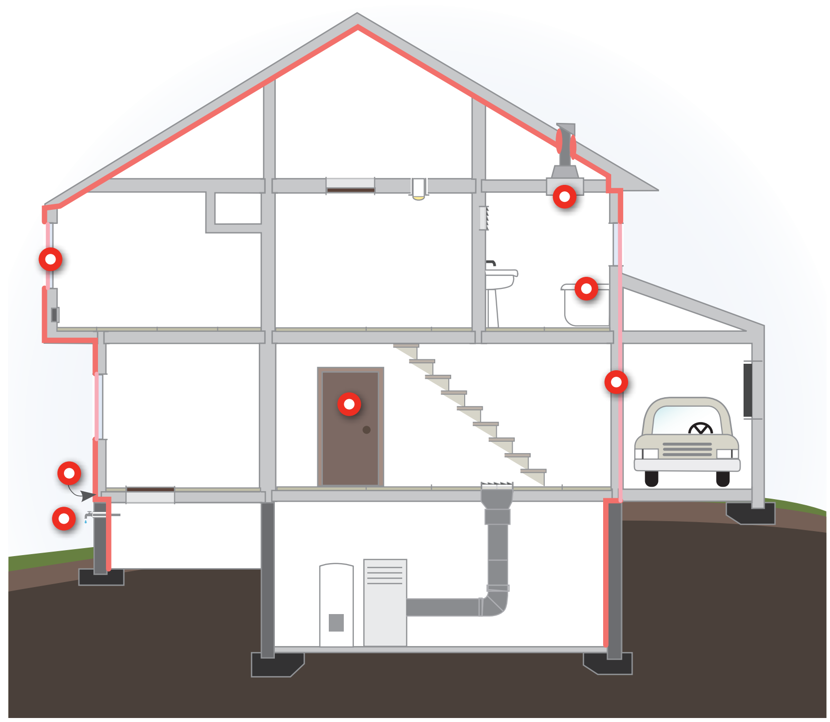


Kneewalls: The taped, mudded drywall forms an air seal for the attic room but floor joist openings below the attic room floor can be a big source of air leakage. Stop this air leakage by one of the following: A) Block the floor joist openings with sheet goods (drywall, rigid foam, OSB) that is cut to fit each opening or pieces of batt insulation that are rolled and put in plastic bags that are stuffed into the openings. Seal around the edges of either with spray foam or caulk to form an air-tight seal; or B) Continue insulation along roof line to roof edge, cover with sheet good that is caulked where it meets wood floor sheathing that is extended to outside wall. This method forms a tempered area with flooring for storage as well.

Interior Air Barrier – Points to Seal



Exterior Air Barrier with Rigid Foam Sheathing – Points to Seal



A comprehensive air-sealing strategy begins with indicating on the house plans the location of the conditioned space by outlining the building envelope. The plans should show the location of complex details like chases, stairwells, dropped ceilings, fireplace penetrations, balconies, and knee walls, so that they can easily be identified as being inside or outside the conditioned space. The plans also should show where insulation and draft stopping should be installed.

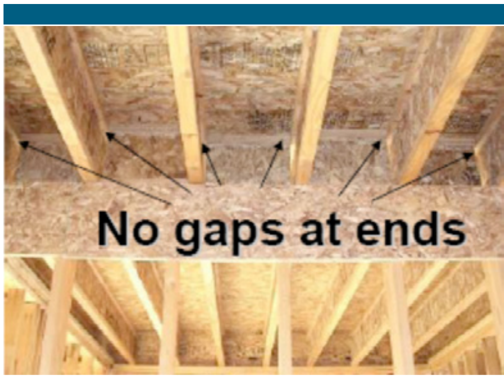
If the air barrier will be on the interior side of the walls, it is important to specify that all drywall joints be caulked, mudded, and taped. To ensure an airtight envelope when the air barrier is on the inside of the building envelope, builders should address the following common sources of air leakage through walls:

- Insulate and air seal behind tubs and shower stalls on the exterior walls by filling the wall cavity with insulation, and then installing and sealing rigid sheathing material on the interior surfaces of the wall before the tub or shower is installed.
- Line fireplace enclosure framing with rigid sheathing material, like gypsum board, plywood, wafer board, or foil-covered pressed paper, and seal edges to box in sides, top, and bottom of fireplace enclosure. Wood-burning fireplaces should have gasketed doors and outdoor combustion air **[per 2009 IECC 402.4.3]**.
- Air seal chimney chases and around the chimney flue where it penetrates the ceiling using sheetmetal and heat-resistant caulk.
- Box in tops and ends of soffits and dropped ceilings with sheathing that is caulked to framing on all edges.
- Fill in the rough opening around windows and doors with foam, caulk, or backer rod.
- Apply housewrap and flashing as shown in Chapter 14.
- Caulk, foam, or seal with gaskets all penetrations for electrical boxes, outlets, switches, and plumbing.

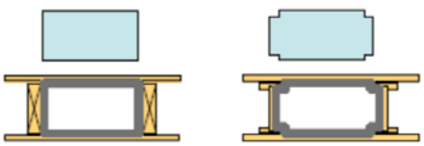
Alternatively, the air barrier can be placed on the outside of the building envelope. One method for doing this is to install rigid foam on the exterior side of the wall under the cladding. This foam sheathing can provide a continuous air barrier when all seams are taped and caulked. This exterior air-barrier system can also help control wind washing.

Cladding should have a drainage space behind it of

- 1 inch for brick **[2009 IRC R703.7.4.2]**
- 3/4 inch for stucco, and
- 1/16 inch for siding.

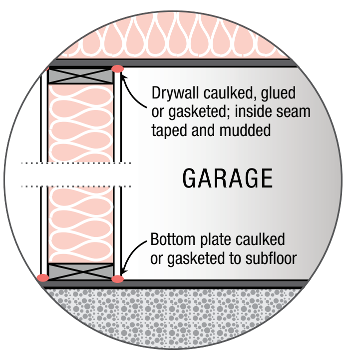


Gaps between garage and conditioned space are properly sealed by carefully cutting and then caulking wood sections to fit between trusses. *(Photo Source: EPA 2008 "Thermal Bypass Checklist")*

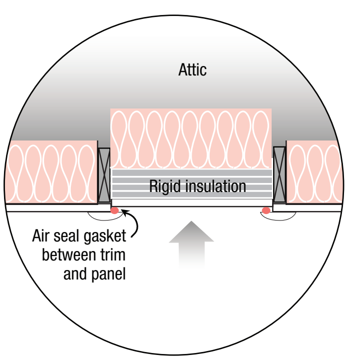


Wood or rigid foam filler blocking is cut to fit the gaps between floor joists and caulked or foamed in place to form an air break between conditioned and unconditioned spaces.

Garage common wall air sealing



Attic access panel air sealing

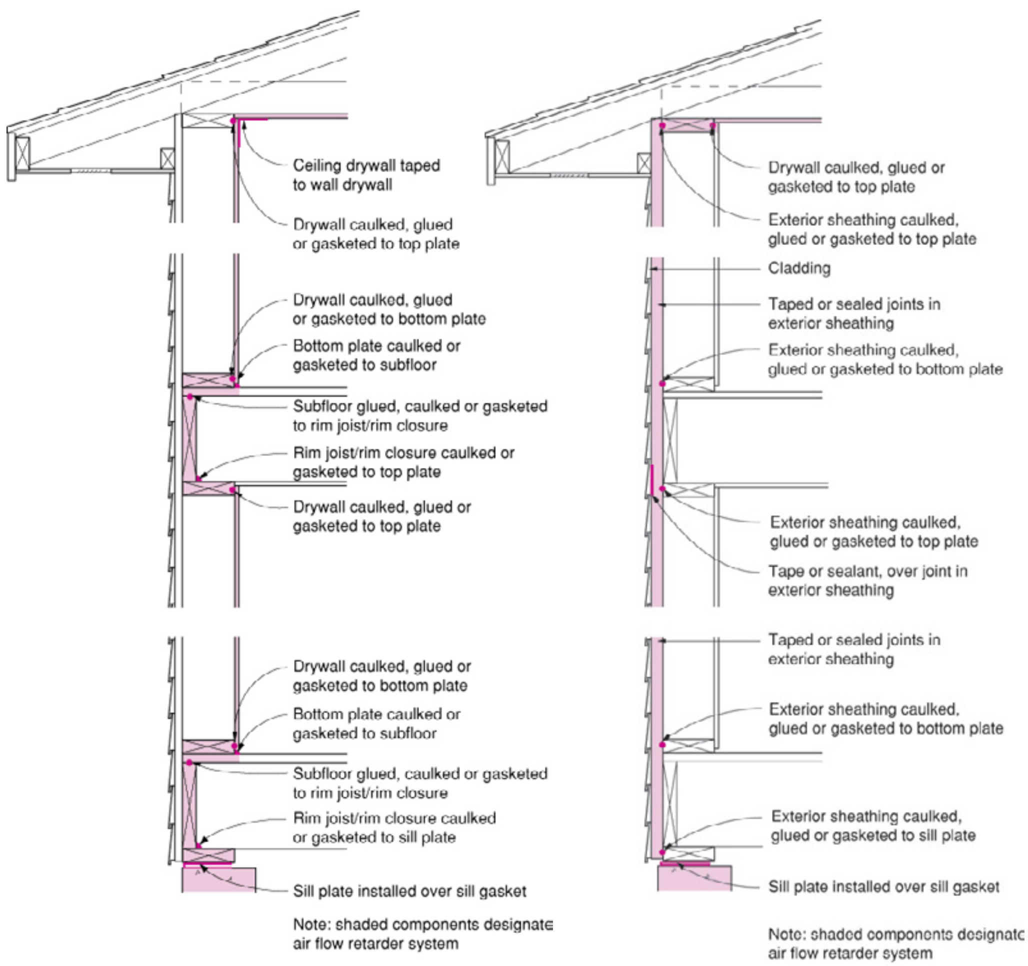


For occupant health and safety, builders should pay close attention to sealing shared walls and ceilings between attached garages and living spaces. When the garage is attached to the house, the gaps created by joists spanning both conditioned space and the garage must be blocked off and sealed. Creating air barriers to close gaps between the garage and the conditioned space is more difficult with irregularly shaped joists, such as I-joists and web-trusses. A simple solution is to plan ahead and align the ends of the joists with the wall adjoining the conditioned space to allow for end blocking.

Envelope Air Sealing

INTERIOR - Using gypsum and flooring

EXTERIOR - Using rigid foam sheathing



(Figure source: Building Science Corporation)

Controlling Heat Flow in Wall Assemblies

The control of heat flow in the building is managed by the type, thickness, location, and proper installation of insulation. **[The 2009 IECC 402 requires a wall R value of R-20 for wood-framed walls (or R-13 cavity plus R-5 insulated sheathing) for IECC climate zones 5 and 6 and R-21 for IECC climate zones 7 and 8. For mass walls (concrete block, concrete, ICF, brick, etc.), the requirement is R-13 for exterior insulation or R-17 if more than half the insulation is on the interior in zone 5, R-15/19 for IECC climate zone 6, and R-19/21 for IECC climate zones 7 and 8.]** Window selection and design are also important.

Consider implementing the following above-code recommendations:

- Use advanced framing techniques to cut lumber costs and provide more space for insulation. Provide advanced framing details on plans.
- Specify that cavity walls separating conditioned and unconditioned spaces be insulated with high-density batt insulation, dense-packed fibrous insulation, or spray-applied foam.
- Specify that spray foam be used to insulate and seal rim joists at areas between floors or where the wall connects to the floor.
- Specify that taped rigid foam insulating sheathing be used on the exterior side of studs in addition to cavity insulation. This sheathing eliminates thermal bridging at the studs.
- Use third-party inspectors or HERS raters to inspect insulation installation before dry walling.
- Specify ENERGY STAR-labeled doors.
- Design roofs and overhangs to shade and protect windows, doors, and 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 a 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.

Code/Above Code
Wall Insulation Above Grade

A comparison of the 2009 IECC climate zones 5–8, and Building America recommendations

Code		
2009 IECC	Wood Framed	Mass Wall***
IECC 5	R-20 or 13+5*	R-13/17
IECC 6	R-20 or 13+5*	R-15/19
IECC 7	R-21	R-19/21
Above Code		
Building America Recommendations	1 to 2 inches rigid foam exterior insulation, taped at seams,** plus R-21 fiberglass batt, or R-19 blown fiberglass or blown cellulose	

** R-13 cavity insulation + R-5 rigid foam sheathing*

*** Insulate the headers with R-10 (2 inches) of rigid foam board*

****The second R-value applies when more than half the insulation is on the interior of the mass wall.*

(top) RDI used a basic roof shape on its homes in Greenfield, Massachusetts, which minimizes the need for complicated flashing and provides the added benefit of more space for photovoltaics and solar water heating panels *(Photo Source: RDI).*

(bottom) Kick-out flashing should be installed to divert water runoff into gutters rather than flowing down the wall.

- 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. Also air seal penetrations to garages and porches.
- Mud, tape, and caulk seams and corners of gypsum board to control air leakage through the walls.
- 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.

Roof Assemblies

Controlling Liquid Water in Roof Assemblies

Roof and wall assemblies must contain surfaces that will drain water in a continuous manner down and off the building. Water must have a path that will take it from its point of impact, around any elements, such as chimneys, windows, doors, and seams, all the way to the exterior ground, and away from the house. Consider implementing the following recommendations:

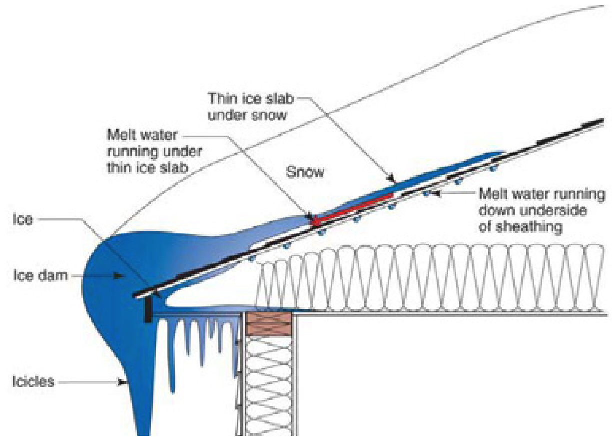
- Properly flash valleys and roof edges.
- Size gutters and downspouts to accommodate anticipated storms. Show gutter sizes on elevations and specify sizes in construction documents.
- Provide downspout drainage to carry water at least 3 feet beyond the building.
- In areas with potentially high winds and heavy rains, install 4-inch to 6-inch "peel and seal" self-adhering water-proofing strips over joints in roof decking before installing the roof underlayment and cover.
- Keep roof geometry simple. The more complex the roof—the more dormers, ridges, and valleys—the more likely the roof will leak.

Ice Dam Protection

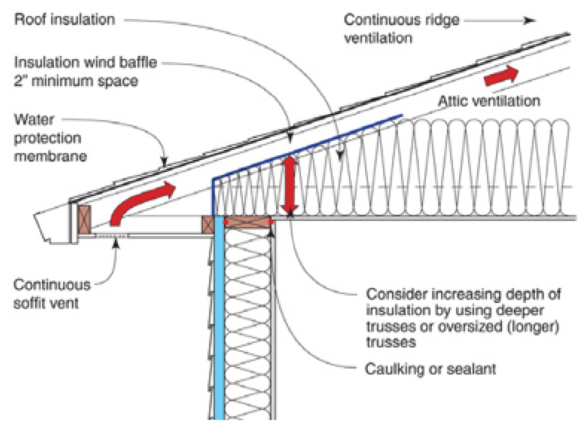
Ice dams can form when the air temperature is below freezing, but the roof deck temperature is above freezing, causing snow on the roof to melt. The melted snow flows to the edge of the roof where it refreezes, forming an ice dam that collects more water. The dam may not be visible under the snow but large amounts of icicle formation are a telltale sign. The water built up behind an ice dam can work its way into the house causing damage to building assemblies; other serious consequences are falling ice and structural collapse from the weight of ice and water buildup. While protective membranes and heating systems may treat the symptoms, the best solution is to keep ice dams from occurring in the first place. In a recent paper Joseph Lstiburek of Building America team partner Building Science Corporation, describes several approaches to ice dam prevention (Lstiburek 2011). The control approach involves keeping heat from the home's interior from reaching the roof deck by thoroughly air sealing the ceiling lid, covering it with a thick layer of insulation, and removing any heat that reaches the roof deck via ventilation of the roof deck. Lstiburek recommends going beyond code to ventilate every truss bay, not every third bay and providing a minimum 2-inch air gap (not the typical code-required 1-inch gap) between the underside of the roof deck and the top layer of insulation in the attic in ice dam-prone regions (where ground snow load exceeds 30 lb/ft^2). Minimize the number of holes through the ceiling (recessed can light fixtures, dropped soffits, etc.) because every air leak carries heat right up to the underside of the roof where it can warm the roof deck, creating ice dam conditions. Furnaces and ducts should not be located over the insulation in an unconditioned attic in the cold climate because of the likelihood of warm air leaks from the ducts and furnace.

A furnace could be located in the attic if the insulation is above the furnace along an unvented roof deck, e.g., if the underside of the roof deck is insulated with spray foam or if rigid foam insulation is placed over a roof sheathing that is covered with a continuous air barrier membrane. In areas with a lot of snow (ground snow load of >50 lb/ft^2), the snow itself can add enough insulation value to the insulated roof deck that the roof deck temperature could exceed freezing even when the air temperature is below freezing. To prevent ice dam formation in this situation, Lstiburek recommends constructing a vented over roof over the unvented compact roof (See Chapter 14, Field Guide for Ice Dam Prevention).

- Use raised heel trusses if needed to ensure adequate insulation directly at edges of attics directly over wall top plates and caulk to air seal top plate to dry wall and wall exterior sheathing.
- Minimize penetrations through ceiling lid and thoroughly air seal around any penetrations – especially wall intersections, recessed lights, soffits, duct chases, etc.
- Vent bath and kitchen exhaust fans out of the attic with sufficient clearance to keep warm air from warming roof.



Ice dams can form when the roof deck temperature is above freezing and the air is below freezing. Snow melts, runs down to the edge of the roof and refreezes forming a dam that traps more water and ice. Air leaks in ceilings and insufficient attic insulation allow heat to rise into attic warming roof deck and encouraging ice dam formation.



Three Steps to Ice Dam Control – 1) Construct an airtight ceiling plane. Limit the number of holes through the ceiling and air seal every one. 2) Insulate well, especially over the top plates, use raised heel trusses if needed to get full insulation coverage. 3) Vent the underside of the roof deck, with vent screens at every rafter bay and a 2-inch airspace under the sheathing where ground snow loads are greater than 30 lb/ft2. For more guidance, including how to prevent ice dams on an unvented roof, see the Ice dam prevention field guide in Chapter 14 *(Source Lstiburek 2011, Building Science Corporation)*

Baffles allow ventilation under roof decking while keeping wind from blowing insulation back from the edges of an attic.

Code/Above Code

Ceiling Insulation

A comparison of the 2009 IECC climate zones 5–8, and Building America recommendations

Code	
2009 IECC	
IECC 5	R-38*
IECC 6	R-49**
IECC 7&8	R-49*/***
Above Code	
Building America Recommendations******	R-49 blown fiberglass or blown cellulose R-49 spray foam on ceiling deck R-49 spray foam along underside of roof deck R-49 rigid foam exterior insulation on top of roof sheathing*

** R-30 if cathedral but cathedral must be limited to 500 ft² or 20% of total insulated ceiling area, whichever is less.*

***R-30 permitted if raised heel trusses used.*

**** R-38 permitted if raised heel trusses used.*

***** Level recommended by NWPCC 2010.*

- Install adequate insulation across the roof and ensure proper insulation levels above exterior walls by using raised-heel roof trusses.
- Apply a water-protection membrane at the eaves in case of ice dam formation.

[Per 2009 IECC 403.8 snow- and ice-melting systems, supplied through energy service to the building, shall include automatic controls capable of shutting off the system when the pavement temperature is above 50°F, and no precipitation is falling and an automatic or manual control that will allow shutoff when the outdoor temperature is above 40°F.]

Controlling Water Vapor in Roof Assemblies

Vapor retarder requirements for roofs are defined in Lstiburek (2006C) as follows: "Zone 5 requires a Class III (or lower) vapor retarder on the interior surface of insulation in ventilated insulated roof or attic assemblies. Zone 5, Zone 6 and Zone 7 require a Class II (or lower) vapor retarder on the interior surface of insulation in unvented insulated roof or attic assemblies and the condensing surface shall be maintained above the dew point temperature of the interior air. The condensing surface is defined as either the interior surface of the structural roof deck or the interior surface of an air-impermeable insulation applied in direct contact to the underside/ interior of the structural roof deck."

Controlling Air Flow in Roof/Attic Assemblies

Air sealing of the ceiling uses techniques similar to those used for the walls including mudding and taping of dry wall seams and caulking of cracks. **[The 2009 IECC 402.4 requires that the building thermal envelope be air sealed, including all joints, seams, and penetrations; dropped ceilings; knee walls; walls and ceilings separating a garage from conditioned space; attic access openings; rim joist junctions; and other sources of infiltration.]**

Air sealing details to consider include:

- Provide details on plans for air sealing and insulating complex structures like kneewalls, gable windows, porch-attic interfaces, and cathedral ceilings.
- Seal all penetrations and seams in ceiling gypsum board so that it functions as a continuous air barrier.
- Draft-stop soffits with rigid air barrier caulked at seams.
- Gasket or weather strip attic access hatches or doors and insulate to ceiling insulation depth **[as required by 2009 IECC 402.2.3]**.

- Install recessed lighting fixtures that are airtight and caulk or gasket the housing to the ceiling drywall **[per 2009 IECC 402.4.5]**.
- Provide a weather-stripped cover for whole-house fans.
- Ensure that skylights have a labeled infiltration rate of no more than 0.3 cfm/ft^2 **[per 2009 IECC 402.4.4].**

Controlling Heat Flow in Roof Assemblies

Maintaining the insulation level throughout the entire plane of the ceiling and over the top of the perimeter walls is key to controlling heat flow through the attic. Raised-heel energy trusses allow the thickness of the ceiling insulation to be maintained above the top plates of the exterior wall framing. Baffles should be installed at each rafter bay to prevent wind washing of thermal insulation and to prevent insulation from blocking ventilation in vented roof assemblies. **[The 2009 IECC 402.1 requires a ceiling R value of R-38 in IECC climate zone 5 and R-49 in IECC zones 6, 7, and 8. If raised heel trusses are used allowing full height of insulation over the wall top plate, then R-30 is permitted instead of R-38 in IECC zone 5 and R-38 is permitted instead of R-49 in zones 6, 7, and 8. A minimum of R-30 is required in cathedral ceilings, but this is limited to 500 ft^2 or 20% of total insulated ceiling area, whichever is less (2009 IECC 402.2.2.)]**

For More Information on Moisture, Air, and Heat Flow Control in Walls and Roofs

2009 IECC. 2009. *International Energy Conservation Code*, Section 402.4 "Air Leakage," International Code Council (ICC), Washington, D.C. www.iccsafe.org/Store/Pages

2009 IRC. 2009. *International Residential Code - One and Two-Family Dwellings*, International Code Council (ICC), Washington, D.C. www.iccsafe.org/Store/Pages

ASTM. 2007. *Standard Practice for Installation of Exterior Windows, Doors, and Skylights*. www.astm.org/Standards/E2112.htm

Buildernews Magazine, May 2004, "Housewrap Felt or Paper: Comparing specs on weather barriers"

Building Science Corporation. *Homeowner Information Resources.* www.buildingscienceconsulting.com/resources/homeowner.htm

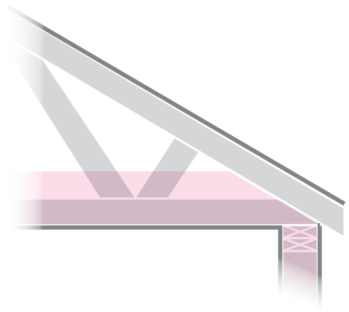
Building Science Corporation. 2006. Info-500: Building Materials Property Table, Building Science Corporation, April 16, 2010, www.buildingscience.com/documents/information-sheets/5-thermal-control/building-materials-property-table

DOE. "Vapor Barriers and Vapor Diffusion Retarders." Energy Savers Fact Sheet, www.energysavers.gov/your_home/insulation_airsealing/index.efm/mytopic=11810

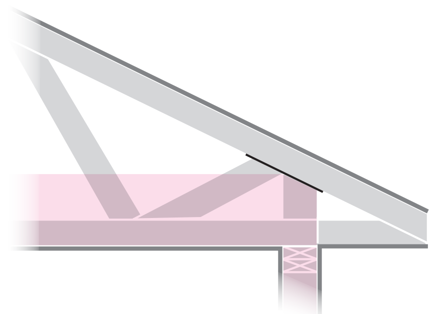
DOE. 2000. *Technology Fact Sheet on Weather-Resistive Barriers.* Prepared by NAHB Research Center, Southface Energy Institute, and Oak Ridge National Laboratory for the U.S. Department of Energy, DOE/GO10099-769, www.toolbase.org/PDF/DesignGuides/weatherresistantbarriers.pdf

DOE. 2009. *Moisture Control in Walls*, Energy Savers, www.energysavers.gov/your_home/insulation_airsealing/index.cfm/mytopic=11800?print

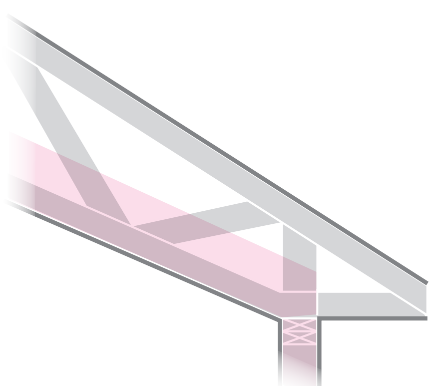
ENERGY STAR. 2008. *Thermal Bypass Checklist Guide* www.energystar.gov/ia/partners/bldrs_lenders_raters/downloads/TBC_Guide_062507.pdf, pg. 13



Traditional roof trusses pinch insulation where the roof meets the walls



Raised heel or energy trusses allow even the corners of the attic to be well insulated; this helps to prevent ice dams in winter and keeps rooms cooler in summer.



Some builders use cantilevered trusses to get full height insulation over the exterior wall.

Forest Products Laboratory. 2010. *Wood Handbook*, FPL-GTR-190, Forest Products Laboratory, U.S. Department of Agriculture, www.fpl.fs.fed.us/products/publications/several_pubs.php?grouping_id=100&header_id=p

Gatland, S. D., Karagiozis, A. N., Murray, C., and Ueno, K. 2007. "The Hygrothermal Performance of Wood-Framed Wall Systems Using a Relative Humidity-Dependent Vapor Retarder in the Pacific Northwest," in *Thermal Performance of the Exterior Envelopes of Buildings X*, proceedings of ASHRAE THERM X, Clearwater, Florida, www.ornl.gov/sci/roofs+walls/staff/papers/148.pdf

IBACOS. 2002. "Moisture Issues in Homes with Brick Veneer" www.eere.energy.gov/buildings/building_america/pdfs/db/36397.pdf

Lstiburek, Joseph. 2004a. *EEBA Builders Guides*. Guides to mixed humid, hot-dry, mixed-dry, and cold climates, for purchase at www.eeba.org/bookstore.

Lstiburek, Joseph. 2004b. *Roof Design*, Research Report 0404, Building Science Corporation, www.buildingscience.com/documents/reports/rr-0404-roof-design.

Lstiburek, Joseph. 2006a. *EEBA Water Management Guide*, available for purchase at www.eeba.org/bookstore/prod-Water_Management_Guide-9.aspx

Lstiburek, Joseph. 2006b. *Understanding Drainage Planes*, Building Science Digest 105, 2006-10-24, Building Science Corporation, www.buildingscience.com/documents/digests/bsd-105-understanding-drainage-planes/

Lstiburek, Joseph W. 2006c. Building Science Digest 106: Understanding Vapor Barriers. Building Science Press. Waterford, Massachusetts. www.buildingscience.com/documents/digests/bsd-106-understanding-vapor-barriers

Lstiburek, Joseph. 2008. *Problems with Housewraps*, Research Report 0106, Building Science Corporation, Building Science Press, www.buildingscience.com/documents/digests/bsd-013-rain-control-in-buildings

Lstiburek, Joseph. 2009. "The Perfect Wall," Building Science Insight 001: last updated 2009/05/21, Building Science Corporation, www.buildingscience.com/documents/insights/bsi-001-the-perfect-wall

Lstiburek, Joseph. 2011. Dam Ice Dam, Insight 046, Feb. 2011, Building Science Corporation, www.buildingscience.com/documents/insights/bsi-046-dam-ice-dam/

NAHBRC. *Moisture Protection of Wood Sheathing*, National Association of Home Builders Research Center, www.toolbase.org.PDF/DesignGuides/MoistureProtectionWoodSheathing.pdf

NWPCC. 2010. *Energy Efficiency: Appendix F: Model Conservation Standards*, Northwest Power and Conservation Council., Council Document 2010-03, www.nwcouncil.org

Straube, John. 2001. "Wrapping it Up," *Canadian Architect*, May 2001, www.cdnarchitect.com/issues/ISarticle.asp?aid=1000115982

Straube, John. 2009a. *Rain Control in Buildings*, Building Science Digest 013: last updated 2009/08/10 www.buildingscience.com/documents/digests/bsd-013-rain-control-in-buildings?full_view=1

Straube, John. 2009b. RR-0907 *Ventilated Wall Claddings: Review, Field Performance, and Hygrothermal Modeling*, Building Science Corporation www.buildingscience.com/documents/reports/rr-0907-ventilated-wall-claddings-review-performance-modeling/view

University of Illinois Extension Office. "Five Steps to a Healthier Garage." http://web.extension.uiuc.edu/will/factsheets/family116.html

Window and Door Assemblies

Choosing highly efficient windows will add expense to your project but will increase comfort, durability, and energy savings. The National Fenestration Rating Council (www.nfrc.org) provides window labeling that includes the following performance information:

- U-factor measures heat transfer—the lower the U-factor, the better the window performs at stopping heat flow. U-factors are the inverse of R-values, which measure a material's insulation effectiveness. U-factor values for windows generally fall between 0.20 and 1.2. **[2009 IECC 402 requires a maximum U-factor of 0.35 with no SHGC requirement specified for IECC climate zones 5-8.]**

- Solar heat gain coefficient (SHGC) 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.

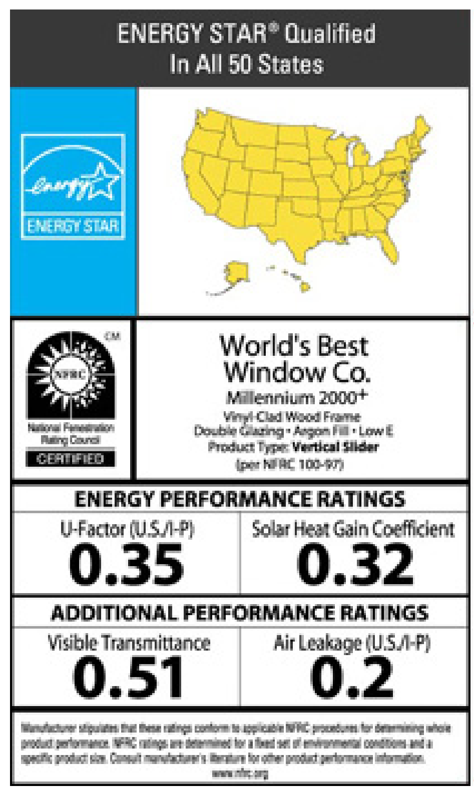
- Visible transmittance (VT) measures how much light comes through a window. VT is expressed as a number between 0 and 1 —the bigger the number, the more clear the glass.

- Air leakage through a window assembly (AL rating) is expressed as the equivalent cubic feet of air passing through a square foot of window area (cfm/ft^2)—the lower the AL, the less the window leaks. A typical rating is 0.2. **[Per the 2009 IECC 402.4.4, windows, skylights, and sliding glass doors should have an air-infiltration rate of ≤ 0.3 cfm/ft^2 and swinging doors of ≤ 0.5 cfm/ft^2.]**

ENERGY STAR qualifies windows based on climate zones and divides the United States into four climate zones. See the charts and map for U-factor and SHGC guidelines for cold climate states.

The DOE-sponsored Efficient Windows Collaborative operates a website that can help designers and consumers choose windows (www.efficientwindows.org/index.cfm). The website includes a tool that allows users to analyze energy costs and savings for windows with different ratings. The website also has fact sheets with comparisons for each state.

RDI could not find a triple-pane window that was affordable enough to use in all of the windows for its affordable-rate homes in western Massachusetts, so it settled on two window types. For south-facing windows, a double-pane window with a U-value of 0.26, an SHGC of 0.37, and a low-emissivity coating on the third (inside) surface was installed. For north, east, and west-facing windows, RDI selected a triple-pane window with low-e coatings on the second and fifth surfaces, a U-value of 0.18, and an SHGC of 0.23.



Example of a window label from the National Fenestration Rating Council and ENERGY STAR.

Code/Above Code

Window U Factor and Solar Heat Gain Coefficient

A comparison of the 2009 IECC climate zones 5–8 and Building America recommendations

Code	U-Factor	SHGC
2009 IECC	0.35	NR
IECC 5	0.35	NR
IECC 6	0.35	NR
IECC 7&8	0.35	NR
Above Code		
Building America Recommendations	≤ 0.30 Double glazing or triple	≤ 0.35

NR - No Requirement
SHGC - solar heat gain coefficient

ENERGY STAR Qualified Windows, Doors, and Skylights Eligibility Criteria *(Version 5.0, 04/07/2009, effective 01/04/2010)*

Windows

Climate Zone	U-Factor[1]	SHGC[2]	
Northern	≤ 0.30	Any	Prescriptive
	=0.31	≥ 0.35	Equivalent Energy Performance
	=0.32	≥ 0.40	
North-Central	≤ 0.32	≤ 0.40	
South-Central	≤ 0.35	≤ 0.30	
Southern	≤ 0.60	≤ 0.27	

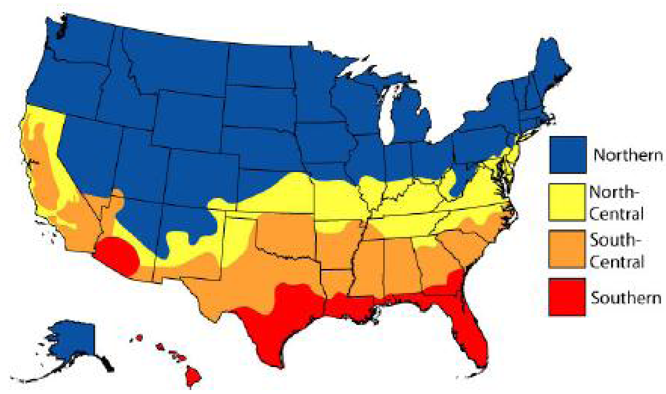
[1] $Btu/h.ft^2.{}^{\circ}F$
[2] Fraction of incident solar radiation

Doors

Glazing Level	U-Factor[1]	SHGC[2]
Opaque	≤ 0.21	No Rating
≤ ½-Lite	≤ 0.27	≤ 0.30
> ½-Lite	≤ 0.32	≤ 0.30

Skylights

Climate Zone	U-Factor[1]	SHGC[2]
Northern	≤ 0.55	Any
North-Central	≤ 0.55	≤ 0.40
South-Central	≤ 0.57	≤ 0.30
Southern	≤ 0.70	≤ 0.30



For More Information on Windows and Doors

American Architectural Manufacturers Association. "Product Certification – Search now for AAMA-Certified Products (windows and doors)." Available at www.aamanet.org/general.asp?sect=2&id=127

ASTM. ASTM E2112 - 07. *Standard Practice for Installation of Exterior Windows, Doors and Skylights*, www.astm.org/Standards/E2112.htm

Carmody, John, Stephen Selkowitz, Dariush Arasteh, and Lisa Heschong. 2000. *Residential Windows: A Guide to New Technologies and Energy Performance*. W.W. Norton & Company, Inc., New York.

ENERGY STAR Efficient Windows Collaborative www.efficientwindows.org/energystar.cfm

ENERGY STAR. Residential Windows, Doors, and Skylights. www.energystar.gov/index.cfm?c=windows_doors.pr_windows

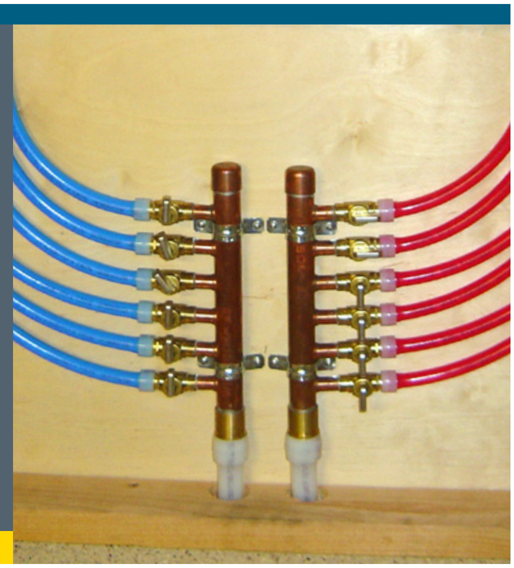
FMA/AAMA 100-07. "Standard Practice for the Installation of Windows with Flanges or Mounting Fins in Wood Frame Construction." Available from AAMA's online store at www.aamanetstore.org/pubstore/ProductResults.asp?cat=0&src=100

Insulating Glass Manufacturers Alliance. www.igmaonline.org/content.php?doc=142

National Fenestration Rating Council. www.nfrc.org

Chapter 9.

Mechanical, Plumbing and Electrical Systems



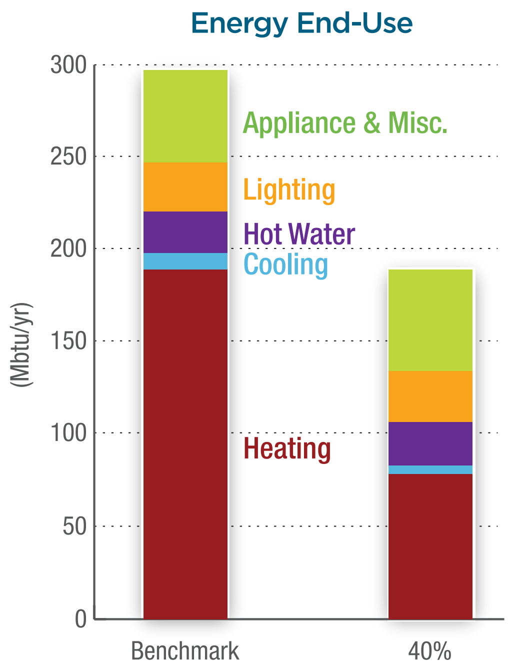
A centrally located manifold water distribution system saves energy by reducing hot water usage.

A home's mechanical systems can have a significant impact on its energy performance and comfort. As envelope performance improves, these systems are becoming more important targets for improved efficiency. The charts below show typical energy usage for the equipment described in this chapter, including HVAC (heating, ventilation, and air conditioning), plumbing and water heating, lighting, and appliances.

CHAPTER TOPICS

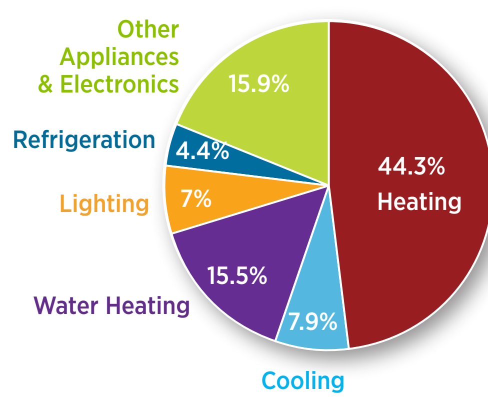
Heating, Ventilation, and Air Conditioning (HVAC)

Using Building America best practices for insulation, windows, and air sealing can improve building envelope performance to such an extent that HVAC system size can sometimes be cut in half and still meet occupant comfort needs. Builders may be surprised to find that properly sizing the HVAC system increases comfort while providing a remarkable opportunity for dollar savings in high-performance homes.



A Comparison of Energy Usage by End Use for a Home Built to Perform with 40% Energy Savings Compared to the Building America Benchmark (a home built to MEC 1993) in the Cold Climate. *Example based on a 2-story, 1,354 ft² house in Pasco, WA. Analysis by BIRA.*

2005 Typical Residential On-Site Energy Consumption End Uses in the Western United States



(Figure source: DOE. 2008. 2008 Buildings Energy Data Book, *based on delivered energy end-uses for an average household in the west.)*

Efficiency Measures for Air Conditioners, Heat Pumps, and Furnaces

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. Heat pumps and air conditioners must have a SEER of 13 or higher (per Federal requirements that went into effect in 2006).

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. Heat pumps and furnaces must have an HSPF of 7.7 or higher (per Federal requirements that went into effect in 2006).

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.

Energy Efficiency Rating (EER) a rating of a central air conditioner's steady-state efficiency at 80°F indoors and 95°F outdoors, measured once the air conditioner is up and running.

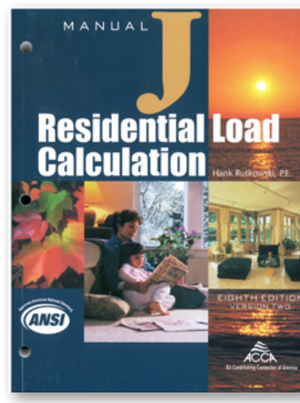
DOE is mandated by Congress to continually review and update appliance efficiency standards. For a schedule of appliance standards updates, see www.standardsasap.org/federal.htm

For the best results in comfort, efficiency, and durability, HVAC and duct design must be integrated in the overall architectural design. Builders should work closely with their HVAC engineer to properly size and select the HVAC equipment, design and install ducts, and provide appropriate ventilation. **[The 2009 IECC 403.1 requires that forced air furnaces come with a programmable thermostat and that heat pumps with electric resistance backup heat be equipped with controls that prevent the supplemental heater from coming on when the heat pump compressor can meet the load.]** These steps will go a long way toward improved energy efficiency, comfort, and cost savings.

Heating and Cooling Equipment

A well-designed house should have an HVAC system properly sized to its demands. The Air Conditioning Contractors of America (ACCA) has published simple but effective methods for determining loads and sizing of ductwork and heating and cooling equipment (available for purchase at www.acca.org).

- **MANUAL S** guides you through the selection of appropriate heating and cooling equipment to meet identified loads.
- **MANUAL J** tells you how to calculate heating and cooling loads.
- **MANUAL D** tells you how to size ducts.
- **MANUAL T** gives you the basics of air distribution for small buildings.
- **MANUAL RS** focuses on comfort, air quality, and efficiency.



Right sizing of HVAC equipment using *Manual J* calculations can minimize energy use and save upfront costs.

[The 2009 IECC 403.6 mandates that heating and cooling equipment be sized in accordance with the 2009 IRC M1401.3, which cites ACCA Manuals S and J for equipment sizing and load calculations. Equipment serving multiple dwelling units should comply with 2009 IECC 503 and 504 for commercial buildings, rather than 403 for residential buildings.]

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 uses of the same plans.

Central Gas-Fired Furnaces

For central gas-fired heating systems, high-efficiency (≥90% AFUE) variable-speed sealed combustion gas furnaces should be installed. 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. Sealed combustion appliances eliminate the potential for back-drafting. Look for ENERGY STAR-qualified furnaces, heat pumps, and air conditioners. Variable speed motors, also known as electrically commutated motors (ECMs), are more efficient than regular furnace blower motors because they can operate at variable speeds allowing enabling the speed to adjust to the heating and cooling needs of the house. Instead of repeatedly blasting on and shutting off, the variable speed motor runs the blower for longer periods at lower speeds, providing quieter operation, and more even heat and cooling. They can be more effective at reducing humidity levels in a home than a central HVAC with a single-stage blower.

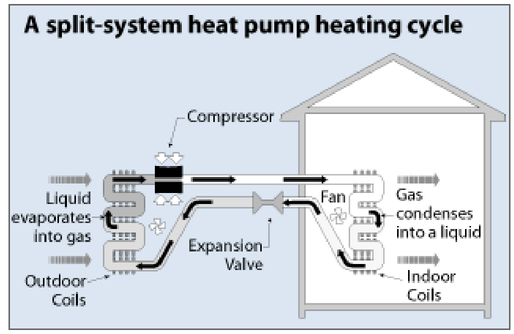
For larger homes (> 2,500 ft^2) and multi-storied homes, the system can be equipped with zoning dampers and controls to provide heat and cooling only where it is needed. With better insulation and air sealing, heating and cooling loads are decreased and even large homes can often be adequately served with one unit where the builder might have specified two or more units in the past.

Electric Heating and Heat Pumps

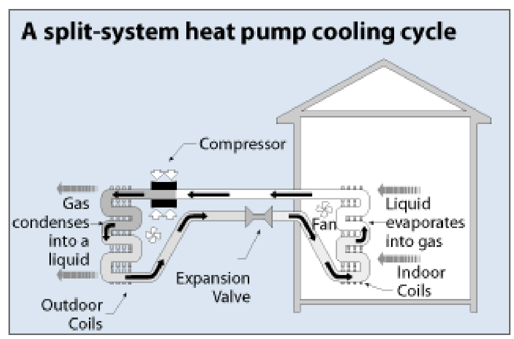
Electric furnaces, electric baseboard heating, and electric resistance wall units are all used in the cold climate but they are expensive and inefficient methods for heating. One recent study reported electric furnace heating costs $2.56/100,000 Btus and electric resistance heating costs of $2.05/100,000 Btus, compared to $1.49/100,000 Btus for gas heat and $0.82 /100,000 Btus for ductless heat pumps (based on fuel costs of $0.07/kWh electric, and $1.10/therm gas) (Pratt 2008).

Heat pumps are preferable to electric resistance heating. A standard heat pump unit with a Heating Seasonal Performance Factor (HSPF) of 7.7 or more (the minimum HSPF required by law as of September 2006), can reduce electricity consumption during heating by 30% or more relative to electric resistance heating systems. In colder areas when temperatures fall below 30°F, standard air source heat pumps typically use an electric resistance back-up system to properly heat a home. This can be a costly method of supplemental heating; a backup gas furnace may be a cost-effective alternative. Heat pumps also provide cooling; per Federal requirements since 2006, heat pumps and air conditioners must have a Seasonal Energy Efficiency Ratio (SEER) of 13 or higher.

How Standard Heat Pumps Work



In heating mode, an air-source heat pump evaporates a refrigerant in the outdoor coil. As the liquid evaporates, it pulls heat from the outside air. After the gas is compressed, it passes into the indoor coil and condenses, releasing heat to the inside of the house. The pressure changes caused by the compressor and the expansion valve allow the gas to evaporate at a low temperature outside and condense at a higher temperature indoors. In cooling mode, the reverse happens.



In cooling mode, an air-source heat pump evaporates a refrigerant in the indoor coil; as the liquid evaporates it pulls heat from the air in the house. After the gas is compressed, it passes into the outdoor coil and condenses, releasing heat to the outside air. The pressure changes caused by the compressor and the expansion valve allow the gas to condense at a high temperature outside and evaporate at a lower temperature indoors.

Ductless heat pumps mount to the wall to provide zonal heating and cooling with exceptional energy performance.

Ductless Heat Pumps

Ductless heat pumps are a more efficient alternative to standard heat pumps which use ducts and a large blower to distribute the hot or cool air. Ductless heat pumps are sometimes referred to as mini-split heat pumps because they consist of a single outside compressor/condenser unit connected to one or more wall- or ceiling-mounted indoor air handler units to provide zone heating and cooling without ducts. The indoor air handlers have dimensions of approximately 12x9x31 inches and weigh as little as 25 pounds. The outdoor units are approximately 25x12x31 and weigh about 88 pounds. The outdoor units are mounted on a concrete pad outside the house; tubing connects the two units through a small hole in the wall.

Ductless heat pumps have been used in Asia and Europe since the 1970s and in U.S. commercial buildings since the 1980s, but they are not yet well known in the U.S. residential market. They are 25% to 50% more efficient than electric baseboard or wall heaters (NEEA 2009).

Ductless heat pumps provide increased energy savings over standard heat pumps in several ways – because they are ductless and mounted inside conditioned space, there are no losses to the attic or crawlspace or through leaky ducts; they provide zonal heating; and advances in technology in recent years have increased performance to the point that HSPF 12/SEER 26 units are now available. These high-performing heat pumps also perform at a much wider temperature range than standard heat pumps: some models can operate at an outdoor temperature range of 5°F to 75°F for heating and 14°F to 115°F for cooling, eliminating or significantly reducing the need for backup heat sources in many locations.

These ductless heat pumps use an inverter-driven compressor technology coupled with a multi-speed or inverter-driven fan to continuously match the heating/cooling load. Unlike conventional air conditioning/heating systems that stop and start repetitively, the inverter technology adjusts the motor speed, allowing the system to adapt more smoothly to shifts in demand with less temperature variation and much lower energy use. When maximum capacity isn't needed, compressor revolution and power decreases, increasing energy efficiency. For example, one model reports a capacity range of 3,100-24,000 Btu's in heating mode and 3,800-14,500 Btu's in cooling mode.

For more information on ductless heat pumps, including installation tips, production selection recommendations, and performance details, see the website for the Northwest Ductless Heat Pump Project (www.newductles.com), conducted by Bonneville Power Administration and Northwest Energy Efficiency Alliance (NEEA) (Bonneville Power

Administration 2010; NEEZ 2009). Begun in 2008, as of February 2011, the project had 9,276 ductless heat pumps installed in Northwest homes, 87 participating utilities, and 746 participating contractors; research results on energy savings will be out in 2012.

Ground-Source Heat Pumps

Geothermal or ground-source heat pumps can be very efficient for heating and cooling because they use the constant temperature of the earth as the exchange medium instead of the outside air temperature. This allows the system to reach fairly high efficiencies (300%-600%) on the coldest of winter nights, compared to 175%-250% for air-source heat pumps on cool days. The disadvantages are their initial cost and the need for yard space to install the piping. For more information on various HVAC technologies, see www.energysavers.gov.

Hydronic heating in condominiums in Aspen, Colorado, uses water that is preheated by solar thermal panels, than heated by a gas boiler, and distributed via baseboard radiators.

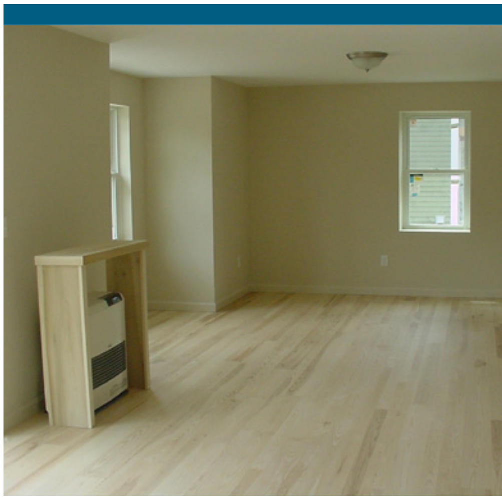
Hydronic Heating

Hydronic heating is particularly suitable for space heating in the cold climate in areas where there is no need for air conditioning (and its associated duct systems). The water can be heated by a gas or oil boiler, ground-source heat pump, or solar water heater. The heated water typically heats the home via a radiant floor system or baseboard convection units. **[If a radiant floor system is selected in a slab-on-grade installation, the 2009 IECC 402.2.8 requires that the slab edge be insulated to R-15 that extends down and out from the building or in under the slab a total of 2 or 4 feet, depending on whether the home is located in IECC climate region 5 (2 feet) or 6 or 7 (4 feet).]** Building America recommends R-15 perimeter insulation, plus R-20 underneath the entire slab. If the hot water serves a fan coil and ducted system, the ducts should be sealed and insulated.

Building America recommends a MERV 8 or higher filter on the HVAC return. MERV (Minimum Efficiency Reporting Value) is a measure of an air filter's efficiency at removing particles. **[This exceeds the ASHRAE 62.2-2010 6.7 recommended MERV 6 or better.]**

Cooling Equipment

The cooling system is shorter in the cold and very cold climates. In a well-insulated home, summer heat may be adequately controlled by ventilation combined with passive design to minimize summer solar heat gain (overhangs, covered porches, awnings, window blinds or shades, and planting of deciduous trees on the south side of homes). Mechanical cooling options include central air conditioning as part of a central gas or electric furnace system, wall unit air conditioners, and heat pumps. Evaporative cooling is not recommended except in dry regions. Heat pumps are more efficient than standard electric air conditioning and new models of ductless heat pumps offer SEER ratings as high as 26 at a wide temperature range. For either system, it is important to verify that the refrigerant level is correct at installation. The EPA reports that 75% of installed air conditioners had the wrong amount of refrigerant when tested. Incorrect



This high-efficiency, sealed-combustion gas space heater heats the entire home at low installation and operating cost.

refrigerant levels can lower efficiency by 5% to 20% and can cause premature component failure, resulting in costly repairs (see EPA Heating and Cooling Refrigerant Charging guidelines www.epa.gov).

Other Heating and Cooling Options

The superior insulation and air sealing of high-performance homes can reduce heating and cooling demand to such a degree that options not typically thought of as energy efficient become acceptable because they can be sized small enough to meet the small demand: for example closed-combustion gas space heaters or electric zonal heating systems. Another option is integrated heating systems, which combine space heating, water heating, heat-recovery ventilation, and air conditioning. The heating input for these systems could be gas, heat pump, or solar.

Low-Cost System Matches Super-Efficient Homes' Low Heat Load with Savings for Homeowners and Builder

When Rural Development, Inc., worked with Building America's CARB research team to design 20 energy-efficient, affordable duplexes in western Massachusetts, the designs they came up with were so well insulated that most furnace systems were too large for the design heat load of the 1,100-1,700-ft^2 homes. Instead RDI installed a small, natural gas-fired space heater on the first floor of each home. The sealed combustion heater has a capacity of 10,200 Btu per hour on low fire and 16,000 Btu/hr on high fire with an annualized fuel utilization efficiency (AFUE) of 83%. Compared to the hydronic baseboard systems they had used on previous homes, the builder saved $5,000 per unit. There is no traditional duct system with this type of space heater. To heat the upstairs bedrooms, CARB designed a system using an exhaust fan in the living room ceiling to pull warm air into the bedrooms.

For More Information on Heating and Cooling Equipment

Air Conditioning Contractors of America. 2007. *ACCA Standard 5; HVAC Quality Installation Specification*, ANSI/ACCA 5 QI-2007, Air Conditioning Contractors of America, 2800 Shirlington Road, Suite 300, 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

ASHRAE. 2007. Standard 52.2-2007, *Method of Testing General Ventilation Air-Cleaning Devices for Removal Efficiency by Particle Size*, available for purchase from ASHRAE's bookstore www.ashrae.org

Baylon, David, Kevin Geraghty, and Kacie Bedney. 2010. "Performance of Ductless Heat Pumps in the Pacific Northwest," in *Proceedings of the 2010 ACEEE Summer Study on Energy Efficiency in Buildings*, prepared by Ecotope Inc. and Bonneville Power Administration.

Bonneville Power Administration. 2010. *Residential Ductless Mini-Split Heat Pump Retrofit Monitoring: 2008-2010 Analysis*, prepared for BPA by Ecotope, www.bpa.gov/energy/N/DHP.cfm

Building Industry Institute. *Procedures for HVAC System Installation.* www.thebii.org/hvac.pdf

Consortium for Advanced Residential Buildings. Steven Winter Associates, Inc. (CARB-SWA). *Designing Forced-Air HVAC Systems.* www.carb-swa.com/Resources

Consortium for Energy Efficiency (CEE) and the Air-Conditioning, Heating, and Refrigeration Institute (AHRI). "Database of Qualifying ENERGY STAR Heat Pumps and Air Conditioners," www.ceehvacdirectory.org

Consortium for Energy Efficiency. *Residential HVAC: CEE-AHRI HVAC Directory.* www.cee1.org/resid/rs-ac/rs-ac-main.php3

Cowan, Laura. 2009. "How Heat Pumps Work." May 13, 2009. http://home.howstuffworks.com/home-improvement/heating-and-cooling/heat-pump.htm

DOE. "Energy Savers – Heating Systems," U.S. Department of Energy. www.energysavers.gov

DOE. "How to Size HVAC Systems Correctly," U.S. Department of Energy Building Energy Codes Resource Center, http://resourcecenter.pnl.gov/cocoon/morf/ResourceCenter/article/137

DOE. "Right-Size Heating and Cooling Equipment," U.S. Department of Energy Technology Fact Sheet, www.toolbase.org/Design-Construction-Guides/HVAC/right-size-hvac-equipment

DOE. 2008. *2008 Buildings Energy Databook*. U.S. Department of Energy, http://buildingsdatabook.eren.doe.gov/

EPA. "Heating and Cooling: Sizing and Installation – Proper Refrigerant Charging," U.S. Environmental Protection Agency. www.energystar.gov/index.cfm?c=heat_cool.pr_properly_sized

Furnace Filter Care. "Understanding MERV Ratings," www.furnacefiltercare.com/merv-ratings.php

NEEA. 2009. Northwest Ductless Heat Pump Project: Project Overview and Installation Best Practices, Northwest Energy Efficiency Alliance, www.nwductless.com/contractors/project-resources

Pratt. 2008. *Ductless Heat Pumps*, BPA Brown Bag Presentation prepared by Jeffrey R. Pratt Inc. for Bonneville Power Administration, www.bpa.gov/energy/n/Utilities_Sharing_EE/Energy_Smart_Awareness/pdf/BPA_DHP_Presentation_022708.pdf

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

Ducts and Air Handlers

Duct System Design and Layout

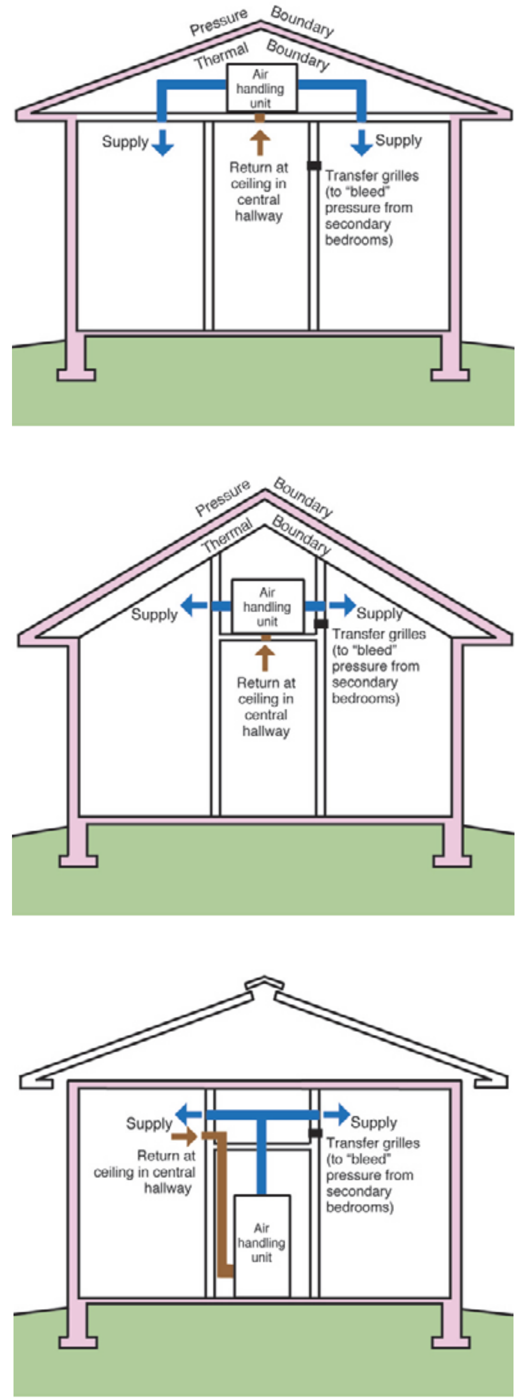
With central forced-air systems, the gas or electric furnace and ducts are often located in unconditioned space in the attic, garage, crawlspace, or unheated basement. As typically installed, this "default" design is assumed in codes to reduce system efficiency by about 20%; whereas placing ducts in conditioned space is assumed to cut air loss to about 4% (ICC 2006 as reported in Lubliner et al. 2008). Numerous studies have shown significant savings from moving the ducts and airhandler into conditioned space. In a modeling study conducted in Spokane, Washington, by Building America research partner Washington State Energy Office, using a home built to the current Washington State Energy code, moving ducts out of a vented crawlspace and into the home resulted in heating energy savings of 28.4% and cooling savings of 17% (Hales et al. 2010).

As data confirm, the best practice is to locate the ducts in conditioned space so that any leakage that does occur will send air to or draw air from conditioned space. Ducts may be run through open-web floor trusses in a two-story home; through a dropped hallway ceiling in a one-story home; or through a conditioned attic, conditioned crawlspace, or conditioned basement. Ducts should not be located in exterior walls. Air handlers should be located in conditioned space, such as a closet inside the home, in a conditioned attic or basement, or in an air-sealed and conditioned closet in the garage.

In all cases, duct systems should be designed using *ACCA Manual D* [2009 IRC M1601.1]; duct runs should be as short as possible, and duct sizes and layouts should be shown on plans. Building cavities should not be used as supply ducts [2009 IECC 403.2.3].

Duct Run Configurations

Here are three example designs for putting ducts in conditioned space.



(Source: Building Science Corporation)

(Top and Bottom) These Building America builders run ducts through open-web floor trusses to keep the ducts in conditioned space (shown here). Open-web trusses allow subcontractors the flexibility to run plumbing, electrical, and ductwork easily between floors, with little to no "trade damage" or "trade fighting." Air handlers are located in conditioned space in the home or in an air-sealed closet in the garage.

"We literally designed the house around the HVAC system."

Eric Jester, East Liberty Development, Inc.

Keeping ducts and air handlers inside conditioned space typically impacts architectural design and should be considered early in the design process. Duct chases or dropped soffits may require thinking through the sequence of how trade contractors will do the installation.

The Seattle-area production builder Quadrant Homes worked with Bob's Heating in Kirkland, Washington, to design systems that brought the furnace and ducts into conditioned space. "It is easier for installers to do a quality job when they are not lying in the mud, deep in a corner of the crawlspace," said Wade Craig of Bob's Heating. When ducts are installed between floors, they are clearly visible to the general contractor and inspector, encouraging better installations. Another major concern is "trade damage" which can occur if electrical or plumbing subcontractors compromise ducts to squeeze their wires and pipes into the same space. With open-web trusses there is enough room for all trades, making each subcontractor's work easier.

Craig said his firm can lower its bid when the HVAC system is moved inside. Additionally, Craig points out that moving the furnace from the attic to a mechanical closet on the second floor facilitates easier equipment servicing and improves worker safety during installation and retrofits. Quadrant is aware of the potential for air leakage pathways between floors and the need to reduce those pathways via proper insulation and air sealing of the rim joists. All ducts in Quadrant homes are well sealed with mastic and tested with a Duct Blaster™ (Lubliner et al. 2008).

If ducts are not in conditioned space, one alternative is to locate the ducts on the ceiling deck of an unconditioned attic and "bury" the ducts with blown-in insulation. In more humid climates this strategy is not recommended because condensation could occur at the duct exterior surface. Building America researchers have investigated burying ducts in attic insulation above ceilings and based on this research, buried ducts may be permissible but the ducts should be directly insulated to R-8, apart from the piled-on insulation. Building America does not recommend using the buried duct approach in climates where the summertime attic dew point temperature is often above 60°F, or if the Jul-Aug monthly average outdoor dew point temperature is above 60°F (refer to Table 6-3 of ASHRAE Standard 90.2-1993). The mixed-humid and hot-humid climates often exceed this dew point and so buried ducts are specifically not recommended there. In other climates, such as cold climates up through the humid river valleys, builders and designers should be cautious.

Locating air handlers and return ducts in the garage is not recommended because of the potential for drawing carbon monoxide and hazardous fumes into the home. If the air handler must be located in the garage, it should be enclosed in an insulated, air-sealed closet. Ducts located in the garage may not have any openings in the garage [2009 IRC R302.5.2] and furnaces and air handlers that supply air to living spaces shall not supply air to or return air from a garage [2009 IRC M1601.6]. The air handler and any return-air ductwork should be thoroughly sealed with UL 181B-M-compliant mastic, with a target leakage between the duct system and the garage of 0 CFM @25 Pa.

Duct Sealing and Insulating

Leaky duct systems cause energy losses, but they can also depressurize the house, which can pull outdoor, unfiltered air into the house from attics, crawlspaces, attached garages, and through building walls.

All ducts, air handlers, and filter boxes should be airsealed and joints and seams should comply with the 2009 IRC M1601.4.1. The 2009 IRC describes several UL 181-approved sealing methods. Building America recommends water-based mastic that complies with UL181B-M, as appropriate. Duct-drywall connections should be sealed with caulk or foam sealant. Leaky ductwork in an unconditioned attic or crawlspace not only leaks energy but it can also 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 rooms intended, rather than leaking into a plenum space. It also minimizes the chances of creating pressure differentials from room to room, can cause drafts. The double-check inherent in the process of sealing each joint reduces the chances of unconnected ductwork, which is a surprisingly common mistake.

Although mastic is the most reliable duct sealing method, the 2009 IRC M1601.4.1 allows certain approved tapes and DOE research has found that some tapes perform adequately for sealing ducts, particularly fiberglass board ducts (see sidebar). However, high-performance tapes may be difficult to identify and traditional duct tape (cloth-backed rubber adhesive tape) should never be used to seal ducts, even if it meets UL ratings. Tapes have low tensile strength and should not be used to mechanically support ducts.

If the ducts are placed in unconditioned spaces, 10% to 30% of the energy used to cool the air can be lost to conduction through the duct surfaces due to the extreme summer temperatures in these spaces. Supply ducts in attics should be insulated to R-8 minimum and all other ducts should be insulated to R-6 minimum; insulation is not required for ducts located inside the building's thermal envelope [per 2009 IECC 403.2].

(1) One technique for placing ducts in conditioned space is to run a duct chase in a dropped ceiling down the main hallway of the house with registers off the sides for each room. This technique allows for compact duct design.

(2) This finished house shows registers going directly from a main duct chase in the dropped hallway ceiling.

(3) This air handler closet is located in the garage space but is isolated with thermal and air barriers.

(Bottom) Mastic provides the most reliable duct sealing method. Ducts should be located in conditioned space. *(Photo source: BAIHP)*

Standards for Duct Sealants

Underwriter 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; UL 181A covers field-assembled duct-board and UL 181B covers 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.

California Title 24 residential building standards require 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). Metal ducts are to be sealed with UL 181 mastic. For duct board, UL 181 tapes are accepted. For flex duct, a combination of UL 181 mastic and strap ties should be used.

Adapted from Sherman and Walker 1998.

Duct air tightness should be verified with duct blaster pressure testing. **[The 2009 IECC 403.2 requires that ducts be tested for air tightness and allows for the testing to occur either before drywall is put up or after drywall is put up. If tested at pre-drywall or rough-in, they must be ≤ 6 cfm per 100 ft^2 of conditioned floor area at 25 Pa; if tested after construction, than ≤ 8 cfm at 25 Pa. (If the airhandler and all ducts are in conditioned space, duct leakage testing is not required.)]** Building America recommends testing at rough-in when leaks can be easily accessed and sealed.

For More Information on Duct Layout and Sealing

2009 IECC. 2009. *International Energy Conservation Code*, Section 403.2.2 "Sealing," and "Table 4.4.5.2(.2) – Default distribution system efficiencies for the proposed design." International Code Council (ICC), Washington, D.C. www.iccsafe.org/Store/Pages

2009 IRC. 2009. *International Residential Code - One and Two-Family Dwellings*, International Code Council (ICC), Washington, D.C. www.iccsafe.org/Store/Pages

Air Conditioning Contractors of America (ACCA). *Manual D: Residential Duct Systems*. 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

California Energy Commission. 2003. *Home Builders Guide to Ducts in Conditioned Space.* P500-03-82-A16. www.sabreargentina.com/downloads/FinalAttachments/A-16_Bldrs_Guide_Ducts_6.3.4.pdf

California Energy Commission. 2005. *2005 Building Energy Efficiency Standards: Residential Compliance Manual*. CEC-400-2005-005-CMF. Sacramento, CA. www.energy.ca.gov/title24/2005standards/residential_manual.html#4Q

D. Griffiths, M. Zuluaga, D. Springer, and R. Aldrich. 2004. "Insulation Buried Attic Ducts – Analysis and Field Evaluation Findings." American Council for an Energy-Efficient Economy (ACEEE). *2004 ACEEE Summer Study on Energy Efficiency in Buildings.* Pacific Grove, CA. August 23, 2004.

DOE. 2004. *Better Duct Systems for Home Heating and Cooling*, NREL/BR-550-30506; DOE/GO-102004-1606. U.S. DOE Building America Program, www.buildingamerica.gov

FSEC. *Designing and Building Interior Duct Systems*, FSEC-PF-365-01. Florida Solar Energy Center, http://securedb.fsec.ucf.edu/pub/pub_show_detail?v_pub_id=4013

Hales, David and David Baylon. 2010. "Moving ducts into conditioned space: getting to code in the Pacific Northwest," *ASHRAE Transactions*, report # 3616

Hedrick, R. 2003. *Home Builders Guide to Ducts in the Conditioned Space*, California Energy Commission, 200-03-082-A16, www.energy.ca.gov/pier/project_reports/500-03-082.html

HGTVPro.com. "How to Seal Ductwork," www.hgtvpro.com/hpro/bp_mechanical/article/0,,HPRO_20151_4583390,00.html

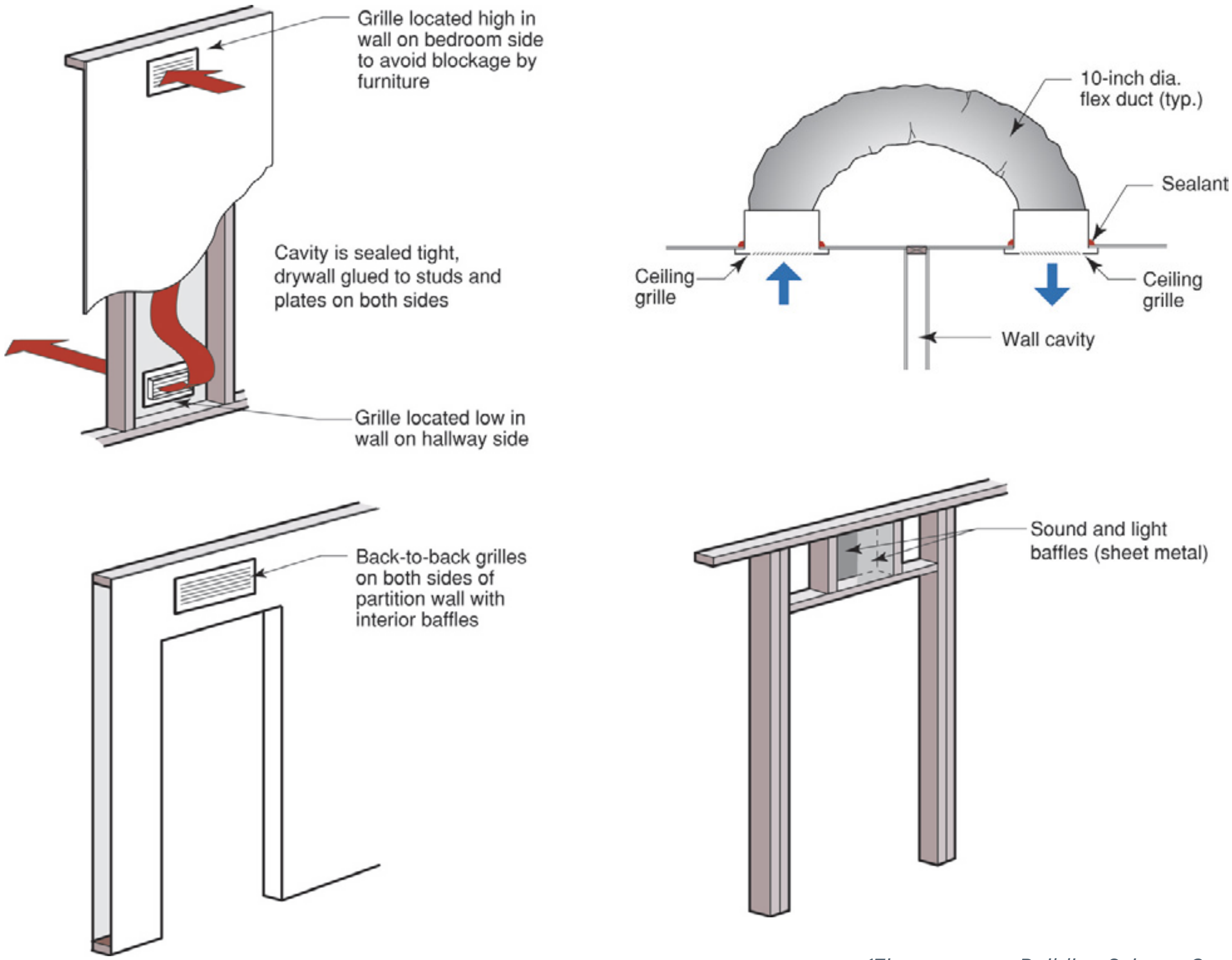
Lubliner, Michael, Ryan Kerr, Andy Gordon, and Chuck Murray. 2008. "Moving Ducts Inside: Big Builders, Scientists Find Common Ground," *In Proceeding of the 2008 ACEEE Summer Study on Energy Efficiency in Buildings*, www.energy.wsu.edu/documents/code/ACEEE_Ducts_Inside.pdf

McIlvaine, j.R., D. Beal, and P. W. Fairey III. 2002. *Design and Construction of Interior Duct Systems*. Florida Solar Energy Center, Cocoa, Florida, FSEC-PF-365-01, www.baihp.org/pubs/pdf/interior_ducts.pdf.

Regional Technical Forum (RTF). 2006. *Deemed Savings for New Construction Homes.* Portland, OR.

Sherman, M, and I. Walker. 1998. "Can Duct Tape Take the Heat?" *Home Energy Magazine*, Berkeley, California. http://homeenergy.org/archive/hem.dis.anl.gov/eehem/98/980710.html

Examples of Jump Ducts and Transfer Grilles for Pressure Balancing



(Figure source: Building Science Corporation)

Pressure Balancing

Pressure imbalances from indoors to outdoors or room to room can draw moisture-laden air into wall cavities. Imbalanced airflows can also cause drafts and temperature differences between rooms or floors, leading to comfort complaints.

One key factor in eliminating pressure imbalances is providing an adequate return air path to the air handler. Four methods for providing a return air path are as follows: 1) ducted returns from each room to the air handler; 2) room-to-room ceiling jump ducts; 3) transfer grilles or transoms; and 4) door undercuts. Door undercuts are not recommended by Building America because they are often too small and/or are blocked by the installation of carpeting.

Sound transmission in jump ducts or transfer grilles can be minimized by the use of flex duct, duct lining with sound-absorbent material, a slightly circuitous path, or some combination of these strategies.

(left) Installing jump ducts from room to room is one way to balance pressures. *(Photo source: IBACOS)*

(right) Transfer grilles help balance air pressure between rooms, which helps to minimize drafts and comfort complaints.

For More Information on Pressure Balancing in Homes

Associated Air Balance Council. *AABC National Standards for Total System Balance*. 2002. www.aabchq.com/resources/national.aspx

National Environmental Balancing Bureau (NEBB). Section 15990 - *Testing, Adjusting, and Balancing*. www.nebb.org/tabspec.htm

Air Distribution Fans

Fan motors on HVAC equipment can have a large impact on year-round energy use because they are often shared by heating, cooling, and ventilation systems. Nearly all furnace manufacturers offer "variable-speed" brushless permanent magnet (BPM) direct current motors. These motors have higher efficiency and, unlike permanent split-capacitor motors, BPM motors retain their high efficiency at reduced fan speeds. Although BPM motors may have a price premium of $200 or more, they are a recommended means of lowering HVAC energy use, and are required for two-stage heating and cooling systems. Some types also maintain a constant air flow as filters become dirty or registers are closed.

Ventilation

Building America recommends that all new homes be equipped with whole-house mechanical ventilation that complies with ASHRAE 62.2. Mechanical ventilation systems for indoor air quality include exhaust-only fans, supply-only systems, and balanced systems. Mechanically balanced systems use heat and energy recovery ventilators; semi-balanced systems use a combination of exhaust and supply techniques.

Supply-Only Ventilation Systems

A supply-only ventilation system brings outside air to the intake side of a home's central air handler. A central fan-integrated supply ventilation system uses an exterior air intake that is ducted to the return air side of the HVAC system. Code requires that outdoor air intakes and exhausts should be equipped with automatic or gravity dampers that close when the ventilation system is not in operation **[2009 IECC 403.5]**. Building America recommends that electronic controls be added, including a motorized damper and timer to open the damper in sync with operation of the HVAC fan for automatic ventilation of the home at regular intervals throughout the day. Advantages to this system are that the fresh air volume can be adjusted to meet ASHRAE 62.2 requirements, outside air is filtered, and fresh air is delivered to every space (Russell, Sherman, and Rudd 2006). A disadvantage of supply-only ventilation is that it can positively pressurize the home.

Supply-only ventilation is not recommended if the fan has a standard one-speed motor because the fan will blow too much air and use too much energy. (One-speed air handler fans can blow up to 1400 cfm when 50 to 100 cfm is desired for ventilation.) Central fan-integrated ventilation works well when the central fan has an energy-efficient variable-speed ECM motor and the system is installed by a knowledgeable contractor who understands how to program the blower operation.

When a supply system is used for ventilation and it is sized to meet ASHRAE 62.2 ventilation rates, Building America partner Building Science Corporation recommends that, to avoid the potential for cold air complaints, not more than 125 cubic feet per minute (CFM) be supplied at one location in bedrooms and not more than 500 cfm at registers in other rooms. Often this means that an 8-inch to 10-inch supply to the master bedroom needs to be split up to two 6-inch or 7-inch supplies. Comfort complaints increase if the homeowners set their thermostat too low (e.g., below 70ºF); because the air will be blowing cooler more often. One means for avoiding these comfort issues is to install an HRV or ERV that uses a heat exchanger to condition the circulating air, as described below.

Exhaust-Only Ventilation

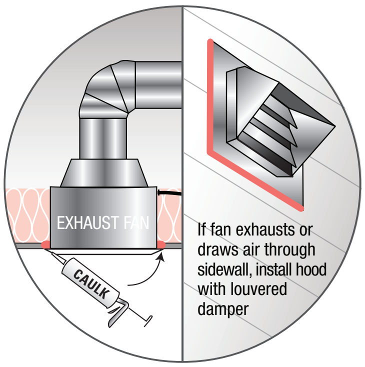
Continuously operating an exhaust fan located in a bathroom or central area of the house provides low-cost ventilation that meets ASHRAE 62.2. High-quality, quiet, efficient fans that have separate speeds for ventilation and exhaust are typically used for this application. A better solution than an isolated exhaust fan is to tie all bathroom exhaust ducts together and route them through a single, continuously operating, high-efficacy axial fan that is vented to the home's exterior.

ASHRAE 62.2

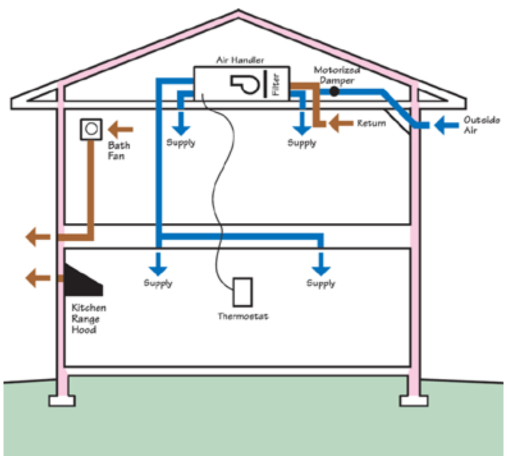
In 2003, the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) established a new standard for indoor ventilation in residences. The standard is ASHRAE 62.2, Ventilation for Acceptable Indoor Air Quality in Low-Rise Residential Buildings (ASHRAE 2003). The Standard is on a three-year publishing cycle and has been republished in 2004, 2007, and 2010 with minor updates. The following information is adapted from the forward that is published with the Standard:

The three primary requirements 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. 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.

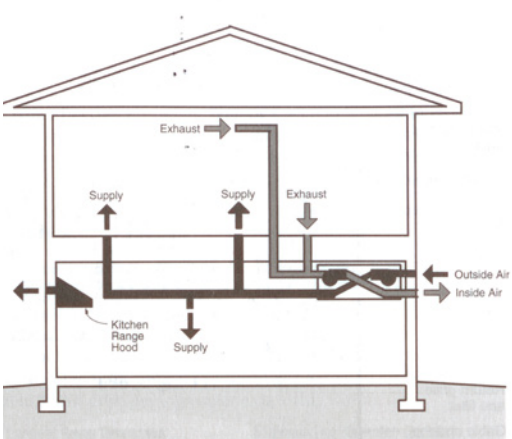
ASHRAE Standard 62.2 requires a continuous ventilation rate of 1 cfm per 100 ft^2 of building area plus 7.5 cfm x (# bedrooms +1). An intermittent fan can meet this requirement if the airflow rate is adjusted upward based on specific ventilation effectiveness requirements published in the standard.



Provide bathroom and kitchen exhaust fans. Duct them to the outside and caulk ducts at the dry wall for an air-tight seal. Use low-sone fans for quiet operation.



Balanced ventilation system using a fresh air intake integrated with HVAC air handler for supply air and exhaust fans.



Balanced ventilation system with heat recovery via an air-to-air heat exchanger. *(Source: Lstiburek 2004)*

Exhaust fans help to improve indoor air quality by removing air contaminants near their source, such as moisture from a shower. Because exhaust fans draw air from leaks in the building envelope, air is not filtered, will not be evenly distributed, and comes from unknown sources. Another concern with exhaust-only ventilation systems is that exhaust systems (which include bath fans, kitchen range fans, and clothes dryers) draw air out of a home, creating a negative pressure in the home. In an inefficient, leaky home, this negative pressure pulls outside air in through cracks around doors and windows and leaks in walls. In a high-performance home, those air leaks have been sealed up so a fresh air intake must be added to the home to supply fresh air. Failing to provide an outside air intake can cause the home to become negatively pressurized. This can increase the risk of backdrafting any atmospheric-vented combustion (fuel-burning) appliances or fireplaces that may be in the home. Backdrafting occurs when the flue's natural ability to draw combustion fumes out of the house is overpowered and, instead, these fumes (including carbon monoxide) are pulled into the house. Negative pressure in a house can also draw in hot outside air, soil gases, garage fumes, and pollens.

Balanced Systems

Heat recovery ventilators (HRVs) and energy recovery (or enthalpy-recovery) ventilators (ERVs) both provide a controlled way of ventilating a home while minimizing energy loss by using conditioned exhaust air to warm or cool fresh incoming air. These ventilators are typically whole-house systems that share the furnace duct system or have their own duct system.

The main difference between an HRV and an ERV is the way the heat exchanger works. With an ERV, the heat exchanger transfers water vapor along with heat energy, while an HRV only transfers heat. The ERV helps keep indoor humidity more constant.

Most energy recovery ventilation systems can recover about 70%–80% of the energy in the exiting air. They are most cost-effective in climates with extreme winters or summers and where fuel costs are high. Consider these recommendations for selecting an HRV or ERV (Holladay 2010b):

- For a small, tight house in a cold climate—especially a house with a large family—choose an HRV.
- For a large house in a cold climate—especially a house with few occupants—choose an ERV.
- In a hot, humid climate, know that an ERV will cost a little less to operate during the summer than an HRV.

- In mixed climates, choose either appliance.
- Understand the most important quality is energy efficiency.
- Find an installer who understands how ERVs and HRVs work and knows how to install them properly.

"Semi-Balanced" System

A lower-cost alternative is a "semi-balanced" system consisting of a combination of the supply and exhaust systems described above. While two of the builders that Building America worked with on these 40% cold best practices chose to install energy recovery or heat recovery ventilators (Devoted Builders and Shaw Construction) two of the builders chose a semi-balanced system (Nelson Construction and S&A Homes) and one chose exhaust-only (RDI). Nelson Construction in Hamilton, Connecticut, decided on a semi-balanced approach that brings outside air into the home through a duct to the return side of the air handler. A flow regulator opens the damper at regular intervals in sync with the fan blower, which circulates the fresh air through the house. Stale air is exhausted through a fan in an upstairs bathroom. This 1-sone-rated fan is connected to the main space with a 6-inch jump duct. To prevent air pressure imbalances, the laundry room has a transfer grille installed to provide pressure relief during dryer operation.

Ventilation for Night Time Cooling

Air conditioning energy use can be significantly reduced by ventilating homes with cool night air. Ventilation cooling is practical in locations where temperature swings of 30° or more between day and night and summer daytime highs above 80°F are common. The simplest form is opening windows at night, but security concerns may prohibit obtaining sufficient window area to provide effective ventilation. Two automated systems have been developed by Building America research partner Davis Energy Group that ventilate and cool the house with outside air. The systems, called SmartVent and NightBreeze, use the HVAC system fan coupled with an outside air intake damper and controlled by temperature sensors to provide filtered outside air without the homeowner having to open windows (Hoeschele 2008).

Nelson Construction attached a fresh air intake with a timed mechanical damper controller to regulate fresh air flow into the return plenum of the HVAC air handler. The damper can be set to open allowing fresh air to be pulled into the air handler by the air handler fan, also operated by the timer. This draws fresh air into the house at regular intervals. When combined with timed exhaust fans, this provides low-cost balanced ventilation.

For More Information on Ventilation Systems

2009 IECC. 2009. *International Energy Conservation Code*, Section 403.5, "Mechanical Ventilation," Section 403.6, "Equipment Sizing," International Code Council (ICC), Washington, DC. www.iccsafe.org/Store/Pages

2009 IRC. 2009. *International Residential Code - One and Two-Family Dwellings*, Section M1502.1 "Clothes Dryer Exhaust – General," International Code Council (ICC), Washington, DC. www.iccsafe.org/Store/Pages

Air Conditioning Contractors of America. *Manual T. Air Distribution Basics for Residential and Small Commercial Buildings*. ACCA, Arlington, VA. www.acca.org

ASHRAE Standard 62.2-2010 *Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings (ANSI/ASHRAE Approved)* can be previewed at www.ashrae.org/technology/page/548

Building Energy Codes Resource Center "Whole-House Mechanical Ventilation – Code Notes," U.S. Department of Energy, http://resourcecenter.pnl.gov/cocoon/morf/ResourceCenter/article/1467

ENERGY STAR Thermal Bypass Checklist Guide, 2008, available at www.energystar.gov/ia/partners/bldrs_lenders_raters/downloads/TBC_Guide_062507.pdf, pg. 13

Hoeschele, Marc. 2008. *Development of an Integrated Residential Heating, Ventilation, Cooling, and Dehumidification System for Residences*, Prepared by Davis Energy Group for the U.S. Department of Energy, www.davisenergy.com/docs/FinalReport_SBIR2_I-HVCD_061808.pdf

Holladay, Martin. 2010a. "Designing a Good Ventilation System: Ventilating Is Easy — It's Ventilating Right That's Hard," Green Building Advisor.com posted June 15, 2010. www.greenbuildingadvisor.com/blogs/dept/musings/designing-good-ventilation-system

Holladay, Martin. 2010b. "HRV or ERV? Choosing the right equipment for a balanced ventilation system," Green Building Advisor.com posted January 22, 2010. www.greenbuildingadvisor.com/blogs/dept/musings/hrv-or-erv

HVI. 2006. "Fresh Ideas in Residential Ventilation." Home Ventilating Institute. Wauconda, IL. www.hvi.org/resourcelibrary/HomeVentGuideArticles.html

Lawrence Berkeley National Laboratory. Thermal Energy Distribution Website at http://ducts.lbl.gov

Minnesota Department of Commerce Energy Information Center. June 23, 2008. "Maintain home ventilation systems to provide healthy air supply." Available at www.state.mn.us/portal/mn/jsp/common/content/include/contentitem.jsp?contentid=536886092

NAHB Research Center. "Whole-House Mechanical Ventilation Strategies," www.toolbase.org/Technology-Inventory/HVAC/whole-house-mechanical-ventilation

Piazza, T., R.H. Lee, M. Sherman, and P. Price. 2007. *Study of Ventilation Practices and Household Characteristics in New California Homes*. CEC-500-2007-033. California Energy Commission, Sacramento, CA., www.energy.cq.gov/2007publications/CEC-500-2007-033/CEC-500-2007-033.PDF

Rudd, Armin. 2006. *Ventilation Guide*. Building Science Press Inc., Energy & Environmental Building Association, Minneapolis, MN, available for purchase at www.eeba.org/bookstore/prod-Ventilation_Guide-10.aspx

Russell, Marion, Max Sherman and Armin Rudd. 2007. "Review of Residential Ventilation Technologies." HVAC&R Research, Vol. 13, No. 2, p. 325-348, March 2007. ASHRAE. http://findarticles.com/p/articles/mi_m5PRD/is_2_13/ai_n25007553

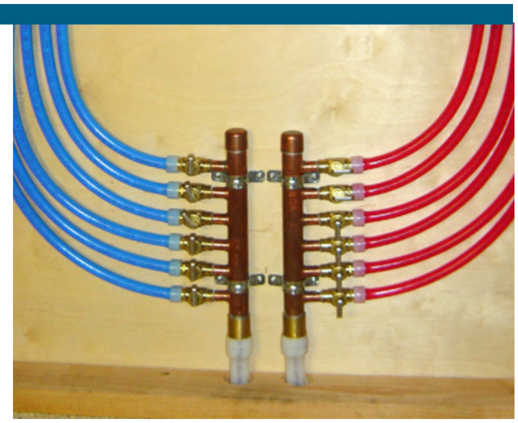
U.S. Environmental Protection Agency. 2009. *Indoor airPLUS Construction Specifications*, www.epa.gov/indoorairplus/index.html

Plumbing and Water Heating

Residential hot water energy use accounts for approximately 19% of the residential energy consumed in the United States, according to the Energy Information Administration. In new, high-performance homes, hot water energy accounts for a higher percentage, typically 21% to 32%. Hot water systems don't use more energy than they used to but they take a relatively larger share of the energy use in homes because in tighter houses less energy is required to heat and cool the homes than in older homes built to less stringent standards.

There are several measures builders can take to reduce the amount of energy needed for water heating:

- Install high-efficiency electric or gas water heaters. Specify sealed-combustion, power-vented, or direct-vented gas water heaters. These models save energy and reduce the risk of backdrafting flue gases into the house.
- Consider alternative technologies like tankless gas or electric water heaters, solar thermal water heaters, and ground source heat pumps and desuperheaters.
- Insulate hot water supply lines to R-4 and install tanks that have at least R-12. [2009 IECC 403.3 requires R-3 minimum.]
- Consolidate bathrooms and other hot water-consuming activities into the same area(s) of the house.
- Place the water heater in a central location inside the home to minimize piping trunk lengths. Use a central manifold distribution system.
- Locate plumbing pipes in the attic and cover with insulation in single-story, slab-on-grade homes. Locate the pipes in interstitial space between floors for multi-story homes.
- Do not install plumbing in exterior walls.
- Do not oversize piping. Use code-permitted minimums. Bigger isn't better.
- Do not use continuous recirculation pumps. If recirculating pumps are specified, the pumps should be controlled by timers or on-demand to stop continuous operation.
- Seal around plumbing penetrations in all exterior surfaces, surfaces that border on unconditioned spaces, and between floors. Use fire-resistant sealant in plates between floors.



In an NAHB Research Center study, the central manifold hot water distribution system provided hot water to the fixtures more quickly than traditional trunk and branch and remote manifold distribution methods.

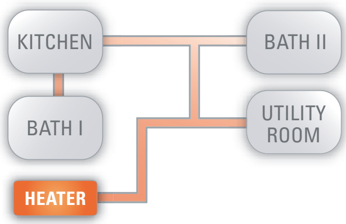
Code/Above Code
Water Pipe Insulation

A comparison of the 2009 Uniform Plumbing Code, state codes, and Building America recommendations

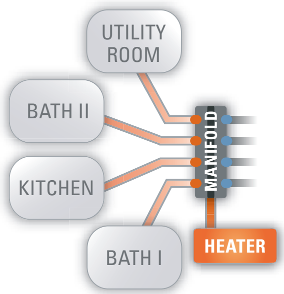
Code	
2009 Uniform Plumbing Code	R-3 insulation for hot or cold piping outside conditioned space
Above Code	
Building America Recommendations	Insulate all piping inside and outside of conditioned space to R-4

Hot Water Distribution Systems

Traditional Trunk System



More Efficient Manifold System



Hot Water Distribution

Essentially there are three types of hot water distribution systems: 1) the traditional "trunk and branch" with a large main line feeding smaller pipes that then flow directly to fixtures or split to serve multiple fixtures; 2) the central manifold (homerun) where the water heater feeds a manifold with dedicated lines running to each household fixture; and 3) the remote manifold system, which includes trunk lines that run to remote manifolds that serve clusters of fixtures, such as in one or more bathrooms or a kitchen.

The NAHB Research Center tested the three water distribution systems—trunk and branch, central manifold, and remote manifold—and found that, while all three supplied sufficient flow, the central manifold system provided the quickest hot water to the fixtures and the most stable pressure when multiple fixtures were used.

Common plumbing pipe materials are copper and PEX (cross-linked polyethylene). PEX installation can save labor and materials and can be cost competitive with rigid pipe systems. The NAHBRC points out that because PEX piping will not corrode and resists scale buildup, maintenance costs may be lower than for rigid piping. Fewer leaks are possible because fewer connections are required.

PEX piping should not connect directly to a hot water tank or solar water heater where the temperature of the water could exceed 200°F. PEX piping should not be used in installations subject to continual ultraviolet light exposure.

Hot Water Circulation Pumps and Controls

Do not use *continuous* recirculation systems for hot water. These systems keep hot water continuously flowing through pipes and result in substantial heat loss. If solar thermal water heating systems are used, the flow-through solar collectors should always be kept separate from any hot water recirculation systems.

If recirculation systems are used, install a push-button control, which will minimize the energy penalty associated with recirculation systems and insulate the pipe to R-2 [per 2009 IECC 403.4]. An on-demand system recirculates the water through the hot water tank only when hot water is needed. This system helps eliminate wasted water down the drain and is best suited for fixtures located far from the water heater. On-demand recirculators do not save energy except in comparison to continuous recirculation systems.

Water Heaters

Performance rating information for conventional storage water heaters, electric heat pumps, and tankless water heaters is available from the Air-Conditioning, Heating, and Refrigeration Institute (AHRI) (www.ahrinet.org). AHRI's members include appliance manufacturers that use all fuel types. Performance rating information for solar thermal collectors and systems is available from the Solar Rating and Certification Corporation (www.solar-rating.org).

Five types of ENERGY STAR-qualified water heaters are now available: high-efficiency gas storage, gas condensing, gas tankless, solar, and heat pump water heaters. (For lists of qualifying products, see www.energystar.gov/index.cfm?c=water_heat.pr_water_heaters.)

Conventional Storage Water Heaters

Conventional gas or electric storage water heaters offer a ready reservoir (storage tank) of hot water. The lowest-priced storage water heater may be the most expensive to operate and maintain over its lifetime. While an oversized unit may be alluring, it carries a higher purchase price and increased energy costs due to higher standby energy losses. Information on properly sizing a water heater is available on the DOE Energy Savers website www.energysavers.gov. Storage heaters work best with steady, continuous use patterns.

The minimum efficiency target for gas combustion storage water heaters is 0.60 or higher. These heaters should be either power vented, which forcibly discharges the products of combustion and draws combustion air from the house; direct vented with dedicated outside air for combustion; or sealed combustion units that draw combustion air from outdoors and fan discharge combustion exhaust outdoors.

Electric storage heaters are generally the most expensive to operate unless rates are very low. Builders should specify the most efficient unit possible and consider the use of solar thermal systems, a propane-fired instantaneous water heater, or a heat pump water heater.

Tankless Water Heaters

Tankless water heaters provide hot water only as it is needed. They have no tank and so do not have the standby energy losses associated with storage water heaters. Typically, tankless water heaters provide hot water at a rate of 2 to 5 gallons (7.6–15.2 liters) per minute. If the demand for hot water does not exceed the heater's ability to produce it, tankless water heaters do not run out of hot water. Gas-fired tankless water heaters produce higher flow rates than electric tankless heaters. Because of their heat-on-demand nature, electric versions can create

The tankless gas-fired water heaters installed by Nelson Construction in Farmington, Connecticut, save energy by eliminating the stand-by losses inherent with storage tank water heaters.

Heat pump water heaters are now commercially available like this one seen at the 2010 International Builders Show.

high peak loads for electric utilities. In areas where utilities charge more for electricity at peak times, these systems could be especially expensive for consumers.

Gas-fired tankless water heaters have been tried in many Building America homes. They are readily available and are a mature technology. In addition to energy savings, other benefits include small size and longer life expectancy. One disadvantage of these units is the time needed for a cold unit to reach operating temperature. This brief warm-up time results in a slight delay in hot water delivery (10 to 20 seconds) and associated water waste. Builders considering installing tankless gas water heaters in a development need to plan for adequate gas line size. Tankless water heaters draw approximately 150,000 BTUs compared to a standard water heater that draws 35,000 BTUs. Therefore, much higher capacity is demanded of the gas lines during peak usage times, such as in the morning.

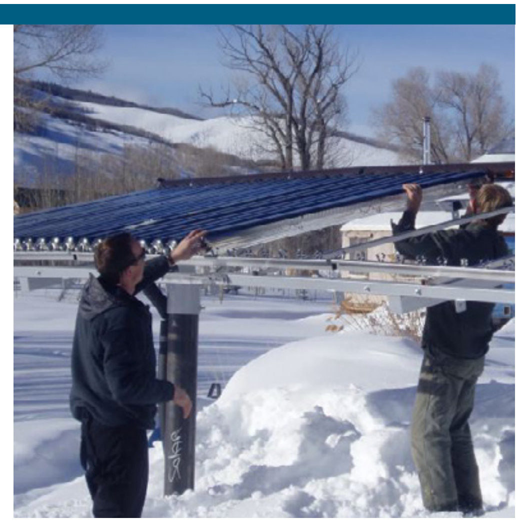
Heat Pump Water Heaters

Air source heat pump water heaters use electric compressors and pumps to move heat from the environment to the water tank. Although they use electricity, they can be two to three times more energy efficient than conventional electric resistance water heaters. One manufacturer estimates $320 savings per year in water heating costs when comparing their ENERGY STAR heat pump water heater, which uses 1,856 kWh/yr, to a standard 50-gallon electric tank water heater, which uses 4,881 kWh/yr.

Because the heat pump water heater draws in air from the room to heat water, some manufacturers recommend that the room the water heater is located in be at least 10 ft x 10 ft x 7 ft (700 cubic feet) or larger. If the room is smaller than 700 cubic feet, the room must have a louvered door or a door that has vents installed near the top and bottom of the door. Each of these vents should have an area of 240 square inches. The units themselves are approximately 63 inches tall by 24 inches wide.

Because they have a fan, heat pump water heaters do make some noise; noise is related to fan speed, the faster the fan speed the more sound is likely. Fans speeds will increase when ambient temperatures are colder and when tank temperature is lower. The heat pump water heater can be located in a utility room inside the home or in a heated basement. The water heater, pipes, and condensate lines should be protected from freezing temperatures. The water heater may add slightly to heating loads in the winter because it pulls some heat from the air but it will also help reduce cooling loads in the summer in the area of the home where it is located.

One concern with heat pump water heaters is their recovery rate. The water heater industry typically measures the recovery rate of a water heater by its first hour delivery (FHD) of hot water. Natural gas and liquid propane water heaters are capable of heating water more quickly than electric water heaters (standard electric or heat pump), and therefore, have quicker recovery rates. A 50-gallon gas water heater has a FHD of 80-90 gallons. A 50-gallon electric standard or heat pump water heater has a FHD of 58-65 gallons. Many heat pump water heaters are hybrid models that use electric elements to provide back-up heat. These can assist with recovery rates. Another solution is to get a slightly larger tank than you would typically size, for example a 50-gallon rather than 40-gallon tank.

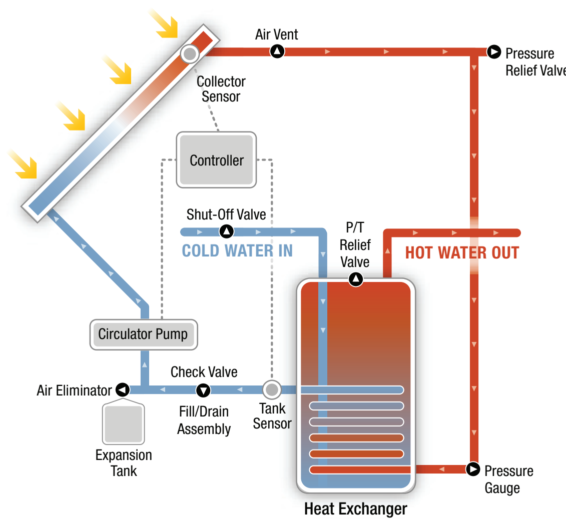


Evacuated tube collectors are one solar water heater type that works well in cold climates.

Geothermal heat pumps can also be used to heat water. These systems draw heat from the ground during the winter and carry heat away from the indoor air during the summer. For water heating, a desuperheater can be added to a geothermal heat pump system. A desuperheater is a small, auxiliary heat exchanger that uses superheated gases from the heat pump's compressor to heat water. This hot water then circulates through a pipe to the home's storage water heater tank.

Desuperheaters can assist both tank and tankless water heaters. In the summer, when the geothermal heat pump runs frequently, it may meet all of a home's hot water demand. During the fall, winter, and spring, when the desuperheater isn't producing as much excess heat, backup from a storage or tankless water heater may be needed.

Ground-source (geothermal) heat pump water heaters can be effective in all climate zones, but they are complex and require a skilled installer. Also, the pricing varies dramatically by region. In an area where no natural gas is available, this system may be a good option.



This solar water heater uses propylene glycol (antifreeze) in the exposed collector, making it safe for use when temperatures are below freezing. The glycol loop heats up on the roof then passes through the tank of potable water to release its heat then it is pumped back to the roof to reheat.

Solar Water Heaters

Solar thermal water heaters use the sun's heat to provide hot water. These systems usually include one or two collectors that typically sit on a house's roof and resemble skylights. Four types of collectors work well for heating water:

- Glazed flat-plate collectors are the most common and can be used in any climate with proper design.
- Evacuated tube collectors use thermos-like evacuated glass tubes. Some also use heat pipes with a special fluid that vaporizes at high temperatures. These collectors tend to be more expensive than other collectors but operate efficiently at high temperatures and can be used in very cold climates with proper design.

Energy-efficient ENERGY STAR-rated fixtures come in many attractive styles, like these CFL-based fixtures. *(Photo source: Progress Lighting)*

- Integrated collector storage systems combine a collector with a storage tank. These systems are one of the lowest cost but should only be used where there is no chance of freezing. They should not be used in the cold climate.
- Unglazed flat plate collectors are simple systems that consist of plastic surfaces incorporating channels for water to flow through. Some manufacturers are offering unglazed collectors for domestic hot water. Their traditional use has been for pool and spa heating. Every swimming pool with a solar exposure should be equipped with a solar pool heater.

Tankless Coil and Indirect Water Heaters

Two technologies that use the home's space heating furnace to also heat water are the tankless coil heater and the indirect water heater. Tankless coil water heaters provide hot water on demand without a tank. Because they rely on the homes' space heating furnace to heat the water, they are most efficient from an energy perspective in homes where the furnace is on often, such as northern parts of the cold climate. Indirect water heaters also use the space heating furnace but instead of heating water directly the furnace heats a fluid that in turn heats water in a water storage tank via a heat exchanger. Because the tank allows for heating with less turning the furnace on and off, indirect water heaters are more efficient.

For More Information on Plumbing and Water Heating

DOE. 2007. *Volume 6 - Building America Best Practices Series – High Performance Home Technologies: Solar Thermal & Photovoltaic Systems*. Washington, D.C. www.buildingamerica.gov

DOE. 2007. *A Consumer's Guide to Energy Efficiency and Renewable Energy*. "Water Heating," DOE Energy Efficiency and Renewable Energy www.eere.energy.gov/consumer/your_home/water_heating/index.cfm/mytopic=12770

DOE. 2011. "Sizing Water Heaters," Energy Savers, U.S. Department of Energy, www.energysavers.gov

ENERGY STAR. *High-Efficiency Water Heaters Provide Hot Water for Less.* U.S. Environmental Protection Agency, Washington, D.C. www.energystar.gov/ia/new_homes/features/WaterHtrs_062906.pdf

2009 IRC. 2009. *International Residential Code - One and Two-Family Dwellings*, Section 403.4, "Circulating Hot Water Systems," International Code Council (ICC), Washington, D.C. www.iccsafe.org/Store/Pages

National Association of Home Builders Research Center (NAHBRC). Undated. *Toolbase Technotes*. Cross-Linked Polyethylene PEX in Residential Plumbing Systems. www.toolbase.org/PDF/DesignGuides/TechNote_Pex.pdf

Solar Rating and Certification Corporation, www.solar-rating.org.

Wiehagen J. and J.L. Sikora. 2003. *Performance Comparison of Residential Hot Water Systems.* NREL/SR-550-32922. National Renewable Energy Laboratory. Golden, CO. www.buildingamerica.gov

High-Performance Lighting

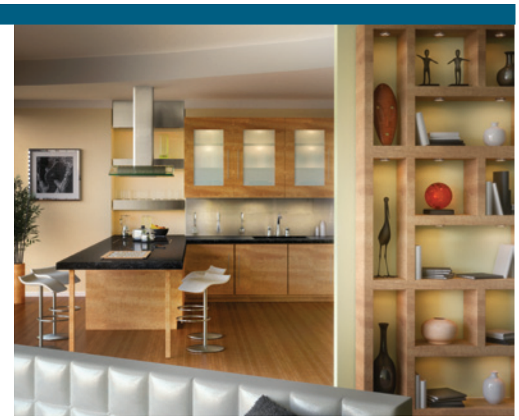
Lighting accounts for an estimated 15% of electricity use in the typical American home (DOE 2009). The typical incandescent lamp wastes 90% of the energy it uses producing heat rather than light. High-performance lighting, including CFL and LED products, provides excellent visual quality that is also very energy efficient.

Compact fluorescent lamps (CFLs) use 70%-75% less energy than their incandescent equivalents with comparable brightness and color rendition. They cost more, but last 10 to 13 times longer than incandescent lamps, making them cost effective if used at least 2-3 hours per day. Compact fluorescent lamps come in both pin-based models and screw-based models that fit most standard fixtures found in homes today. ENERGY STAR first established criteria for CFL lamps in 2007. Today thousands of models of ENERGY STAR-labeled CFL bulbs and fixtures are available in a wide variety of sizes, shapes, and color renditions.

Light emitting diode (LED) lights are becoming more commonplace as new models are developed with better lighting performance, higher efficiency, and lower cost. DOE tracks and tests LED products as they enter the market via its CALiPER program and other lighting programs (see www.ssl.energy.gov). ENERGY STAR criteria for solid-state lighting (LED) went into effect in September 2008. To earn the ENERGY STAR label, LED products have to offer a three-year warranty and meet stringent performance requirements for color rendering, luminaire efficiency, and light output over the life of the lamp, which is at least 25,000 hours for indoor, residential products.

[The 2009 IECC 404 requires that at least 50% of the lamps in permanently installed lighting fixtures be high-efficacy lamps.] It is likely this requirement will be raised to 75% in the 2012 IECC. Building America recommends 100% high-efficacy lamps. Almost all fluorescent lamps equipped with electronic ballasts qualify as high-efficacy light sources. LEDs and metal halide lamps can also be high efficacy. Incandescent, quartz halogen, low-voltage halogen MR, and mercury vapor lamps do not qualify as high efficacy.

Recessed "can" ceiling fixtures, or downlights, that are recessed into insulated ceilings are required **[by the 2009 IECC 402.4.5]** to be rated for insulation contact (so that insulation can be placed over them). The housing of the fixture should be airtight to prevent conditioned air from escaping into the ceiling cavity or attic, and unconditioned air from infiltrating from the ceiling or attic into the conditioned space. **[Per the 2009 IECC 402.4.5]** the fixture should bear a label showing it meets the ASTM E 283 guideline of ≤2.0 cfm of air movement from



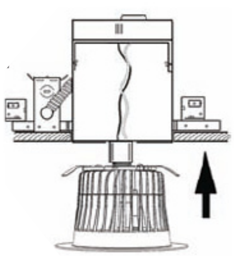
LED fixtures are becoming more efficient and affordable and are now available in several applications for homes like the under-cabinet, in-cabinet, and spot lighting shown here.

These CFL-based lights designed by Maxlite won grand prize in the 2008 Lighting for Tomorrow design competition co-sponsored by DOE. *(Photo source: Maxlite)*

LIGHTING for tomorrow

Installation

- Designed to easily install in standard 6" downlight housings from Cree and other manufacturers.
- Quick install system utilizes a unique retention feature. Simply attach socket to LR6. Move light to ready position and slide into housing. Rotate module 1/4 turn to the right to lock in place.
- Reference www.CreeLEDLighting.com for a list of compatible housings



LED Can Lights Give off 650 Lumens from 6.5 Watts

This LED lamp, the LR6 LED downlight by Cree LED Lighting Solutions, Inc, fits into a standard recessed can fixture and provides comparable light output to CFL and incandescent bulbs, at lower wattage and much longer life. In 2010, Cree came out with a model that produces 697 lumens of light with only 6.5 Watts of power. *(Photo and Figure Source: Cree Lighting Solutions, Inc.)*

the conditioned space to the ceiling cavity when tested at 75 Pa and the housing should be caulked or gasketed where it meets the ceiling. IC-rated downlight fixtures are available for CFL lamps.

DOE partners with lighting organizations to host three CFL and LED lighting design competitions. Visit the competition websites to see competition winners, including some of the most energy-efficient, eye-catching designs on the market: Lighting for Tomorrow (www.lightingfortomorrow.com), Next Generation Luminaires (www.ngldc.org), and the L-Prize (www.lightingprize.org).

Residential lighting controls represent a significant opportunity for energy savings. Lighting controls generally refer to technologies that turn off (or turn down) lighting systems when they are not needed. Examples include occupancy sensors, vacancy sensors, photo sensors, dimmers, and timers.

Example of Recessed Downlight Performance Using Different Lighting Sources

MEASURE	INCANDESCENT*	FLUORESCENT*		LED**
	65W R-30 Halogen	13W triple tube Spiral CFL	15W R-30 CFL	LR6 LED downlight by Cree
Delivered light output (lumens), initial	678	466	653	697
Luminaire wattage (nominal W)	65	10	13	6.4
Luminaire efficacy (lm/W)	11	46	49	109
Price (average prices as of Aug 2009)	$3	$8	$5	$80
Life Span	2,500 hrs	12,000 hrs	6,000 hrs	50,000 hrs

*Based on photometric and lamp lumen rating data for products available July 2010. Actual downlight performance depends on reflectors, trims, lamp positioning, and other factors. Assumptions available from PNNL.

**LED tested through DOE CALiPER program. For more about CALiPER, see www.ssl.energy.gov

For More Information on Lighting

California Energy Commission. 2009. *California's Energy Efficiency Standards for Residential and Nonresidential Buildings: Title 24*. Sacramento, CA. www.energy.ca.gov/title24/

California Lighting Technology Center. www.cltc.ucdavis.edu

ENERGY STAR. 2007. Light Bulbs and Fixtures website. www.energystar.gov

IBACOS. High-Performance Lighting Guide website www.ibacos.com

U.S. Department of Energy. Solid-State Lighting (SSL) website www.ssl.energy.gov

Appliances

When it comes to selecting appliances and electronic equipment, look for the EnergyGuide and ENERGY STAR labels. Building America recommends using best-in-class products for appliances that are not currently rated by ENERGY STAR.

EnergyGuide Label

The Federal Trade Commission requires EnergyGuide labels on most home appliances (except for stove ranges and ovens, and home electronics, such as computers, televisions, and home audio equipment). EnergyGuide labels provide an estimate of the product's energy consumption or energy efficiency. They also show the highest and lowest energy consumption or efficiency estimates of similar appliance models.

A refrigerator labeled with both the ENERGY STAR label and the EnergyGuide label.

ENERGY STAR Label

ENERGY STAR labels appear on appliances and home electronics that meet strict energy efficiency criteria established by the U.S. Department of Energy and U.S. Environmental Protection Agency. The ENERGY STAR labeling program includes most home electronics and appliances except for stove ranges and ovens.

For More Information on ENERGY STAR and EnergyGuide Labeling

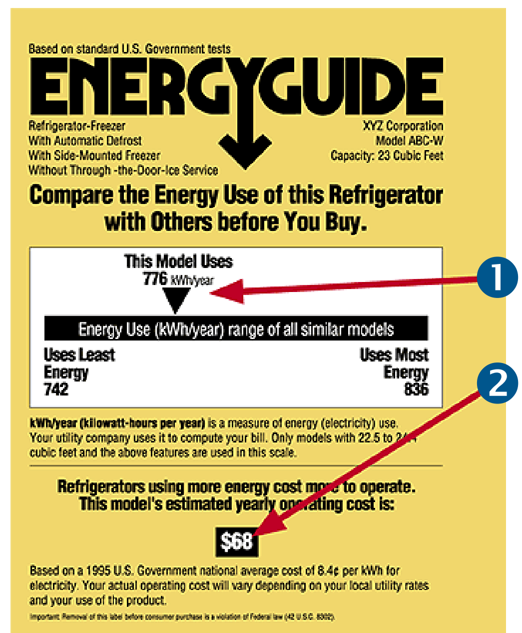
California Energy Commission Consumer Energy Center "EnergyGuide," www.consumerenergycenter.org/home/appliances/energyguide.html

ENERGY STAR. www.energystar.gov

ENERGY STAR Windows. www.efficientwindows.org/energystar.cfm

SRP. "Energy Guide Labels help you compare," www.srpnet.com/energy/energyguide.aspx

The U.S. Department of Energy "Best Practices" Builders Guides www.eere.energy.gov/buildings/building_america/



The EnergyGuide label helps consumers compare the energy efficiency of appliances

1. Estimated energy consumption on a scale showing a range for similar models
2. Estimated yearly operating cost based on the national average cost of electricity.

Chapter 10.

Occupant Health and Safety

(top) Some cabinet makers are now specializing in low-VOC cabinetry to meet growing consumer demand.

(bottom) Several low-VOC adhesives are now available.

As houses become tighter, indoor air quality becomes a more important issue. To address occupant health and safety, the EPA has developed an Indoor airPlus checklist, shown at the end of this chapter, that recommends these actions (www.epa.gov/indoorairplus): 1) moisture control including improved control of condensation and better roof, wall, and foundation drainage; 2) radon control including testing and radon abatement techniques; 3) pest management including caulking, sealing, and screening at entry points; 4) HVAC quality including a properly engineered system, sealed ducts, and whole-house and spot ventilation; 5) combustion venting including sealed combustion heating equipment, installation of carbon monoxide detectors, and sealing and ventilation of attached garages; and 6) selection of low-chemical-content materials, keeping materials dry during construction, and airing out the home prior to move in.

The following safety and health features should be included in house designs:

- Avoid installing atmospheric-venting (standard efficiency) fuel-fired furnaces and water heaters in conditioned space including laundry rooms. These devices draw air from the room in which they are located and are recognizable by the "hat" or "skirt" around the base of the flue (where it meets the furnace or water heater) just above the open combustion air intake. These devices depend on stack effect to establish an exhaust draft, but the stack effect can be overcome by dryers, exhaust fans, supply duct leakage, or other conditions that depressurizes the house, causing back drafting of exhaust gases. **[ASHRAE 62.2-2010, citing NFPA 54, permits atmospherically vented combustion appliances inside provided the total net flow of the two largest exhaust fans does not exceed 15 cfm/100 ft^2 of occupiable space when in operation at full capacity.]**

Dryer vent exhausts must have a closeable gravity or automatic damper. A single hinged door with a 2½-inch effective opening is not as effective as a louvered damper.

(top) This fresh air intake has a mechanical damper to control the intake of fresh outside air into the air handler for distribution via the central HVAC system.

(bottom) Atmospheric venting water heaters, like the one shown here, can backdraft through the opening at the base of the flue. Use of closed-combustion appliances eliminates this risk.

- Use only sealed-combustion or power-vented appliances in the conditioned space. Specifically, Building America recommends any furnace inside conditioned space should be a sealed-combustion 90%+ (AFUE of 90 or greater) unit. Any water heater inside conditioned space should be sealed-combustion, direct-vented, or power-vented.

- Avoid appliance models that incorporate passive combustion air supply openings or do not have outdoor supply air ducts directly connected to the appliance.

- Install carbon monoxide detectors (hard-wired units) (at one per every approximately 1,000 square feet) in any house containing combustion appliances and/or an attached garage, and even in those houses with no combustion appliances in case one should be installed at a future date. **[NFPA 720 says CO detectors shall be installed near bedrooms, and on every occupiable level of a dwelling unit, including basements, excluding attics and crawl spaces. NFPA 101 Section 24.3.4.1 requires smoke alarms in all sleeping rooms, outside of each separate sleeping area, in the immediate vicinity of the sleeping rooms, and on each level of the dwelling unit, including basements.]**

- Direct vent gas cooking ranges and all exhaust fans to the outside. Range hoods capable of exhausting more than 400 cfm must provide makeup air at a rate equal to the exhaust air rate **[2009 IRC M1503.4]**.

- Use sealed-combustion gas fireplaces that vent harmful combustion gases to the outside.

- Vent bathrooms, kitchens, toilets, and laundry rooms directly outdoors. Outdoor air intakes and exhausts should be equipped with automatic or gravity dampers that close when the ventilation system is not in operation **[per 2009 IECC 403.5]**. Kitchen fans should ventilate at a rate of 100 cfm intermittent or 25 cfm continuous; bathroom fans should ventilate at a rate of 20 cfm continuous or 50 cfm intermittent **[2009 IRC Table M1507.3]**. Use energy-efficient and quiet fans (see Chapter 9, ventilation section).

- Vent clothes dryers and central vacuum cleaners directly outdoors. Smooth, rigid metal ducts with louvered vents and straight runs provide the most efficient ducting systems. Check code **[2009 IRC M1502.4.4]** and manufacturer's specifications for limits on duct length. Avoid sags in ducts. Insulate ducts to avoid condensation; flash and caulk wall penetrations. Vinyl, nylon, and foil ducts do not meet code **[2009 IRC M1502]**.

- Provide filtration for forced air systems that provide a minimum atmospheric dust spot efficiency of 30% or MERV of 8 or higher. MERV (Minimum Efficiency Reporting Value) is a measure of an air filter's efficiency at removing particles. [This exceeds the ASHRAE 62.2-2010 6.7 recommended MERV 6 or better.]

- Maintain indoor humidity in the range of 30% to 50% by controlled mechanical ventilation, mechanical cooling, or dehumidification.

- Maximize hard surface areas (tile, vinyl, hardwood) to better manage dust for health purposes.

- Install a central (also known as "whole-house") vacuum system that exhausts to the outdoors, to facilitate cleaning and minimize reintroduction of vacuumed dust.

- Provide occupants with information on safety and health related to the operations and maintenance of the systems that provide control over space conditioning, hot water, and lighting.

- Isolate attached garages from conditioned spaces [per 2009 IECC 402.4.1 and ASHRAE 62.2-2010, 6.5.1]. Common walls and ceilings between attached garages and living spaces should be visually inspected to ensure they are air-sealed before insulation is installed. All connecting doors between living spaces and attached garages should include an automatic closer, and they should be installed with gasket material or be made substantially air-tight with weather stripping.

- Install an exhaust fan in attached garages with a minimum installed capacity of 70 cfm that is rated for continuous operation, vent the fan directly outdoors. If automatic fan controls are installed, they should activate the fan whenever the garage is occupied and for at least 1 hour after the garage has been vacated. The fan carries pollutants outside and creates a negative pressure that helps stop garage air from migrating into the house.

- If fireplaces are included (gas-fired or solid-fuel-burning), install units that have a dedicated outside air intake for combustion air, directly vent effluents outside, and are equipped with tight-fitting glass doors.

- Use low-VOC (volatile organic compound) paints, finishes, varnishes, and adhesives whenever possible. Keep windows open while paints and adhesives are applied and until they are dry to dissipate initial concentrations.

This Building America home used low-VOC paints and finishes (shown in lower photo) to meet local green building guidelines.

American Lung Association: Nine Features of a Healthy House

- Foundation waterproofing and moisture control
- Advanced framing techniques
- Air sealing and advanced insulation techniques
- Energy-efficient, high-performance windows
- Energy-efficient and sealed combustion appliances
- High-efficiency air filtration
- Whole house ventilation
- Humidity control
- Low-VOC interior finishes.

(Source: Health House, American Lung Association of the Upper Midwest, www.healthhouse.org/build/components.cfm)

For More Information on Healthy Homes and Combustion Safety

American Lung Association. 2008. "Health House: Builder Guidelines." ALA, Saint Paul, MN. www.healthhouse.org/build/2008HHbuilderguidelines.pdf

American Lung Association. "Health House Tipsheet on Backdrafting," ALA, Saint Paul, MN. www.healthhouse.org/tipsheets/TS_backdrafting.pdf

ASTM D6670 – 01. 2007. "Standard for Full-Scale Chamber Determination of Volatile Organic Emissions from Indoor Materials/Products," www.astm.org/Standards/D6670.htm

Building Performance Institute, Inc., "Combustion Safety Test Procedure for Vented Appliances," 4/07. www.bpi.org/documents/Gold_Sheet.pdf

California Air Resource Board (CARB). "Airborne Toxic Control Measure (ATCM) to Reduce Formaldehyde Emissions from Composite Wood Products" Fact Sheet, www.arb.ca.gov/toxics/compwood/factsheet.pdf

California Air Resource Board (CARB). "Regulation for Reducing Volatile Organic Compound Emissions from Consumer Products," available online at www.arb.ca.gov/consprod/regs/cp.pdf

Canadian Standards Association CSA 6.19-01. Residential Carbon Monoxide Alarming Devices. www.shopcsa.ca/onlinestore/GetCatalogDrillDown.asp?Parent=571

Canadian Standards Association. "Carbon Monoxide Alarms," www.csa-international.org/consumers/consumer_tips?default.asp?load=carbon_monoxide&language=english

Center for ReSource Conservation. Before you buy...Cabinets. Article available at www.greenerbuilding.org/buying_advice.php?cid=4

Consumer Product Safety Commission (CPSC). What You Should Know About Combustion Appliances and Indoor Air Pollution (CPSC Document #452), www.cpsc.gov/cpscpub/pubs/452.html

ENERGY STAR. 2007. *ENERGY STAR Indoor Air Package Specifications*, Version 2. U.S. Environmental Protection Agency. www.energystar.gov/ia/partners/bldrs_lenders_raters/downloads/IAP_Specification_041907.pdf

Florida Solar Energy Center. 2007. "Indoor Air Quality," available at www.fsec.ucf.edu/en/consumer/buildings/homes/airqual.htm

Greenguard Environmental Institute. www.greenguard.org

International Code Council, Inc., "UL 2034 History – CO Alarms," May 4, 2005. www.iccsafe.org/cs/cc/ctc/CO/CO_UL2034History.pdf

2009 IECC. 2009. *International Energy Conservation Code*, International Code Council (ICC), Washington, DC. www.iccsafe.org/Store/Pages

2009 IRC. 2009. *International Residential Code - One and Two-Family Dwellings*, Section M1502.4.1, "Material and Size," and M1502.4.4 "Duct Length," International Code Council (ICC), Washington, DC. www.iccsafe.org/Store/Pages

KCMA Environmental Stewardship Program 01-06. www.greencabinetsource.org/index.cfm?fuseaction=Defining.Welcome

National Association of Home Builders Research Center. "Low- or No-VOC Paints, Finishes and Adhesives," www.toolbase.org/Home-Building-Topics/Indoor-Air-Quality/low-voc-paints

National Green Building Standard 901.10, August 10, 2007, pg. 70. www.nahbgreen.org/Guidelines/ansistandard.aspx

NFPA 720: Standard for the Installation of Carbon Monoxide (CO) Warning Equipment in Dwelling Units. www.nfpa.org/aboutthecodes/AboutTheCodes.asp?DocNum=720&Cookie%5Ftest=1

Raub, J. A., M. Mathieunolf, N. B. Hampson, and S. R. Thom. 2000. "Carbon Monoxide Poisoning—a Public Health Perspective." *Toxicology* (145):1-14. www.ncbi.nlm.nih.gov/pubmed/10771127

South Coast Air Quality Management District. Rule 1168 – Adhesive and Sealant Application. www.arb.ca.gov/DRDB/SC/CURHTML/R1168.pdf

Sustainable Buildings Industry Council (SBIC). 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/storeindex.cfm

The American Lung Association. Health House tipsheet on carbon monoxide www.healthhouse.org/tipsheets/TS_CarbonMonoxide.pdf

The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE). Top Ten Things that homeowners can do to provide good indoor air quality. www.contractorconnect.net/GoodAir.html

UL 2034. 1996. *Standard for Single and Multiple Station Carbon Monoxide Alarms,* Edition 2, October 29, 1996. www.alliedsalescompany.com/ul/2034.pdf

University of Illinois Extension Service. "Five Steps to a Healthier Garage," http://web.extension.uiuc.edu/will/factsheets/family116.html

U.S. Department of Energy. "The House as a System: Combustion Safety," www.eere.energy.gov/buildings/building_america/pdfs/db/31046.pdf

U.S. Department of Energy. 2000. "Combustion Equipment Safety," DOE Fact Sheet, May 2000. DOE/GO 10099-784. www.earthcrafthouse.com/documents/factsheets/CES-Combustion-Safety%2000-784.pdf

U.S. Environmental Protection Agency. 2009. "Indoor airPLUS Construction Specifications," www.epa.gov/indoorairplus

U.S. Environmental Protection Agency. "Indoor Air Quality Carbon Monoxide Fact Sheet," www.epa.gov/iaq/co.html

U.S. Environmental Protection Agency. "Wood Coating Case Studies by Company," www.epa.gov/ttn/atw/wood/low/casebyco.html

U.S. Green Building Council, LEED for Homes. 2008. www.greenhomeguide.org/documents/leed_for_homes_rating_system.pdf

EPA United States Environmental Protection Agency

Indoor airPLUS Verification Checklist

EPA Indoor airPLUS QUALIFIED HOME

Address or Div/Lot#:

City/State/Zip: **Date:**

Section		Requirements (see Indoor airPLUS Construction Specifications for details)	N/A	Verified by Builder	Verified by Rater
Moisture Control		**Water-Managed Site and Foundation**			
	1.1	Site & foundation drainage: sloped grade, protected drain tile, & foundation floor drains		☐	☐
	1.2	Capillary break below concrete slabs & in crawlspaces (Exception - see specification)	☐	☐	☐
	1.3	Foundation wall damp-proofed or water-proofed (Except for homes without below-grade walls)	☐	☐	☐
	1.4	Basements/crawlspaces insulated & conditioned (Exceptions - see specification)	☐	☐	☐
		Water-Managed Wall Assemblies			
	1.5	Continuous drainage plane behind exterior cladding, properly flashed to foundation		☐	☐
	1.6	Window & door openings fully flashed		☐	☐
		Water-Managed Roof Assemblies			
	1.7	Gutters/downspouts direct water a minimum of 5' from foundation (Except in dry climates)	☐	☐	☐
	1.8	Fully flashed roof/wall intersections (step & kick-out flashing) & roof penetrations		☐	☐
	1.9	Bituminous membrane installed at valleys & penetrations (Except in dry climates)	☐	☐	☐
	1.10	Ice flashing installed at eaves (Except in Climate Zones 1 - 4)	☐	☐	☐
		Interior Water Management			
	1.11	Moisture-resistant materials/protective systems installed (i.e., flooring, tub/shower backing, & piping)			☐
	1.12	No vapor barriers installed on interior side of exterior walls with high condensation potential		☐	☐
	1.13	No wet or water-damaged materials enclosed in building assemblies		☐	☐
Radon	2.1	Approved radon-resistant features installed (Exception - see specification)	☐	☐	☐
	2.2	Two radon test kits & instructions/guidance for follow-up actions provided for buyer (Advisory-see specification)	☐	☐	☐
Pests	3.1	Foundation joints & penetrations sealed, including air-tight sump covers			☐
	3.2	Corrosion-proof rodent/bird screens installed at all openings that cannot be fully sealed (e.g., attic vents)		☐	☐
HVAC	4.1	HVAC room loads calculated, documented; system design documented; coils matched			☐
	4.2	Duct system design documented & properly installed OR duct system tested (check box if tested) ☐	☐		☐
	4.3	No air handling equipment or ductwork installed in garage; continuous air barrier required in adjacent assemblies			☐
	4.4	Rooms pressure balanced (using transfer grills or jump ducts) as required OR tested (check box if tested) ☐	☐		☐
	4.5	Whole house ventilation system installed to meet ASHRAE 62.2 requirements			☐
	4.6	Local exhaust ventilation to outdoors installed for baths, kitchen, clothes dryers, central vacuum system, etc.			☐
	4.7	Central forced-air HVAC system(s) have minimum MERV 8 filter, no filter bypass, & no ozone generators			☐
	4.8	Additional dehumidification system(s) or central HVAC dehumidification controls installed (In warm-humid climates only)	☐		☐
Combustion Pollutants		**Combustion Source Controls**			
	5.1	Gas heat direct vented; oil heat & water heaters power vented or direct vented (Exceptions - see specifications)	☐		☐
	5.2	Fireplaces/heating stoves vented outdoors & meet emissions/efficiency standards/restrictions	☐		☐
	5.3	Certified CO alarms installed in each sleeping zone (e.g., common hallway) according to NFPA 720			☐
	5.4	Smoking prohibited in common areas; outside smoking at least 25' from building openings (Multi-family homes only)	☐	☐	☐
		Attached Garage Isolation			
	5.5	Common walls/ceilings (house & garage) air-sealed before insulation installed; house doors gasketed & closer installed	☐		☐
	5.6	Exhaust fan (minimum 70 cfm, rated for continuous use) installed in garage & vented to outdoors (controls optional)	☐		☐
Materials	6.1	Certified low-formaldehyde pressed wood materials used (i.e., plywood, OSB, MDF, cabinetry)		☐	☐
	6.2	Certified low-VOC or no-VOC interior paints & finishes used		☐	☐
	6.3	Carpet, adhesives, & cushion qualify for CRI Green Label Plus or Green Label testing program	☐	☐	☐
Final	7.1	HVAC system & ductwork verified dry, clean, & properly installed			☐
	7.2	Home ventilated before occupancy OR initial ventilation instructions provided for buyer		☐	☐
	7.3	Completed checklist & other required documentation provided for buyer		☐	☐

Rater/Provider: **Builder:**

Company: **Company:**

Signature: **Signature:**

Guidance for Completing the Indoor airPLUS Verification Checklist:

1. Only ENERGY STAR qualified homes verified to comply with these specifications can earn the Indoor airPLUS label. See Indoor airPLUS Construction Specifications for full descriptions of the requirements, terms, exceptions, abbreviations, references, and climate map used in this checklist. Verification is not complete until this checklist is completed in full and signed.
2. Check one box per line. Check "N/A" for specifications that do not apply for specific conditions (e.g., climate) according to the Exceptions described in the Indoor airPLUS Construction Specifications. Check either "Builder" or "Rater" for all other items to indicate who verified each item. Items may be verified visually on site during construction, by reviewing photographs taken during construction, by checking documentation, or through equivalent methods as appropriate. If using a performance testing alternative to meet requirement 4.2 or 4.4, the box marked "Tested" must be checked and testing documentation must be provided in the Home Energy Rating System/Builder Option Package (HERS/BOP) file.
3. The rater who conducted the verification, or a responsible party from the rater's company, must sign the completed verification checklist. The builder must sign the checklist if any items in the "Builder" column are checked, and by so doing accepts full responsibility for verifying that those items meet Indoor airPLUS requirements.
4. The builder provides one copy of the completed and signed checklist for the buyer. The HERS/BOP provider or rater files a copy with HERS/BOP and ENERGY STAR documentation (e.g., Thermal Bypass Checklist) for the home.
5. The checklist may be completed for a batch of homes using a RESNET-approved sampling protocol when qualifying homes as ENERGY STAR. For example, if the approved sampling protocol requires rating one in seven homes, then the checklist will be completed for the one home that was rated.

Note: The Indoor airPLUS Construction Specifications are designed to help improve indoor air quality (IAQ) in new homes compared with homes built to minimum code. These measures alone cannot prevent all IAQ problems; occupant behavior is also important. For example, smoking indoors would negatively impact a home's IAQ and the performance of the specified Indoor airPLUS measures.

Notes:

For further information on the Indoor airPLUS program, visit epa.gov/indoorairplus.

EPA Indoor airPLUS QUALIFIED HOME

Qualified homes earn the Indoor airPLUS label. Place it next to the ENERGY STAR label.

energy ENERGY STAR

All Indoor airPLUS qualified homes meet strict guidelines for energy efficiency set by ENERGY STAR, the nationally-recognized symbol for energy efficiency.

Chapter 11.

Inspecting, Testing, and Commissioning

Duct blaster testing confirms that ducts are well sealed *(Photo source: NREL).*

CHAPTER TOPICS

Building America believes in real results. The only way to confirm results is to test for them. Therefore, in addition to required inspections by the code inspector, Building America recommends that site supervisors conduct systematic inspections during the course of construction, and that a formal commissioning be conducted before handing the keys to new homeowners. The steps described in this chapter will confirm your workmanship, giving you peace of mind while reducing the likelihood of costly callbacks. Some of the activities recommended here are now required by the 2009 IECC, as noted in green in this section.

These commissioning steps can reduce callbacks and litigation risks for builders:

- Develop a commissioning plan appropriate to the home and the equipment installed.
- Test every house.
- Review commissioning results with installers.
- Provide the homeowner with information on the proper operation and maintenance of mechanical systems and other equipment.

Walk-Throughs During Construction

General walk-throughs and inspections are especially good at critical times during construction before the next step makes it impossible to detect a problem or make a repair. Especially when energy-efficient systems-designed housing is new to your subcontractors, you should conduct multiple inspections to ensure that the subcontractors have understood what is required of them and how to implement it. After the process has become more routine, you might get by with spot inspections. HotSpot

Before the drywalling starts, you should conduct a pre-drywall inspection to test ducts and make sure insulation is properly installed and test moisture levels in framing.

"Monitoring progress is the only way you are going to change behavior."

Nat Hodgson, vice president of construction, Pulte Homes Las Vegas Division

inspections done by the site supervisor and pre-job/post-job checklists filled out by the subcontractor can help solve recurring problems. These are both described in Chapter 12. A checklist for designers in Chapter 13 contains many of the provisions that site supervisors should look for and work to include.

Building Commissioning

Basic commissioning of the house and its mechanical systems is vital for high-performance housing and should be completed before the home is considered ready for the homeowner to take possession. Commissioning activities include verifying the installation and operation of HVAC equipment, especially for advanced systems like combination water/space heating systems, ground-source heat pumps, solar thermal systems, and photovoltaic arrays. Combustion safety testing should be conducted if any combustion appliances (including fireplaces) are installed. Additional testing recommended by Building America includes whole-house air leakage testing with a blower door test, duct air tightness testing, and pressure balance testing of each room. These activities are described below.

Pre-Dry Wall Inspection and Duct Pressure Testing

[The 2009 IECC 403.2 requires that ducts be tested for air tightness and allows for the testing to occur either before or after drywall is put up. If tested at pre-drywall or rough-in, they must be ≤ 6 cfm per 100 ft^2 of conditioned floor area at 25 Pa; if tested after construction, then ≤ 8 cfm at 25 Pa. (If the air handler and all ducts are in conditioned space, duct leakage testing is not required.)] Building America recommends performing a duct pressure test ("duct blaster" test) before drywalling, with the HVAC contractor present. If the ductwork fails to meet the pressure criteria, a smoke test will reveal the worst leaks and they can be sealed while they are still accessible. The HVAC contractor should also test the HVAC system to ensure that thermostats and zone dampers are operating correctly and that bypass dampers are properly adjusted. The pre-drywall inspection is also a good time to ensure that insulation and draft-stopping have been properly installed.

Whole-House Pressure Testing and HERS Rating

After completion of the home, including all interior and exterior finishes but before occupancy, whole-house air tightness is tested. **[The 2009 IECC 402.4.2 gives two options for demonstrating building air tightness. The home can be blower door tested and must show**

leakage of less than 7 air changes per hour at 50 Pa. Or, the 2009 IECC allows an extensive visual inspection of all of the areas listed in the 2009 IECC 402.4.2.2.] Building America recommends a blower door test. Also, at this time, you should verify that all specified energy-efficient lighting and appliances were installed and check the air-conditioner or heat pump refrigerant charge if your HVAC contractor has not already done so.

Duct testing and whole-house pressure tests can be conducted by a certified HERS rater. The HERS rater should conduct a combustion safety test of all fuel-fired equipment as part of the rating certification. The HERS rating itself can be a valuable marketing tool for an energy-efficient house; a HERS score of 70 or lower can qualify a home for DOE's Builders Challenge certification if other criteria are met (see Chapter 2 of this guide or www.builderschallenge.gov for more information).

To identify a certified rater in your area, check the registry at the Residential Energy Services Network (RESNET) website: www.natresnet.org.

SnapShot Form

Building Science Corporation developed a commissioning checklist called the SNAPSHOT form. This form is shown on the next page and is available at www.buildingscience.com/documents/reports/rr-0413-the-snapshot2014a-quick-description. Also, the Air Conditioning Contractors of America (ACCA) has developed guidance on commissioning of residential mechanical systems, *HVAC Quality Installation Specification*, ANSI/ACCA 5 QI-2007, which is available at www.acca.org/quality/.

Homeowner Education

Homeowners should also be given information on maintenance and operation of the HVAC equipment in their new home. Building Science Corporation put together a homeowner's manual for the EcoVillage project in Cleveland, Ohio, that can serve as a sample for builders wishing to create a homeowner's manual for their developments. The manual can be downloaded at www.buildingscience.com/documents/reports/rr-0310-ecovillage-homeowner-handbook.

For More Information on Inspecting, Testing, and Commissioning

Air Conditioning Contractors of America (ACCA) *HVAC Quality Installation Specification* – ANSI/ACCA 5 QI-2007, www.acca.org/quality/

Building Science Corporation. 2004. *The "SNAPSHOT"- A Quick Description*, Research Report 0413a, www.buildingscience.com/documents/reports/rr-0413-the-snapshot2014a-quick-description

Building Science Corporation. 2004. *EcoVillage Homeowner Handbook*, Research Report 0310, www.buildingscience.com/documents/reports/rr-0310-ecovillage-homeowner-handbook

Building Science Corporation. 2008. *Quality Assurance Roadmap for High Performance Residential Buildings*, www.toolbase.org/PDF/BestPractices/QualityAssuranceRoadmap.pdf

SNAPSHOT© "The Form"

Lot #:	Subdivision:	Address:	Date and time:
Model:			

INITIALIZATION

	Square feet	sq. ft.
	Surface area (all outside surfaces, including foundation)	sq. ft.
	Volume	cu. ft.
	Windspeed (approximate mph)	mph
	Outside temperature (estimated)	° F
	Check that all registers and bedroom doors are open.	Yes☐ No☐
	Measure static pressure in return between fan & filter.	pa
	Static pressure in Supply and Return	S Pa / R Pa
	Is there a ventilation system?	Yes☐ No☐
	Type of ventilation system (e.g., exhaust-only, HRV, ERV)	
	If there is an AirCycler™, enter the off / on times.	off on
	Enter outside air duct pressure.	pa
	Type of outside air duct (flex/sheet metal; diameter)	
	Is there an adjustable outside air damper?	Yes☐ No☐
	Is there a fireplace or wood stove?	Yes☐ No☐
	Duct location (approximate % in attic, conditioned space, basement, etc.)	

PRESSURE TESTING

	Stack Pressure (baseline with blower door installed; covers on)				pa
	Dominant Duct Leak Effect (baseline with HVAC system running)				pa
	Master Bedroom Door Closure Effect (ÄP from main space to outdoors)				pa
	All Doors Closed Effect (ÄP from main space to outdoors)				pa
	Fireplace/Wood Stove Zone HVAC Test				pa
	Pressure In Each Closed Room (room label and pressure)		pa		pa
			pa		pa
			pa		pa
			pa		pa
			pa		pa

BLOWER DOOR TESTING (BDT)

	Blower Door Location	
	Total CFM50 (add C & n values if available on multipoint test)	CFM50= C= n=

DUCT AIRTIGHTNESS TESTING (DAT)

	DAT CFM25 TOTAL	
	DAT CFM25 OUTSIDE	

MECHANICALS

	Furnace or air handler	Make:	Model:
	Air Conditioning	Make:	Model:
	Domestic hot water	Make:	Model:

Building Science Corporation

Snapshot Form

RR-0413b: Snapshot Form

Chapter 12.

Construction Site Documents, Scheduling, and Training

Getting a high-performance home requires having good plans; the proper contracts, permits, and materials; and properly trained and competent installers, who are scheduled at the right time and whose work is verified with testing.

Construction and Contract Documents

Builders should use construction and contract documents [in compliance with 2009 IECC 103] including plans and specifications, scopes of work, and job-ready and job-complete checklists, to describe and define exactly what you want from your subcontractors.

PLANS AND SPECIFICATIONS – Elevations, floor plans, and equipment layout should clearly identify all details related to energy efficiency, such as duct layout, advanced framing techniques, moisture management techniques, and air sealing details. Plans and specifications should include sufficient building and equipment details for the code inspector [as required by the 2009 IECC 103].

SCOPES OF WORK – Scopes of work define expectations and explain unfamiliar sequences of work. The Building America research teams have put together an extensive set of sample scopes of work, builders can include with contract documents, covering the foundation, framing, walls/drainage plane, windows, HVAC, and air sealing. See Appendix E of *Achieving 30% Whole-House Energy Savings Level in Marine Climates*. BAIHP et al. 2006, http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/39743.pdf.

JOB-READY CHECKLIST – Signed by the site supervisor and trade contractor, the job-ready checklist includes all items that must be installed or prepared on the job site, by other trade contractors, before the contractor's work can begin.

CHAPTER TOPICS

"It is one thing if you know what to do, but it is really the workers installing the products that need to understand how AND why. The quality of the installation is critical with energy-efficient construction; otherwise, it will not perform well and will defeat the purpose."

David Hall, project manager, Shaw Construction, Junction City, Colorado

(left) Use plans to spell out details that will ensure energy efficiency and durability like framing techniques, duct layouts, housewrap, flashing, and air sealing.

(right) Hold a pre-construction meeting with all subcontractors present to talk about the schedule and trade interactions, especially any changes from the typical routine to accommodate new methods or technologies.

"We have every trade fill out job-ready and job-complete forms. We want to know what was ready and what wasn't when they showed up at their job. Those delays frustrate them and cost us money."

Vern McKown, co-owner of Ideal Homes, in Norman, Oklahoma, shared these tips at the EEBA National Conference in Denver, Colorado, September 2009

"We work tightly with our trade contractors. They know our system and what we expect. When we started using ICFs in 2002 we had to do a lot of training. Now they understand."

Fred Giacci, owner, Devoted Builders, Kennewick, WA

JOB-COMPLETE CHECKLIST – Signed by the site supervisor and trade contractor, it confirms that the contractor's work was completed as specified.

Site supervisors should review construction documents before they are folded into contracts and should continue to provide recommendations as these documents are put into practice to make them as effective as possible. The popular management term for ongoing feedback and dialogue is "continuous improvement," a term coined by W. Edwards Deming. The point here is that when workers in the field find ways to improve designs or construction processes, that information needs to be communicated back to designers and managers so that documentation can capture those improvements. Although individual improvements may seem small, capturing these in construction documents helps you achieve superior building in the field.

Contract Documents

Clear contract documents make for clear expectations with trade contractors. Ensure that trade contracts include the following provisions adapted from the NAHB Research Center Toolbase:

- Trade contractors are contractually obligated to ensure that workers fully understand field specifications and builder quality assurance processes using pre-job and post-job checklists.
- A competent crew leader will be in charge of all crews and be able to communicate with the builder's site supervisor.

- All work must be completed in accordance with field specifications, applicable building codes, and industry standards.
- Trades must identify recurring errors in their work and train crews as needed to reduce similar errors (see HotSpots example in this chapter).
- Trades must self-inspect each phase of work before reporting the work complete to the site supervisor. Trades will confirm in writing that all materials and equipment were installed according to field specifications and manufacturers' instructions, using pre-job and post-job checklists.
- Copies of both field specifications and the manufacturers' instructions should be available on the job site.

Quadrant Homes, a Building America builder in Bellevue, Washington, builds its wall panels in a factory to ensure consistency and shorten site construction time.

For More Information on Construction and Contract Documents

NAHBRC. 2006. "Quality Matters: Six Ways to Improve Trade Contracts." *ToolBase News*, Summer 2006: Volume 11, Issue 3.

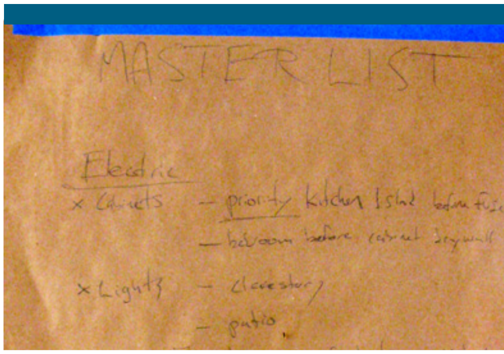
Scheduling

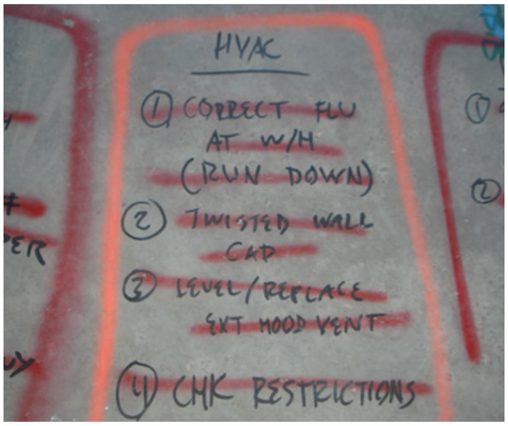
Building an energy-efficient home requires careful attention to scheduling. Several new construction techniques require changing the order of subcontractors or a shifting of responsibilities, and some new activities will need to be added into the schedule. Here are some important schedule considerations:

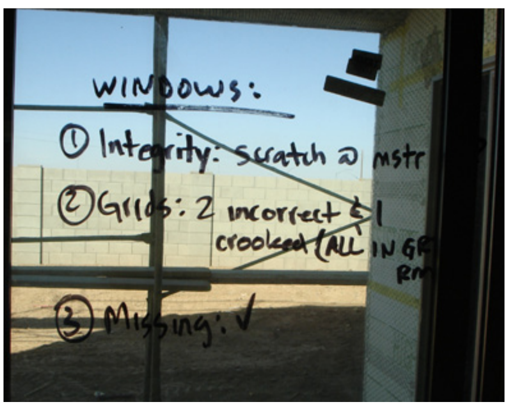
- Schedule HVAC rough-in before plumbing and electrical. It is far more important for the ductwork to have unconstricted access and pathways than it is for wires or pipes. However, be sure needs for other systems, such as drain pitch, are coordinated.
- If using an insulated, conditioned attic, schedule insulating under the roof deck before HVAC is installed. The insulators must be able to do their job without tromping on the carefully placed ductwork.
- Be sure to schedule caulking of electrical and plumbing penetrations before the drywall is completed and after the lines have been installed.
- Don't forget to schedule for pipe insulation under the slab.

"Quadrant gives us a schedule and we know we can count on it. With most of our other builders, if they have a job they want us to start tomorrow, we need to stop by and make sure the work will be ready. With Quadrant, we don't have to do that. They are predictable and reliable, and that is very nice from a trade standpoint."

Wade Craig, manager of Bob's Heating and Air Conditioning, the HVAC contractor for Quadrant Homes of Bellevue, Washington







Make your expectations clear with onsite meetings and visible inspection checklists.

- Be sure to schedule pre-drywall insulation inspections, flashing inspections, and envelope and duct pressure tests. Inspect at key points to ensure that insulation and envelope sealing take place before areas become inaccessible. Inspections are much more likely to happen if scheduled, and subcontractors may be a bit more conscientious if they know their work will be evaluated.
- If ducts are installed in conditioned space, drywall must be installed behind duct chases and soffits before they are framed.

Some situations that may require a shifting of responsibilities include the following:

- If using advanced framing techniques that include two-stud corners and floating drywall corners, someone must attach drywall clips. The framer is a more likely candidate than the drywall installer for framing modifications.
- Some caulking work needs to be done by the HVAC subcontractor. In particular, the main supply and return trunks that lead through the walls need to be caulked by the person connecting them to the equipment. Don't let the drywall finisher do this with mud—it is neither a good sealant nor durable enough. Also, all duct terminations, including jump ducts, must be sealed when registers are installed.
- Some post-finish caulking can be avoided by having the electrician use pre-fabricated airtight electrical boxes.
- If installations of windows and drainage planes are done by different subcontractors, the window installer must be careful to leave flashing unattached at the bottom so that the first row of building paper may be tucked under it (see Chapter 14 for an installer's guide to window flashing, housewrap, and sealants).
- If you are using insulated headers, the framer will need to install insulation inside any double headers (using sandwiched foam insulation). Open headers may be left for the insulation contractor. Pre-fabricated, insulated headers are another alternative.
- Draftstops must be installed behind bathtubs and stairwells on exterior framed walls as well as attic knee walls. The framer or insulator should do this, but be sure that insulation is installed before the draftstopping material. The plumber can be asked to install the draftstopping and insulation.

Efficient scheduling of subcontractors can bring huge rewards in reduced costs and improved quality.

"You can expect what you inspect."

Dr. W. Edwards Deming, the originator of total quality management

Training Installers

High-performance home construction does not just happen. Training is essential. Training need not involve days off the work site sitting in big lecture halls. Hands-on training is the most common approach and can happen constantly. Here are some ideas for training:

- Schedule a pre-construction meeting with all of your subcontractors present to review required interactions between trades.
- Meet with your subcontractors at the job site to explain how to use new techniques and materials.
- Provide your contractors with manufacturers' installation instructions and material data sheets and go through those instructions together. Other installation guides you may want to share with subcontractors include the field guides for installers shown in Chapter 14 of this guide, or the DOE Building Energy Code Program's Code Notes (see examples in Appendix 2).
- Encourage in-house staff and regular subcontractors to take advantage of web-based videos, online training, and classroom training at community colleges during the off season.

Training on the job site can include reviewing manufacturers' installation instructions, going through job-ready and job-complete checklists, and using HotSpot forms.

Training Tips from Cold Climate Builders

Cold-climate builders who worked with Building America on demonstration projects (see case studies at the back of this guide), offered several recommendations for training. "Spend the time planning the work. Use proven technologies. Use subcontractors that understand and believe in this type of construction. Train your employees, especially the people doing the work in the field," said David Hall, project manager for Shaw Construction, who built Burlingame Ranch Phase 1 for the City of Aspen, Colorado. "We held a project foreman seminar with Dr. Lstiburek at the beginning of the project and held several smaller training sessions at each "critical" construction phase with the subcontractor's foreman and all employees that were onsite at the time. These training sessions covered window installation, installing perimeter flashing, setting doors, installing roofing materials, spray foam in walls, each mechanical, electrical and plumbing rough-in stage, installing the heat recovery ventilators, setting wall panels, etc." Shaw produced one-page visual "training cards" in English and Spanish showing how to install particular components. Hall noted that the *Builder's Guide to Cold Climates* (by Joe Lstiburek, published by EEBA) was also very useful. Shaw also conducted ongoing quality inspections with the field staff at each stage of construction.

"We hold meetings with our trade contractor steering committee. We ask our employees and our subs, what can we do better? The construction supervisor walks the sites to identify any recurring issues. And we do NAHB quality certification audits of the whole company on a regular basis."

Vern McKown, co-owner of Ideal Homes, in Norman, Oklahoma, shared these tips at the EEBA National Conference in Denver, Colorado, September 2009

Building America's team lead IBACOS took an active role in subcontractor training on the East Liberty project in Pittsburgh. IBACOS prepared mockups of field assemblies at its warehouse and provided hands-on training sessions. "We had the actual crew who would be performing the work in the field practice by working on the mockups. If they had any questions or suggestions for improving the process, we could work this out before we got into the field," said Kevin Brozyna, an IBACOS building performance specialist.

Training Opportunities

Building America research partners provide training to the builders with whom they work. In addition, these Building America partners and building science organizations offer national training and certifications.

Certification Training

Two certifications are recognized nationally by practitioners of building energy efficiency: BPI (Building Performance Institute) and RESNET (Residential Energy Services Network). In addition, many states acknowledge Weatherization Inspector/Auditor certifications. The following websites provide information about training toward pursuing these certifications:

- The BPI website at www.bpi.org/affiliates.aspx provides a database search function for identifying approved courses at specific locations for upcoming training.
- The RESNET website at http://resnet.us/rater/map provides a U.S. map for identifying approved courses at specific locations for upcoming training.
- For specific state weatherization programs, Google the state name and the words "weatherization programs," which should lead to a link for that state's program with contact information, training requirements, and training resources.
- For online training, Saturn Resource Management at www.saturnonline.biz offers self-paced interactive courses for earning specific certifications.

Training Offered by Building America Partners

Building America team members and partners are among the most respected building scientists in the industry. These partners provide a variety of professional building science training courses, available at the links listed at the end of the chapter..

HotSpot Inspections and Training

Systematically checking work is an important aspect of quality construction. The NAHB Research Center developed the concept of HotSpot Inspections and HotSpot Training. A "HotSpot" is a recurring issue that requires some form of remediation in order to get a site ready for the next trade or a home ready for move-in by a buyer. Builders can create their own HotSpot forms using the sample below.

HOTSPOT INSPECTIONS

Job Inspection Record-Schuck and Sons Construction

Date:	Release #:	Sequence #:	Production #:	Unit #:	Lot #:

Inspector/Date:

Key Requirements (for review)	HotSpots (must be verified)
Layout: ➢ Accurate foundation dimensions ➢ Square foundation ➢ Flat foundation ➢ Safe site conditions	Supervisor: ______________ ❑ Back to front max deviation: __________ ❑ Side max deviation: ____________ ❑ Square deviation: ___________ ❑ Flat max deviation: ____________
Exterior walls: ➢ Window size, level, and plumb ➢ Temporary power ➢ Header sizes ➢ Shear properly nailed ➢ Strap location and nailed properly ➢ Walls plumb ➢ Window margins even, level sill, & plumb trimmers ➢ Glass block opening size, plumb & level ➢ Backing for interior wall connections ➢ Swept out house	Foreman:_______________ ❑ Studs flush with inside of bottom plates ❑ Tower walls & patio columns strapped & srp4 on studs and fire stopped ❑ Proper number of trimmer & king studs at openings
Interior walls: ➢ Temporary power ➢ Walls plumb ➢ Skylights framed in and straight & plumb ➢ Wrapped openings plumb, sides straight, header level, and bottoms square ➢ Nitches level & plumb ➢ Drops lined & tied up ➢ Interior shear walls frames and tied ➢ Fire stop ➢ Ceiling backing ➢ Swept out house	Foreman:_______________ ❑ Small bottom plates secured by glue ❑ Closet openings plumb, level & double studs at opening [insert] ❑ Garage door backing 99" sides, 119" center ❑ Pony wall level top, plumb ends
Trusses: ➢ Temporary power ➢ Hang backing installed ➢ Sway bracing installed with gable ties ➢ Gable vents ➢ Swept out house	Foreman:_______________ ❑ Nailing of H-1's and H-2.5's
Roof foreman:_______________ ➢ Temporary power ➢ Overhangs proper length ➢ Face straight ➢ Pigeonhole size ➢ Nailing per layout marking ➢ Skylight opening with plumb trusses and curbs built ➢ OSB gapped on roof ➢ Fireplace stack built & installed (where necessary) ➢ Swept out house	❑ OSB nailed where over-framing occurs

Cooling the HotSpots

- Identify quality issues through job inspections, builder feedback, and comprehensive quality reviews. Include the problems that show up often on your punch lists time and again.
- Add HotSpot checkpoints to the inspection form where improvement is needed.
- Distribute and discuss HotSpot inspection forms in weekly production meetings.
- Train site supervisors in procedures to prevent identified problems.
- Develop one-page diagrams that address specific problem areas and use these in toolbox talks to train crews.
- Monitor the use of the new processes and the quality of installations. HotSpot inspection forms are used by supervisors on every job. Results provide feedback on the effectiveness of the improvements.
- Celebrate success. When a HotSpot is no longer an issue, remove it from the HotSpot list and put it in a reminder section. In time, items may leave the inspection form altogether.

Adapted from the ToolBase Resources Website at www.toolbase.org/Best-Practices/Business-Management/Hot-Spot-Inspections. This website includes examples of HotSpot inspection forms.

Table 12.1. Training Opportunities

- **Affordable Comfort** at www.affordablecomfort.org/events_ceu.php?PageID=59
- **Building Knowledge, Inc.** at www.buildingknowledge.com/training/index.html
- **Building Media Inc.** at buildingmedia.com/education.html
- **Building Science Corporation** at www.buildingscienceseminars.com/
- **ConSol** at www.consol.ws/services/consulting/bect.php
- **EcoBroker® International** at www.ecobroker.com/eb/default.aspx
- **Energy Center of Wisconsin** at www.ecw.org/university/index.php
- **Energy & Environmental Building Alliance (EEBA)** at www.eeba.org
- **Florida Solar Energy Center** at www.fsec.ucf.edu/en/education/index.htm
- **Gas Technology Institute** at www.gastechnology.org/webroot/app/xn/xd.aspx?it=enweb&xd=3TrainingConfer/3_0TrainingHome.xml
- **Green Building Alliance** at www.gbapgh.org/content.aspx?ContentID=78
- **Green Builder College** at www.greenbuildercollege.com/
- **Integrated Building and Construction Solutions (IBACOS)** at www.ibacos.com/product-service/coaching-and-training-green
- **Jay Hall and Associates** at www.jayhall.com/services.htm
- **Lutron Corporation** at www.lutron.com/Education-Training/LCI/AboutLCI/Pages/About.aspx
- **MaGrann Associates** at www.magrann.com/engineering-consulting-services.html
- **Manufactured Housing Institute** at www.factorybuilthousing.com/educational_institute/
- **The Midwest Energy Efficiency Alliance** at www.mwalliance.org/programs/training-education
- **National Association of Home Builders (NAHB) Research Center** at www.nahbrc.com/builder/consultation/index.aspx
- **National Communities Council** at www.mhcommunities.org/cm/education/default.asp
- **NeighborhoodWorks® America** at www.nw.org/network/training/training.asp
- **ONTILITY** at www.ontility.com/training/solar-training-solar-education/about-ecotraining
- **Partnership for Achieving Construction Excellence (PACE)** at www.engr.psu.edu/pace/pace/dbia_boot_camp.aspx?p=40
- **Potomack Group** at www.potomack.net/iso-consulting.html
- **Pratt Center for Community Development** at www.prattcenter.net/contractor-training
- **Sacramento Municipal Utilities District** at www.smud.org/en/education-safety/Pages/index.aspx
- **San Diego Gas & Electric** www.sdge.com/business/rebatesincentives/training/workshops.shtml
- **Schneider Electric** at www.schneider-electric.com/sites/corporate/en/products-services/training/training.page
- **Steve Easley and Associates** at www.buildingmedia.com/steve.html
- **Steven Winter Associates, Inc.** at www.swinter.com/training/
- **Southface Energy Institute** at www.southface.org/learning-center/trainings/
- **TexEnergy Solutions** at www.texenergy.org/training.php
- **University of Florida's Program for Resource Efficient Communities** at www.prattcenter.net/contractor-training
- **Verified Green** at www.verifiedgreen.org/course-offerings.html
- **Washington State University Energy Extension Program** at www.energy.wsu.edu/apps/training.aspx

Chapter 13.

Durability and Energy Efficiency Checklist

This checklist summarizes the measures presented in Chapters 6–12.

Designers, use this checklist as a reminder to investigate these measures throughout the design process. It is important to develop specifications and drawings to ensure that selected features are included in construction documents.

This list can aid site supervisors by providing a master list of recommended home features. Use this list to develop customized onsite pre-job and post-job inspection checklists for each trade contractor.

CHAPTER TOPICS

Foundation Assemblies

Slab, crawlspace, and basement foundation types are all common in the cold climate. The checklists below address control of moisture, airflow, and heat flow in each foundation type.

Controlling Moisture in All Foundation Types

- ☐ Maintain a surface grade of at least a 6-inch drop for at least 10 feet around and away from the entire structure [2009 IRC R401.3].
- ☐ Drain impervious surfaces such as driveways, garage slabs, patios, stoops, and walkways away from the structure at ≥ 2% drop within 10 feet of the building [2009 IRC R401.3].
- ☐ Specify and show in details that 6-mil polyethylene sheeting or rigid foam insulation is to be placed directly beneath the slab or basement floor. The sheeting should continuously wrap the slab as well as footings up to grade [2009 IRC R406.3.2].

- ☐ Damp proof all below-grade portions of the exterior foundation [2009 IRC R406]. Damp proof the exposed portion of the foundation with latex paint or other sealant.
- ☐ Specify that footings poured independent of slabs or foundation walls are to be treated with a bituminous damp-proof coating of masonry capillary-break paint, or a layer of 6-mil polyethylene plastic to isolate the footing from the remainder of the assembly.
- ☐ Ensure that the lowest excavated site foundation level is above the local groundwater table at its maximum elevation [2009 IRC R408.6].
- ☐ Place a 4-inch-deep, ¾-inch gravel bed directly beneath the polyethylene sheeting to act as a capillary break and drainage pad.
- ☐ Do not place a sand layer between the vapor retarder and the concrete slab or basement floor. Differential drying and cracking is better handled with a low water-to-concrete ratio and wetted burlap covering during initial curing.

Controlling Moisture in Crawlspace and Basement Foundations

- ☐ Install a perimeter drain below the drainage plane along (not on top of) footings for all basements and crawlspaces where the floor is below grade (use perforated PVC pipe covered with gravel, landscape fabric, and backfill).
- ☐ In all crawlspaces, install 6-mil polyethylene across the entire ground surface. Overlay all seams by 12 inches and tape. Seal the polyethylene at least 6 inches up the walls or to a height equal to ground level.

Controlling Air Infiltration in All Foundation Types

- ☐ The foundation details should indicate that a sill gasket be installed between the foundation and the bottom plate of the exterior framed wall. This gasket also serves as a capillary break.

Controlling Heat Flow in Slab Foundations

- ☐ Slabs may be insulated at the perimeter with borate-treated foam board or rigid fiberglass insulation. Use only insulation approved for below-grade use. [R-Values are specified in 2009 IECC Table 402.1.1]
- ☐ Exterior insulation should be applied from the top of the foundation wall to the bottom of the frost line. Cover the exterior face of the insulation exposed to outside air using flashing, fiber cement board, parging, treated plywood, or membrane material. [R-Values are specified in 2009 IECC Table 402.1.1]

Controlling Heat Flow in Crawlspace Foundations

- ☐ The preferred approach is to install insulation on the exterior side of the foundation wall. Products such as borate-treated foam board or rigid fiberglass insulation work well. Insulate the exterior side of the beam to R-5.6 **[2009 IRC 403.3]**.
- ☐ Insulation that is exposed above grade must be covered with a protective coating such as flashing, fiber cement board, parging, treated plywood, or membrane material.
- ☐ If insulation is placed on the interior, it must extend down the wall to a depth at least 2 feet below grade level and be rated for crawlspace and basement exposure.
- ☐ If the floor is insulated instead, insulate to R-30 in IECC climate zones 5 and 6, R-38 in climate zones 7 and 8 (or sufficient to fill the framing cavity, at least R-19) **[2009 IECC 402]**.

Controlling Heat Flow in Basement Foundations

- ☐ Wall insulating in basements is similar to the approaches described for crawlspaces. Basement floors are insulated similarly to slabs. **[2009 IECC 402 requires R-10 rigid foam on the interior or exterior surface of the walls or R-13 cavity insulation on interior basement walls in IECC climate zone 5. In IECC climate zones 6, 7, and 8, the requirement is R-15 continuous rigid foam insulated sheathing on the interior or exterior, or R-19 interior cavity, or R-5 exterior plus R-13 cavity insulation. In IECC climate zone 5, R-10 slab floor edge insulation is required extending 2 feet horizontally under the slab or out from the building. In IECC zones 6, 7, and 8, this increases to R-15 and 4 feet.]**
- ☐ Exterior wall insulation is preferable in basement foundation applications.
- ☐ Material in contact with the foundation wall and the concrete slab must be moisture tolerant. A capillary break must be placed between materials that transport moisture and moisture-sensitive materials.
- ☐ Interior insulation, if used, should employ one of the following methods:
  - ○ Use foil-faced polyisocyanurate rigid insulation attached directly to the above-grade portion of the wall. Extruded or expanded polystyrene can be attached to the below-grade portion of the wall. The polystyrene would require a gypsum board or equivalent covering. Foam sill seal or foam board can be used between the bottom plate of the wall and the concrete floor to provide a capillary break.
  - ○ Use either expanded or extruded polystyrene foam board attached to the entire foundation wall. Additional insulation can be added to a frame wall built on the interior of the foam insulation. If no frame wall with additional insulation is added, wood furring strips can be attached over the foam and gypsum board attached to the furring strips.
  - ○ Use pre-cast concrete foundation walls that come with a minimum of 1 inch of rigid foam insulation attached to the interior.

Other Foundation Issues

RADON CONTROL

- ☐ Use a layer of gravel under the slab to provide a path for radon and other soil gas to escape to the atmosphere rather than being drawn into the house.
- ☐ Use a vapor retarder to block soil gas entry into the house.
- ☐ See EPA website: www.epa.gov/iaq/whereyoulive.html for information about local variations in radon levels. **[Also see radon map and radon control recommendations in the 2009 IRC Appendix F.]**
- ☐ Include a sub-slab-to-roof vent system to vent radon and soil gases.
- ☐ Include an active radon reduction system with fan if your homes are built in zone 1 (high radon potential).

PEST CONTROL

- ☐ Use local code and Termite Infestation Probability (TIP) maps to determine environmentally appropriate termite treatments, bait systems, and treated building materials for assemblies that are near soil or have ground contact **[2009 IRC R318.1.]**.
- ☐ Provide roof drainage to carry water at least 3 feet away from the building.
- ☐ Apply decorative ground cover no more than 2 inches deep within 18 inches of the foundation.
- ☐ Keep plantings at least 18 inches from the foundation with supporting irrigation directed away from the finished structure.
- ☐ Specify and install an environmentally appropriate soil treatment and a material treatment (treated wood, termite blocks) for wood materials near grade.
- ☐ Install a metal termite shield at the sill plate **[2009 IRC R318.3]**.

Wall Assemblies

Controlling Liquid Water in Wall Assemblies

- ☐ Install flashing at all intersections of the wall with roofs and other building elements.
- ☐ Properly flash and seal windows, doors, and other penetrations through the wall.
- ☐ Specify and show in elevations building paper, housewrap **[2009 IRC R703.2]**, or taped insulating sheathing (rigid foam insulation) behind the exterior cladding to serve as a drainage plane.
- ☐ In walls with brick facades, provide an airspace between the brick and the drainage plane.
- ☐ For the drainage plane behind stucco cladding, include insulating sheathing and two layers of building paper or housewrap to avoid chemically contaminating the housewrap.

- ☐ If building paper is used as a drainage plane in areas prone to severe storms, use two layers to increase resistance to leakage at fasteners and to allow for more flexible installation.
- ☐ Overlap housewrap seams shingle style and tape seams. Properly lap at window flashing (over the flashing above the windows and to the side, and under the flashing beneath the window).
- ☐ Run housewrap top and bottom edges past top and bottom plates by at least one inch and seal at the edges.
- ☐ Use overhangs to keep water away from walls and penetrations and to provide shade.

Controlling Water Vapor in Wall Assemblies

- ☐ Back-prime wood and fiber cement cladding to avoid water saturation and migration.
- ☐ Do not install vapor barrier (e.g., polyethylene sheeting, foil-faced batt insulation, reflective radiant-barrier foil insulation) on the interior side of walls in air-conditioned structures. Wall assemblies should be able to dry to at least one side and in many cases both sides of the assembly.
- ☐ Do not use impermeable coverings, such as vinyl wallpaper, on exterior walls.
- ☐ Indicate on plans the methods, materials, and locations where sealing is needed to form the house-air pressure barrier. Specify the approach to be taken to meet vapor barrier code requirements.
- ☐ Use a Class 3 vapor retarder (latex paint) on interior side of walls with vented cladding over wall sheathing **[2009 IRC 601.3]**.
- ☐ Leave a drainage space of at least 1/16-inch behind lap siding and ¾ inch between stucco and plastic housewraps to control liquid phase water penetration. A 1-inch air gap is needed behind brick veneer **[as required by 2009 IRC R703.7.4.2]**.

Controlling Air Infiltration in Wall Assemblies

- ☐ Use interior gypsum board as the interior air infiltration barrier. Tape and mud gypsum board at all joints and the intersections of the wall with the floor and the ceiling **[2009 IECC 402.4]**.
- ☐ Create an exterior air infiltration barrier using taped and sealed exterior rigid foam insulating sheathing to control wind washing and to keep air from entering the wall from the exterior.
- ☐ Use the ENERGY STAR Thermal Bypass Checklist.
- ☐ Install insulation and draftstopping between bathtubs, dropped ceilings, dropped soffits, and stairwells on exterior walls.
- ☐ Seal all exterior wall penetrations (exterior lights, phone lines, vents, faucet pipes, cables, etc…) with caulk, gaskets, or other sealants.
- ☐ For occupant health and safety, verify sealing at all shared walls and ceilings between attached garages and living spaces.
- ☐ For homes with attached garages, block and seal any gaps at joists spanning both conditioned space and the garage.

Controlling Heat Flow in Wall Assemblies

- ☐ Use 2x6 advanced framing techniques and specify framing details in plans.
- ☐ Insulate wall cavities that separate conditioned and unconditioned spaces with high-density, unfaced fiberglass batts, spray-applied cellulose, or spray-applied foam. **[The 2009 IECC 402 requires a wall R value of R-20 for wood-framed walls (or R-13 cavity plus R-5 insulated sheathing) for IECC climate zones 5 and 6 and R-21 for IECC climate zones 7 and 8. For mass walls (concrete block, concrete, ICF, brick, etc.), the requirement is R-13 for exterior insulation or R-17 if more than half the insulation is on the interior in zone 5. The requirements are R-15/19 for IECC climate zone 6 and R-19/21 for IECC climate zones 7 and 8.]**
- ☐ Properly install wall insulation to ensure the cavity is completely free of voids.
- ☐ Use spray foam to insulate and seal rim joists (and where the wall connects to the roof in non-vented attics).
- ☐ Install taped rigid foam insulating sheathing (in addition to cavity insulation) on the exterior side of the wall to control heat, moisture, and air infiltration.
- ☐ Install efficient windows with maximum U-values of 0.3 **[2009 IECC Table 402.1.3 requires ≤ 0.35 U-value]**.
- ☐ Use ENERGY STAR-labeled doors.
- ☐ Use roof overhangs to provide shade and protect windows, doors, and walls.

Roof Assemblies

Controlling Liquid Water in Roof Assemblies

- ☐ In areas with potentially high winds and heavy rains, apply 4-inch to 6-inch "peel and seal" self-adhering water-proofing strips over joints in roof decking before installing the roof underlayment and cover.
- ☐ Install roofing materials shingle-fashion to provide a continuous drainage plane over the entire surface of the roof.
- ☐ Properly flash roof valleys and edges and use kick-out flashing where roof edges abut walls.
- ☐ Size gutters and downspouts to accommodate anticipated storms. Roof drainage should carry water at least 3 feet from the building.

Controlling Water Vapor in Roof Assemblies

- ☐ Install roof, ridge, and soffit ventilation in vented attics.
- ☐ Do not use any kind of interior vapor barrier material in the ceiling (e.g., polyethylene sheeting).

Controlling Air Flow in Roof Assemblies

- ☐ Tape and seal all ceiling gypsum board seams so that the gypsum board functions as an air barrier. Ensure an air seal at the intersection between the walls and ceilings in attics, cathedral ceilings, and knee walls.
- ☐ Use spray foam for tight sealing of the wall-roof intersection in non-vented attics.
- ☐ Caulk all intersections of ceiling with other components (soffits, ceiling fans, duct registers, light fixtures, etc.) **[2009 IECC 402.4]**.
- ☐ Use draftstopping in dropped ceiling areas.
- ☐ Use ceiling light fixtures that are rated for insulation contact and airtight (ICAT); install with proper trim and caulk cracks around light fixtures.
- ☐ Air seal all penetrations through top plates.
- ☐ Weatherstrip and insulate attic access hatches or doors.
- ☐ Seal all penetrations through the ceiling and the roof, including holes for flue stacks, wiring, fans, etc.

Controlling Heat Flow in Roof Assemblies

- ☐ Consider a non-vented attic.
- ☐ Install blown-in insulation at the appropriate depth on the top surface of ceiling gypsum board. **[The 2009 IECC Table 402.1.1 requires a ceiling R value of R-38 in IECC climate zone 5 and R-49 in IECC zones 6, 7, and 8. A minimum of R-30 is required in cathedral ceilings, but this is limited to 500 ft^2 or 20% of total insulated ceiling area, whichever is less (2009 IECC 402.2.2.)]** Maintain the ceiling insulation level throughout the entire plane of the ceiling and over the top of the perimeter walls. A depth gauge should be visible from the attic hatch.
- ☐ Use raised-heel energy trusses to maintain the thickness of ceiling insulation directly above the top plates of the exterior wall framing. **[If raised heel trusses are used allowing full height of insulation over the wall top plate, then R-30 is permitted instead of R-38 in IECC zone 5 and R-38 is permitted instead of R-49 in zones 6, 7, and 8.]**
- ☐ In vented attics, install baffles to prevent blocking of soffit vents and wind washing (when thermal insulation is blown back from the edges of the attic by wind blowing through the soffit vents).

Whole-House Air Leakage

- ☐ Have building envelope tested for air leakage by a HERS rater who uses a blower door test. **[The 2009 IECC 402.4.2 requires that whole house air tightness be demonstrated by a blower door test or extensive visual inspection. If the home is blower door tested air leakage must be less than 7 air changes per hour at 50 Pa.]**

Mechanical Systems

Heating and Cooling Equipment

- ☐ Size heating and cooling equipment using ACCA Manual J [2009 IECC 403.6].
- ☐ Specify central air conditioners at a minimum 13 SEER (10 EER) for cooling, and specify heat pumps at a minimum of 7.7 HSPF for heating.
- ☐ Install ENERGY STAR-qualified equipment.
- ☐ Install sealed combustion gas furnaces in conditioned space.
- ☐ Install HVAC equipment equipped with brushless, permanent magnet, direct-current motors.
- ☐ Isolate HVAC system and ducts from areas with potential pollutants including garage spaces.
- ☐ Have the refrigerant charge on the air conditioner or heat pump verified in writing by the installer to be within design specifications, using the superheat method for non-Thermostatic Expansion Valve (TXV) systems or the subcooling method for TXV systems.
- ☐ Filter HVAC return air through a 4-inch standard filter or a Minimum Efficiency Reporting Values (MERV) 8 normal-thickness filter. Make the filter easy to access for cleaning or replacement and design the filter slot so there is no air bypass around the filter when the HVAC system is operating. The maximum air velocity through the filter should not exceed 400 fpm. [ASHRAE 62.2-2010 6.7 recommends MERV 6 or better.]
- ☐ Keep pressurization balanced from room to room by providing individual ducted returns for each room or by providing jump ducts or transfer grilles located in the walls of each room. Use flex duct and staggered grille locations or ducts lined with sound-absorbent material to minimize sound transfer through jump ducts.
- ☐ Consider alternative energy-efficient equipment such as variable refrigerant flow, mini-split ductless heat pumps or geothermal heat pumps.

Ducts

- ☐ Specify location, size, and type of ducts and registers on construction plans. Include heating and cooling ducts, passive return air ducts or transfers, location of the mechanical ventilation air inlet, and the locations of all exhaust outlets. Indicate the location of dedicated chases for ductwork.
- ☐ Place ducts and air handlers in conditioned space when possible.
- ☐ Size ducts using ACCA Manual D [2009 IRC M1601.1].
- ☐ Keep duct runs as short as possible. Consider using a central duct chase in a dropped hallway ceiling with registers located along it providing air directly to rooms along the hallway.
- ☐ Use ducts made of galvanized sheet metal, duct board, or flex duct.

- ☐ Air seal insulated ducts running outside conditioned spaces, by use of proper duct-sealing techniques. Use these duct-sealing materials:
  - ○ For metal ducts: UL 181 mastic.
  - ○ For duct board: UL 181 tapes.
  - ○ For flex duct: a combination of UL 181 mastic and strap ties.
- ☐ Seal drywall connections to ducts with caulk or foam sealant.
- ☐ Insulate ducts in unconditioned spaces. Insulate supply ducts to R-8 minimum and return ducts to R-4 minimum.
- ☐ Insulate ducts in conditioned space to R-8 for supply and R-4 for return ducts to avoid condensation formation.
- ☐ Equip each bedroom with a separate return duct, transfer grille, or jump duct.
- ☐ Don't use "pan ducts" (spaces between joists and in stud cavities) as supply or return air ducts **[2009 IECC 403.2.3]**.
- ☐ Don't locate ducts in exterior walls.
- ☐ Seal any return-air ductwork or air handler located in the garage with UL 181-approved mastic.
- ☐ Don't put the air handler in the garage unless it is in an air-sealed, insulated closet. Ducts located in the garage may not have any openings in the garage **[2009 IRC R302.5.2]** and furnaces and air handlers that supply air to living spaces shall not supply air to or return air from a garage **[2009 IRC M1601.6]**. The air handler and any return-air ductwork should be thoroughly sealed with UL 181B-M-compliant mastic, with a target leakage between the duct system and the garage of 0 CFM @ 25 Pa.
- ☐ Verify duct air tightness with a duct blaster pressure test. Test at rough-in when leaks can be easily accessed and sealed. **[The 2009 IECC 403.2 requires that ducts be tested for air tightness and allows for the testing to occur either before drywall is put up or after drywall is put up. If tested at pre-drywall or rough-in, they must be ≤ 6 cfm per 100 ft^2 of conditioned floor area at 25 Pa; if tested after construction, than ≤ 8 cfm at 25 Pa. (If the airhandler and all ducts are in conditioned space, duct leakage testing is not required by the 2009 IECC but is recommended by Building America to ensure ducts are properly connected and that air flow is balanced]**.

Ventilation

- ☐ Install whole-house mechanical ventilation compliant with ASHRAE Standard 62.2.
- ☐ Provide a fresh-air intake ducted to the return air side of the air handler to provide fresh air and air pressure balancing for homes ventilated primarily with exhaust-only kitchen and bath fans.
- ☐ Filter ventilation air through a 4-inch standard filter or a new MERV 8 normal-thickness filter. Make the filter easy to access for cleaning or replacement and design the filter slot so there is no air bypass around the filter when the HVAC system is operating.
- ☐ Install ENERGY STAR-qualified low-sone exhaust fans in bathrooms and kitchens. Sone ratings should not exceed 1.5.

- [ ] Seal bathroom and kitchen fans to drywall with caulk or gaskets.
- [ ] Equip outdoor air intakes and exhausts with automatic or gravity dampers that close when the ventilation system is not in operation [2009 IECC 403.5].
- [ ] Consider installing a night ventilation cooling system in appropriate subclimates.

Plumbing

- [ ] Locate bathrooms and other hot water-consuming activities near each other in house layout.
- [ ] Centrally locate the water heater to minimize piping trunk lengths.
- [ ] Bury plumbing in attic insulation for single-story, slab-on-grade homes and in interstitial space between floors for multi-story homes.
- [ ] Install code-permitted or manufacturer-approved minimum size lines.
- [ ] Insulate hot water supply lines to R-4. [2009 IECC 403.3 requires R-3 minimum.]
- [ ] Insulate tanks to at least R-12.
- [ ] Use a central manifold (home-run) water distribution system.
- [ ] Use PEX (high-density polyethylene) piping. Use approved connectors so PEX pipes are not connected directly to water heaters or solar collectors.
- [ ] Do not install continuous recirculation pumping systems on hot water lines. Use an on-demand switch if recirculation controls are desired to minimize the energy penalty of a circulation system.
- [ ] Use gas-fired instantaneous power-vented or direct-vented water heaters inside conditioned space.
- [ ] Consider alternative technologies like on-demand gas or electric water heaters, solar thermal water heaters, and ground-source heat pumps for water heating. If using solar-thermal water heating, use systems with freeze protection.
- [ ] Use unglazed solar pool water heaters on spas and swimming pools in the cold and very cold climates, and use two-speed pool filter pumps and controls to reduce energy.

Electrical

- [ ] Use ENERGY STAR-qualified compact fluorescent lights (CFLs) in all fixtures expected to be on more than 2 hours per day. [The 2009 IECC 404 requires that at least 50% of the lamps in permanently installed lighting fixtures be high-efficacy lamps.]
- [ ] Use recessed ceiling lights that are ICAT rated (approved for insulation contact and airtight) [2009 IECC 402.4.5].
- [ ] Use occupant sensors, photocells, and motion sensors to automate lighting operation.
- [ ] Use air-sealed electrical boxes in all exterior walls and ceilings adjacent to unconditioned attics.
- [ ] Use ENERGY STAR-qualified appliances.

Occupant Health and Safety

- ☐ Use only sealed combustion or power-vented combustion appliances in conditioned space.
- ☐ Direct vent gas cooking ranges to the outside **[2009 IRC M1503.4]**.
- ☐ Do not use combustion appliances that rely on passive combustion air supply openings or outdoor supply air ducts that are not directly connected to the appliance.
- ☐ Use sealed-combustion gas fireplaces to eliminate the threat of harmful combustion gases entering the house.
- ☐ Install CO detectors and smoke alarms **[NFPA 720 and NFPA 101 24.3.4.1]**.
- ☐ Use filtration systems for forced air systems that provide a minimum atmospheric dust spot efficiency of 30% or MERV 8 or higher.
- ☐ Maintain indoor humidity in the range of 30% to 60% by controlled mechanical ventilation, mechanical cooling, or dehumidification.
- ☐ Install carbon monoxide detectors (hard-wired units, one approximately every 1,000 square feet) in any house containing combustion appliances and/or an attached garage.
- ☐ Maximize hard surface areas (tile, vinyl, hardwood) to enable homeowners to better manage dust for health purposes. For slab-on-grade houses, this also reduces cooling loads.
- ☐ Provide occupants with information about the safe, healthy operation and maintenance of the building systems that provide space conditioning, hot water, and lighting.
- ☐ Ventilate attached garages with a 100 cfm (ducted) or 80 cfm (un-ducted) exhaust fan, venting to outdoors and designed for continuous operation. Or, install automatic fan controls that activate the fan whenever the garage is occupied and for at least 1 hour after the garage is vacated.
- ☐ Completely seal the garage from the conditioned areas of the house to keep car exhaust and chemical fumes from entering the home **[2009 IECC 402.4.1 and ASHRAE 62.2-2010, 6.5.1]**.
- ☐ Vent clothes dryers and central vacuum cleaners directly outdoors **[2009 IRC M1502.4.1]**.
- ☐ Use low-VOC paints, finishes, varnishes, and adhesives whenever possible.

Commissioning

- ☐ Test ducts for air leakage at rough-in. **[Per 2009 IECC 403.2, at rough-in, duct leakage to the outdoors should be ≤ 6 cfm/100ft² of conditioned floor area at 25 Pa.]**
- ☐ Test whole-house air leakage with a blower door. **[Per 2009 IECC 402.4.1, blower door air leakage results should be ≤ 7 ACH @ 50 Pa.]**
- ☐ Do combustion safety testing.
- ☐ Provide homeowners with operation and maintenance guidance to HVAC and mechanical systems.

Chapter 14.

Field Guides for Installers

On the following pages you will find step-by-step, easy-to-follow illustrated instructions for implementing key energy-efficiency technologies.

These guides are designed to be easily duplicated and distributed. Hand them to your subcontractors when you meet with them at the job site, to help them understand what you expect.

- Advanced Framing
- Foundation System, Insulation, Moisture and Air Leakage Control
- Masonry Construction
- Housewrap
- Window Flashing
- Wall-to-Roof Flashing
- Interior Air Sealing
- Exterior Air Sealing with Insulating Sheathing Panels
- Plumbing Air Sealing
- Electrical Air Sealing
- Installing Fiberglass Batt Insulation
- Installing Windows in Walls with External Rigid Foam Insulation
- Duct Location
- Air Handler and Duct Sealing
- Ductless Heat Pump Installers Guide (from Northwest Energy Efficiency Alliance www.ductless.com)
- Ice Dam Prevention

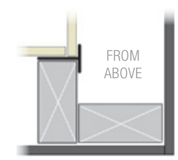
Advanced Framing

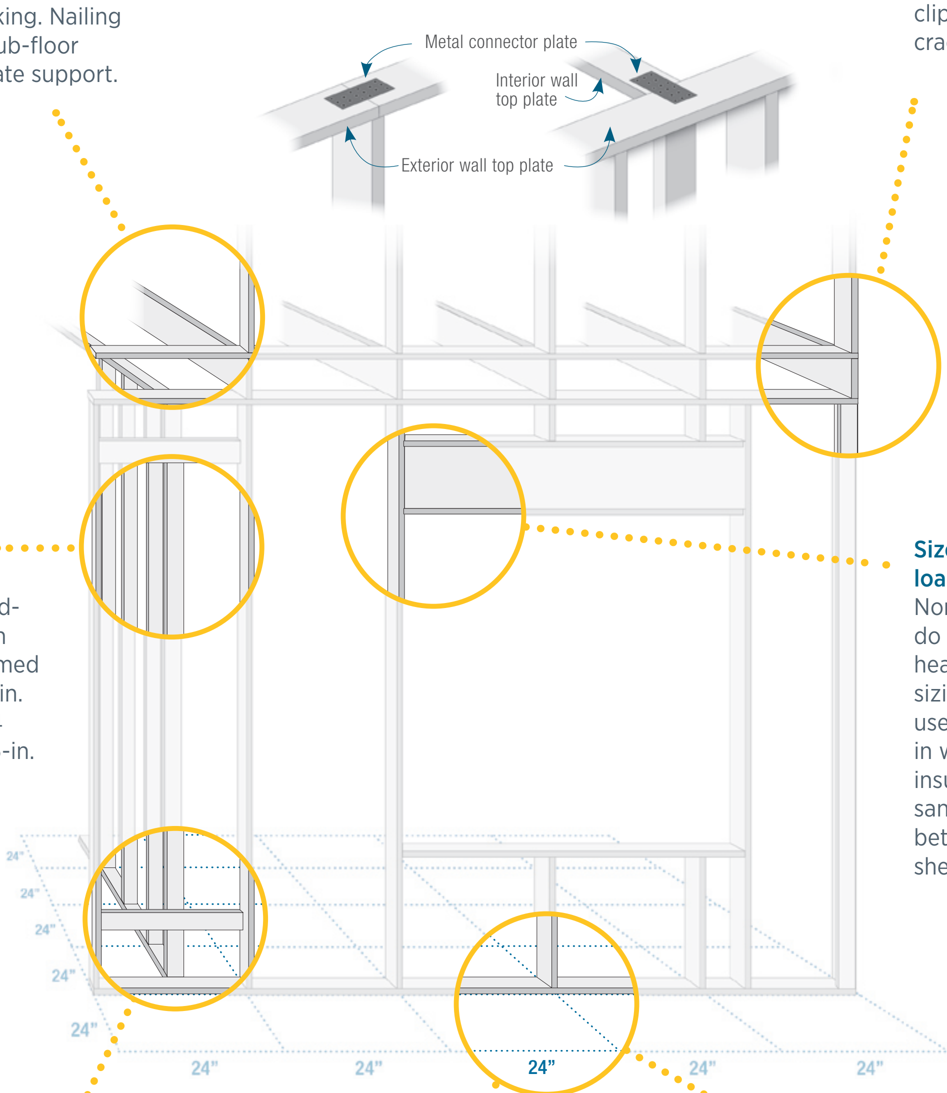
The following tips show examples of framing techniques that can create more open space to hold insulation while reducing framing costs and waste. The following page shows an example of a detailed framing plan. Such detailed plans should be included in construction documents.

Eliminate redundant floor joists: Double floor joists aren't needed below non-load-bearing partitions. Partitions parallel to overhead floor or roof framing can be attached to 2x3 or 2x4 blocking. Nailing directly to the sub-floor provides adequate support.

Align framing members and use a single top plate: Plate sections are cleated together using metal flat plate connectors. Metal connectors can be used at partition wall intersection. Underside blocking is another option for single top plate butt joints. For multistory homes, this may increase the stud size on lower floors to 2x6.

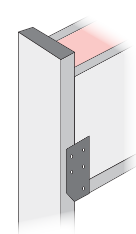
Use two-stud corners: Rather than using a third stud as a nailing edge for interior gypsum board, use drywall clips, a 1x nailer strip, or a recycled plastic nailing strip. Using drywall clips also reduces drywall cracking and nail popping.





Use 2x3s for partitions: Interior, non-load-bearing partition walls can be framed with 2x3s at 24-in. on center or 2x4 "flat studs" at 16-in. on center.

Size headers for actual loading conditions: Non-load-bearing walls do not need structural headers. Proper sizing may allow for the use of insulated headers in which foam insulation is sandwiched between sheathing.



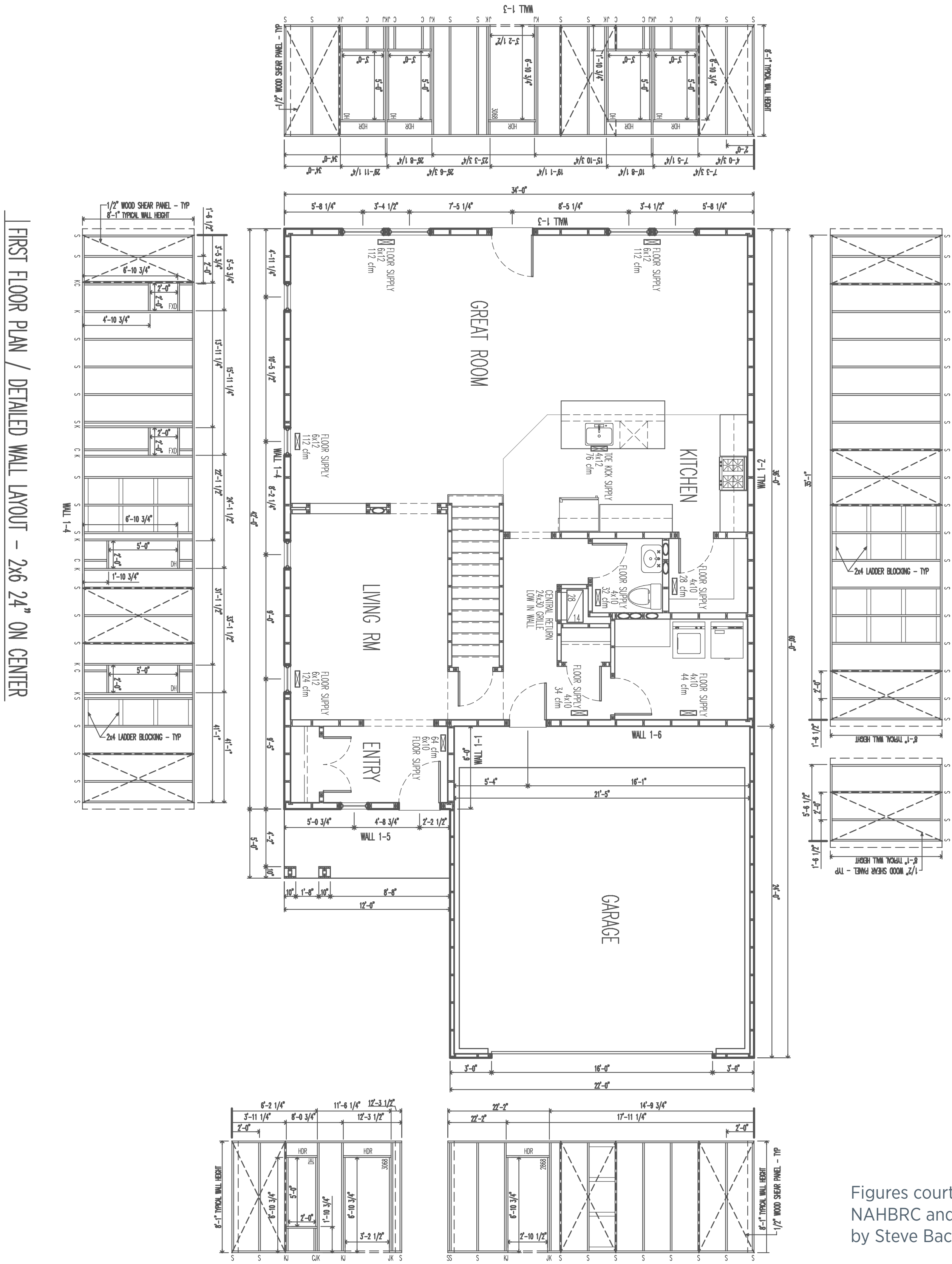
Ladder-block exterior wall intersections: Partitions can be nailed either directly to a single exterior wall stud or to flat blocks inserted between studs.

Two-Foot Module Design: Starting with the foundation, the house footprint should be based on 2-foot increments. Layouts should be based on this 2-foot grid to minimize material waste.

Frame 24-in. on center: 24-in. on center studs are structurally adequate for most residential applications. Even when the stud size must be increased from 2x4 to 2x6, 24-in. spacing can significantly reduce framing lumber needed.

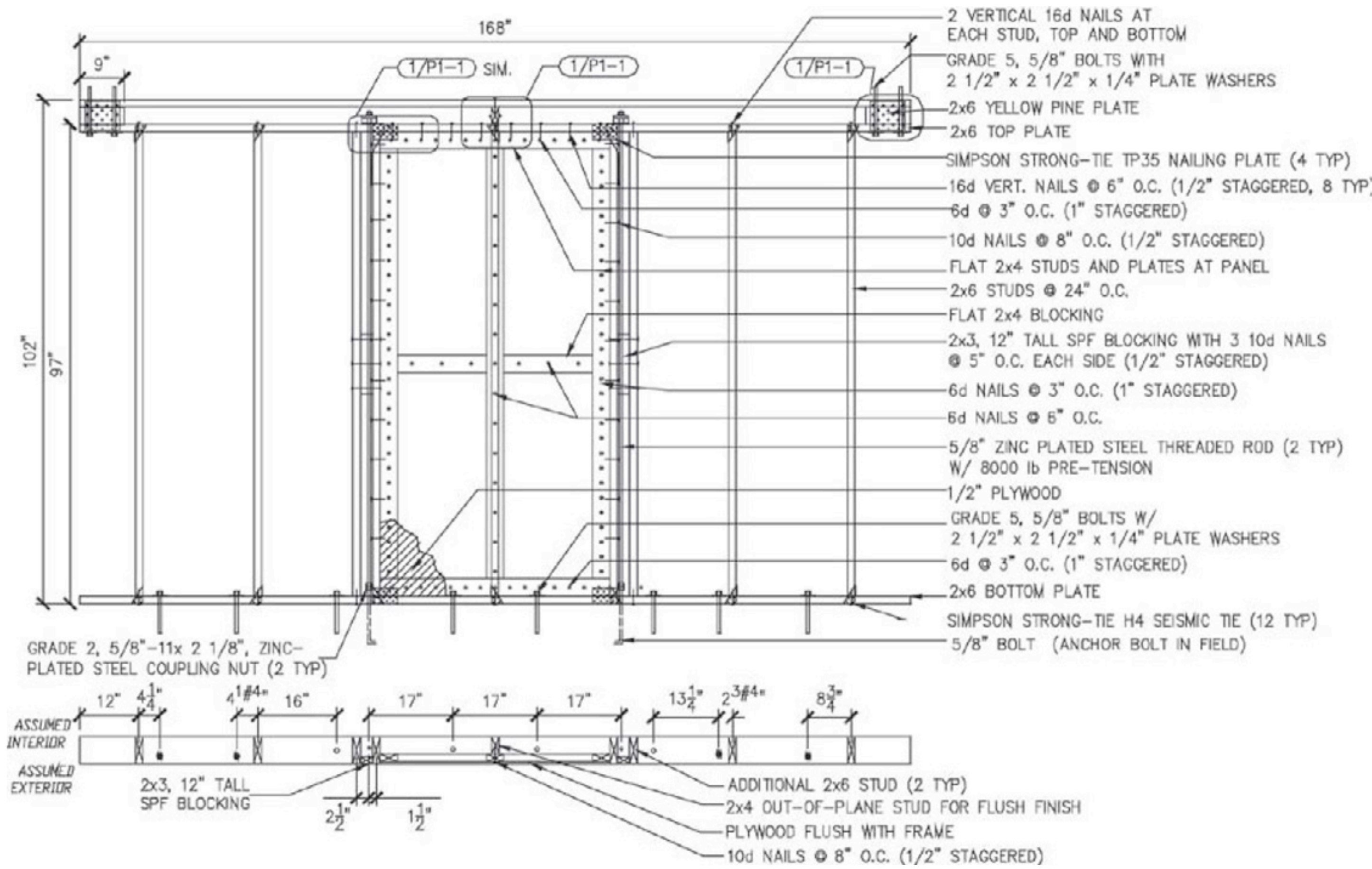
Detailed Wall Framing Layout

Use detailed layouts like this to make sure studs align from first floor to second floor to roof and design on a 24-inch grid.



Figures courtesy of the NAHBRC and prepared by Steve Baczek.

Wall Design for Seismic Regions



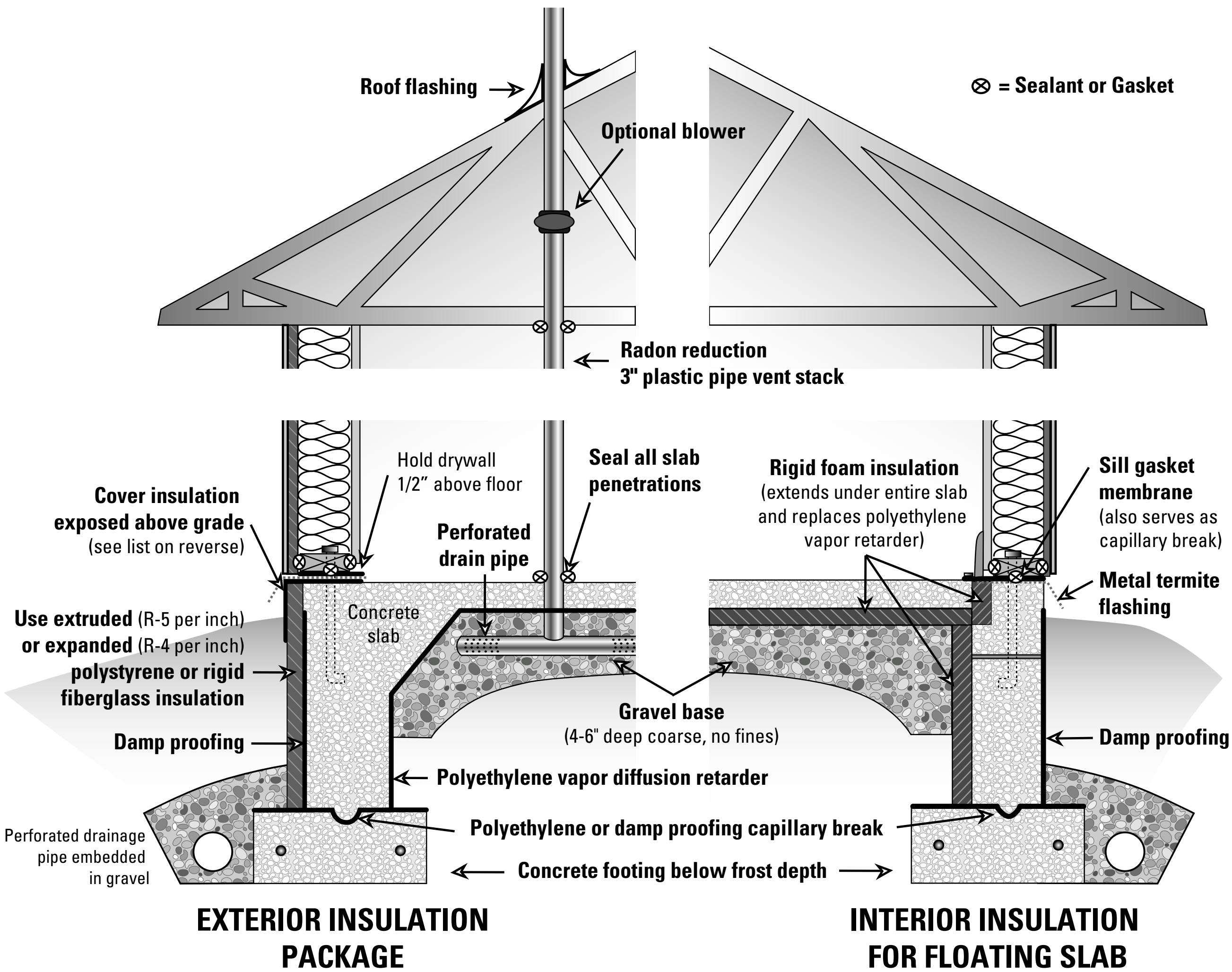
This advanced framing wall panel for seismic regions was designed and tested by Building Science Corporation and the U.S. Army Construction Engineering Research Laboratory (CERL) with funding from DOE's Building America program. The panel was designed to provide lateral capacity that is as good as or better than traditional plywood-sheathed shear panels, while not interfering with the installation of insulation sheathing directly to the framing members. It has an allowable design capacity of 650 lb/ft or 2,600 lb per panel. *(Figure Source: Building Science Corporation)*

Sources and Additional Information

Building Science Corporation. 2009. *Enclosures That Work - Building Profile: Hot-Dry/Mixed-Dry: Sacramento*, 2009, www.buildingscience.com/documents/profiles/etw-sacramento-profile/#F11

NAHB Research Center. "Advanced Framing Techniques: Optimum Value Engineering (OVE)," Available at www.toolbase.org/Construction-Methods/Wood-Framing/advance-framing-techniques accessed 6-4-08

Foundation System, Insulation, Moisture and Air Leakage Control



See more information on the following page.

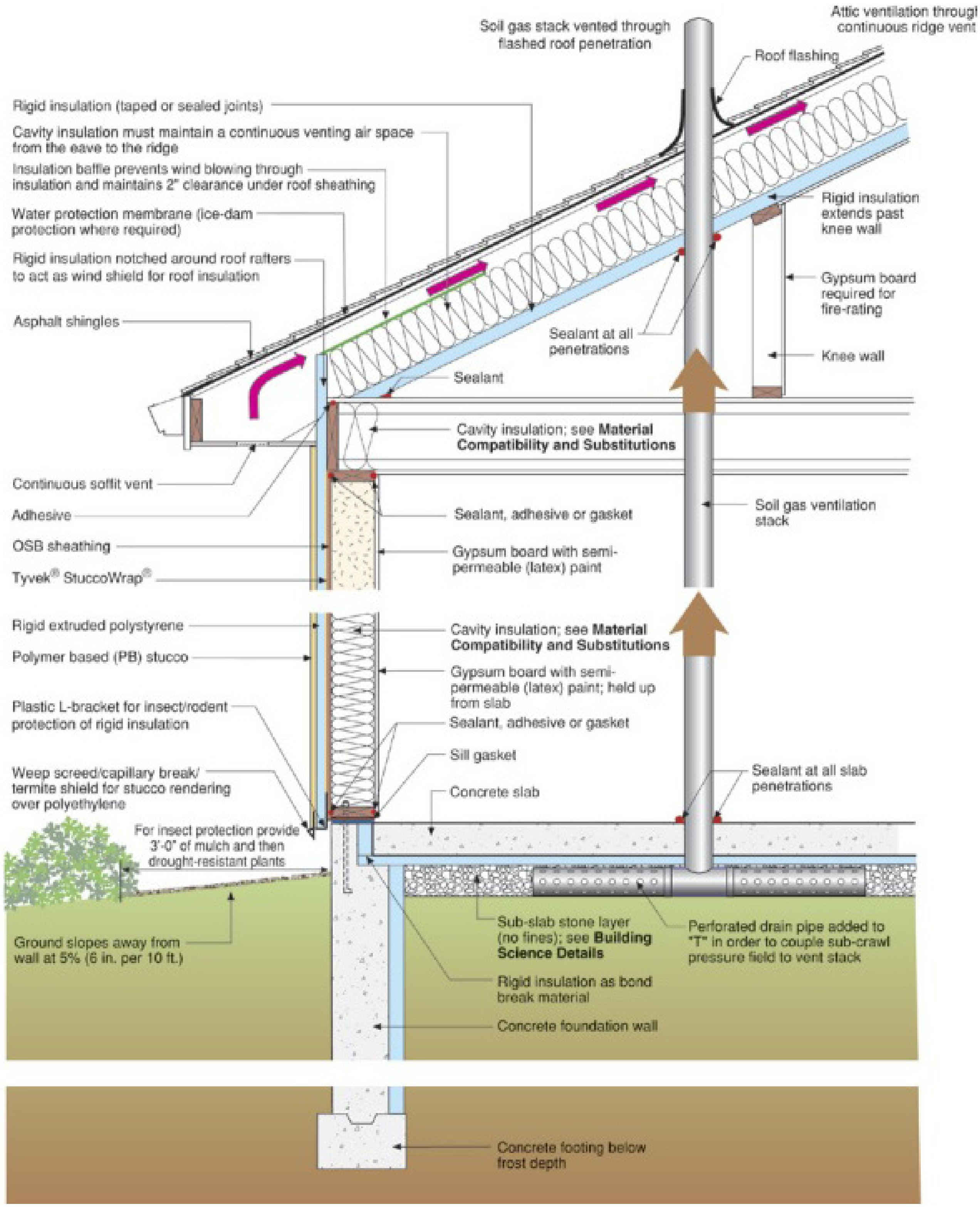


Figure Source: Building Science Corporation

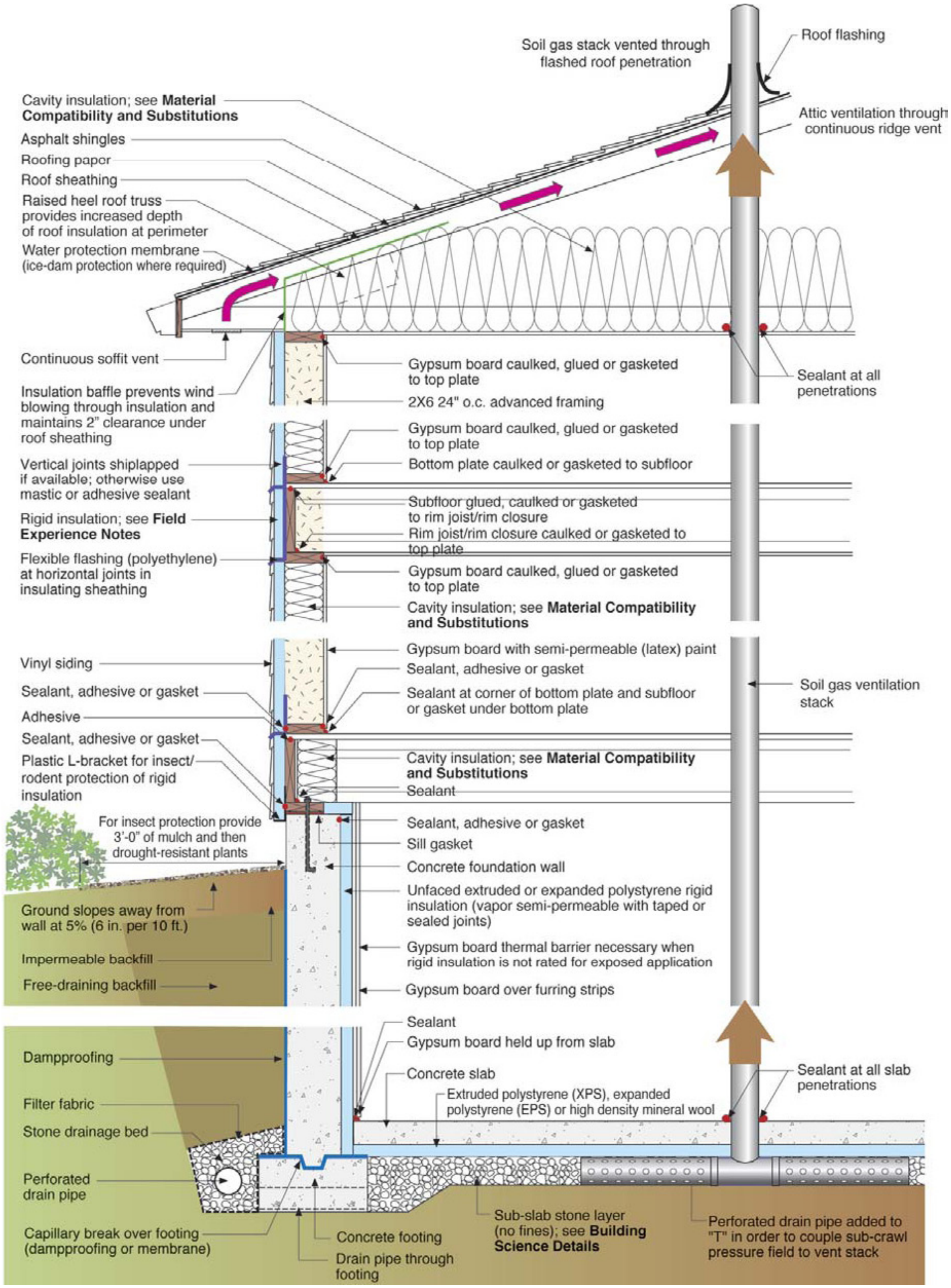


Figure Source: Building Science Corporation

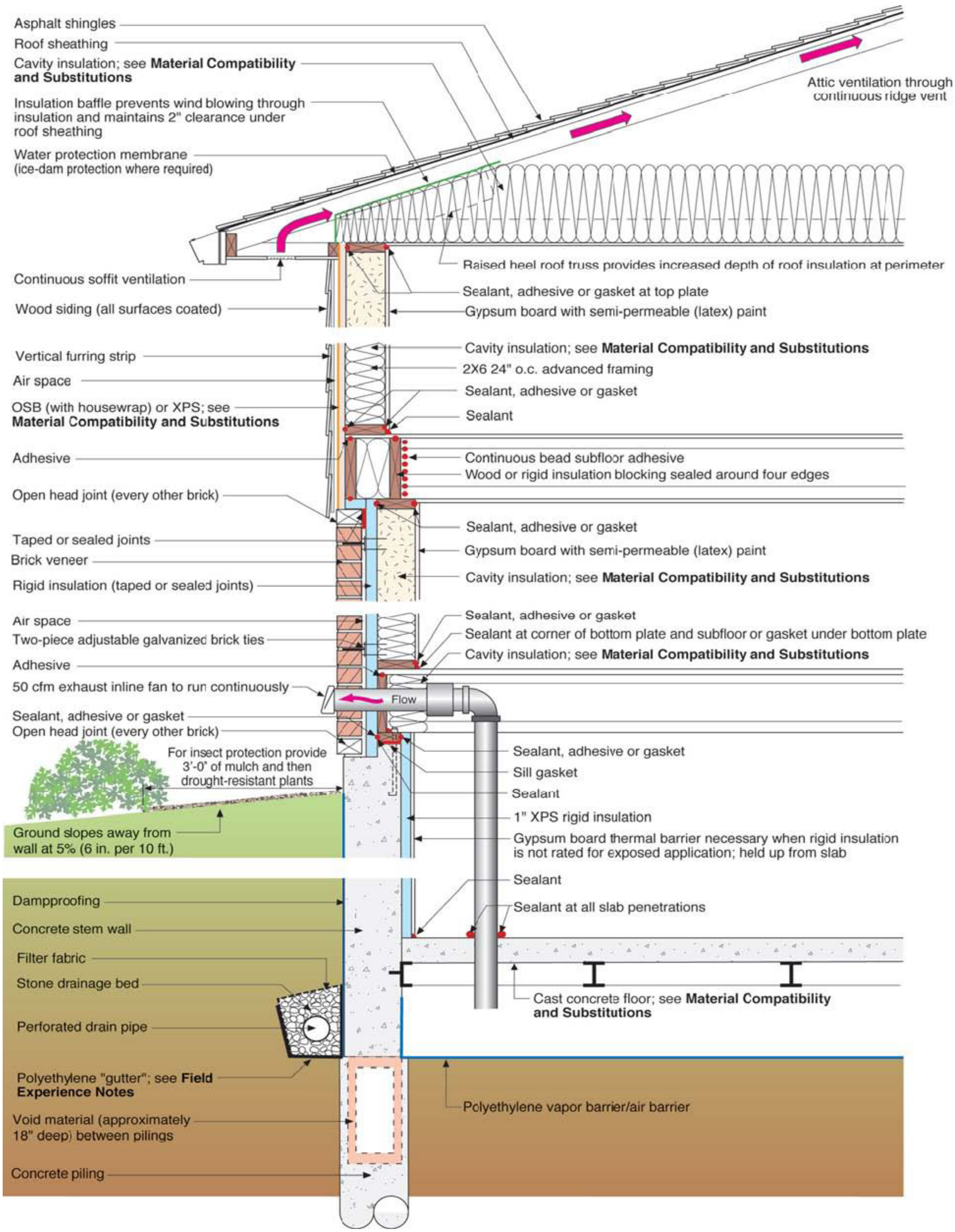


Figure Source: Building Science Corporation

Slab Foundation System, Insulation, Moisture and Air Leakage Control

- Keep all untreated wood materials away from contact with earth and concrete.
- Design the house structure with overhangs, gutters, drainage planes, and flashing to shed rainwater and conduct it away from the house.
- Slope the earth away from the house and ensure that no irrigation strikes near the foundation.
- Use a sill gasket for air sealing.
- Install a protective shield such as metal flashing, plastic L bracket, or a membrane (such as EPDM flexible roofing material*) to block capillary water wicking into the wall from the foundation. The protective shield may also serve as a termite shield.
- Slabs require a foundation drain where the slab (or floor) is located below grade. Install a foundation drain alongside the footing (not above it). The drain should rest in a bed of coarse gravel (no fines) that slopes away from the foundation and is covered with filter fabric.
- Exterior rigid fiberglass insulation may provide a drainage plane that will channel water to the foundation drain and relieve hydrostatic pressure.
- Exterior foundation wall insulation requires a protective coating at above-grade applications. Examples of protective coverings for exterior, above-grade insulation include flashing, fiber-cement board, parging (stucco type material), treated plywood, or membrane material (EPDM* flexible roofing).
- Note that some code jurisdictions may require a gap between exterior insulation and wood foundation elements to provide a termite inspection area.
- Install damp proofing or a polyethylene sheet over the footing to block capillary water wicking into the foundation side wall.
- Install a capillary break and vapor retarder under the entire slab consisting of at least a 6-mil polyethylene sheet or continuous rigid foam insulation approved for below-grade applications, on top of 4 to 6 inches of coarse gravel.
- Install radon control measures (check local requirements and EPA recommendations).

**EPDM stands for Ethylene Propylene Diene Monomer.*

Sources & Additional Information

U.S. DOE, *Technology Fact Sheet on Slab Insulation.*

U.S. EPA, *Building Radon Out: A Step-By-Step Guide oni How to Build Radon Resistent Homes.*

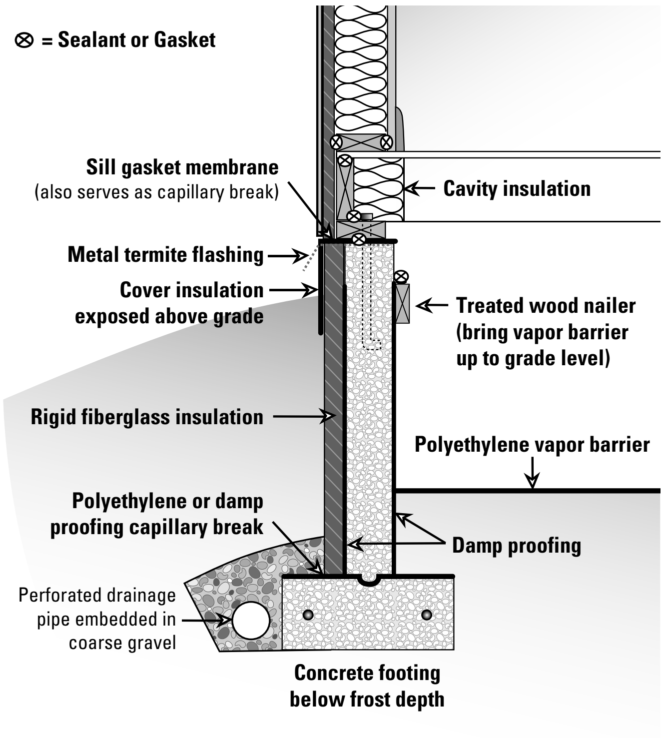
Southface Energy Institute. *Fact Sheets #29: Insulating Foundation and Door*s.

Southface Energy Institute. *Fact Sheets #30: Radon-Resistant Construction for Builders.*
www.southface.org/home/sfpubs/techshts/30_radonresistantconst.pdf

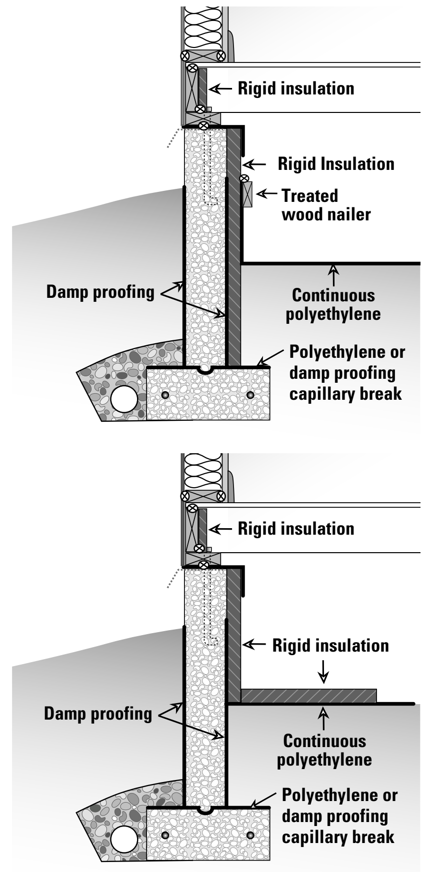
Building Science Consortium. *Introduction to Building Systems Performance: Houses that Work II*.

Basement & Conditioned Crawlspace Insulation, Moisture and Air Leakage Control

EXTERIOR CRAWLSPACE INSULATION

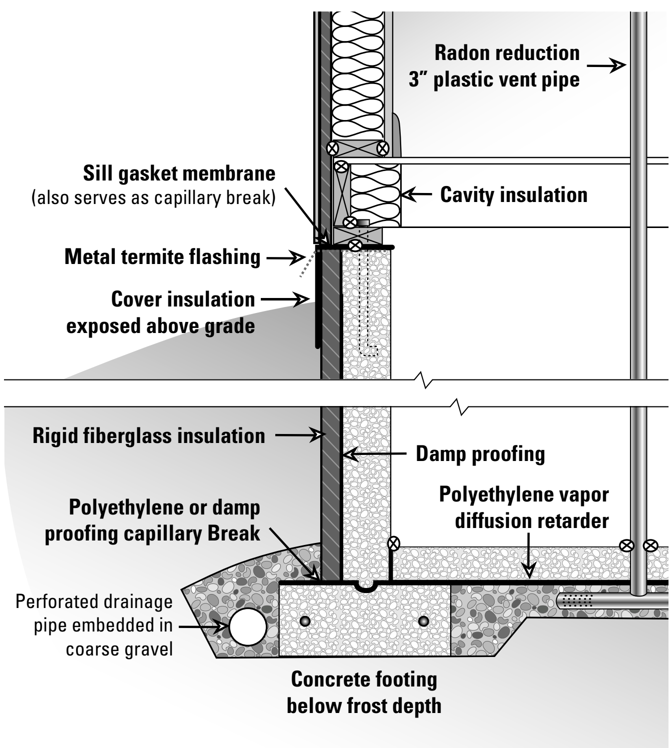


INTERIOR CRAWLSPACE INSULATION

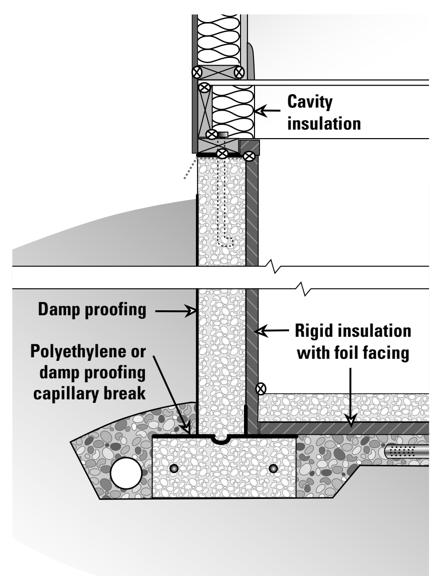


If depth does not extend two feet below grade, place remaining insulation horizontally along the ground.

EXTERIOR BASEMENT INSULATION



INTERIOR BASEMENT INSULATION



See more information on the following page.

Installation Tips

- Exterior and interior insulation approaches may be combined to provide needed insulation levels.
- Properly installed exterior rigid fiberglass insulation provides the best moisture management properties of the available insulation types.
- Interior nailing strips for finished walls should be installed over interior rigid foam insulation (extruded polystyrene is more moisture tolerant than expanded polystyrene) so that the foam is sandwiched between the nailing strip and the basement wall.
- When interior foam insulation is applied directly to foundation walls, seal joints in the foam panels with adhesive or mastic.
- If interior blanket or batt insulation is used, it should be combined with exterior or interior rigid insulation attached directly to the foundation wall. The blanket or batt insulation should be unfaced or have a facing that allows moisture to pass through. In a conditioned basement, the insulation should be covered with drywall that is tightly air sealed to keep interior moist air from condensing on the foundation wall.

Crawlspace and Basement Foundation System Moisture and Air Leakage Control

- Keep all untreated wood materials away from contact with earth and concrete.
- Design the house structure with overhangs, gutters, drainage planes, and flashing to shed rainwater and conduct it away from the house.
- Slope the earth away from the house and ensure that no irrigation strikes near the foundation.
- Damp-proof all below-grade portions of the exterior foundation wall to prevent the absorption of ground water.
- Use a sill gasket for air sealing.
- Install a protective shield such as metal flashing, a plastic L bracket, or a membrane (such as EPDM flexible roofing material*) to block capillary water wicking into the wall from the foundation. The protective shield may also serve as a termite shield.
- Crawlspaces require a foundation drain when the crawlspace floor is located below grade. Always install a foundation drain in basements. Install a foundation drain alongside the footing (not above it). The drain should rest in a bed of coarse gravel (no fines) that slopes away from the foundation and is covered with filter fabric.
- Exterior rigid fiberglass insulation may provide a drainage plane that will channel water to the foundation drain and relieve hydrostatic pressure.
- Exterior foundation wall insulation requires a protective coating at above-grade applications. Examples of protective coverings for exterior, above-grade insulation include flashing, fiber-cement board, parging (stucco type material), treated plywood, or membrane material (EPDM* flexible roofing).
- Note that some code jurisdictions may require a gap between exterior insulation and wood foundation elements to provide a termite inspection area.
- Install damp proofing or a polyethylene sheet over the footing to block capillary water from wicking into the foundation side wall.
- Install a capillary break and vapor retarder under slabs and basement floors consisting of at least a 6-mil polyethylene sheet or continuous rigid foam insulation approved for below-grade applications, on top of 4 to 6 inches of coarse gravel.
- Install radon control measures (check local requirements and EPA recommendations).

**EPDM stands for Ethylene Propylene Diene Monomer.*

Sources & Additional Information

IBACOS. 2002. *Consider the Crawlspace* (www.buildingamerica.gov)

IBACOS. 2002. *Don't Forget About the Basement* (www.buildingamerica.gov)

Lstiburek, Joseph. 2004. *Builders Guide to Cold* Climates (www.eeba.org/bookstore)

U.S. DOE, *Technology Fact Sheet: Basement Insulation* (www.buildingamerica.gov)

U.S. DOE, *Technology Fact Sheet: Crawlspace Insulation* (www.buildingamerica.gov)

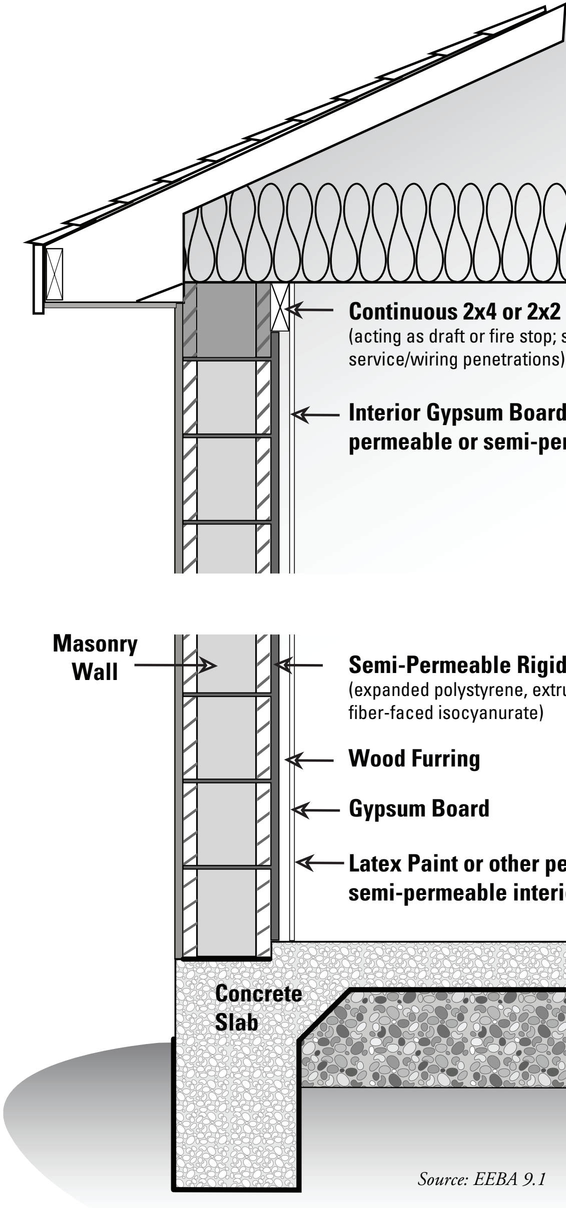
U.S. EPA, *Building Radon Out: A Step-By-Step Guide on How to Build Radon Resistent Homes* (www.epa.gov/1999/iaq/radon)

Yost and Lstiburek. 2002. *Basement Insulation Systems* (www.buildingamerica.gov)

Masonry Construction

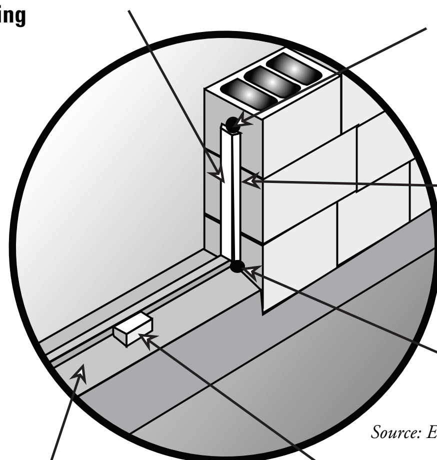
- Semi-vapor permeable rigid insulations used on the interior of wall assemblies should be unfaced or faced with permeable skins. Foil facings and polypropylene skins should be avoided.

- Wood furring should be installed over rigid insulation; the rigid insulation should be continuous over the surface of the wall, except for the 2x4 furring near the ceiling. This blocking attaches directly to the masonry block and is above the insulation, not behind it.

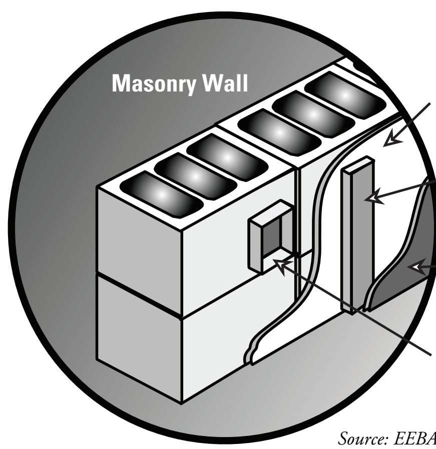


Source: EEBA 9.1

WINDOW SILL DRAINAGE



Source: EEBA 9.5



Source: EEBA 9.7

ELECTRICAL BOX

- Electrical boxes can be surface-mounted, eliminating chiseling or chipping masonry

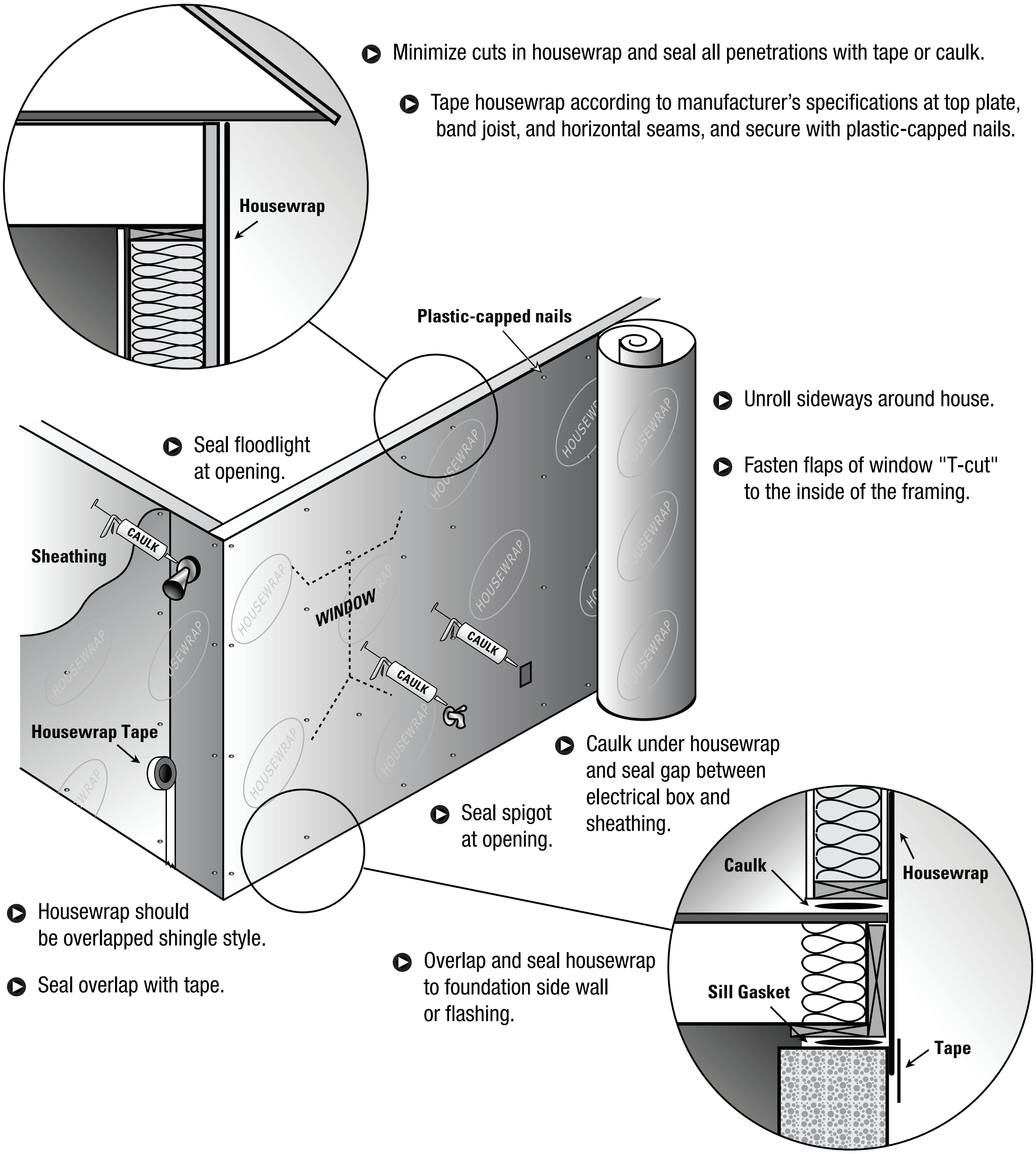
Sources & Additional Information

Building Science Corporation. 2010. "Enclosures That Work: Building Profiles," Building Science Corporation, www.buildingscience.com/doctypes/enclosures-thatwork/etw-building-profiles

Lstiburek, J. W. 2000. *Builders Guides*. Minneapolis, MN. Energy and Environmental Building Association. www.eeba.org.

Housewrap

Example of housewrap strategies



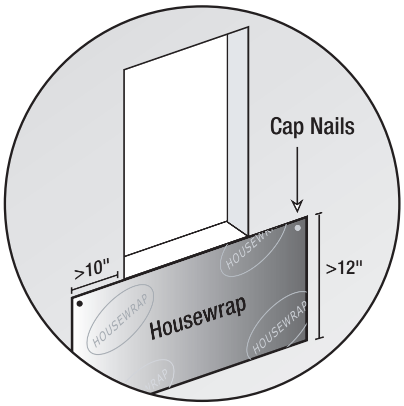
DO's and DON'Ts of Housewrap

- **Do** follow manufacturer's instructions.
- **Do** lap all layers properly—the upper layer should always be lapped over the lower layer.
- **Do** weatherboard-lap horizontal joints at least 6 inches.
- **Do** lap vertical joints 6 to 12 inches (depending on the potential for wind-driven rain).
- **Do** use 1-inch minimum staples or housewrap nails spaced 12 to 18 inches throughout.
- **Do** tape joints with housewrap tape.
- **Do** allow drainage at the bottom of the siding.
- **Do** extend housewrap over the sill plate and foundation joint.
- **Do** install housewrap such that water will never be allowed to flow to the inside of the wrap.
- **Do** avoid complicated details in the design stage to prevent water-intrusion problems.
- When sealant is required:
  - **do** use backing rods as needed,
  - **do** use sealant that is compatible with the climate, and materials it is being applied to,
  - **do** make sure surfaces are clean (free of dirt and loose material).
- **Do** integrate wrap correctly with window flashing so that wrap goes over top edge of flashing.
- **Don't** forget to cover the gable ends.
- **Don't** forget to cover the band joists. If you wrap the wall before standing it, go back and insert a strip of house wrap to cover the band joist. The strip should extend 6 to 12 inches underneath the bottom edge of the wall wrap.
- **Don't** forget to cover outside corners. Do overlap wrap 6 to 12 inches at corners.
- **Don't** rely on caulk or self-sticking tape to "fix" improper lapping of housewrap. Caulk will fail over time.

Window Flashing

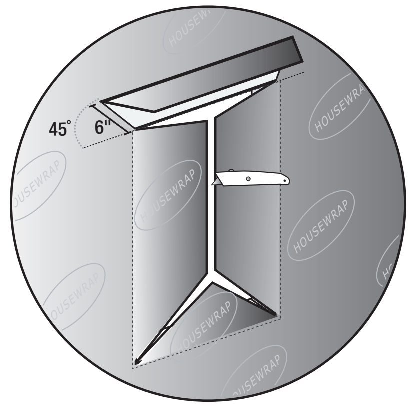
Window flashing details for home with housewrap and plywood or OSB wall sheathing

STEP 1 - IF HOUSEWRAP HAS NOT YET BEEN INSTALLED



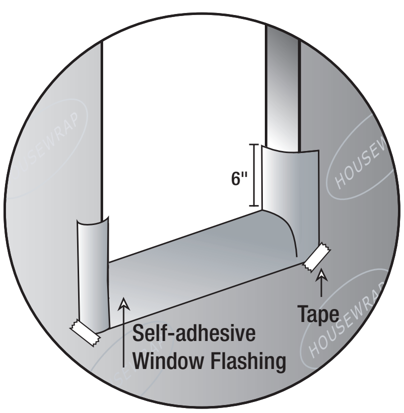
- Apply at least a 12-inch flap, or apron, of building paper or housewrap just below the window sill.
- If the window sill is close to the sill plate, the apron can extend all the way to the sill plate.
- The apron should extend at least 10 inches past the sides of the window opening, or to the first stud in open wall construction.
- Attach only the apron's top edge with cap nails.

STEP 1 - IF HOUSEWRAP HAS BEEN INSTALLED



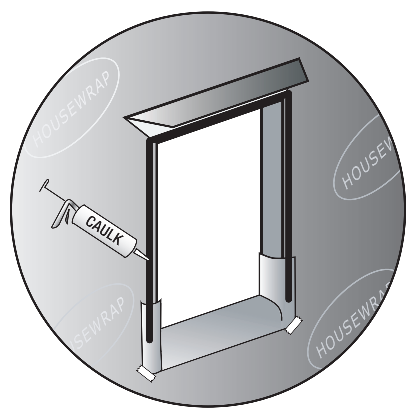
- Cut the housewrap covering the rough opening in the shape of a modified "Y."
- Fold the side and bottom flaps into the window opening and secure.
- Above the window opening, cut a head flap and flip it up to expose sheathing, and loosely tape in place out of the way.

STEP 2 - SILL FLASHING



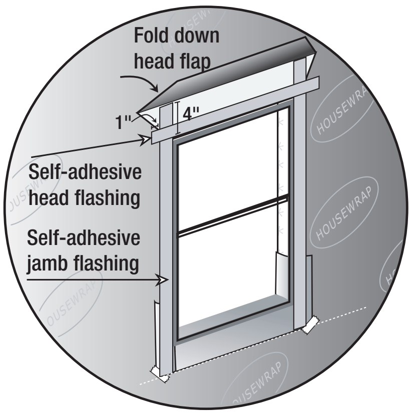
- Install self-adhesive flashing to the sill, ensuring that the flashing extends up jambs at least 6 inches.
- One commercial product comes with two removable strips over the adhesive. Remove the first strip to expose half of the adhesive and apply this area to the sill. Begin pressing in the middle of the sill and work towards the sides. Remove the second strip to expose the adhesive that will be used to apply the flashing below the window to the outside wall.
- Tape down the bottom corners of the flashing.

STEP 3 - JAMB CAULKING



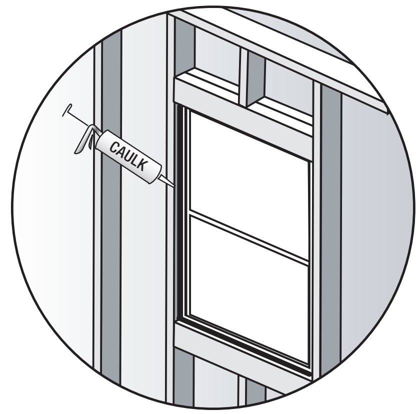
- Caulk the outside edges of the head and side jambs.
- Do not caulk across the sill.
- Install the window using corrosion-resistant nails and following manufacturer's specifications.

STEP 4 - JAMB AND HEAD FLASHING



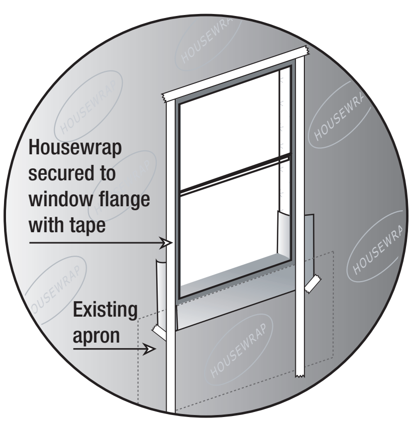
- Install self-adhesive jamb flashing extending 4 inches above the top of the head flange and even with the bottom of the sill flashing.
- Install self-adhesive head flashing extending 1 inch beyond the jamb flashing.
- If housewrap has been installed, be sure that the head flap, when it is folded down, will cover the top of the flashing.

STEP 5 - SEAL ROUGH OPENING GAP



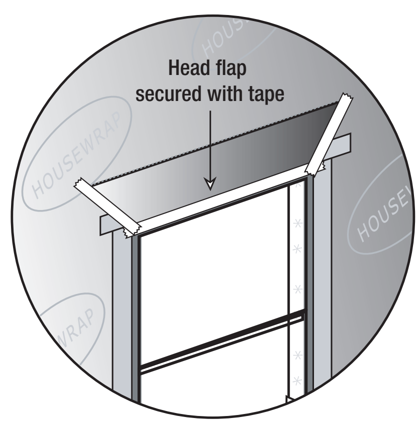
- On the interior side of the window, seal the gap between the window and the rough opening with a backer rod or non-expanding foam and caulk.

STEP 6 - IF APRON WAS INSTALLED



- If an apron was installed under the window, slip the housewrap or building paper under the apron.
- Tape the edges where the housewrap meets the window flange if housewrap is installed after flashing.
- If building paper is used, embed the edges in a bead of sealant where the paper meets the window flange.

STEP 6 - IF HEAD FLAP WAS CREATED

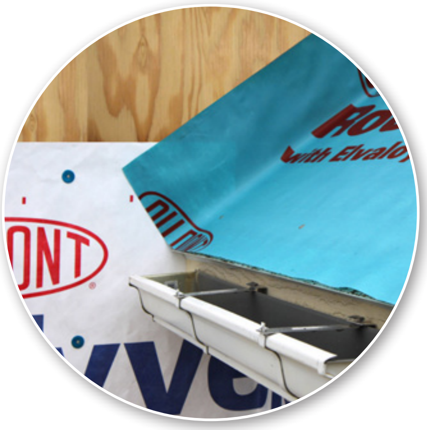


- If a head flap was created, fold it over the head flashing and tape across the top window flange and the 45° angle seams.

Wall-to-Roof Flashing

Kick-Out Diverter Flashing Details

Water runoff from roof-wall intersections can flow down the exterior wall and eventually find its way into the wall where it can cause serious damage. Anywhere roof sections adjoin wall sections, kick-out flashing should be used to divert water away from the walls and preferably into rain gutters where it can be carried down and away from the structure.



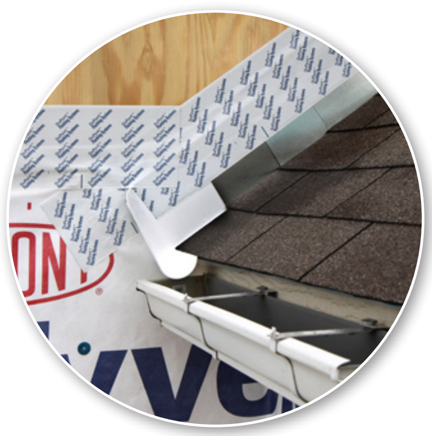
STEP 1 Apply drip edge and roof underlayment over roof deck. Continue lapping up the sidewall and over the water-resistive barrier (in this case housewrap) a minimum of 6 inches.

STEP 2 Install shingle starter strip at roof eave in accordance with roofing manufacturer's instructions.

- Place seamless one-piece of non-corrosive kick-out diverter flashing as the first piece of step flashing.
- Slide kick-out diverter up roof plane until the starter trough stops at the shingle starter strip.
- The diverter must be flat on the roof and flush to the sidewall.
- Fasten and seal diverter to the roof deck and starter strip. (Do not fasten to the sidewall.)

STEP 3 Place first shingle and next section of sidewall flashing over the up-slope edge of diverter, lapping a minimum of 4 inches over diverter. (Sidewall flashing height requirement should be determined by design professional and local building codes.)

STEP 4 Install remaining sidewall flashing, appropriate counter flashing, and shingles in accordance with manufacturer's instructions.



STEP 5 Apply self-adhesive flashing over top of wall flashing, diverter, and housewrap.

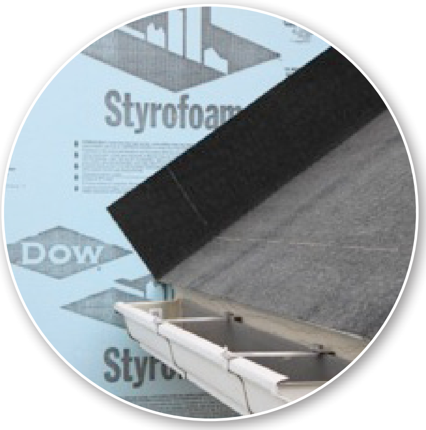
STEP 6 Install house wrap; cut the house wrap to fit over the self-adhesive flashing and sidewall flashing.

STEP 7 Apply siding over housewrap.

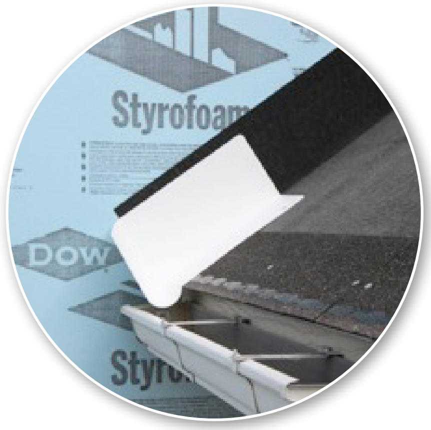
Wall-to-Roof Flashing

Kick-Out Diverter Flashing Details - Rigid Foam Insulation Installed as a Water-Resistive Barrier

Water runoff from roof-wall intersections can flow down the exterior wall and eventually find its way into the wall where it can cause serious damage. Anywhere roof sections adjoin wall sections; kick-out flashing should be used to divert water away from the walls and preferably into rain gutters where it can be carried away from the structure.

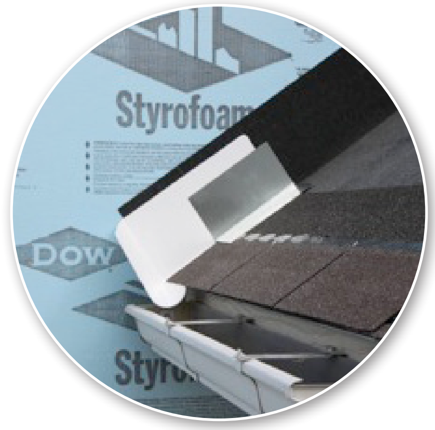


STEP 1 Apply drip edge and roof underlayment over roof deck and continue lapping up the sidewall and over the water-resistive barrier (in this case rigid foam insulation) a minimum of 7 inches.



STEP 2 Install shingle starter strip at roof eave in accordance with roofing manufacturer's instructions.

- Place seamless, one-piece, non-corrosive kick-out diverter flashing as the first piece of step flashing.
- Slide kick-out diverter up roof plane until the starter trough stops at the shingle starter strip.
- Diverter must be flat on the roof and flush to the sidewall.
- Fasten and seal diverter to the roof deck and starter strip. (Do not fasten to the sidewall.)



STEP 3 Place first shingle and next section of sidewall flashing over up-slope edge of diverter, lapping a minimum of 4" over diverter.

(Sidewall flashing height requirement should be determined by design professional and local building codes.)

STEP 4 Install remaining sidewall flashing, appropriate counter flashing and shingles in accordance with manufacturer's instructions.

STEP 5 Apply self adhesive flashing over top of wall flashing, diverter and rigid foam insulation.

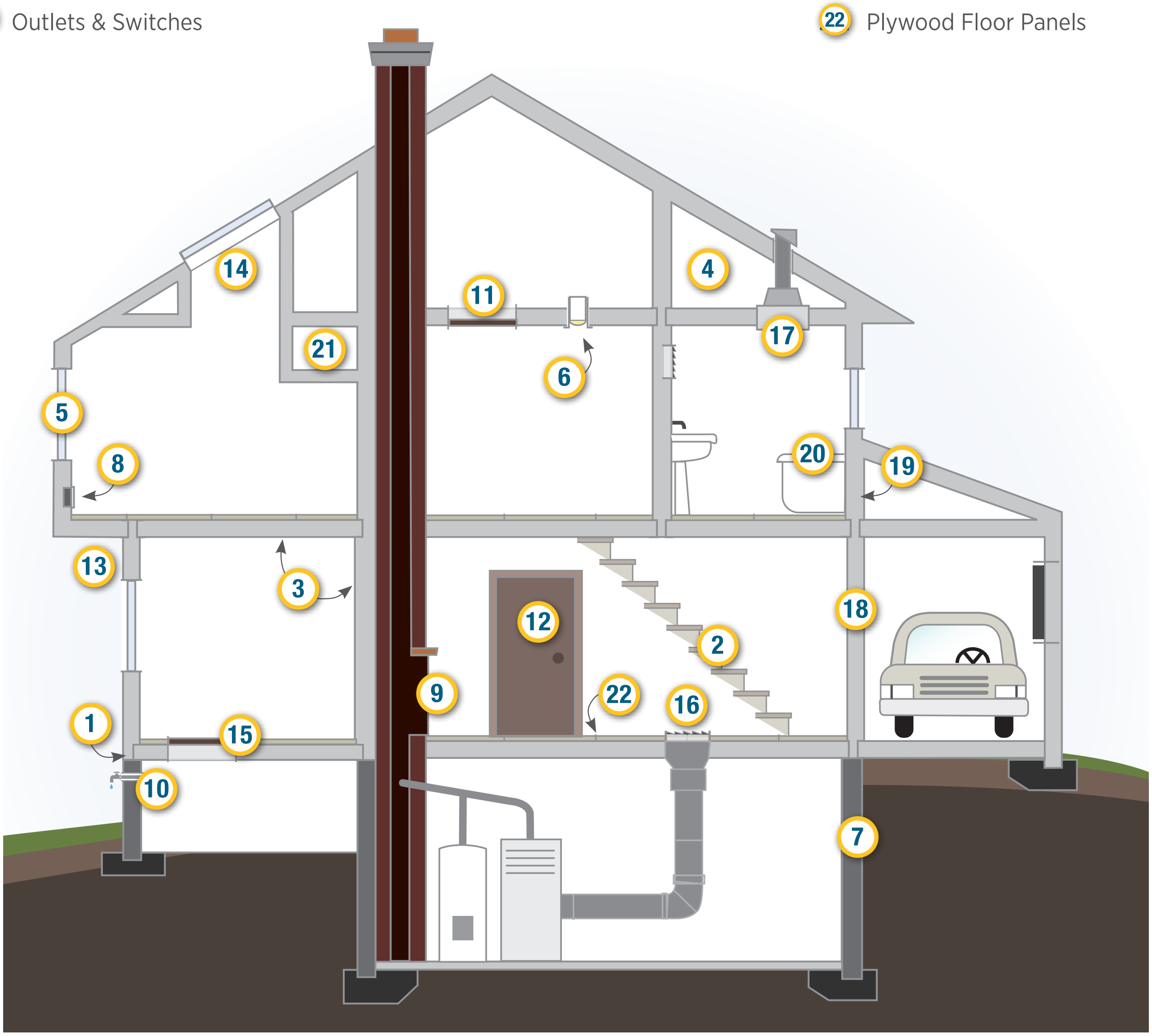
STEP 6 Apply construction tape over the self-adhered flashing.

STEP 7 Apply siding over rigid foam insulation.

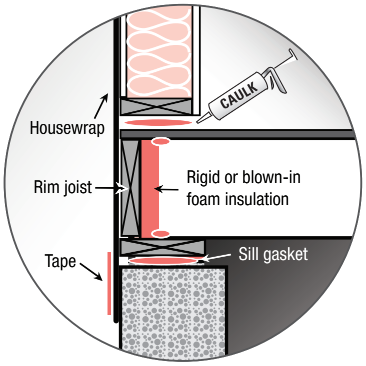
Interior Air Sealing

Conventional construction requires tracking down and sealing multiple air leaks that ultimately lead to or through the exterior shell.

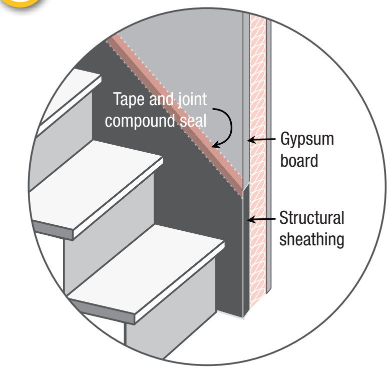
1. Sill Plate & Rim Joist
2. Stairs
3. Wall & Ceiling Drywall
4. Kneewalls
5. Windows
6. ICAT Can Light
7. Electric Circuit Box
8. Outlets & Switches
9. Fireplace
10. Plumbing Penetrations
11. Attic Access
12. Doors
13. Cantilever
14. Skylight
15. Crawlspace Access
16. Registers
17. Exhaust Fan
18. Garage Common Wall
19. Wall Adjoining Cavity
20. Tub
21. Interior Soffit
22. Plywood Floor Panels



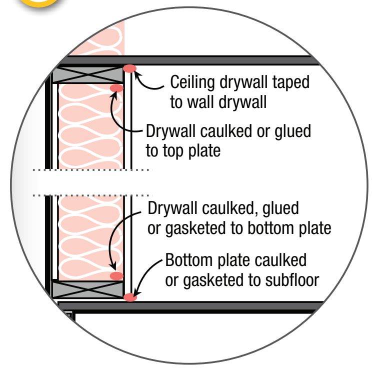
1 Sill Plate & Rim Joist



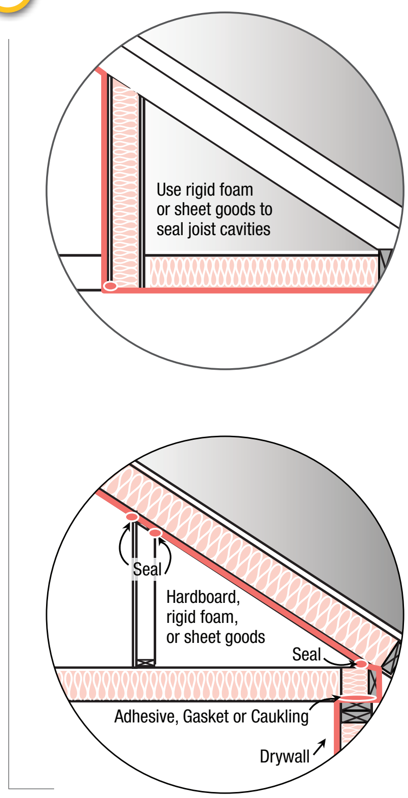
2 Stairs



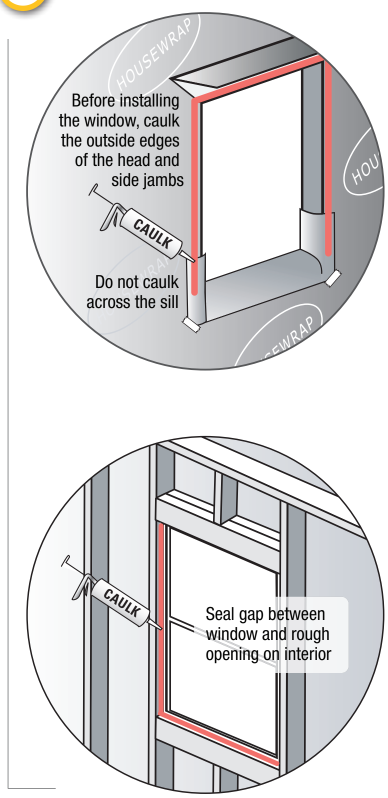
3 Wall & Ceiling Drywall



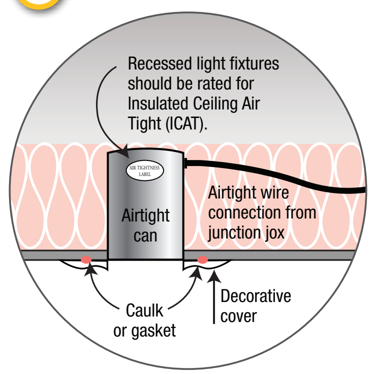
4 Kneewalls



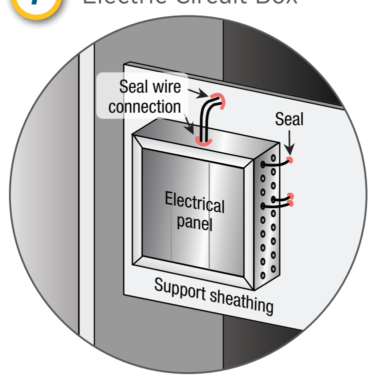
5 Windows



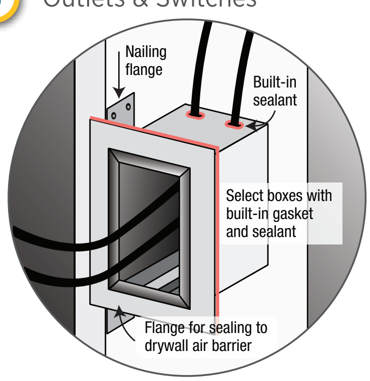
6 ICAT Can Light



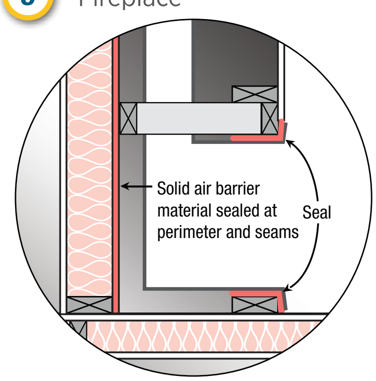
7 Electric Circuit Box



8 Outlets & Switches

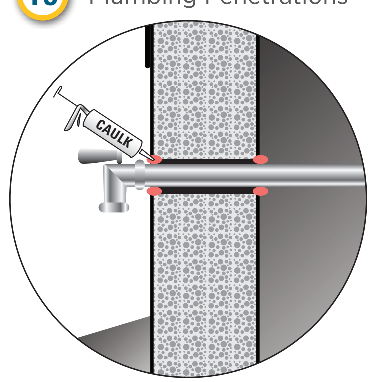


9 Fireplace

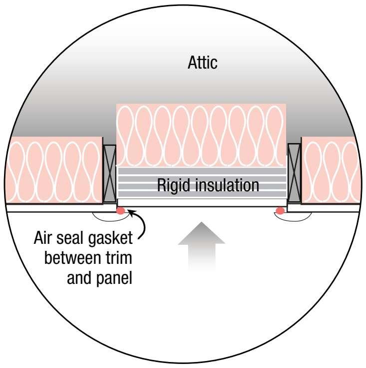


Direct vent fireplace through outside wall; no chimney needed, but seal fireplace alcove.

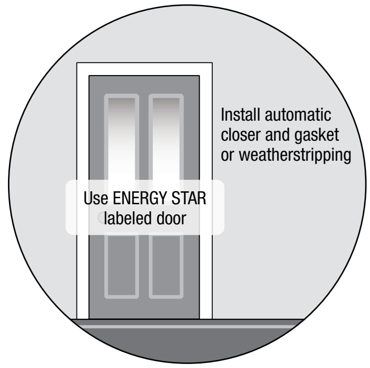
10 Plumbing Penetrations



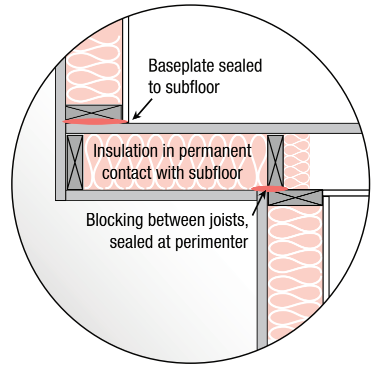
11 Attic Access



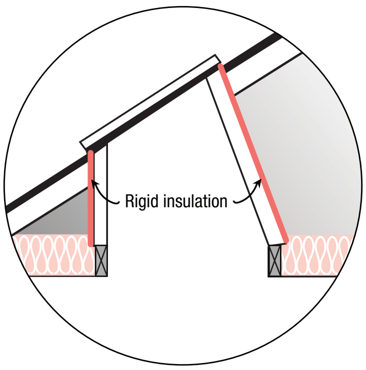
12 Doors



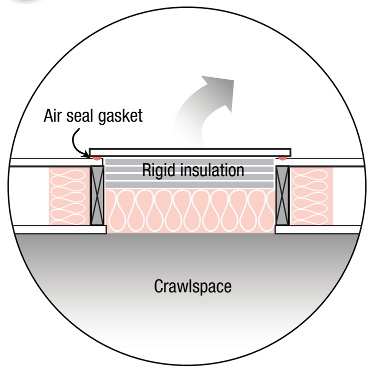
13 Cantilever



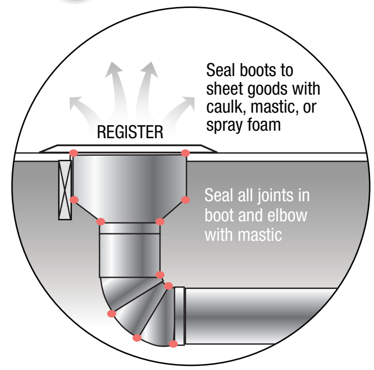
14 Skylight



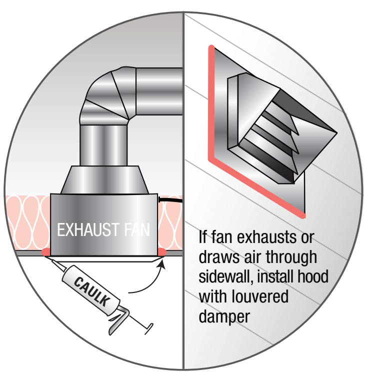
15 Crawlspace Access



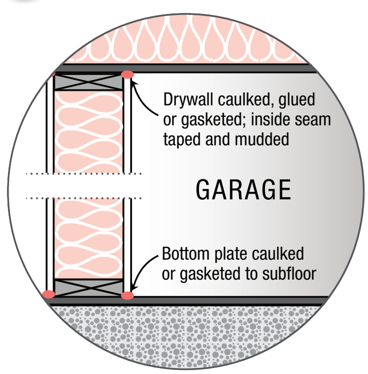
16 Registers



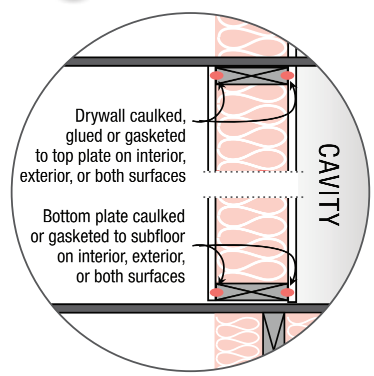
17 Exhaust Fan



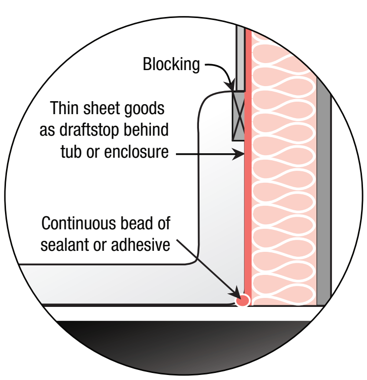
18 Garage Common Wall



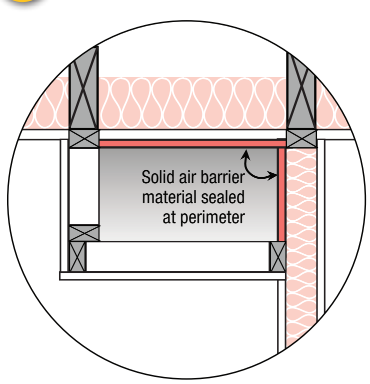
19 Wall Adjoining Cavity



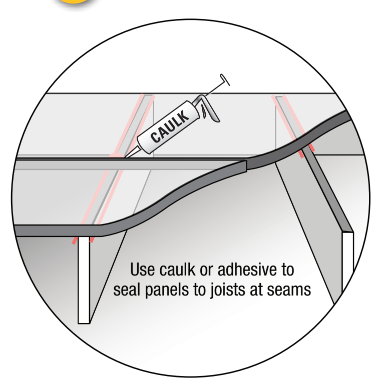
20 Tub



21 Interior Soffit



22 Plywood Floor Panels

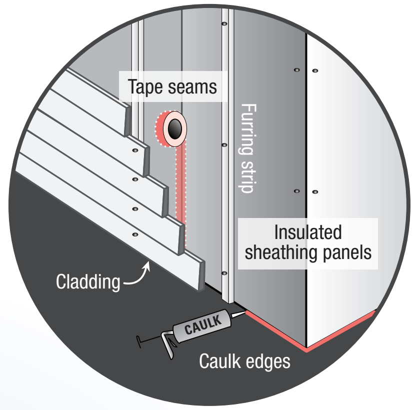


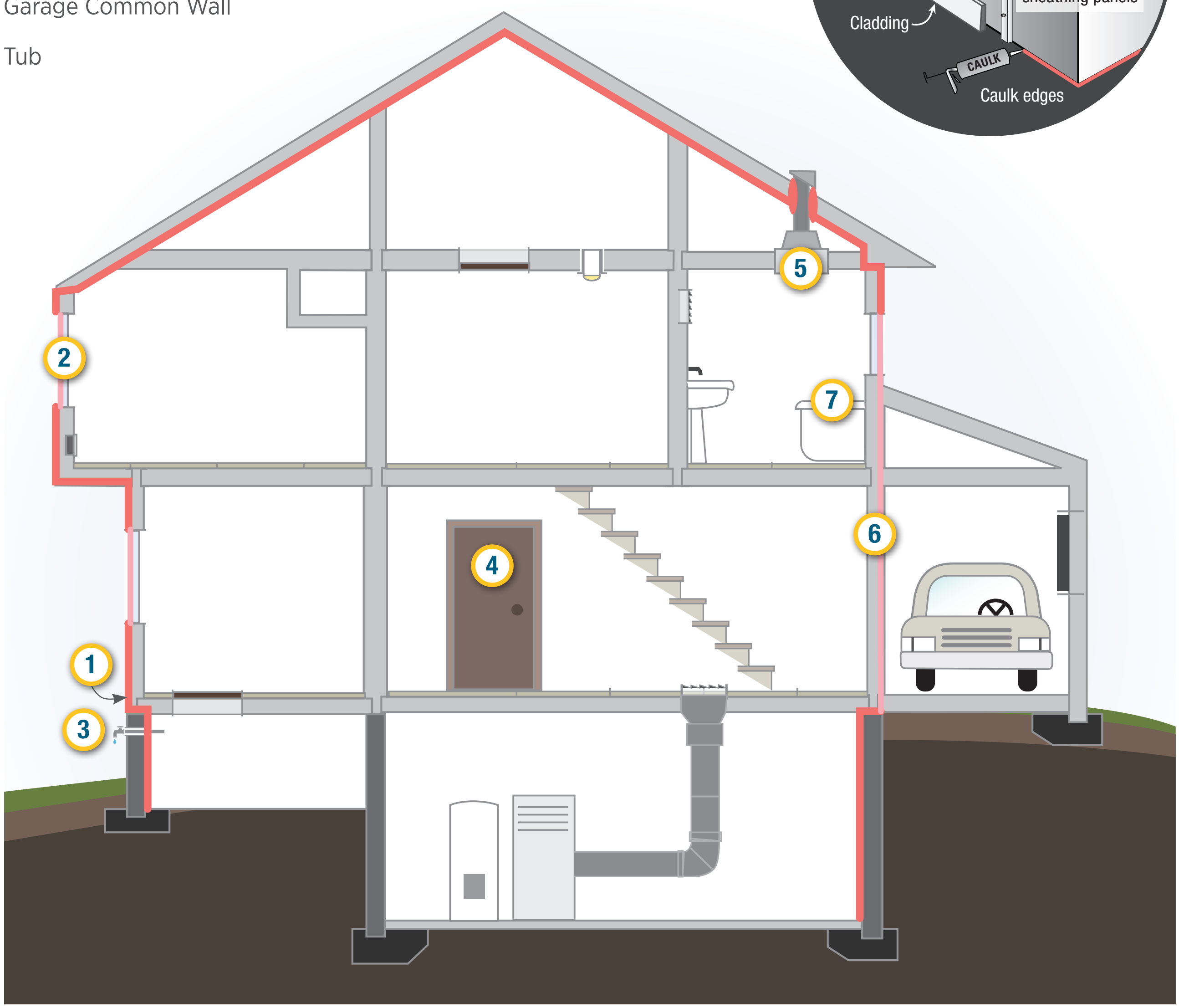
Exterior Air Sealing with Insulating Sheathing Panels

This figure shows an approach to construction used in some Building America homes. The red line represents the thermal boundary, which is provided here by rigid insulation that is on the external side of the walls and the interior side of the foundation walls and roof. This exterior insulating sheathing provides both an air and thermal barrier for the walls. The non-vented attic is sealed and insulated along the roofline. Particular attention is paid to the intersection of the foundations, walls, and roof. Sealed combustion furnaces and water heaters do not require a vertical chimney.

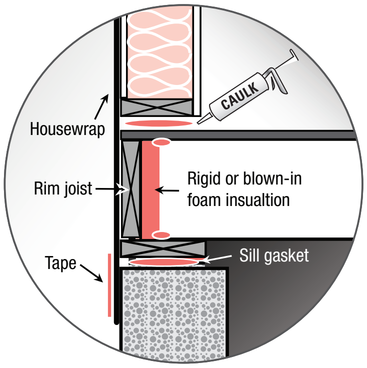
1. Sillplate & Rim Joist
2. Windows
3. Plumbing Penetrations
4. Doors
5. Exhaust Fan
6. Garage Common Wall
7. Tub

Insulating Sheathing Detail

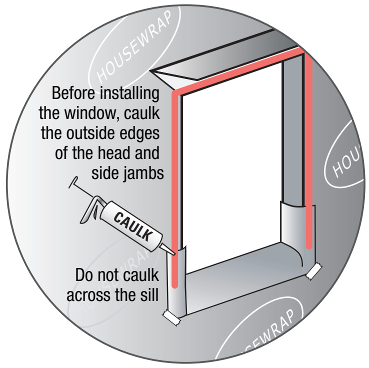


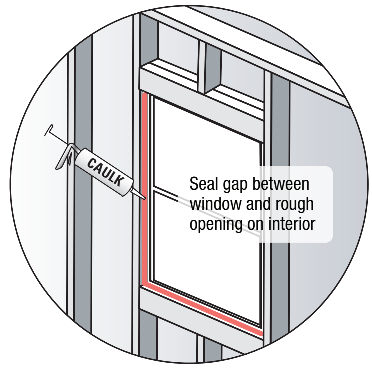


1 Sill Plate & Rim Joist

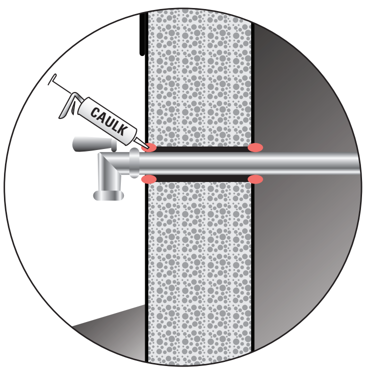


2 Windows

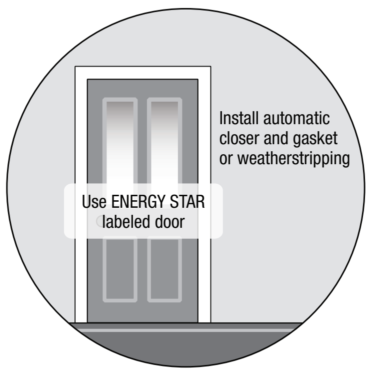




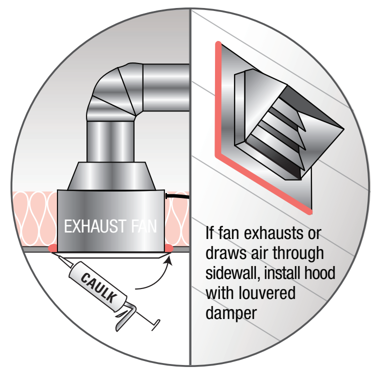
3 Plumbing Penetrations



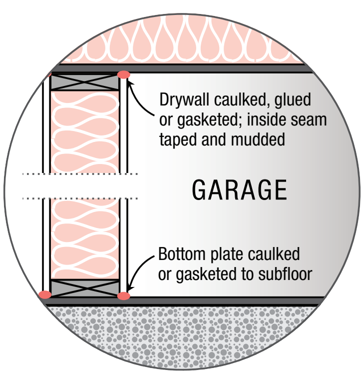
4 Doors



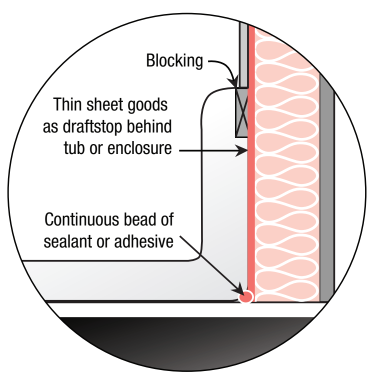
5 Exhaust Fan



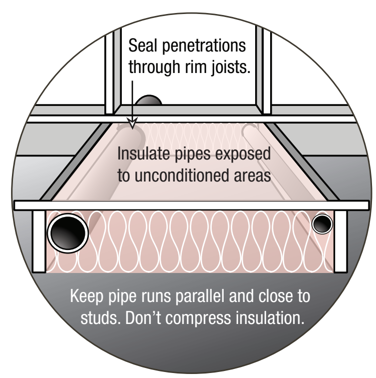
6 Garage Common Wall



7 Tub

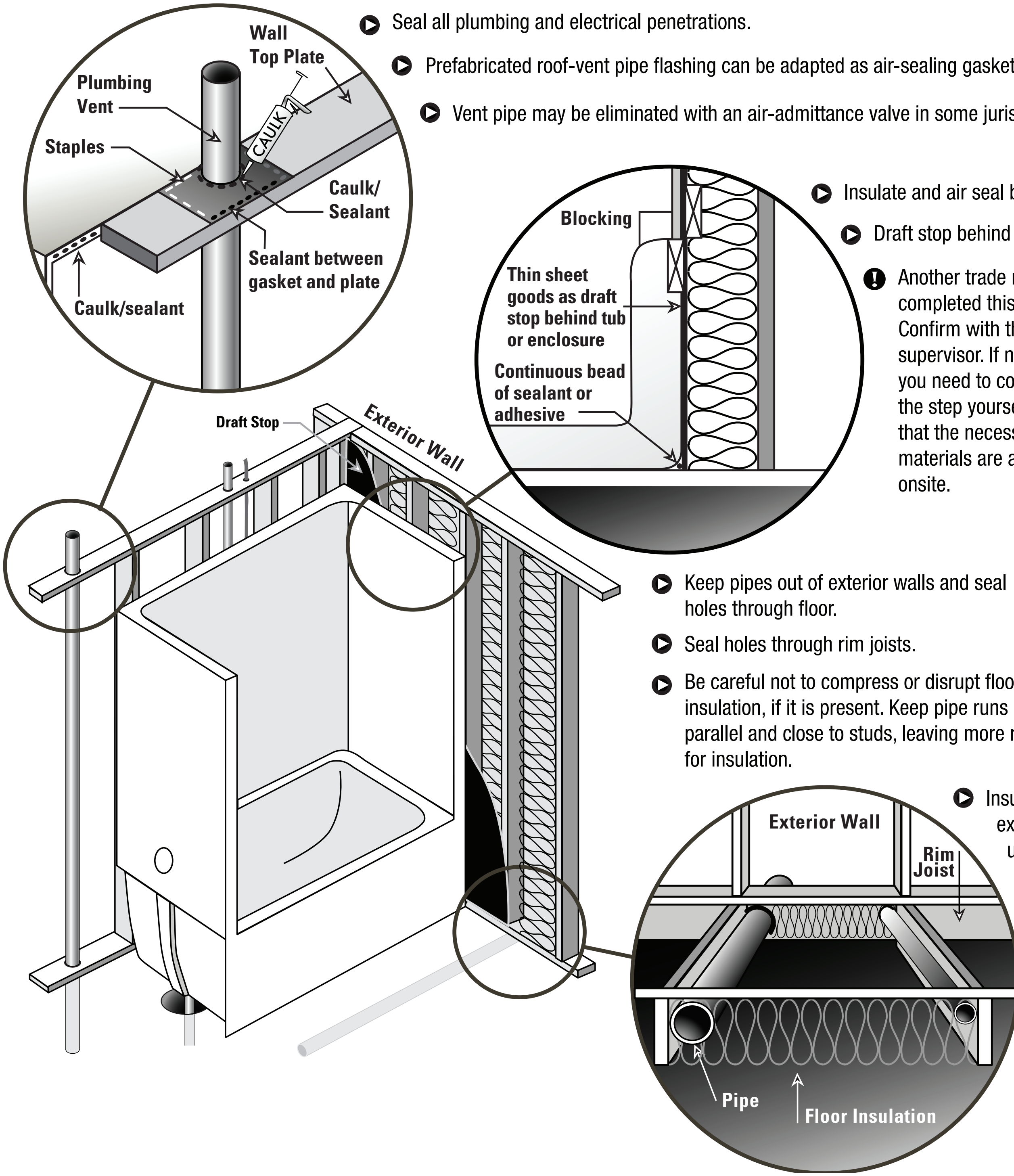


Plumbing Floor Penetrations



Keep pipes out of exterior walls and seal penetrations through floor.

Plumbing Air Sealing



- Seal all plumbing and electrical penetrations.
- Prefabricated roof-vent pipe flashing can be adapted as air-sealing gaskets.
- Vent pipe may be eliminated with an air-admittance valve in some jurisdictions.
- Insulate and air seal behind tub.
- Draft stop behind enclosure.
- ! Another trade may have completed this step. Confirm with the site supervisor. If not, and you need to complete the step yourself, ensure that the necessary materials are available onsite.
- Keep pipes out of exterior walls and seal holes through floor.
- Seal holes through rim joists.
- Be careful not to compress or disrupt floor insulation, if it is present. Keep pipe runs parallel and close to studs, leaving more room for insulation.
- Insulate pipes exposed to unconditioned areas

Sources & Additional Information

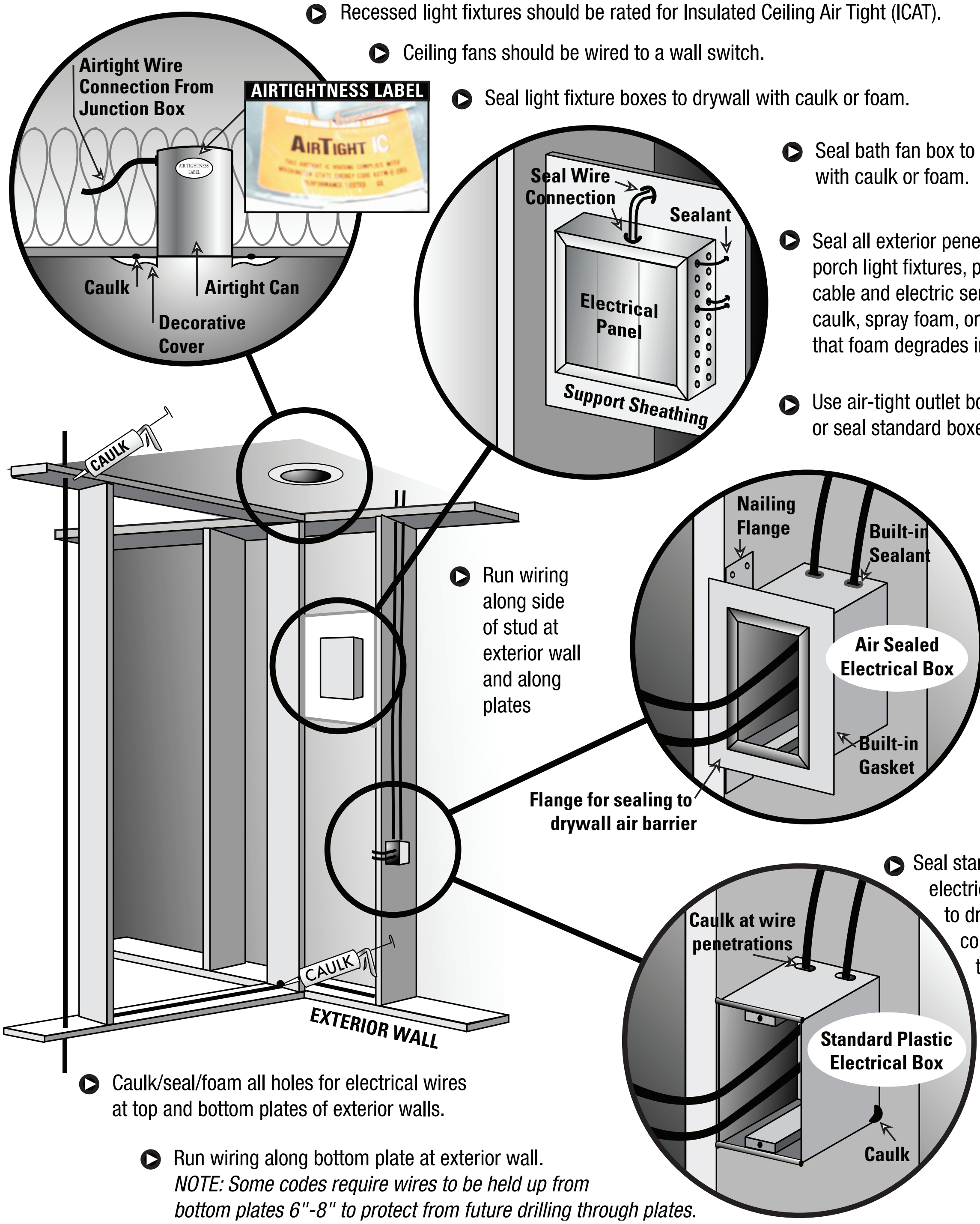
Lstiburek, J. W. 2000. *Builders Guides*. Energy and Environmental Building Association. www.eeba.org.

U.S. DOE. *Technology Fact Sheet on Air Sealing*.

NAHB Research Center. www.toolbase.org: click on *New Building Technology > Plumbing > Distribution Systems > Air Admittance Vents*

Electrical Air Sealing

- Recessed light fixtures should be rated for Insulated Ceiling Air Tight (ICAT).
- Ceiling fans should be wired to a wall switch.
- Seal light fixture boxes to drywall with caulk or foam.
- Seal bath fan box to drywall with caulk or foam.
- Seal all exterior penetrations, such as porch light fixtures, phone, security, cable and electric service holes, with caulk, spray foam, or gaskets - note that foam degrades in sunlight.
- Use air-tight outlet boxes or seal standard boxes.
- Run wiring along side of stud at exterior wall and along plates
- Seal standard plastic electrical box at face to drywall with joint compound or cover the plate gasket with caulk or foam.



- Caulk/seal/foam all holes for electrical wires at top and bottom plates of exterior walls.
- Run wiring along bottom plate at exterior wall. *NOTE: Some codes require wires to be held up from bottom plates 6"-8" to protect from future drilling through plates.*

Sources & Additional Information

Lstiburek, J.W. 2000. *Builder Guide Hot-Humid Climates*. Minneapolis, MN: Energy and Environmental Building Association (ww.eeba.org).

U.S. DOE. *Technology Fact Sheet on Air Sealing* (www.eere.energy.gov/buildings/documents/pdfs/26448.pdf).

Installing Fiberglass Batt Insulation

Always:

- ☐ Avoid gaps, tight turns, and compressions.
- ☐ Cut insulation to fit snugly in non-standard spaces.
- ☐ Slit batts to fit around wiring and plumbing.
- ☐ Notch out around electrical boxes and use scraps to fill in behind.
    - Install long runs first – then use scraps to fill in smaller spaces and gaps.
    - Use unfaced batts in humid climates.
    - Even if blown-in insulation is to be generally applied, use fiberglass batts to insulate areas that will be inaccessible to the blown-in insulation, such as behind bath enclosures and fireplaces.

Walls:

- ☐ Friction-fit the batts in place until covered by drywall or sheathing.
- ☐ Insulate before installing stairs, tubs, and other features that will block access.

Knee Walls:

- ☐ Seal knee wall to create a continuous air barrier. Close air gaps between floor joists under attic rooms. Insulate and air seal the rafter space along the sloping ceiling of the knee wall attic space or insulate and air seal the roofline, wall, and floor.
- ☐ Rafters should receive R-19 or R-30 insulation.
- ☐ Cover rafters with a sealed air barrier (such as drywall or foam board).
- ☐ Caulk the barrier to the top plate of the wall below the attic space and to the top plate of the knee wall itself.
- ☐ Seal all other cracks and holes.

Ceilings:

- ☐ Insulate and seal the attic access door
- ☐ Install insulation over ICAT-rated recessed cans.
- ☐ Verify ventilation pathways.
- ☐ Install insulation baffles between attic rafters in vented attics.

Band Joists:

- ☐ Place insulation in the cavities between joists and subfloor.
- ☐ Caulk bottom plate to subfloor.
- ☐ Caulk band joist to subfloor and plates and insulate.
- ☐ Caulk bottom plate to subfloor.

Under Floor Insulation:

- ☐ An insulated, unvented crawlspace is preferred rather than insulating under the floor. If under-floor insulation is to be used, it can be held in place with metal staves, lathe, stainless steel wire, or twine.
- ☐ If truss systems are used under floors, an approach better than batt insulation is to install netting or rigid insulation to the underside of the floor trusses and fill the joist cavity with blown-in insulation.

Installing Windows in Walls with External Rigid Foam Insulation

Installing rigid foam insulation on exterior walls reduces thermal bridging and may reduce the chance of condensation in wall cavities. Many cold-climate builders now install 4 or 6 inches of EPS, XPS, or polyisocyanuarate rigid insulation on exterior walls.

Innies or Outies?

Builders installing thick exterior wall foam can install windows two ways: with the window flanges in the same plane as the back of the siding or with the window flanges in the same plane as the OSB or plywood wall sheathing.

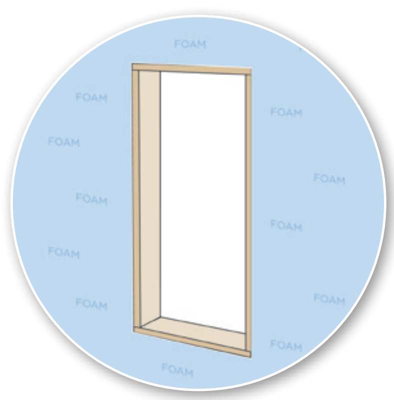
The following apply to any window installation:

1. Foam panels should be installed with windows in mind—windows should not be installed where there is a seam in the foam sheathing, even if the foam is taped.
2. Water management details should specify that flashing around the perimeter of the window must tie into a water-resistive barrier regardless of the approach taken.
3. Ensure that foam sheathing does not bear the weight of the window. The weight of the window should be supported by the wall frame.

Interior Ledge Window Installations:

STEP 1 Rough in window openings, oversizing by 1 ½ inches in both dimensions.

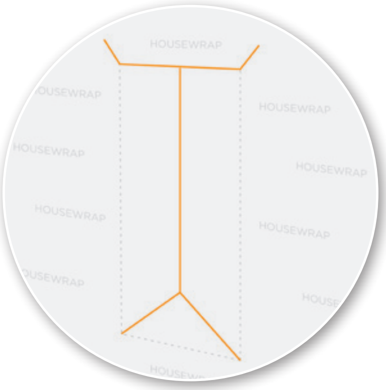
STEP 2 Line rough opening with a frame made of plywood strips ¾" thick by wall dimension + width of foam (the plywood should be flush on the interior surface and extend to the anticipated outside face of the foam).



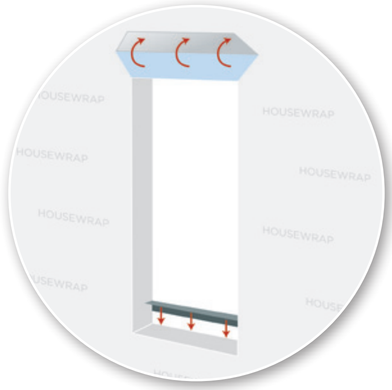
STEP 3 Install the exterior foam. The outer face of the foam should be flush with the outer edge of the plywood frame.

Continued on following page

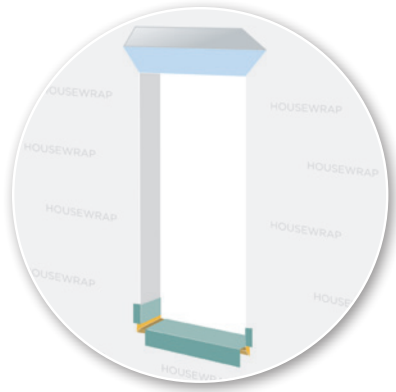
Interior Ledge Window Installations - *Continued*



STEP 4 Install housewrap. Cut modified "I" over window.



STEP 5 Fold in housewrap at jambs and sill. Fold back temporarily at jamb. Install backdam on sill.



STEP 6 Install adhesive-backed sill flashing and corner flashing patches at sill. Apply sealant at jambs, head, and sill.

STEP 7 Install window; plumb, level, and square as per manufacturer's instructions.

STEP 8 Install jamb flashing first; install a drip cap (if applicable); install head flashing.

STEP 9 Fold down head housewrap; apply corner patches at head; air seal window around the entire perimeter on the interior with sealant or non-expanding foam.

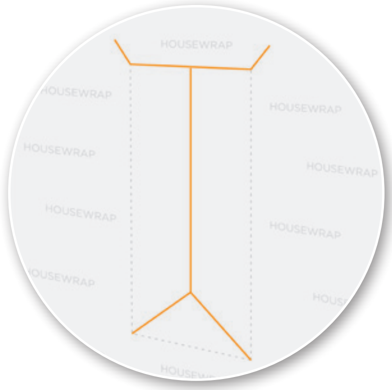
STEP 10 Install vertical wood strapping on top of the foam and housewrap to use when attaching siding.

Sources & Additional Information

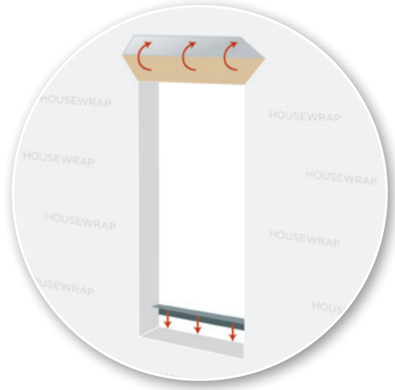
Building Science Corporation. 2007. *Guide to Insulating Sheathing*, Building Science Corporation, www.buildingscience.com/documents/guides-and-manuals/gm-guide-insulating-sheathing

Exterior Ledge Window Installations:

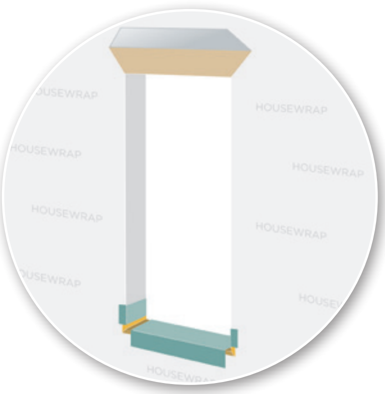
STEP 1 Install OSB and housewrap on wood frame wall.



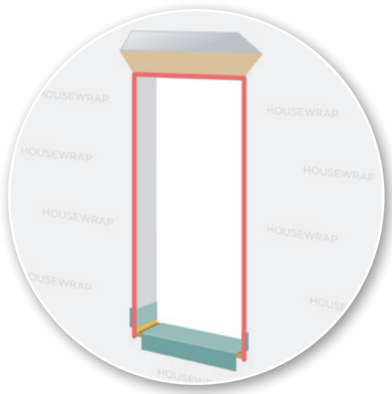
STEP 2 Cut modified “I” in housewrap



STEP 3 Fold housewrap in at jambs and sill. Temporarily fold up housewrap at head. Install backdam.



STEP 4 Install adhesive-backed sill flashing and corner flashing patches at sill.

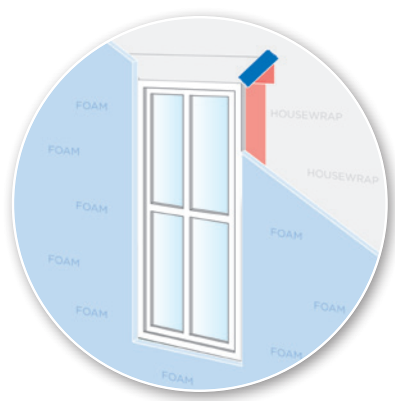


STEP 5 Apply sealant at jambs, head, and sill.

STEP 6 Install window; plumb, level, and square as per manufacturer’s instructions.

STEP 7 Install jamb flashing first; install a drip cap (if applicable); install head flashing.

STEP 8 Fold down head housewrap.



STEP 9 Apply corner patches at head; air seal window around entire perimeter on the interior with sealant or non-expanding foam; install foam sheathing over housewrap.

Duct Location – Dropped Ceiling Soffit

Ducts can be placed in a dropped ceiling soffit to keep them in conditioned space.

STEP 1 Use Manual J to determine appropriate HVAC size.

STEP 2 Design duct layout plan emphasizing compact layout with inside wall throws and air handler located in conditioned space. For cost savings consider using transoms over doors and one central return instead of ducted returns.

STEP 3 Hold meeting at home site after dry-in with designer, HVAC installer, framer, sheetrocker, other pertinent trades to discuss approach, if this is a new method.

STEP 4 Install sheetrock above chase. One method is to keep top plate of non-load bearing interior walls ¾ inch from bottom cord of roof trusses. Slip drywall in this space.

STEP 5 Fabricate and seal ducts on the ground. Use hard ducts wherever possible. Fabricate a duct board box affixed to trunk line to serve as supply boot.

Original method

Improved method

After framing

Supply boot comes directly from main trunk, as shown in "improved method" rather than connecting boot to trunk with a length of flex duct, as shown in original method. Thus duct chase can be narrower.

STEP 6 Hang duct from the drywall using 2" nylon strapping material.

Hard Duct

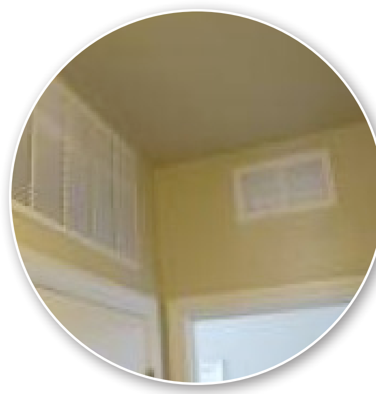
Hard ductwork is used wherever possible.

Flex Duct

STEP 7 Install sheetrock around ducts to form chase, when sheetrocking the rest of the house (this is the second visit for sheetrockers).

Ducts are enclosed in soffits that add architectural interest to finished rooms.

STEP 8 Install air handler in conditioned space in interior closet with large return air grill located over air handler. Use transoms over bedroom doors for return air path.



Air handler is located in the home in a closet with return grill above. Transoms over interior doors provide a return air path.

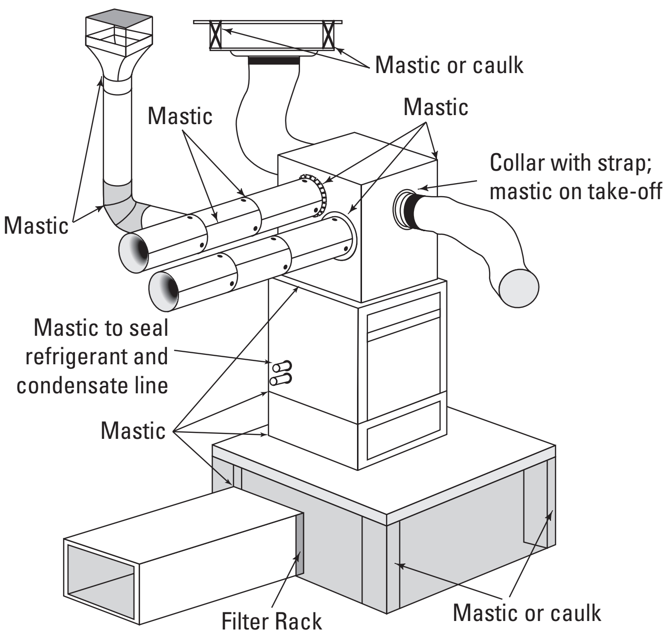
Fonorow, Ken, Dave Jenkins, Stephanie Thomas-Rees, and Subrato Chandra. 2010. "Low-Cost Interior Duct Systems for High-Performance Homes in Hot Climates," *Proceedings of the 2010 ACEEE Summer Study on Energy Efficiency in Buildings*, Pacific Grove, CA, http://www.aceee.org/conf/10ss/index.htm

Duct Location – In Open Web Floor Trusses Between Floors

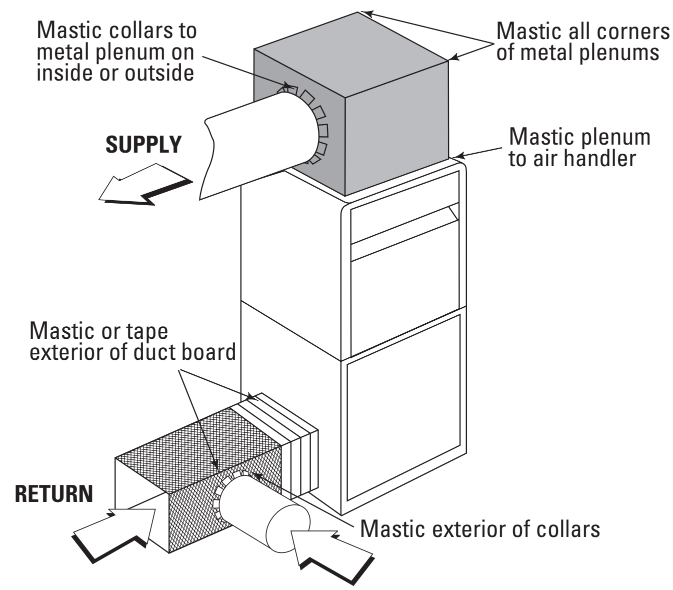
Ducts can be placed in open web trusses between floors to keep them in conditioned space. Rim joists must be thoroughly air sealed.

Air Handler and Duct Sealing

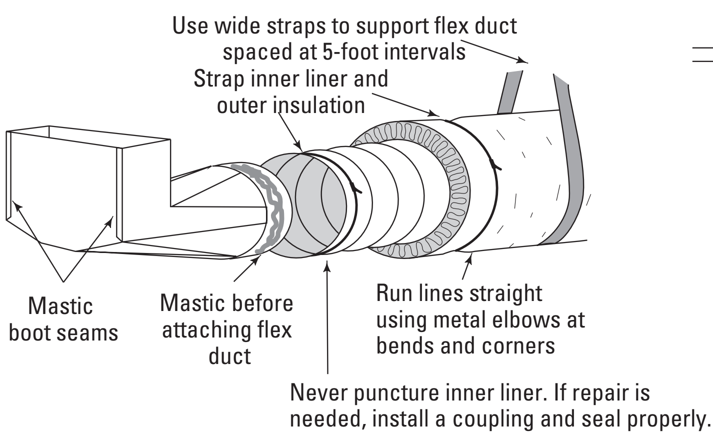
AIR HANDLER



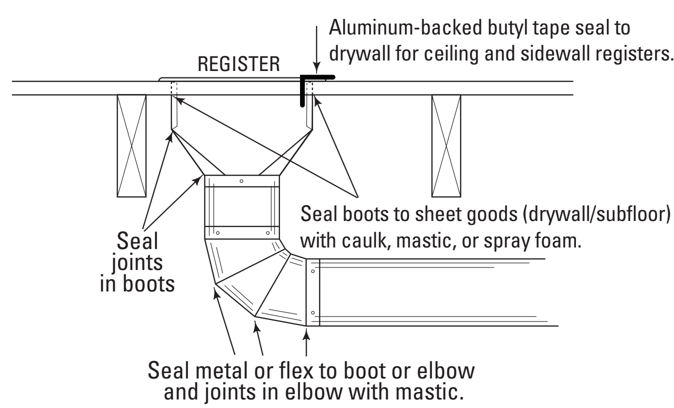
SUPPLY AND RETURN PLENUMS



FLEX DUCT



BOOTS



Mastic is a gooey adhesive that is applied wet. It fills gaps and dries to a soft solid. Mastics may or may not contain reinforcing fibers, and they may be used with reinforcing mesh tape.

Ductless Heat Pump Installers Guide

Northwest Energy Efficency Alliance Ductless Heat Pump Project www.ductless.com

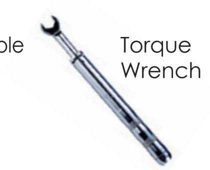
Best Practices for Ductless Heat Pump Installations *A Contractor's Guide*

A quality ductless heat pump installation results from attention to details including: tools, installation and homeowner education. This guide provides information and suggestions to help you achieve successful ductless heat pump installations. Quality installations result in minimal call backs, more customer referrals, and increased awareness of ductless heat pump technology.

Required Tools

R410A Specific Flaring Tools

Programmable Refrigerant Charging Scale



Torque Wrench

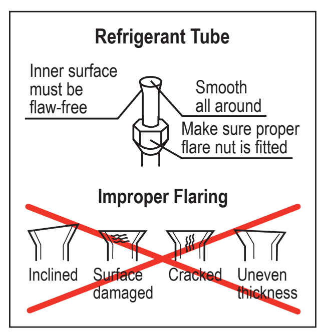
R410A Gauge and Hose Set

Installation Best Practices

- Follow manufacturers' installation instructions. This guide is not intended to replace manufacturers' specifications.

Outdoor Unit (Compressor):
- Set the unit on a stable, level surface.
- Risers are essential to prevent snow and debris build-up and should be installed to allow better drainage of defrost water.
- Outdoor units should be secured to the pad, risers, and/or surface on which they are set using bolts and/or adhesive.

Refrigerant Tubing:
- Factory tubing flares and fittings are NOT TO BE REUSED.
- Create new flares using appropriate R410A flaring tool & measurement gauge.
- Apply refrigerant oil to the end of each flare.
- Connect tubing with R410A nuts (supplied with indoor and outdoor units) using a torque wrench tightened to manufacturer's specifications.



Refrigerant Charge:
- Adjust refrigerant charge ONLY IF NECESSARY. Most installations do not require adjustment from pre-charge levels.
- Gauges are not needed to verify refrigerant levels. (A scale should be used when adding or removing refrigerant.)
- Consult the manufacturer's installation manual to verify refrigerant protocols, specifications can often change.

Line Set Insulation and Protection
- Insulation must cover entire line set length to avoid condensation and decreased efficiency.
- Once insulated, protect the outdoor portion of line set with rigid line hide to avoid premature degradation damage to the insulation.
- All penetrations through the shell of the home must be sealed with an insulative sealant.

Condensate Drain:
- Must slope downhill and can be routed with line set or run to a different termination point.

Northwest Energy Efficency Alliance Ductless Heat Pump Project www.ductless.com

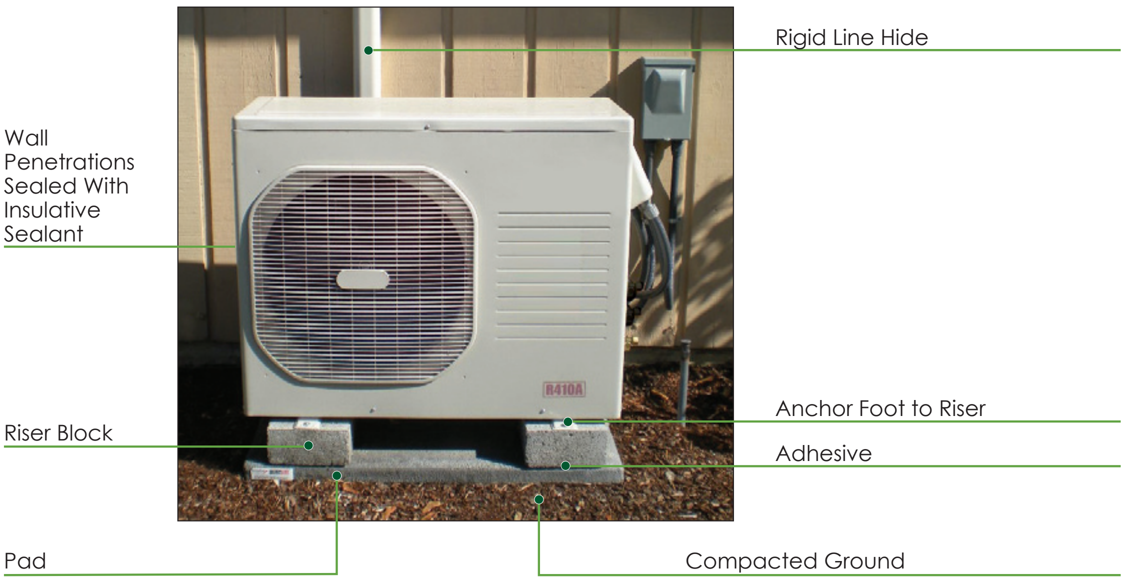
Homeowner Education

- Ensure homeowner has a copy of the Manufacturers Operation Manual that is provided with the indoor unit. Refer to this manual as you perform a walkthrough of unit operation.
- Provide homeowner with a copy of the "Homeowner's Guide" and remind homeowners of www.GoingDuctless.com for more information about ductless heating and cooling systems.
- Educated homeowners reduce call backs and promote your services!

Contractor Resources

- For information on becoming a Project-oriented contractor, visit www.NWDuctless.com or call (503) 808-9003. Project-oriented contractors are eligible to perform installations that receive utility rebates of up to $1,500!

Well Installed Outdoor and Indoor Unit = Happy Homeowner

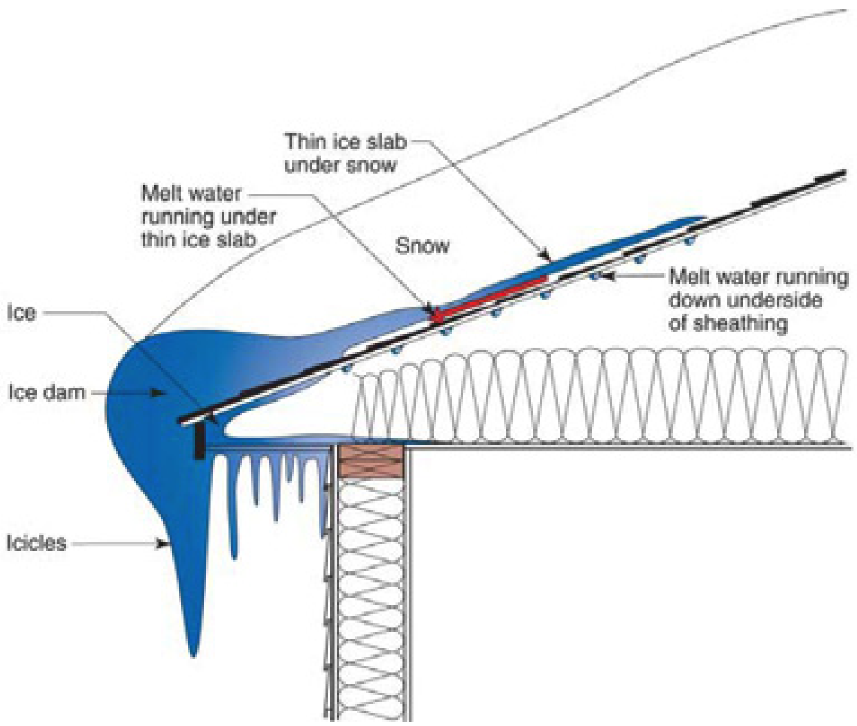


Disclaimer: This document is only to be used as a general guide for providing quality installations. For complete information regarding installation requirements, features, benefits, operation, and maintenance, review the manufacturer's installation manual of the product being installed. Images of specific manufacturer product lines are not placed as endorsements, nor does this guide guarantee their quality.

An initiative of the Northwest Energy Efficiency Alliance, an alliance of NW Utilities and energy efficiency partners.

Ice Dam Prevention

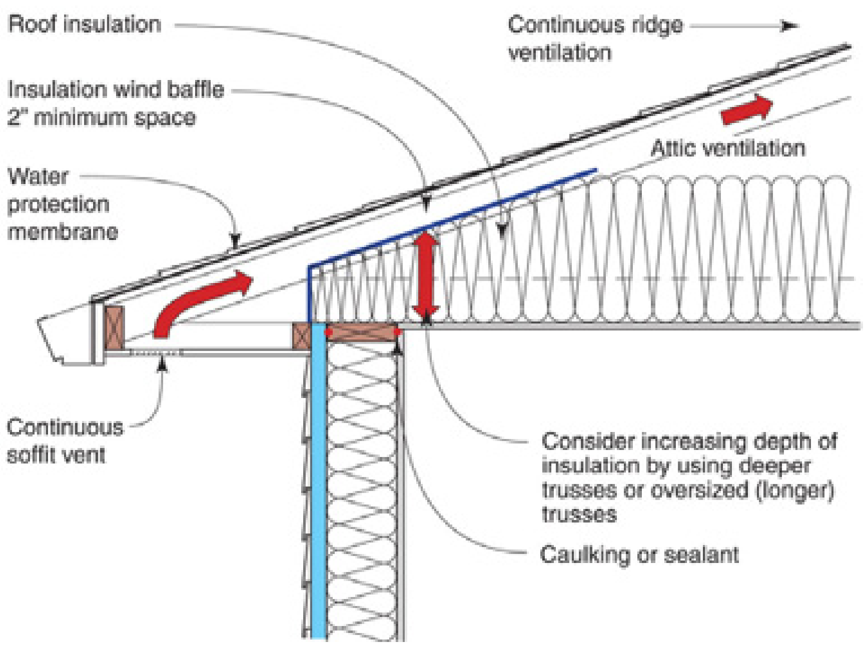
Ice dams are hazardous for buildings and people. Use the following guidance to minimize chances of ice dams forming on your homes.



Ice Dam Formation -

Ice dams can form when the roof deck temperature is above freezing and the air is below freezing.

Melted snow eventually reaches the colder edge of the roof where it refreezes, creating an ice dam that collects more water and ice. The ice dam is often not visible under the snow layer on the roof except for the telltale icicles, which indicate melting is occurring somewhere on the roof. *(Source Lstiburek 2011, Building Science Corporation)*



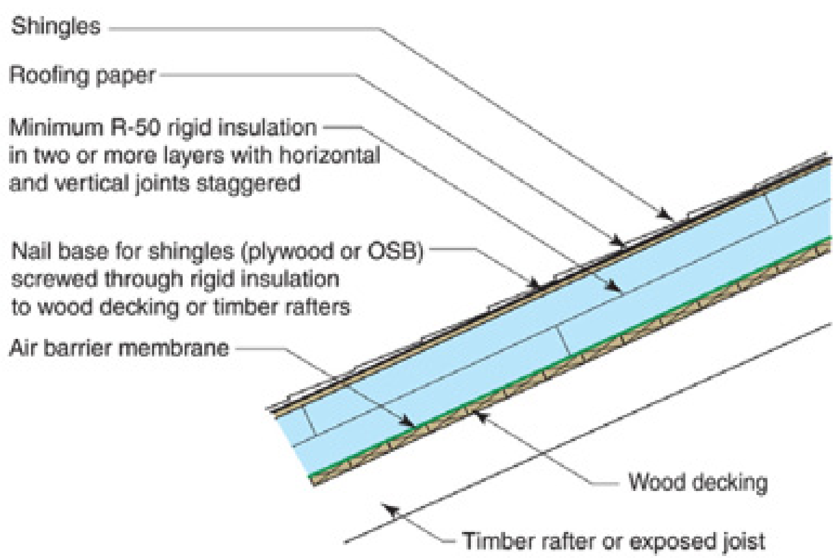
Three Steps to Ice Dam Control in a Vented Attic –

1) Construct an airtight ceiling plane. Limit the number of holes through the ceiling and air seal every one.

2) Insulate well, especially over the top plates, use raised heel trusses if needed to get full insulation coverage.

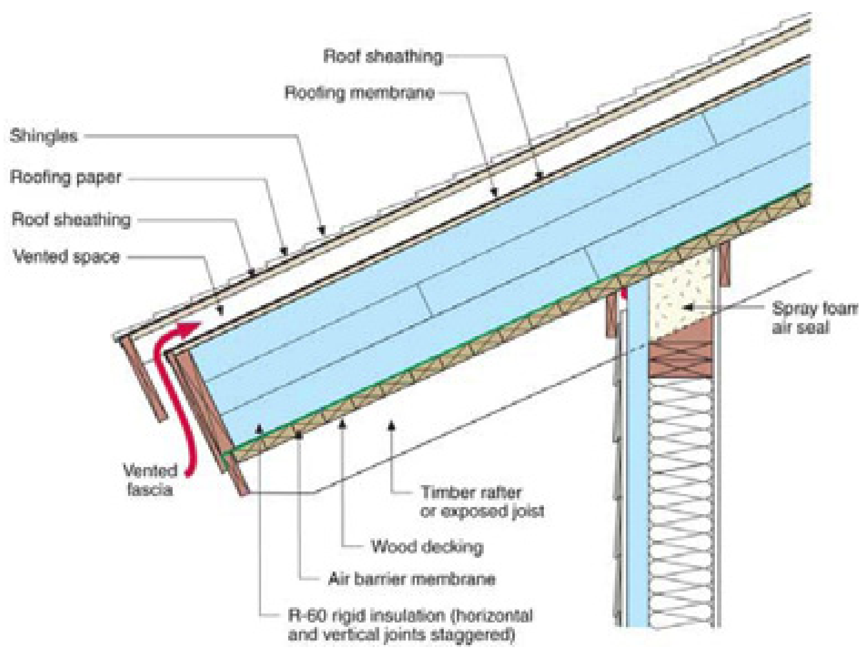
3) Vent the underside of the roof deck, with vent screens at every rafter bay and a 2-inch airspace under the sheathing where ground snow loads are greater than 30 lb/ft^2.

(Source Lstiburek 2011, Building Science Corporation)



Ice Dam Control in an Unvented Attic with Insulation above Roof Deck –

Cover roof sheathing with a fully adhered air barrier membrane. Install two layers (to R-50 or greater) of rigid insulation over air barrier, stagger the seams. Note there is no vented space under the roof cladding to compensate for the insulation value of the snow layer. This roof should be used where the ground snow load is less than 50 lb/ft². With ground snow loads greater than 50 lb/ft², provide a ventilation space under the roof cladding as shown in Figure 4 *(Source Lstiburek 2011, Building Science Corporation).*



Ice Dam Control in an Unvented Attic with Insulation above Roof Deck in High-Snow-Load Areas –

In regions with snow loads greater than 50 lb/ft², the snow can provide enough thermal resistance to allow the roof cladding to be above freezing even when the air temperature is below freezing (one foot of snow = R-10 to R-15). To prevent ice damming with an unvented attic in these conditions, construct a "vented over-roof" over the top of the "unvented compact roof" as shown above *(Source Lstiburek 2011, Building Science Corporation)*.

Sources & Additional Information

Lstiburek, Joseph. 2011. *Dam Ice Dam*, Insight 046, Feb. 2011, Building Science Corporation, www.buildingscience.com/documents/insights/bsi-046-dam-ice-dam/

40% Whole-House Energy Savings in the Cold and Very Cold Climates

Case Studies

Several builders are building energy-efficient homes in the cold and very cold climates. The following case studies showcase five cold climate builders who worked with Building America research team to build homes that exceeded the Building America benchmark by 40% or more. The energy-efficient measures they incorporate in their homes are summarized in the table below.

Table 1. Summary of Energy-Efficiency Measures Incorporated in Case Study Homes in the Cold Climate

Measure	Devoted Builders Kennewick, WA	Nelson Construction Farmington, CT	Rural Development Incorporated, Turners Falls, MA	S&A Homes Pittsburgh, PA	Shaw Construction Grand Junction, CO
Project	Mediterranean Villas, Pasco WA; 230 duplex & triplex units, 1,140-2,100 ft^2, market rate	Hamilton Way, Farmington CT; 10 single-family homes, 2,960-3,540 ft^2, market rate	Wisdom Way Solar Village, Greenfield, MA; 20 duplex units, 1,140-1,770 ft^2, affordable	East Liberty Development Inc., 6 single-family urban infill, 3,100 ft^2, above market rate	City of Aspen Burlingame Ranch Phase 1, 84 units in 15 multi-family buildings, 1,325 ft^2, affordable
HERS	54-68	53-54	8-18	51-55	54-62
Walls	R-25 ICF	2x6 24-in. o.c.	Double walled (two 2x4 16-in. o.c. walls, 5" apart)	2x6 24-inch o.c.	2x6 24-in. o.c.
Wall Insulation	R-25 ICF	2-inch foil-faced polyisocyanurate R-13 sheathing, plus R-19 cellulose in stud cavities	R-42 dense-pack, dry blown cellulose	R-24 blown fiberglass	R-24 of 3.5-in. high-density spray foam
Attic Insulation	R-49 blown-in cellulose on ceiling	R-50 blown-in fiberglass on ceiling	R-50 blown-in cellulose on ceiling	R-49 blown-in fiberglass on ceiling	R-50 high-density spray foam on sloped ceiling, R-38 on flat ceiling

Measure	Devoted Builders Kennewick, WA	Nelson Construction Farmington, CT	Rural Development Incorporated, Turners Falls, MA	S&A Homes Pittsburgh, PA	Shaw Construction Grand Junction, CO
Foundation Insulation	R-25 ICF perimeter foundation insulation with floating slab	2-inch/R-10 XPS below slab; 2-inch/R-10 XPS in thermomass basement walls	Full uninsulated basement with R-40 blown cellulose under first floor	Precast concrete basement walls with steel-reinforced concrete studs and 2.5 in. XPS R-12.5	Slab w R-13 XPS edge; some basements with R-13 interior polyisocyanurate; R-28 spray-foam insulation on ground under slab.
Ducts	In conditioned space or in attic covered with spray foam and blown cellulose	In conditioned space in dropped ceiling or between joists	No ducts	In conditioned space in open-web floor trusses	No ducts
Air Handler	In conditioned space	In conditioned basement	None	In conditioned basement	None
Tested Air Leakage and Sealing	Tested at 0.8 to 2.0 ACH at 50 Pa; spray foam ceiling deck	Tested at <3.0 ACH at 50 Pa; foam critical seal of rim and floor joists	Tested at 1.1 to 1.5 ACH at 50 Pa	Tested at 3.0 ACH at 50 Pa; all penetrations and studs sealed	Tested at 2.5 in^2 leakage per 100 ft^2 of envelope
HVAC	8.5 HSPF/14 SEER heat pumps	94% AFUE gas furnace; SEER 14 air conditioner	Small sealed-combustion 83% AFUE gas-fired space heater on main floor; no AC	Two-stage 96% AFUE gas furnace w multi-speed blower; SEER-14 AC	0.9 AFUE condensing gas boiler with baseboard hot water radiators
Windows	U-0.29	U-0.32, SHGC 0.27, double-pane, low-e, vinyl-framed	Triple-pane U-0.18 on north/east/west sides; double-pane U-0.26 on south side	U-0.33, SHGC 0.30, double-pane	U-0.37, SHGC-0.33 fiberglass-framed, double-pane
Water Heating	84% EF tankless gas water heater	82% EF tankless gas water heater	Solar thermal with tankless gas backup	82% EF tankless gas water heater	Solar thermal with gas boiler backup
Ventilation	Energy-recovery ventilator	Temp- and timer-controlled fresh air intake; exhaust fan ducted to draw from main living space; transfer grilles	Continuous bathroom exhaust	Passive fresh air duct to return plenum; fan-cycler on 50% of time for fresh air circulation, bath exhausts	Heat-recovery ventilator

Measure	Devoted Builders Kennewick, WA	Nelson Construction Farmington, CT	Rural Development Incorporated, Turners Falls, MA	S&A Homes Pittsburgh, PA	Shaw Construction Grand Junction, CO
Green	3-star BuiltGreen certified homes	2008 "Best Energy Efficient Green Community" by CT Home Builders Association; 2010 NAHB Energy Value Housing gold award	LEED Platinum	Meets LEED (not certified)	LEED Certified
Lighting and Appliances	70% CFL lighting; refrigerators, dishwashers, and clothes washers	100% CFLs; optional appliances	100% CFLs; refrigerator, dishwasher	100% CFLs; refrigerator, dishwashers, and clothes washer	90% CFL; refrigerator, dishwashers, clothes washers, ceiling fans
Solar	No	Optional 7-kW PV systems	2.8- to 3.4-kW PV; solar thermal water heating	None	10-kW PV on one building; solar hot water heating on all buildings
Verification	100% 3rd party tested and inspected, all met federal tax credit criteria since 2007	All Builders Challenge certified	All HERS rated	All Builders Challenge certified	All federal tax credit qualified

AC = air conditioner
ACH = air changes per hour
CFL = compact fluorescent lights
Ef = energy factor
ICf = insulated concrete form
o.c. = on center wood framed walls
Pa = Pascals
PV = photovoltaic
SHGC = solar heat gain coefficient
XPS = extruded polystyrene

Building America Best Practices Series

Volume 12. Builders Challenge Guide to 40% Whole-House Energy Savings in the Cold and Very Cold Climates

Case Study: Devoted Builders, LLC

Mediterranean Villas | Pasco, WA

Devoted Builders of Kennewick, Washington, worked with Building America's BIRA team to achieve the 50% Federal tax credit level energy savings on 81 homes at its Mediterranean Villas community in eastern Washington.

BUILDER PROFILE

Builder: Devoted Builders, LLC
www.mvtownhomes.com

Where: Kennewick, WA

Founded: 2002

Development: Mediterranean Villas

Size: 230 homes

Square Footage: 1, 1.5, and 2-story, duplexes and triplexes, 2- and 3-bdrm, 1,140 to 2,100 ft^2

Price Range: $145,000 to $300,000

Energy-Efficiency Commitment: All Northwest ENERGY STAR since 2006, all Built Green since 2007

Builder Fred Giacci's decision to "raise the bar" led him into a collaboration with the U.S. Department of Energy's Building America program that has resulted in homes with HERS scores of less than 60 and calculated energy savings to homeowners of over $1,300 a year compared to the Building America Benchmark (a home built to the 1993 Model Energy Code). Working with Building America's Building Industry Research Alliance team through its local research partner Washington State University (WSU) Extension Energy Program, Giacci built 81 homes to achieve the 50% energy savings level required for the Federal tax credit. Although the Federal tax credit ended in December 2009, Giacci has committed to building the remaining 31 homes in his 230-unit Mediterranean Villas community in Pasco, Washington, to achieve these exceptional energy savings and he continues to look for ways to raise the bar even higher.

Since 1988 Giacci has built 300 homes in southeastern Washington. In 2002 Giacci became the first production builder in his area to use insulated concrete form (ICF) walls. In 2006 he committed to building all of his homes to qualify for Northwest ENERGY STAR. Devoted Builders was named a Northwest ENERGY STAR builder of the year in 2008-09. In 2007 Giacci helped the local home builders' association start a Built Green program and since then has achieved a 3-star rating on all his homes (the local program does not have a 4-star level yet).

In 2006, David Hales of the WSU Extension Energy Program approached Giacci about working on a demonstration project for DOE's Building America program. "We got involved with Giacci because he was the first production builder in Washington state that was taking advantage of the Federal tax credit. With ICF, heat recovery ventilators, and good windows, Devoted Builders was fairly easily qualifying for the tax credit," said Hales.

Building America® U.S. Department of Energy

(left) Spray foam is used to insulate and air seal the "lid" or ceiling deck and any ducts located in the attic in Devoted Builders' homes in Pasco, Washington. The spray foam is covered with more than 12 inches of blown cellulose for the equivalent of R-49 of attic insulation.

(right) Insulated concrete form walls provide superior insulating, air sealing, and sound proofing capabilities.

Energy-Efficiency Features

Devoted Builder's exceptional energy performance starts with insulated concrete form wall construction. Giacci first looked at ICFs in 2002 during the planning stages of Mediterranean Villas. "I wasn't happy with sticks. I analyzed many different methods—brick, blocks, etc. Then I zeroed in on ICF and found a contractor who could put them together," said Giacci.

Giacci chose an ICF product consisting of 16-inch by 4-foot rigid expanded polystyrene (EPS) foam blocks separated at 4 or 6 inches by plastic spacers, which are connected to heavy plastic studs set vertically in the foam every 6 inches. The location of these studs is marked on the outside of the foam blocks making it easy to locate them for screwing in drywall on the interior or siding on the exterior side of the finished wall. The foam blocks are stacked, like Legos™, to form the home's exterior walls. Vertical and horizontal rebar is set in the spacers and concrete is poured between the two 2 and 5/8-inch-thick layers of rigid foam to fill the gap.

"The kind of building they're doing has set Devoted apart from other builders in the area."

David Hales, *project manager, Washington State University Extension Energy Program, a Building America research partner*

The ICF walls provide an insulation value of R-25. The exterior of the walls is covered with a gray coat of cement and polymer, which provides some waterproofing. Stucco is applied directly to the gray coat. The ICF foundation wall goes down into the ground 30 inches so it provides adequate frost protection as well as R-25 of perimeter slab insulation.

Any ducts in the attic are mastic sealed, then the ducts and the lid of the ceiling deck are covered with an inch of spray foam. This is topped with more than a foot of blown cellulose to achieve R-49 attic insulation.

Spray foam ceiling insulation and ICF walls have helped Giacci achieve very low air leakage rates of below 2.0 air changes per hour at 50 Pascals on all homes. All homes are blower door tested. Some are as low as 0.8 ACH at 50 Pa.

With such low infiltration rates, fresh air must be brought in through intentional means to maintain healthy indoor air quality. Each home has an energy-recovery ventilator (ERV) to distribute tempered air throughout the home via small ducts located in conditioned space. The ERV is located either in conditioned space or in the garage.

With input from WSU, Devoted Builders transitioned from gas furnaces to standard heat pumps with a gas furnace backup in 2007. In 2009, Devoted stopped installing gas furnaces and upgraded to advanced heat pumps that are rated at 8.5 HSPF for heating and 14 SEER for cooling. The Sanyo heat pumps extract heat from the air down to 10°F; backup heat is provided by in-line electric resistance heaters. While this system can be mounted to the wall as a ductless unit, concerns about buyer reactions to the look of the wall-mounted inside units led Giacci to install the inside units in a distribution box located in conditioned space in a closet with a fan to distribute conditioned air through ducts, some of which are located in the attic.

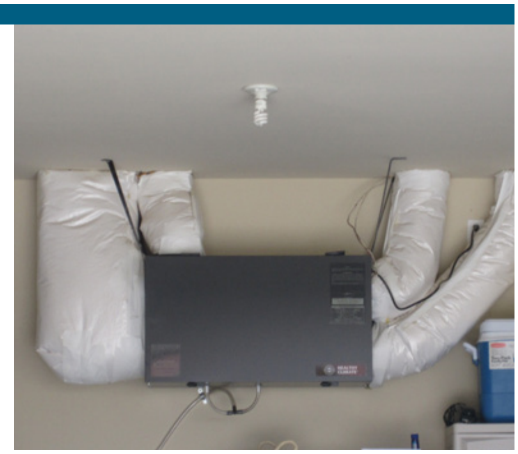
The homes come equipped with ENERGY STAR dishwashers and 70% of the fixtures are hardwired with compact fluorescent lighting.

As part of its strong commitment to quality assurance, Devoted has 100% of its homes third-party tested and inspected. Since 2007, all of Devoted Builder's homes have met the Federal tax credit level of 50% savings over the 2004 IECC. These homes also are calculated to save 43% over the Building America benchmark.

Anticipated future improvements include solar hot water or heat pump water heaters, PV-ready designs, ductless heat pumps, 100% CFLs, and BuiltGreen community layout, with a goal of reaching net zero energy homes. Because Devoted Builders is already meeting the Building America and the Federal tax credit savings levels, Giacci does not anticipate any difficulty in implementing the 2009 IECC.

Dollars and Sense

The table below compares calculated energy usage and energy savings for one of Devoted Builders' house plans and the Building America benchmark home (a home built to the 1993 Model Energy Code). The usage and savings were calculated by Building America research partner WSU Extension Energy program. WSU calculated that the Devoted Builders' home would have 25% energy savings over the 2006 Washington State energy code and 43% energy savings over the Building America benchmark home. The home would save $1,333 in energy costs each year. After subtracting out the increased mortgage costs to cover the increased initial cost of the energy-efficiency measures, the homeowner would net $524 per year over the 30 years of the mortgage.



(top) Every home is equipped with an energy-recovery ventilator to provide conditioned fresh air throughout the home.

Energy-Efficient Features

- HERS scores 54-68
- R-25 insulated concrete form (ICF) exterior walls
- R-49 blown cellulose in attic
- 0.29 U-value windows
- Whole house air leakage 3.0 ACH or less at 50 Pa
- Duct leakage less than 6 cfm at 50 Pa to exterior
- 8.5-HSPF, 14-SEER heat pump with backup 93% AFUE gas furnace
- 70% hardwired CFL lighting
- ENERGY STAR refrigerator, dishwasher, clothes washer
- Energy-recovery ventilator, 75% total efficiency
- 3-star Built Green certified
- ENERGY STAR certified
- 50-year, 110-mph, composition roof

"We showed a positive cash flow for the homeowner from day 1. There is no question there is some added expense for the ICF. But the homeowner is coming out ahead," said Hales.

Devoted Builders offers a 2-year warranty on craftsmanship and materials and a 10-year structural warranty. Homes sell for $145,000 to $300,000. Most homes are sold through presales.

Giacci has seen competition from builders willing to build inexpensive models that just meet code. Although their energy performance is so exceptional, Giacci markets the Mediterranean-style duplex condominiums based on their location, design, and ease of maintenance.

Table 1. Added Costs and Savings of Energy-Efficient Measures for Devoted Builders

Total Energy Savings	54%
Total Added Builder Costs*	$10,132
Annual Mortgage Payment Increase**	$809
Annual Utility Savings	$1,333
Annual Net Cash Flow to the Homeowner	$524

*Costs are based on builder estimates, and manufacturers' data. These costs do not reflect rebates, incentives, and subsidies.

**The annual mortgage payment is an estimate calculated by CARB and is based on a 30-year mortgage with a 7% fixed interest rate.

"We sell a lot of homes to engineers; they are all over our product. But the general public needs more education on the value of energy efficiency," said Giacci. Giacci commented that in the Seattle and Denver areas, green homes sell for more and realtors are more aware of the differences because the multiple listing sheets list the home's green and energy-efficient features, but that is not the case in eastern Washington.

The Bottom Line

According to Hales, Giacci is positioning his company well for the future. "Energy is just going to get more expensive. Fred has always been open to new technologies and new ways to produce a high-performance home. He is very committed to the idea that it's the right thing to do. He's consistently building the highest performing homes in the state that I've seen and I expect he will continue to lead in energy-efficient home building," said Hales.

For More Information

www.buildingamerica.gov
EERE Information Center
1-877-EERE-INF (1-877-337-3463)
eere.energy.gov/informationcenter

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

PNNL-SA-76313 February 2011

Building America Best Practices Series

Volume 12. Builders Challenge Guide to 40% Whole-House Energy Savings in the Cold and Very Cold Climates

Case Study: S&A Homes

East Liberty | Pittsburgh, PA

S&A Homes worked with Building America's IBACOS and architects Pfaffmann & Associates and Moss Associates to design energy-efficient homes for urban in-fill lots. This is a new market for S&A Homes, which builds over 500 homes a year using suburban designs.

BUILDER PROFILE

Builder: S&A Homes

Where: State College, PA

Founded: 1980s

Employees: 150

Development: East Liberty

Size: 3 bedroom, 3 baths

Square Footage: 3,108 ft², includes 1,004 ft² basement

Price Range: $216,000 to $305,000

East Liberty Development, Inc., worked with the U.S. Department of Energy's Building America team lead IBACOS and builder S&A Homes to build six homes in Pittsburgh's East End that achieved Home Energy Rating Scale (HERS) scores of 51 to 55.

"We literally designed the house around the HVAC system," said Eric Jester, a project manager with East Liberty Development, Inc.

"In standard building, the mechanical systems are an afterthought," said Kevin Brozyna, an IBACOS building performance specialist. "Your typical builder will frame the house and then the mechanical contractor will figure out how to route the ductwork around the framing. From the start, we wanted to design an integrated solution."

IBACOS worked with the architects Pfaffmann & Associates and Moss Architects to help them meet the project requirements: designs that could fit on narrow in-fill lots 25 to 40 feet by 110 feet deep, incorporating Building America-recommended energy-efficiency specifications, while using S&A Home's typical procedures and material suppliers where possible.

East Liberty Development, Inc., is a non-profit community development corporation focused on neighborhood renewal, whose efforts sparked a renaissance in this older Pittsburgh neighborhood. Now employers like Google, new retail stores like Whole Foods and Target, and new restaurants join a growing number of new homeowners and investors in this previously forgotten part of the city.

"Real estate is perception. These homes give a strong perception that investing in East Liberty is a good idea, and people are following that cue," said Jester. "We have seen a plummeting crime rate (down 60%) and an increase in single-family house values across the neighborhood of 100% or more."

(top) In a market where the median house price is $100,000, East Liberty Development, Inc., has sold three of its super-energy-efficient homes at prices starting at $216,000.

(bottom) The HVAC equipment is located in conditioned space in the basement, which is thoroughly insulated and air sealed with precast concrete walls that come to the site with 2.5 inches of foam insulation and steel-reinforced insulated concrete studs already installed.

"Codes are improving. Trades are aware that things are becoming more strict, and they are going to be required to be more diligent in their work. Have a discussion with the trades to let them know what you expect and make sure they are committed to pulling it off."

Kevin Brozyna, *IBACOS*

Energy-Efficiency Features

The first step in designing the homes was to put all of the HVAC equipment and ductwork within the highly insulated and air-sealed thermal envelope. The completed homes blower door tested at 3.0 air changes per hour (ACH) at 50 Pascals, compared to 9 ACH at 50 Pa for a typical home.

The tight building shell consists of 2x6 24-inch-on-center stud wall cavities filled with R-24 blown-in fiberglass. The walls are sheathed with ½-inch OSB and housewrap and clad with LP SmartSiding®, a compressed wood product impregnated with a zinc borate preservative. "Every single stud was air sealed. Every single penetration was air sealed with a low-expansion foam," said Todd Winnor, the project manager for S&A Homes. Double-pane windows with a low U-value of 0.33 and a low SHGC of 0.30 complete the wall assembly.

The unconditioned attic contains R-49 blown-in fiberglass insulation. "We used raised-heel trusses to get the full depth of insulation over the exterior wall," said Winnor.

All of the HVAC equipment is located in the basement. The insulated, precast-concrete wall system (Superior Wall xi™) includes 2½-inch Dow® extruded polystyrene insulation (R-12.5) within a 1¾-inch concrete exterior. This insulated wall panel comes factory-assembled with steel-reinforced steel-faced concrete studs at 24 inches on center.

"Originally, we looked at enhancing the stud cavities with an R-13 batt," said Winnor, "but when we tried this with the first home, we had a very cold winter and got some condensation. So we ended up pulling out the batts, and now it works just fine."

In the basement and first-floor ceilings, open-web floor trusses contain the ducts. Brozyna, the building scientist with IBACOS, notes, "The open-web floor trusses were not selected primarily as an energy feature, but they allowed us to more efficiently route the mechanical systems."

Two-stage, 96% AFUE natural gas-fired furnaces with a multi-speed blower are located in the basement. A SEER-14 system provides air conditioning. Fresh air is provided through a 6-inch supply-air duct connected to the return plenum, and a fan-cycler provides ASHRAE 62.2 rates for fresh air at a 50% run time. The natural-gas-fired tankless water heater supplies heated water with a 0.82 energy-efficiency rate.

IBACOS prepared mockups of field assemblies at its warehouse for hands-on training sessions for the subcontractor crews. "If they had any questions or suggestions for improving the process, we could work this out before we got into the field," said Brozyna.

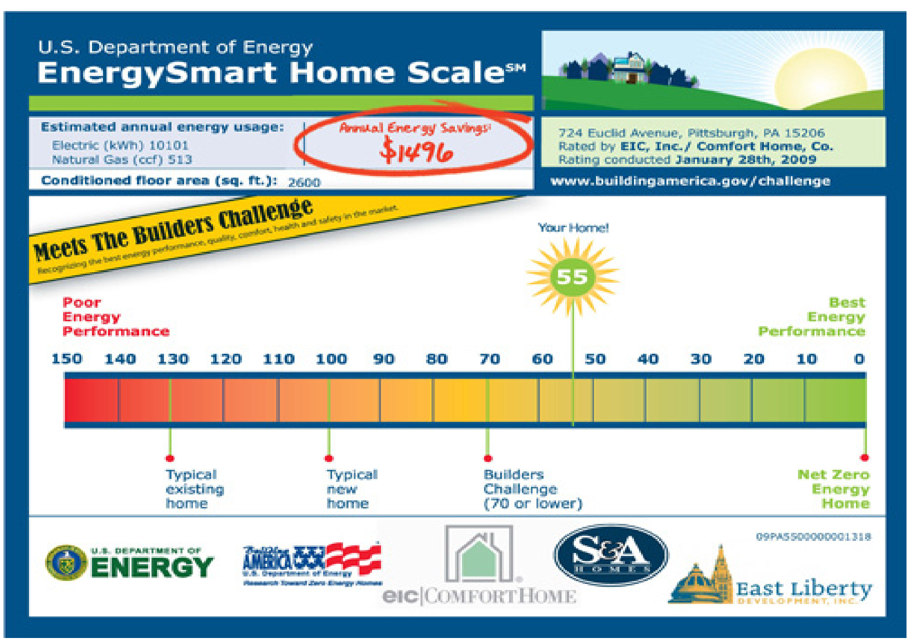
Community Development

East Liberty Development, Inc., bought lots in a challenged east end neighborhood in Pittsburgh where "gangs, absentee landlords, trash and drug raids stained the scenery" (*Pittsburgh Post-Gazette*, December 22, 2008). The non-profit demolished blighted properties and built the six new Building America homes. East Liberty Development, Inc., currently has control of 60 properties in a 10-block area and plans to build and rehabilitate additional houses as these homes sell. It has committed to building all of its new homes to the Building America energy savings target of 40% or higher.

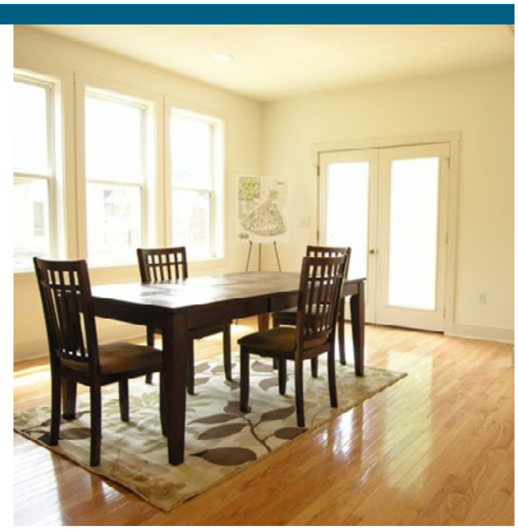
"In 2005, single-family home values in the neighborhood ranged from $40,000 to $50,000," said Jester. "Our highest sale was $315,000, nearly 630% higher." In the first half of 2010, average prices for existing single-family homes in East Liberty climbed to $145,000 as prices dropped citywide, thanks in part to East Liberty Development, Inc.'s community develoment efforts.

Dollars and Sense

Building America analysis shows the estimated cost above code for the energy-efficient improvements to be about $9,900 per house (or $3.42/ft^2), assuming a 30-year loan with 7% interest (Table 1). However, the energy-efficiency measures can result in an annual utility bill savings of $1,699 compared to the Building America benchmark (a home built to code requirements of the mid-1990s), which results in a return on investment in less than 5 years.



East Liberty Development, Inc., uses a modified Builders Challenge label in its marketing efforts.



High-performance windows and 100% fluorescent lighting add to the energy savings in these craftsman-style homes.

Energy-Efficient Features

- HERS 51-55
- 2x6, 24-inch-on-center advanced framing
- Wall insulation: R-24 blown-in fiberglass
- Attic insulation: R-49 blown-in fiberglass insulation
- Foundation insulation: Superior Wall xi™ includes 2½-inch Dow® extruded polystyrene insulation (R-12.5)
- Windows: Double-pane, U = 0.33 and SHGC = 0.30
- Air sealing tightness: blower door testing of 3.0 ACH at 50 Pa
- 96%-AFUE natural gas-fired furnace with a multi-speed blower
- 14-SEER cooling system
- 0.82 EF (energy factor) tankless gas-fired hot water heater
- Ducts in conditioned space
- 100% CFL lighting
- ENERGY STAR appliances

Table 1. Added Costs and Savings of Energy-Efficient Measures for S&A Homes

Total Energy Savings	49%
Total Added Builder Costs*	$9,419
Annual Mortgage Payment Increase**	$752
Annual Utility Savings	$1,651
Annual Net Cash Flow to the Homeowner	$899

*Costs are based on builder estimates, RS Means, DEER, and manufacturers' data. These costs do not reflect rebates, incentives, and subsidies.

**The annual mortgage payment is an estimate calculated by CARB for comparison purposes and is based on a 30-year mortgage with a 7% fixed interest rate and a 10% builder markup over added first cost.

Overcoming Challenges

Training the subs was difficult," said Winnor. "We have subcontractors who have been doing things the same way for 20 years, and they needed to start thinking differently about this. Every single person building the house, even the painter, plays a role in energy efficiency."

IBACOS took an active role in subcontractor training by preparing mockups of field assemblies at its warehouse and providing hands-on training sessions. "We had the actual crew, who would be performing the work in the field, come to participate in the build-outs at the mockup site [for learning and practicing]. If they had any questions or suggestions for improving the process, we tried to work this out before we got into the field," said Brozyna.

"My advice to other builders," says Winnor, "is to take it slow. Get your best subcontractors and get them involved early in the process because you want their feedback. Create partnerships with them to move forward. Make sure it is a guy who will be around awhile because you are making a huge investment in your subcontractors when you do something like this."

The Bottom Line

"My experience working with the Building America program has been a great one. I have learned more things about energy efficiency in a year than a typical home builder would in several years. This project has provided us a road map to achieve the high-performance house of today and the net-zero energy home of tomorrow," said Winnor.

And tomorrow is now. S&A Homes is working with IBACOS to build a "lab home" that tests the materials and construction practices needed to reach net-zero energy in a cold climate. "The lab house pushes us even further into tomorrow so we understand now what we need to do for 10 to 15 years ahead when the code changes," said Winnor.

For More Information

www.buildingamerica.gov

EERE Information Center

1-877-EERE-INF (1-877-337-3463)

eere.energy.gov/informationcenter

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

PNNL-SA-76316 February 2011

Building America Best Practices Series

Volume 12. Builders Challenge Guide to 40% Whole-House Energy Savings in the Cold and Very Cold Climates

Case Study: Nelson Construction

Hamilton Way | Farmington, CT

Building America's research team lead Building Science Corporation helped Nelson Construction achieve HERS scores of 53 and 54 on ten homes in Farmington, Connecticut.

BUILDER PROFILE

Builder: Nelson Construction
www.nelsonconstructionct.com

Where: Farmington, CT

Founded: 1992

Employees: 12

Development: Hamilton Way

Construction Date: 2007–2009

Size: 10 two-story single-family homes, 2,960–3,540 ft^2

Price Range: $650,000+ (all 10 homes sold within 2 months of being listed)

Nelson Construction, the first builder to work with Building America in Connecticut, built 10 homes that received the U.S. Department of Energy's Builders Challenge certification. All 10 homes achieved energy savings of 50% over the Building America benchmark.

"We have been an ENERGY STAR builder as long as it has been around, and we wanted to push the limits for energy efficiency," said Chris Nelson, president of Nelson Construction. "Teaming up with Building Science Corporation through Building America gave us the confidence to push way beyond what we might have tried on our own."

Nelson Construction partnered with Building America's research team lead Building Science Corporation on the energy-efficiency design and analysis of the 10 homes located in the Hamilton Way development that Nelson built with Landworks Realty in Farmington, just outside of Hartford, Connecticut. Selling prices started at $649,000. Each home has two stories (ranging from 2,960 to 3,540 square feet), four bedrooms, 3½ to 4½ baths, and heated basements (for an additional 1,404 to 1,653 square feet).

Energy-Efficient Features

"Our first step is to do as much as we can [to achieve energy savings] for zero cost to the builder," said Peter Baker, a senior associate with BSC who worked with Armin Rudd, a principal at BSC, on this project.

Design-stage computer analysis estimated that 18.5% of the energy-efficiency savings could be achieved by reducing air infiltration. "Chris Nelson is a very conscientious, high-quality builder," said Baker. "Previously, he was doing a full flash- and-batt approach, which involves using a thin layer of spray foam in all of the wall cavities."

(top) All lights were hard-wired for CFLs.

(middle) Sprayed urethane closed-cell foam provided a critical seal along floor joists separating the garage from the living space above. Further insulation was provided by unfaced batt.

(bottom) Nelson Construction sealed the rim joists with spray foam to air seal and insulate from foundation wall to subfloor.

"Teaming with Building America is a great marketing tool because we can honestly say we are building houses better. The HERS certificate from the DOE proves it."

Chris Nelson, *president, Nelson Construction*

Building America research showed minimal difference between spray foaming the entire opaque surface of a wall and simply spray foaming insulation into areas known for leaks. The team used this "critical seal" approach for reducing air infiltration and saving money. Urethane closed-cell foam was sprayed into the air gaps at the basement rim joists, at the rim joists between the first and second floors, around windows, and at any mechanical/electrical penetrations. Air tightness targets were set at 3.0 air changes per hour, and all of the homes tested approximately 25% below the target. The only place where full coverage was used was in the ceiling of the garage to ensure no potential air leakage to the living space above.

Building America analysis estimated 11.5% of the energy savings were possible through increased insulation. Nelson filled his 2x6 24-inch on-center wood stud wall cavities with R-19 damp-spray cellulose cavity insulation, and sheathed the walls with two inches (R-13) of foil-faced polyisocyanurate insulating sheathing, Tyvek wrap, and vinyl siding.

The vented attic has R-50 blown-in fiberglass insulation. Two inches of R-10 extruded polystyrene foam (XPS) is under the foundation slab. The basement walls use a Thermomass® System, consisting of 2 inches of XPS sandwiched between two 4-inch layers of concrete.

The improved thermal boundary (insulation and air barrier) enabled the team to downsize the HVAC system from two air handlers (one in the attic and one in the basement) to one in the basement that uses zone-control dampers for the first floor/basement and second floor. The first and second floors each contain one ducted return with jump ducts at the bedrooms.

Heat is supplied by a 94% AFUE sealed-combustion gas furnace. The 14 SEER air conditioner was downsized from 4.5 or 5.0 tons to 3.0 or 3.5 tons. "What we are hearing from the homeowners is that the systems are working great and very comfortable," said Baker.

Domestic hot water is provided by a 0.82-efficiency factor instantaneous gas water heater. The homes are 100% hardwired for CFLs.

To date, Nelson Construction has less than a year of utility data for the homes, but the data so far indicate that the homes are consuming 50% less energy than the Building America benchmark, a house built to the 1993 Model Energy Code. The homes achieved Home Energy Rating System (HERS) scores of 53 and 54.

Nelson offered a photovoltaic option, and three homeowners chose the 7-kW photovoltaic systems. "They are making way more energy than they are using. They are 8 months into the year, and they are so far ahead of the utility company that they will not pay utility bills this year other than service charges," Nelson said.

(left) The basement walls use a Thermomass® system, which is 2 inches of extruded polystyrene foam sandwiched between 4 inches of concrete.

(right) In this heating-dominated climate, the 94% AFUE sealed-combustion gas furnace helps ensure enough heat on the coldest days.

Health, Durability, Sustainability

With such air-tight construction, it was essential to design in ventilation. The team decided on a semi-balanced approach using a controlled fresh air intake with exhaust fans. For supply ventilation, an Aprilaire VCS 8126 brings outside air into the home through a duct to the return side of the air handler. A flow regulator provides fixed outside air-supply quantities independent of air-handler blower speed, and the HVAC system provides circulation and tempering. Stale air is exhausted through a fan in an upstairs bathroom. This 1-sone-rated fan is connected to the main space with a 6-inch jump duct. The laundry room has a transfer grille installed to provide pressure relief during dryer operation.

The supply system is sized to meet ASHRAE 62.2 ventilation rates. To avoid the potential for cold air complaints when the fan blows without the furnace firing, BSC recommends that not more than 125 cubic feet per minute (CFM) be supplied per register in bedrooms and not more than 500 CFM be supplied per register in other rooms. To achieve this, an 8-inch to 10-inch supply duct to the master bedroom should be split into two 6-inch or 7-inch supply ducts. Homeowners should be educated to keep their winter thermostat set points at 70ºF or above.

Dollars and Sense

Hamilton Way experienced a high volume of sales in a market where sales had almost completely stopped. All 10 Builders Challenge homes in the development sold within 2 months of completion.

"It only costs about $18,000 extra per house [to make the energy-efficient upgrades]. That is about 4% [of the sales price] to achieve about $250 a month in energy savings," said Nelson. "If you take the added mortgage on $18,000 at 5% interest, it is costing you $80 to $90 a month, but you are saving $250 a month in utility costs."

Energy-Efficient Features

- HERS scores 53-54
- 24-inch-on-center advanced framing of 2x6 studs
- Wall insulation: 2-inch foil-faced polyisocyanurate sheathing (R-13) and stud cavities filled with R-19 cellulose
- Attic insulation: R-50 blown fiberglass
- Foundation insulation: R-10 2-inch extruded polystyrene foam (XPS) below slab; R-10 2-inch XPS cast in walls (Thermomass)
- Windows: Double-glazed, low-emissivity, argon-filled, vinyl-framed; U = 0.32, SHGC = 0.27
- Air sealing tightness: infiltration of 3.0 to 3.3 air changes per hour (ACH) at 50 pascals
- 94% AFUE sealed-combustion gas furnace
- 14 SEER air conditioner
- 0.82 EF (energy factor) instantaneous gas hot water heater
- Ducts in conditioned space with less than 5% leakage (R-6 flex runouts in dropped ceiling or in floor joists)
- 100% hardwired CFL lighting

Each of the 10 DOE Builders Challenge homes sold within 2 months of completion.

The largest single cost upgrade resulted from the two inches (R-13) of foil-faced polyisocyanurate insulating sheathing at a cost of $10,000 per home. The approximate incremental cost per square foot of all energy upgrades was $6.97.

"We sold all the homes in less than two months. The people who were buying our homes wanted to buy something that was built better."

Chris Nelson, *president, Nelson Construction*

Building America analysis predicted between $2,429 and $3,447 annual utility savings compared to the Building America benchmark, depending on the house plan. When the annual mortgage increase is subtracted from the savings, results still yield a positive cash flow to homeowners of $1,392 per year for the building (see Table 1).

Table 1. Added Costs and Savings of Energy-Efficient Measures for Nelson Construction

Energy Savings vs Benchmark	48%
Annual Mortgage Payment Increase (without PV)*	$2,055
Annual Utility Savings	$3,447
Annual Net Cash Flow to the Homeowner	$1,392

*The annual mortgage payment is an estimate calculated by BSC and is based on a 30-year mortgage with a 7% fixed interest rate.

The Bottom Line

"This experience has definitely helped us raise the bar on all the houses we build. It has become part of our company identity that we build energy-efficient, healthy, sustainable homes," Nelson added. "Now we have a marketing advantage. We are looked at as one of the experts in the industry related to energy efficiency. From a developer's side, it helps us get approvals, which is really a big deal and nothing we were thinking about when we decided to do this. Towns want to work with builders who are doing things better."

For More Information

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PNNL-SA-76314 February 2011

Building America Best Practices Series

Volume 12. Builders Challenge Guide to 40% Whole-House Energy Savings in the Cold and Very Cold Climates

Case Study: Rural Development, Inc.

Wisdom Way Solar Village | Greenfield, MA

The 20 duplexes built by Rural Development, Inc., in Greenfield, Massachusetts, with help from Building America's CARB team have HERS scores of 8 to 18.

BUILDER PROFILE

Builder: Rural Development, Inc.
www.ruraldevelopment.org

Where: Greenfield, MA

Founded: 1991

Employees: 6

Development: Wisdom Way Solar Village

Size: 20 homes in 10 duplexes

Square Footage: 1,140-1,770 sq. ft.

Price Range: $110,000 (subsidized) to $240,000

Energy-Efficiency Commitment: Better than 50% energy savings

Wisdom Way Solar Village is an appropriate moniker for the 20-unit community of energy-efficient duplexes in Greenfield, Massachusetts. The homes meet the requirements of the U.S. Department of Energy's Builders Challenge, achieving HERS scores of 8 to 18 by packing energy-efficiency features into the compact, heavily insulated homes and adding solar water heating and photovoltaics on top, to net home owners energy cost savings of at least $2,500 per year per home.

The homes are so well insulated, a small (10,000 to 16,000 Btu) gas-fired space heater is all that is needed to heat them. Most homeowners are spending less than $500 per year for natural gas. The space heaters cost builders about $5,000 less per unit than a typical central gas or electric furnace.

The homes were built by Rural Development Incorporated (RDI), a non-profit organization focused on energy-efficient, affordable housing in western Massachusetts. The Consortium for Advanced Residential Buildings (CARB), a U.S. Department of Energy Building America research team led by Steven Winter Associates, provided design assistance and analysis on the project.

CARB's preliminary analysis of utility bills showed most homeowners getting credits from the electric utility throughout the winter months thanks to the combination of energy-saving features and electricity-producing photovoltaic panels. "Homeowners are thrilled with their negative electric bills," said Robb Aldrich, an engineer with CARB. "If you can get the building shell this well insulated, you are going to see significant heating energy savings, almost regardless of what heating system you choose," Aldrich noted.

Building America U.S. Department of Energy

(top) The double-stud wall consists of two 2x4 16-inch-on-center framed walls set 5 inches apart.

(bottom) A vapor-permeable mesh is stapled to the inside surface of the inside wall forming a 12-inch-deep cavity to hold R-42 of dry-blown cellulose insulation.

With a better thermal envelope, builders can offer homeowners "protection" from high fuel bills.

Energy-Efficient Features

A unique feature of the homes is their double-walled construction. The exterior 2x4 16-inch-on-center framed wall is built first; it is sheathed on the exterior side with OSB, but no interior gypsum. Then the second 2x4 framed wall is built inside with a 5-inch gap between the two walls. A mesh liner is stapled to the inner wall's studs to form a 12-inch-deep cavity between the two walls. The cavity is filled with dense-pack dry-blown cellulose insulation at 3.4 pounds per cubic foot density for an R value of 42, with no thermal bridging. RDI employs its own carpentry staff and uses a basic rectangle-shaped house design to decrease complications with this nonstandard framing. CARB visited the site at least once a month during construction and provided training to the trades. Blower door tests by a third-party inspector found air leakage to be 200–350 cfm or 1 to 1.5 air changes per hour at 50 Pascals.

The vented attic incorporates ridge and soffit vents with baffles at every truss bay to minimize disturbance to the 14 inches of loose blown cellulose, which provides R-50 attic insulation. The homes have full, unconditioned basements. Although CARB would typically recommend insulating the basement walls, in this case RDI chose to insulate under the floor joists with R-40 of blown cellulose held in place with vapor-permeable mesh stapled to the I joists, after energy modeling showed that 3 inches of rigid insulation would have been needed to get the same performance, and at considerably higher cost because the local building department would have required that gypsum be installed to cover the foam due to flamability.

Because the homes are so well insulated and have compact designs (1,137 ft^2 to 1,773 ft^2), RDI was able to meet the design heat load of 12,000 Btu per hour with a space heater. RDI chose a sealed-combustion, natural gas-fired heater that was placed in the living room on the homes' first floor. The heater has a capacity of 10,200 Btu per hour on low fire and 16,000 Btu per hour on high fire with an annualized fuel utilization efficiency (AFUE) of 83%. In previous projects, RDI had used hydronic baseboard heating with a gas or oil boiler. By installing the space heater instead, RDI saved about $5,000 per home. Because the units are sealed combustion with piping directly to the outside to bring in combustion air and send out flue exhaust fumes, there is little danger of backdrafting.

There is no traditional duct system with this type of space heater. Instead, CARB suggested putting an exhaust fan in the living room ceiling above the space heater. In winter the fan "exhausts" warm air into each of the upstairs bedrooms through PVC "ducts" connecting the fan to duct registers located 1 foot above the floor on the inside wall of each room. CARB measured the air flow at each register and found the flow to be fairly evenly distributed at 20 to 30 CFM per outlet. CARB also found temperatures were very consistent from room to room when occupants followed CARB's recommendations to leave the thermostat at one temperature with no day/night setbacks.

For north, east, and west-facing windows, RDI selected a triple-pane window with low-emissivity coatings on the second and fifth surfaces, a U-value of 0.18, and an SHGC of 0.23. To save costs and increase desired solar gain, on south-facing windows, RDI installed a double-pane window with a U-value of 0.26, an SHGC of 0.37, and a low-emissivity coating on the third (inside) surface.

RDI installed a 2.8- or 3.4-kW photovoltaic system on the roof of each home. In the first 6 months of occupancy (Nov. 2009 – April 2010) most of the homeowners reported negative electric bills. Water heating is provided by flat-plate solar thermal collectors with gas-fired tankless water heaters for backup.

Dollars and Sense

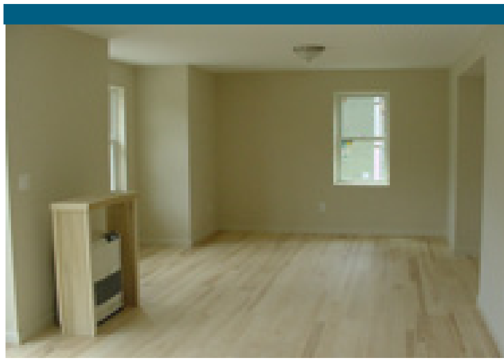
CARB collected natural gas billing data for four of the homes for November through April 2010 and found that natural gas bills totaled $242 to $354/home for the 6 months, or $40 to $59/month (for the space heater, a gas clothes dryer, a backup on-demand gas water heater, a cook stove with oven, and monthly service charges). This is about one-fourth the $1,930 average annual oil heating bill in New England based on 2005 data from the U.S. Energy Information Administration. The energy-efficient gas heater offers a stable alternative to heating with oil, which has seen erratic prices over the past two years, ranging from $2.50 to $4.50/gallon.

As shown in Table 1, CARB estimated that RDI spent about $11,800 more to add energy-efficiency features compared to a house built to the Building America benchmark. The largest expense was $9,750 to purchase and install the solar water heating system. RDI saved $5,000 per unit by replacing a gas or oil boiler and radiators with the ductless gas-fired space heater. CARB calculated the annual increased mortgage cost to cover these expenses at $1,050 per year, assuming a 30-year mortgage at 7%. The annual utility savings was calculated at $2,192, yielding a net gain to the homeowner each year of $1,142.

The photovoltaic panels are not included in the builder costs on Table 1. They would have cost $25,000 to purchase and install at market rate; however, RDI got state, federal, and local grants to cut the costs. If the solar electricity benefit were included in Table 1, the 3.4-kW systems would generate $635–$700 worth of electricity per year at $0.17/kWh and the 2.8-kW systems would generate about $525 to $575 annually.

Energy-Efficient Features

- Foundation: Full basement with R-40 dense-blown cellulose under first floor
- Walls: 12-inch double 2x4 wall with R-42 dense blown cellulose
- Attics: Vented attic with R-50+ loose blown cellulose
- Windows: East, north, and west: vinyl-framed, triple-pane, U = 0.18, SHGC = 0.23. South: double-pane, U = 0.26, SHGC = 0.37
- Doors: 0.20
- Infiltration: 200-350 cfm at 50 Pa, based on blower-door test
- Heating System: Small (10,200/16,000 Btu) space heater located in main living area; sealed-combustion gas-fired 83% AFUE (Monitor Products model GF1800)
- Cooling System: None
- Water Heater: Solar thermal system with tankless gas auxiliary
- ENERGY STAR Appliances: Refrigerators and dishwashers; 100% hard-wired fluorescent lights
- Ventilation: Continuous exhaust fan with variable-speed motor



The homes are so well insulated that a 10,200-Btu gas-fired space heater on the main floor, (shown in wood cabinet in top photo and alone in bottom photo), provides all the heat needed.

"This project shows that, with a highly efficient envelope, simple, low-cost space-heating systems can provide an affordable, efficient method for heating homes, even in a cold climate.

Robb Aldrich,
DOE's CARB Building America Team

Table 1. Added Costs and Savings of Energy-Efficient Measures for Rural Development, Inc.

Total Energy Savings	56.5%
Total Added Builder Costs*	$11,844
Annual Mortgage Payment Increase**	$1,050
Annual Utility Savings	$2,192
Annual Net Cash Flow to the Homeowners	$1,142

*Costs are based on builder estimates, and manufacturers' data. These costs do not reflect rebates, incentives, and subsidies.

**The annual mortgage payment is an estimate calculated by CARB for comparison purposes and is based on a 30-year mortgage with a 7% interest rate.

The 20 two, three, and four-bedroom houses were offered at $110,000 (subsidized) to $240,000 (market rate) to buyers who qualified at different income levels. As of August 2010, all but the five homes still under construction had sold.

The Bottom Line

RDI has been building ever more energy-efficient homes for low- and moderate-income buyers since building its first ENERGY STAR homes in the year 2000. Anne Perkins, RDI's director of home ownership programs, noted that RDI has worked with Building America through its CARB team since 2006 when CARB's Robb Aldrich assisted RDI with development of a prototype solar home in Colrain, Massachusetts. That home achieved a HERS score of 21. The homes at Wisdom Way received HERS scores of 8 to 18.

"RDI could not have advanced to build near zero net energy homes without the design training and technical support it received from the CARB team led by Steven Winter Associates and DOE's Building America," said Perkins of the Wisdom Way project. "The technical information, the drawings, the modeling and monitoring made it possible."

For More Information

www.buildingamerica.gov
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eere.energy.gov/informationcenter

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

PNNL-SA-76315 February 2011

Shaw Construction built 84 energy-efficient, affordable condominiums for the City of Aspen that achieved HERS scores of less than 62 with help from Building America's research team lead Building Science Corporation. *(Photo Source: Shaw Construction)*

Building America Best Practices Series

Volume 12. Builders Challenge Guide to 40% Whole-House Energy Savings in the Cold and Very Cold Climates

Case Study: Shaw Construction

Burlingame Ranch Phase 1 | Aspen, CO

BUILDER PROFILE

Builder: Shaw Construction
www.shawconstruction.net

Where: Aspen, CO

Founded: 1962

Development: Burlingame Ranch

Construction Dates: 2005–2007

Size: Phase 1: 84 units in 15 multi-family buildings. Total build out: 248 units in 30 multi-family buildings plus 10 single-family homes: one- and two-story, 1-, 2-, or 3-bedroom, avg. 1,325 ft^2

Price Range: Subsidized housing

Building America U.S. Department of Energy

Aspen, Colorado's winter wonderland setting has attracted myriads of the rich and famous, but the town's resort home prices have made subsidized housing a necessity for most of the working class families of the community. Over the past 30 years, the City of Aspen has organized dozens of affordable housing projects. In 2007, Aspen completed Phase 1 of its largest and most energy-efficient project to date, the Burlingame Ranch community, where it has achieved Home Energy Rating System (HERS) scores of 54 to 62 on 84 condominium units, with assistance from the U.S. Department of Energy's research team lead Building Science Corporation and the National Renewable Energy Laboratory.

To make homes that are truly affordable, the city has increasingly encouraged energy-efficient home construction. In 2004, the city took bids to design Phase 1 of Burlingame Ranch, an affordable housing development that will eventually number 258 units. For Phase 1 the city selected Shaw Builders of Grand Junction, Colorado, and the design team of Bill Poss Architects and DHM Design. The city also asked the Building Science Corporation to participate.

BSC helped design the project's energy-efficiency measures and solar hot water and heating systems, and reviewed energy code compliance reports. In 2007, BSC worked with DOE's National Renewal Energy Laboratory to conduct field testing of the mechanical, solar, and ventilation systems and short- and long-term monitoring of one of the buildings before and after homeowners moved in.

In Phase 1, all 84 homes met the Federal Tax Credit goal of 50% savings over the 2004 International Energy Conservation Code (IECC) and the Building America target of 40% savings over the Building America benchmark (a home built to the 1993 Model Energy Code).

(top) Deep overhangs and deciduous trees provide shade from intense Colorado sun. Low-maintenance exterior materials like cement siding and composite decking are specified. *(Photo Source: Ed Hancock, National Renewable Energy Laboratory)*

(bottom) Even snow cover and lack of icicles show the roofs are well insulated with little air leakage from the sealed attics. Two layers of ice and water shield are used for ice dam protection. *(Photo Source: Shaw Construction)*

Building in Snow Country

- Reduce the need to move or store snow. Face entrances, driveways, and walkways to south.
- Don't locate balconies, stairs, parking, or entrances at eaves.
- Design to avoid ice dams – use two layers of ice and water shield on roof. Place any roof penetrations high toward the ridge. Air seal well.
- Avoid electric snowmelt systems and gutters.
- Protect entrances under overhangs or gable ends.
- Use evergreens for windbreaks and direct drifting away from entrances.
- Use low-maintenance, high-durability exterior cladding, decking, and roofing.

Energy-Efficiency Features

Energy-saving features include a spray-foamed building envelope for excellent air tightness and thermal performance. The 2x6 24-inch-on-center advanced framed walls were filled with high-density spray foam insulation to R-24. The unvented attics were spray foamed with R-50 worth of insulation in cathedralized roof sections and R-38 under flat roof sections.

The edges of the slab foundation were covered with R-13 of XPS rigid foam insulation. Some units had walk-out basements insulated with R-13 (2 inches) of polyisocyanurate on the interior of the basement walls. Basement floors were insulated to R-28 with 4 inches of high-density, closed-cell spray foam that was sprayed directly onto the 4-inch layer of gravel under the foundation slab; this foam served as a vapor barrier as well.

The one- and two-story units were clustered in buildings containing two, four, six, or eight units per building. Each building has a central mechanical room containing two 93% AFUE condensing gas-fired boilers to provide hot water for the hydronic baseboard heating systems as well as domestic hot water. The domestic hot water is preheated from a solar hot-water system consisting of 192 ft^2 of solar panels mounted on the roof of each building with a 120-gallon storage tank located in the mechanical room.

In Phase 2, the City will request individual water- and space-heating systems, said Steve Bossart, project manager of the City's capital assets department, because the City believes that individual furnaces and water heaters provide more incentive for individuals to conserve water and energy, and reduce homeowner association maintenance of the complex central systems. For Phase 2, the City is considering gas furnaces or electric baseboard heating. Because the building enclosures are so efficient, large furnaces are not needed. The City is also considering individual solar hot-water heating.

Ventilation is provided with continuous heat-recovery ventilators (HRVs) in each unit. There is no installed cooling system. Windows are low-emissivity, double-glazed, and fiberglass-framed. ENERGY STAR compact fluorescent lamps provide 90% of the lighting and units come with ENERGY STAR dishwashers, refrigerators, clothes washers, and ceiling fans installed. A passive radon-protection system is installed.

Each dwelling unit was tested for whole house air leakage by a third-party tester (Lightly Treading Inc. Energy & Design of Denver, who also did the ENERGY STAR rating certifications). Infiltration was found to be 2.5 $in.^2$ leakage area per 100 ft^2 of envelope.

One building was outfitted with a roof-mounted 10-kW photovoltaic panel array for electricity production.

Bossart noted that in Colorado, pounding sun and heavy snow loads can take a toll on building materials. “Our area has extreme sun exposure year round. Anything we can do to specify low-maintenance exterior materials saves time, money, and manpower for the owners. Also, shielding western exposures from intense afternoon sun is important,” said Bossart.

The builder on Phase 1, Shaw Construction of Grand Junction, Colorado, took an especially proactive approach in developing a “sustainable culture” on the Burlingame project. Rock crushers were set up to crush rock onsite to use for backfill, rip rap, and gabion basket retaining walls. Long-lasting and sustainable building products were installed including bamboo flooring, wool carpet, Forest Stewardship Council (FSC) wood, finger-jointed studs, cement siding, metal roofs or 50-year shingles, fiberglass-framed windows, corn-based closed-cell insulation, prefabricated roof trusses, and offsite panelization of wood framed walls. Shaw used native grasses for landscaping and a planted, open-ditch concept for water runoff control. Shaw made a concerted effort to use local materials like local cement and drywall, and standing dead wood for columns.

“This project did not simply use sustainable products, everything about this project is sustainable. From the time workers carpooled in each morning to the time the workers cleaned up their work areas and put their trash into segregated recycle containers at the end of the day, the workers helped this project be “sustainable” in every way,” said David Hall, project manager for Shaw Construction.

Dollars and Sense

Because homes in Aspen are so expensive, demand for the affordable homes at Burlingame Ranch was very high, with up to 30 applications for every unit. All of the units were sold before completion with buyers chosen by lottery. “The city sponsors these subsidized projects to sustain a professional working class in the city limits,” said Bossart. Projects are funded via a real estate transfer tax or bonds.

Building Science Corporation calculated the added costs of building to the designed level of 51% more efficient than a home built to the Building America benchmark (a home built to the 1993 MEC). For one unit the added cost was approximately $6,180 in upfront costs, with almost half of this coming from the solar hot water system (see Table 1 below).

Energy-Efficient Features

- 51% energy savings over Building America benchmark
- Estimated cost savings $775 per unit
- R-50 high-density foam at sloped roof, R-38 at flat roofs
- 2x6, 24-inch on-center advanced frame stud walls with 3.5 inches of high-density spray-foam cavity insulation (R-24)
- Slab insulation with 2 in. XPS perimeter insulation extending 2 ft below grade
- Milgard fiberglass-framed, double-pane windows, U = 0.37, SHGC = 0.33
- 10-kW PV system (on one building)
- Roof-mounted solar thermal panels for domestic hot water (on all buildings)
- 3rd party whole-house air-leakage testing of every unit. Infiltration averaged 2.5 in.^{2} leakage area per 100 ft^2 envelope
- 93% AFUE condensing boiler in conditioned space
- Heat-recovery ventilator
- 90% hard-wired fluorescent lighting
- ENERGY STAR dishwasher, refrigerator, clothes washer, ceiling fans
- Water-conserving faucets, showerheads, and toilet

“Superior enclosures with heat-recovery ventilation have allowed us to reduce heating costs and maintain indoor air quality.”

Steve Bossart, *City of Aspen*

Solar water heating panels were mounted on each multifamily building to provide domestic hot water and pre-heat water for the hydronic baseboard space heating system.

Table 1. Added Costs and Savings of Energy-Efficient Measures for Shaw Construction

Total Energy Savings	51%
Total Added Builder Costs (per unit)*	$6,178
Annual Mortgage Payment Increase**	$498
Annual Utility Savings	$775
Annual Net Cash Flow to Homeowner	$277

*Costs are based on builder estimates, RS Means, DEER, and manufacturers' data. These costs do not reflect rebates, incentives, and subsidies. Costs assume a 10% builder markup.

**The annual mortgage payment is an estimate based on a 30-year mortgage with a 7% fixed interest rate.

When these costs are spread over a 30-year fixed-rate mortgage at 7% interest, the increased annual mortgage cost is $498. The measures incorporated in the homes to achieve the 51% savings would provide $775 per year per unit in utility cost savings, based on local electricity and natural gas prices, which are relatively low. When the annual mortgage increase is subtracted from this, results still yield a positive cash flow to homeowners of $277 per unit.

The Bottom Line

"This project was a great model for us and has helped promote energy-efficient construction to all of our employees and clients. Staying at the forefront of energy-efficient construction helps keep Shaw ahead of our competition. It differentiates us from the pack," said David Hall, project manager for Shaw Construction.

For More Information

www.buildingamerica.gov
EERE Information Center
1-877-EERE-INF (1-877-337-3463)
eere.energy.gov/informationcenter

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

PNNL-SA-76317 February 2011

Appendix I.
Homebuyer's Checklist

Homebuyers, take this with you when you go house shopping to make sure you get an energy-efficient home.

MEASURE	Building America Recommendations	Builder #1	Builder #2	Builder #3
HEATING AND COOLING EQUIPMENT				
ENERGY STAR qualified air conditioning of SEER* 13 or greater	Yes			
ENERGY STAR qualified heat pump	Yes			
ENERGY STAR qualified boiler	Yes			
ENERGY STAR qualified sealed combustion gas furnace of 90 AFUE* or higher	Yes			
ENERGY STAR qualified programmable thermostat	Yes			
Ductwork sealed with mastic (no duct tape)	Yes			
5% or less duct leakage found with pressure test 10% allowed if all ducts are located in the conditioned space.	Yes			
Duct Insulation: R-4 in conditioned space, R-8 in attic, R-6 in crawlspace	Yes			
House plans show duct layouts	Yes			
Ducts located in conditioned space	Yes			
Ducts sized according to industry standards in Manual D	Yes			
Heating and cooling equipment sized according to industry standards in Manual J	Yes			
House pressure balanced with jump ducts or transfer grills	Yes			
HVAC* equipment and duct work inspected and tested after installation	Yes			
Filter with MERV rating of 8 or higher installed on the central air handler	Yes			
Air handler isolated from garage by a thermal barrier (insulation) and air barrier (e.g., drywall sealed at seams)	Yes			

MEASURE	Building America Recommendations	Builder #1	Builder #2	Builder #3
INSULATION (take a look at a house under construction before sheetrock is installed)				
Insulation installed behind tubs, landings, and other hard to reach places	Yes			
Insulation fills entire cavities—no voids or compressed batts—Attic insulation level without gaps and covers entire attic floor	Yes			
Where fiberglass batt insulation is used it is high-density	Yes			
Rim joists are insulated	Yes			
Rigid foam insulation applied under exterior siding or stucco	Yes			
WINDOWS (take a look at a house under construction before exterior siding is installed)				
ENERGY STAR qualified windows, doors, and skylights	Yes			
Windows flashed to help repel water	Yes			
Windows rated to U-factor of 0.40 or less and SHGC of 0.40 or less	Yes			
MOISTURE MANAGEMENT (take a look at a house under construction before exterior siding is installed)				
Ground slopes away from house	Yes			
Housewrap, building paper, or rigid foam exterior insulation, taped at seams and caulked at edges, covers OSB walls in wood-framed houses	Yes			
Roof flashing in valleys, where walls and roofs intersect, and at other places where water may enter the house—the more complex the roof, the more flashing you should see	Yes			
Air gap between stucco, brick, or masonry cladding and housewrap	Yes			
Overhangs for shade and to direct water away from walls	Yes			
Trees planted ten feet from house, no overhanging branches	Yes			
Plantings 18 to 36 inches away from the foundation	Yes			
No wood or siding in direct contact with ground	Yes			
AIR BARRIERS				
Follow ENERGY STAR Thermal Bypass Checklist	Yes			
All penetrations through exterior walls sealed	Yes			
Careful sealing of sheetrock or exterior sheathing	Yes			
Canned lights rated as airtight and for insulated ceiling (ICAT)	Yes			
Electrical boxes on exterior walls caulked or gasketed	Yes			
Holes into attic sealed	Yes			
Attic hatch weather-stripped and insulated	Yes			
Air leakage determined with house depressurization test	Yes			
Wall-roof intersection carefully sealed to avoid ice dams	Yes			
Draft stops installed behind tubs, showers, stairs, and fireplaces	Yes			
Garage completely sealed from conditioned areas of house	Yes			
Careful sealing around bathtubs, landings, fireplaces, kneewalls, cantilevered floors, etc.	Yes			
Sill plates gasketed or sealed	Yes			

MEASURE	Building America Recommendations	Builder #1	Builder #2	Builder #3
FOUNDATION MEASURES				
Radon control measures installed	Yes			
4 to 6 inch gravel base under slab and basement floors	Yes			
Polyethylene (plastic) vapor barrier between gravel and slab	Yes			
Conditioned crawlspace	Yes			
Exterior slab insulation	Yes			
Termite flashing added at sill plate	Yes			
PLUMBING				
No pipes in exterior walls	Yes			
Pipe insulation	Yes			
VENTILATION				
Whole-house mechanical ventilation installed	Yes			
Spot ventilation installed in kitchen and bathrooms	Yes			
Clothes dryers are vented to the outside	Yes			
Gas-fired furnaces or water heaters sealed combustion, direct vented, or power vented	Yes			
Carbon monoxide detector installed in homes with a combustion appliance or attached garage	Yes			
Attached garages are ventilated	Yes			
FRAMING				
Use Optimum Value Engineering (also called Advanced Framing): - 2x6 24 in. oc instead of 2x4 18 in. oc studs - Align framing members from floor joists to wall studs to rafters - Use single top plates and single headers where possible - Use two-stud corners and drywall clips instead of 3-stud corners	Yes			
OTHER				
Low VOC interior coatings	Yes			
Low VOC adhesives	Yes			
Low emission cabinets	Yes			
CFL lighting	Yes			
OTHER FEATURES FOR COMPARISON				

**SEER: Seasonal Energy Efficiency Ratio | *AFUE: Annual Fuel Utilization Efficiency | *HVAC: heating, ventilation, and air conditioning*

Appendix II.

DOE Building Energy Code Resource Center Code Notes

A meeting with the building department before construction is well advised. Should your code official need information in support of the new techniques you may use in an energy-efficient home, this appendix contains websites and a sample document that may be helpful. A set of draft code notes are available on DOE's Building Energy Codes Resource Center website. These draft documents are written for code officials and provide a description of energy-efficiency techniques, citations to relevant codes, and guidance for plan reviews and field inspections.

Here is a list of available code notes that can help re-assure your local code official that the proposed techniques are both safe and in compliance with the model codes. The code notes are available at www.energycodes.gov/support/code_notes.stm.

- Single Top Plate
- No Headers in Nonbearing Walls
- Header Hangers in Bearing Walls
- Open Spaces as Return-Air Options
- Details for Mechanically Vented Crawl Spaces
- Ventilation Requirements for Condensing Clothes Dryers
- Drywall Clips
- Rigid Board Insulation Installed as Draft Stop in Attic Kneewall
- Whole-House Mechanical Ventilation
- Residential Heating and Cooling Load Calculation Requirements
- Conditioned Attics.

We have included one of these Code Notes as a sample in this document, the Code Note for *Rigid Board Insulation Installed as Draft Stop in Attic Kneewall*. You will find it on the pages that follow.

Building Energy Codes RESOURCE CENTER

Rigid Board Insulation Installed as Draft Stop in Attic Kneewall - Code Notes (DRAFT)

Framing kneewall

Rigid board insulation (foam plastic) is an effective draft stop and also increases the R-value of the attic kneewall if installed on the attic side of the kneewall, replacing the need for separate draft stop and insulation products. The IRC requires foam plastic insulation to be protected against ignition by using fiberglass batt insulation, gypsum board or other products that meet the flame and smoke density requirements. Foam plastic products rated for flame and smoke density can be installed without such a protective covering.

Insulating attic kneewalls between a conditioned space with vaulted ceilings and the attic is important to reduce energy loss through the wall, especially in the summer months. To be effective, the insulation installed in the kneewalls must be supported so that it stays in contact with the gypsum board, and protected against air moving through the insulation.

Building Energy Codes Resource Center

photo by Britt-Makela Group

The R-value of the kneewall sheathing insulation should equal the R-value of the exterior wall insulation.

Foam plastic insulation can be installed on the attic side of the attic kneewall (see Figure) to both act as a draft stop between the conditioned house and the unconditioned attic and to increase the insulation R-value of the attic kneewall. Installing such an insulating backing in the kneewall supports the fiberglass batt insulation between framing members, replaces an air barrier, and adds insulating value to the attic kneewall.

Plan Review

1. Verify that plastic insulation called out on the construction detail meets the ASTM E 84 requirements for flame spread and smoke development. Require manufacturer literature or an ICC Evaluation Service report.
2. Verify that the insulation R-value of the foam plastic insulation called out on the building plans meets or exceeds the R-value requirements called for on the energy code compliance documentation (only if credit has been taken for the foam plastic insulation).

Field Inspection

1. Verify that the foam plastic insulation installed in the field is consistent with that called out on the building plans.
2. Verify that the insulation R-value specified on the insulation meets or exceeds the R value called out on the plans or documentation.
3. Verify that that sealant has been installed around the edges of the insulation and that any holes or penetrations in the foam plastic insulation are sealed.

Code Citations

Appendix III.

Energy & Housing Glossary

Accreditation

The process of certifying a Home Energy Rating System (HERS) as being compliant with the national industry standard operating procedures for Home Energy Rating System.

AFUE Annual Fuel Utilization Efficiency (AFUE)

Measures the amount of fuel converted to space heat 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. AFUE includes any input energy required by the pilot light but does not include any electrical energy for fans or pumps.

Air Barrier

Any material that restricts air flow. In wall assemblies, the exterior air barrier is often a combination of sheathing and either building paper, housewrap or board insulation. The interior air barrier is typically gypsum board.

Air Flow Retarder

Air flow retarders are used to form a home's pressure boundary. They retard air flow through the home's walls, floors, and ceiling. Common air flow retarder materials include drywall that is taped and mudded at seams; OSB or plywood subflooring that is caulked at seams; plastic sheets placed between drywall and framing (should not to be used in hot and humid climates); exterior rigid foam insulating sheathing that is taped at seams; and building paper that is taped at seams.

Building Envelope

The outer shell, or the elements of a building, such as walls, floors, and ceilings, that enclose conditioned space. *See also Pressure Boundary and Thermal Boundary.*

Btu (British Thermal Unit)

A standard unit for measuring energy. One Btu is the amount of energy required to raise the temperature of one pound of water by one degree Fahrenheit from 59 to 60. An Inches-Pounds unit.

CABO (Council of American Building Officials)

The previous umbrella organization for the three nationally recognized model code organizations in the United States: the Building Officials & Code Administrators International, Inc. (BOCA), the International Conference of Building Officials (ICBO), and the Southern Building Code Congress International (SBCCI). All were incorporated into the International Code Council in ICC in November of 1997 with the goal of developing a single national building code in the United States.

Capacity

The rate at which a piece of equipment works. Cooling capacity is the amount of heat a cooling system can remove from the air. For air conditioners total capacity is the sum of latent capacity, the ability to remove moisture from the air, and the sensible capacity, the ability to reduce dry-bulb temperature. Heating system capacity indicates how much heat a system can provide. Heating and cooling capacities are rated in Btu per hour.

Chase

An enclosure designed to hold ducts, plumbing, electric, telephone, cable, or other linear components. A chase designed for ducts should be in conditioned space and include air flow retarders and thermal barriers between it and unconditioned spaces such as attics.

Construction Documents

The drawings (plans) and written specifications that describe construction requirements for a building.

COP (Coefficient of Performance)

A measure of efficiency typically applied to heat pumps. The COP for heat pumps is the ratio, at a given point in time, of net heat output to total energy input expressed in consistent units and under designated conditions. Heat pumps result in a COP greater than 1 because the system delivers or removes more heat energy than it consumes. Other specific definitions of COP exist for refrigeration equipment. See HSPF for a description of a unit for seasonal efficiency.

Debt-to-Income Ratio

The ratio, expressed as a percentage, which results when a borrower's total monthly payment obligations on long-term debt are divided by their gross monthly income. This is one of two ratios (housing expense-to-income ratio being the other) used by the mortgage industry to determine if a prospective borrower qualifies (meets the underwriting guidelines) for a specific home mortgage. Fannie Mae, Freddie Mac and FHA underwriting guidelines set an upper limit of 36% on this value for conventional loans but increase ("stretch") the ratio by 2% for qualifying energy-efficient houses.

Dry-Bulb Temperature

The temperature of air indicated on an ordinary thermometer, it does not account for the affects of humidity.

ECM (Energy Conservation Measure)

An individual building component or product that directly impacts energy use in a building.

EEM (Energy-Efficient Mortgage)

Specifically, a home mortgage for which the borrower's qualifying debt-to-income and housing expense-to income ratios have been increased ("stretched") by 2% because the home meets or exceeds CABO's 1992 version of the Model Energy Code (MEC). This so-called "stretch" mortgage is nationally underwritten by Fannie Mae, Freddie Mac and the Federal Housing Administration (FHA). This term is often used generically to refer to any home mortgage for which the underwriting guidelines have been relaxed specifically for energy efficiency features, or for which any form of financing incentive is given for energy efficiency.

EER (Energy Efficiency Ratio)

A measurement of the instantaneous energy efficiency of cooling equipment, normally used only for electric air conditioning. EER is the ratio of net cooling capacity in Btu per hour to the total rate of electric input in watts, under designated conditions. The resulting EER value has units of Btu per watt-hour.

EF (Energy Factor)

A standardized measurement of the annual energy efficiency of water heating systems. It is the annual hot water energy delivered to a standard hot water load divided by the total annual purchased hot water energy input in consistent units. The resultant EF value is a percentage. EF is determined by a standardized U.S. Department of Energy (DOE) procedure.

Energy (Use)

The quantity of onsite electricity, gas or other fuel required by the building equipment to satisfy the building heating, cooling, hot water, or other loads or any other service requirements (lighting, refrigeration, cooking, etc.)

Energy Audit

A site inventory and descriptive record of features impacting the energy use in a building. This includes, but is not limited to all building component descriptions (locations, areas, orientations, construction attributes and energy transfer characteristics); all energy using equipment and appliance descriptions (use, make, model, capacity, efficiency and fuel type) and all energy features.

ENERGY STAR® Home

A home, certified by the U.S. Environmental Protection Agency (EPA), that is at least 30% more energy efficient than the minimum national standard for home energy efficiency as specified by the 1992 MEC, or as defined for specific states or regions. ENERGY STAR is a registered trademark of the EPA.

Envelope

See Building Envelope

Fannie Mae (FNMA - Federal National Mortgage Association)

A private, tax-paying corporation chartered by the U.S. Congress to provide financial products and services that increase the availability of housing for low-, moderate-, and middle-income Americans.

FHA (Federal Housing Administration)

A division of the U.S. Department of Housing and Urban Development (HUD). FHA's main activity is the insurance of residential mortgage loans made by private lenders.

Freddie Mac (FHLMC - Federal Home Loan Mortgage Corporation)

A stockholder-owned organization, chartered by the U.S. Congress to increase the supply of mortgage funds. Freddie Mac purchases conventional mortgages from insured depository institutions and HUD-approved mortgage bankers.

Grade Beam

A foundation wall that is poured at or just below the grade of the earth, most often associated with the deepened perimeter concrete section in slab-on-grade foundations.

HERS (Home Energy Rating System)

A standardized system for rating the energy-efficiency of residential buildings.

HERS Energy-Efficient Reference Home (EERH)

The EERH is a geometric "twin" to a home being evaluated for a HERS rating and according to a newly revised system, is configured to be minimally compliant with the 2004 International Energy Conservation Code.

HERS Provider

An individual or organization responsible for the operation and management of a Home Energy Rating System (HERS).

HERS Rater

An individual certified to perform residential building energy efficiency ratings in the class for which the rater is certified.

HERS Index

The HERS Index is a scoring system established by the Residential Energy Services Network (RESNET) in which a home built to the specifications of the HERS Reference Home (based on the 2006 International Energy Conservation Code) scores a HERS Index of 100, while a net zero energy home scores a HERS Index of 0. The lower a home's HERS Index, the more energy efficient it is in comparison to the HERS Reference Home.

Each 1-point decrease in the HERS Index corresponds to a 1% reduction in energy consumption compared to the HERS Reference Home. Thus a home with a HERS Index of 85 is 15% more energy efficient than the HERS Reference Home and a home with a HERS Index of 70 is 30% more energy efficient.

Housing Expense-to-Income Ratio

The ratio, expressed as a percentage, which results when a borrower's total monthly housing expenses (P.I.T.I.) are divided by their gross monthly income. This is one of two ratios (debt-to-income ratio being the other) used by the mortgage industry to determine if a prospective borrower qualifies (meets the underwriting guidelines) for a specific home mortgage. Fannie Mae, Freddie Mac and FHA underwriting guidelines set an upper limit of 28% on this value for conventional loans but increase ("stretch") the ratio by 2% for qualifying Energy-Efficient Mortgages (EEM).

Housewrap

Any of several spun-fiber polyolefin rolled sheet goods for wrapping the exterior of the building envelope.

HSPF (Heating Season Performance Factor)

A measurement of the seasonal efficiency of an electric heat pump using a standard heating load and outdoor climate profile over a standard heating season. It represents the total seasonal heating output in Btu divided by the total seasonal electric power input in watt-hours (Wh). Thus, the resultant value for HSPF has units of Btu/Wh.

Infrared Imaging

Heat sensing camera which helps reveal thermal bypass conditions by exposing hot and cold surface temperatures revealing unintended thermal flow, air flow, and moisture flow. Darker colors indicate cool temperatures, while lighter colors indicate warmer temperatures.

Insulated Concrete Forms (ICFs)

Factory-built wall system blocks that are made from extruded polystyrene insulation. Steel reinforcing rods are added and concrete is poured into the voids, creating a very air-tight, well insulated and sturdy wall as the insulation is inherently aligned with the exterior and interior air barriers.

Insulation Contact, Air-Tight (ICAT) Lighting Fixture

Rating for recessed lights that can have direct contact with insulation and constructed with air-tight assemblies to reduce thermal losses.

Jump Duct

A flexible, short, U-shaped duct (typically 10-inch diameter) that connects a room to a common space as a pressure balancing mechanism. Jump ducts serve the same function as transfer grilles.

Load

The quantity of heat that must be added to or removed from the building (or the hot water tank) to satisfy specific levels of service, such as maintaining space temperature or hot water temperature at a specified thermostat setting (see also the definitions of energy and thermostat).

Low-E

Refers to a coating for high-performance windows, the "E" stands for emissivity or re-radiated heat flow. The thin metallic oxide coating increases the U-value of the window by reducing heat flow from a warm(er) air space to a cold(er) glazing surface. Low-E coatings allow short-wavelength solar radiation through windows, but reflect back longer wavelengths of heat.

MEC (Model Energy Code)

A "model" national standard for residential energy efficiency. The MEC was developed through a national consensus process by the Council of American Building Officials (CABO) and is the accepted national minimum efficiency standard for residential construction. Since MEC is a model code, it does not have the "force of law" until it is adopted by a local code authority. The MEC is used as the national standard for determining Energy-Efficient Mortgage (EEM) qualification, and it serves as the national "reference point" used by Home Energy Rating Systems (HERS) in the determination of energy ratings for homes.

Mechanical Ventilation

The active process of supplying or removing air to or from an indoor space by powered equipment such as motor-driven fans and blowers, but not by devices such as wind-driven turbine ventilators and mechanically operated windows.

Optimal Value Engineering (OVE)

A strategy for reducing thermal bridging by minimizing wall framing needed for structural support. Common techniques include 2x6 framing with 24" on-center spacing, single top plates where trusses align with wall framing below, properly sized headers, two-stud corners, lattice strips at exterior/interior wall intersections, and the elimination of excessive fire blocking and window framing. This results in much more open framing for insulation to improve energy efficiency and comfort.

Performance Test

An on-site measurement of the energy performance of a building energy feature or an energy using device conducted in accordance with pre-defined testing and measurement protocols and analysis and computation methods. Such protocols and methods may be defined by national consensus standards like those of the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) and the American Society for Test and Measurement (ASTM).

P.I.T.I.

An abbreviation which stands for principal, interest, taxes, and insurance. These generally represent a borrower's total monthly payment obligations on a home loan. The taxes and insurance portion are often paid monthly to an impound or escrow account and may be adjusted annually to reflect changes in the cost of each.

Pressure Boundary

The point in a building at which inside air and outside air are separated. If a building were a balloon, the rubber skin would form the pressure boundary. Where inside and outside air freely mingle there is no pressure boundary.

Pressurization Test

A procedure in which a fan is used to place a house, duct system, or other container, under positive or negative air pressure in order to calculate air leakage.

RESNET (Residential Energy Services Network)

The national association of energy rating providers.

Rated Home

A specific residence that is evaluated by an energy rating.

R-Value

Measures a material's ability to slow down or resist the transfer of heat energy, also called thermal resistance. The greater the R-value, the better the resistance, the better the insulation. The effective R-value of an insulation material will be reduced by gaps, voids, compression or misalignment. R-values are the reciprocal of U-values. See U-values for more information.

Sealed Combustion

Sealed combustion means that a combustion appliance, such as a furnace, water heater, or fireplace, acquires all air for combustion though a dedicated sealed passage from the outside; combustion occurs in a sealed combustion chamber, and all combustion products are vented to the outside through a separate dedicated sealed vent.

SEER (Seasonal Energy Efficiency Ratio)

A measurement similar to HSPF except that it measures the seasonal cooling efficiency of an electric air conditioner or heat pump using a standard cooling load and outdoor climate profile over a standard cooling season. It represents the total seasonal cooling output in Btu divided by the total seasonal electric input in watt hours (Wh). The SEER value are units of Btu/Wh.

Semi-Permeable

The term vapor semi-permeable describes a material with a water vapor permeance between 1 and 10 Perms. Water vapor can pass through a semi-permeable material but at a slow rate.

Shading Coefficient (SC)

The ratio of the total solar heat admittance through a given glazing product relative to the solar heat admittance of double-strength, clear glass at normal solar incidence (i.e., perpendicular to the glazing surface).

Site Energy

The energy consumed at a building location or other end–use site.

Solar Heat Gain Coefficient (SHGC)

SHGC measures how well a 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. The number is the ratio of a window's solar heat admittance compared to the total solar heat available on the exterior window surface at normal solar incidence (i.e., perpendicular to the glazing surface).

Sone

A sound rating. Fans rated 1.5 sones and below are considered very quiet.

Source Energy

All the energy used to deliver energy to a site, including power generation and transmission and distribution losses (also called primary energy). Approximately three watts (or 10.239 British thermal units) of energy is consumed to deliver one watt of usable electricity. Building America energy saving targets are measured in terms of source energy rather than site energy.

Structural Insulated Panels (SIPs)

Factory-built insulated wall assemblies that ensure full alignment of insulation with integrated air barriers. Composed of insulated foam board glued to both an internal and external layer of sheathing (typically OSB or plywood). Many SIP panels are manufactured with precut window and door openings.

Supply ducts

The ducts in a forced air heating or cooling system that supply heated or cooled air from the furnace or air conditioner to conditioned spaces.

Thermal Boundary

The border between conditioned and unconditioned space where insulation should be placed.

Thermal Bridging

Accelerated thermal flow that occurs when materials that are poor insulators displace insulation.

Thermostat

A control device that measures the temperature of the air in a home or the water in a hot water tank and activates heating or cooling equipment to cause the air or water temperature to remain at a pre-specified value, normally called the set point temperature.

Ton(s) of Refrigeration

Units used to characterize the cooling capacity of air conditioning equipment. One ton equals 12,000 Btu/h.

U-Value

Measures the rate at which heat flows or conducts through a building assembly (wall, floor, ceiling, etc.). The smaller the U-value the more energy efficient an assembly and the slower the heat transfer. Window performance labels include U-values (calling them U factors) to help in comparing across window products.

Ventilation

The controlled movement of air into and out of a house.

W (watt)

One of two (Btu/h is the other) standard units of measure for the rate at which energy is consumed by equipment or the rate at which energy moves from one location to another. It is also the standard unit of measure for electrical power.

Wet-Bulb Temperature

A measure of combined heat and humidity. At the same temperature, air with less relative humidity has a lower wet-bulb temperature. *See Dry-Bulb Temperature.*

Wind Baffle

An object that serves as an air barrier for the purpose of blocking wind washing at attic eaves.

Wind-Washing

Air movement due to increased pressure differences that occur at the outside corners and roof eaves of buildings. Wind-washing can have significant impact on thermal and moisture movement and hence thermal and moisture performance of exterior wall assemblies.

Xeriscaping

Landscaping that minimizes outdoor water use while maintaining soil integrity and building aesthetics. Typically includes emphasis on native plantings, mulching, and no or limited drip/subsurface irrigation.

Zero Energy House

Any house that over time, averages out to net-zero energy consumption. A zero energy home may supply more energy than it needs during peak demand, typically using one or more solar energy strategies, energy storage and/or net metering.

Appendix IV.

Acronyms and Abbreviations

ACCA	Air Conditioning Contractors of America
ACH	air changes per hour
ACI	Affordable Comfort Incorporated
ACT2	Advanced Customer Technology Test for Maximum Energy Efficiency
AFUE	Annual Fuel Utilization Efficiency
AHU	air-handler unit
AL	air leakage
ALA	American Lung Association
APA	The Engineered Wood Association
ASCE	American Society of Civil Engineers
ASHRAE	American Society of Heating, Refrigerating, and Air Conditioning Engineers
ASTM	American Society for Testing and Materials
BECT	Building Energy Code Training
BEopt	Software developed by NREL for identifying optimal building design
BESTEST	A benchmark for building energy simulation: Building Energy Simulation Test and Diagnostic Method
BII	Building Industry Institute
BIRA	Building Industry Research Alliance
BPI	Building Performance Institute
BSC	Building Science Corporation
BSC	Building Science Consortium
BTU	British Thermal Unit
CAD	computer-aided design
CARB	Consortium for Advanced Residential Buildings
CDCU	Community Development Corporation of Utah
CDD	cooling degree days
CEC	California Energy Commission
CFL	compact fluorescent light
CFM	cubic feet per minute
CGSB	Canadian General Standards Board
COP	coefficient of performance
CR	condensation resistance
CRI	color-rendering index
CT	color temperature
DHW	domestic hot water
DOE	U.S. Department of Energy
DOE2	Building energy analysis program that can predict the energy use and cost for all types of buildings
ECM	electronically commutated motor (or energy conservation measure)
EDHA	Eastern Dakota Housing Alliance
EEBA	Energy and Environmental Building Alliance
EEM	Energy-efficient mortgages
EER	Energy Efficiency Rating
EERH	Energy-Efficient Reference Home

EF	energy factor
EFL	Environments for Living®
EGUSA	Energy-Gauge USA software (FSEC's residential front-end user interface for DOE2.1E simulation tool)
EPDM	Ethylene Propylene Diene Monomer
EPA	U.S. Environmental Protection Agency
EPS	expanded polystyrene
ERV	energy recovery ventilator
EVHA	Energy Value Housing Award
FEMA	Federal Emergency Management Agency
FF	framing factor
FFA	finished floor area
FG	fiberglass
FHA	Federal Housing Administration
FSEC	Florida Solar Energy Center
GAMA	Gas Appliance Manufacturers Association
GenOpt	generic optimization program
HVAC	heating, ventilating, and air conditioning
HDD	heating degree days
HERS	Home Energy Rating System developed by RESNET
HPL	high-performance lighting
HRV	heat recovery ventilator
HSPF	Heating Seasonal Performance Factor
HUD	U.S. Department of Housing and Urban Development
IAQ	Indoor air quality
IBACOS	Integrated Building and Construction Solutions
IBHS	Institute for Business and Home Safety
IC	insulated ceiling
ICAT	Insulation-Contact Air-Tight
ICC	International Code Council
IDEC	Indirect-Direct Evaporative Cooler
IDP	Integrated Design Process
IECC	International Energy Conservation Code
IEQ	Indoor Environmental Quality
IHP	Industrialized Housing Partnership
IOSEU	incremental overall source energy use
IRC	International Residential Code
Mcf	million cubic feet
MEC	Model Energy Code (supplanted by IECC in 1998)
MEF	modified energy factor
MERV	Minimum Efficiency Reporting Value
NAECA	National Appliance Energy Conservation Act
NAHB	National Association of Home Builders
NAHB RC	National Association of Home Builders Research Center
NASEO	National Association of State Energy Officials
NATE	North American Technician Excellence
NFRC	National Fenestration Rating Council
NHQ	National Housing Quality
NREL	National Renewable Energy Laboratory
NZEH	net-zero energy home
OA	outdoor air
OASys	a high-efficiency indirect/direct evaporative cooler developed by Davis Energy Group
oc	on center
ODOE	Oregon Department of Energy
ORNL	Oak Ridge National Laboratory
OSB	oriented strand board
Pa	Pascal, unit of pressure measurement
PATH	Partnership for Advancing Technology in Housing
PEX	cross-linked Polyethylene tubing
PITI	principal, interest, tax, and insurance
PNNL	Pacific Northwest National Laboratory
PSC	permanent split-capacitor motors
PV	photovoltaics

R-Value A measure of thermal resistance used to describe thermal insulation materials in buildings

R.A.P. return-air pathway

RESNET Residential Energy Service Network

RH relative humidity

SA supply air

SBIC Sustainable Buildings Industry Council

SC shading coefficient

SEER seasonal energy efficiency ratio

SHGC solar heat gain coefficient

SHW solar hot water

SLA specific leakage area

SIP structural insulated panels

TAB testing, adjusting, and balancing

TIP Termite Infestation Probability

TMY2 Typical Meteorological Year weather data

TOU time of use

TXV thermostatic expansion valve

UL Underwriter's Laboratory

USDA US Department of Agriculture

USGBC US Green Building Council

U-Value The thermal transmittance of a material, incorporating the thermal conductance of the structure along with heat transfer resulting from convection and radiation.

UA heat loss coefficient

UL Underwriter's Laboratories

UV ultraviolet

VA Veterans Administration

VOC volatile organic compounds

VT visible transmittance

WAC Washington Administrative Code

WSBCC Washington State Building Code Council

WSU Washington State University

WUFI Modeling program for simulating heat and moisture transfer

XPS extruded polystyrene

ZEH zero energy home

ZNE zero net energy

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