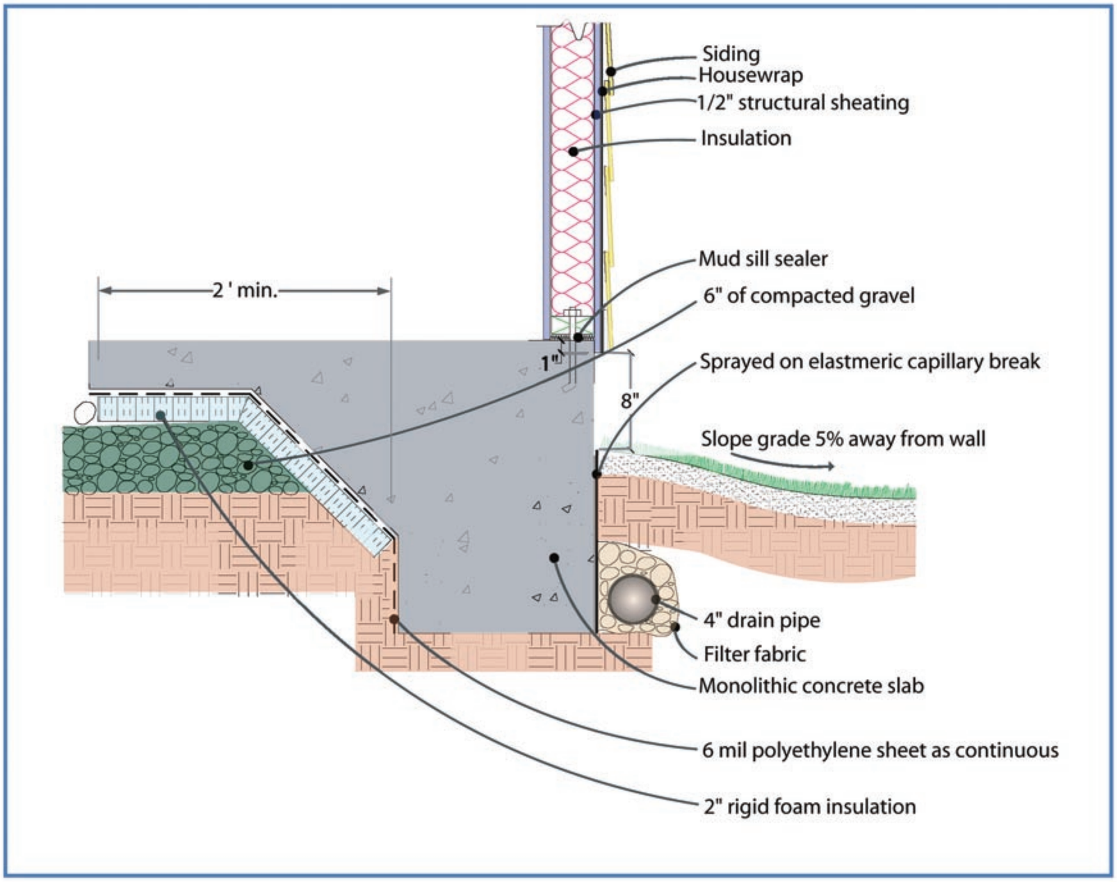
July 2004 • NREL/SR-550-34007

IBACOS Builder System Performance Packages

January 2003–December 2003



IBACOS
Pittsburg, Pennsylvania

U.S. Department of Energy
Energy Efficiency and Renewable Energy
Bringing you a prosperous future where energy is clean, abundant, reliable, and affordable

Building Technologies Program

July 2004 • NREL/SR-550-34007

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Definitions

Acronym	Description	Units
ACH	air changes per hour	
AFUE	annual fuel utilization efficiency	
AHU	air handling unit	
COP	coefficient of performance	
EF	energy factor	
EER	energy efficiency ratio	
ERV	energy recovery ventilator	
HERS	home energy rating system	
HRV	heat recovery ventilator	
HSPF	heating seasonal performance factor	Btu/Wh
HVAC	heating, ventilation, and air-conditioning	
ICF	insulating concrete forms	
MEC	Model Energy Code	
OVE	optimum value engineering	
Pa	Pascals	
RESNET	Residential Energy Services Network	
R-x	resistance value	ft^2•h•°F/Btu
SEER	seasonal energy efficiency ratio	Btu/Wh
SHGC	solar heat gain coefficient	
SIPS	structural insulated panel system	
U-x	overall heat transfer coefficient	Btu/ft^2•h•°F

Term	Definition
Air distribution system	includes the ducts and the air handler for space heating and cooling

Scope of Work

Deliverable Description

Based on overall results from systems-engineering research studies in previous and existing projects that met 30% to 40% space-conditioning energy-savings targets, the subcontractor will prepare a report summarizing system design recommendations (including both envelope and equipment specifications) for builders and contractors. The reports will clearly identify the appropriate climate, building type, energy performance level, and building systems addressed by the recommendations. The reports will clearly identify the benefits that have resulted from the use of the recommendations in Building America projects. The reports will summarize the building science knowledge and quality-control tools that are required to successfully implement system design recommendations. The reports will be written as a "how-to" manual for other builders to use to achieve similar energy savings in the same climate and building type.

Abstract

This report presents system design packages for cold and mixed-humid climates. Builders and contractors can use these design packages to construct homes that achieve a Home Energy Rating System (HERS) score between 86 and 88. This represents a reduction in space-conditioning and domestic hot-water energy consumption of between 30% and 40%, compared to a similar home built to meet the 1993 Model Energy Code. The six different design packages, three for each climate zone, give the builder flexibility in their design strategy by allowing them to choose the most cost-effective approach. The recommendations presented in these design packages are based on more than 10 years of experience that IBACOS (Integrated Building and Construction Solutions) has had working with builders throughout the United States on Building America projects.

Keywords

IBACOS

cold climate

mixed-humid climate

system performance packages

Builder System Performance Packages Overview

The focus of the IBACOS Building America Builder Program activities is working with builders through research to construct homes that perform significantly better than their current version, while advancing residential building products and technologies. As part of these activities, design recommendations are made for each home to meet energy efficiency and building-durability performance goals, including significant reductions in energy used for space heating and cooling.

For 10 years, IBACOS has been working with builders all across the United States, in different climate zones, to achieve the established energy efficiency goals through research and technical solutions. Based on this experience, we have been able to formulate packages of design recommendations that are applicable for the cold and mixed-humid climate zones (Building America 2002) and consider the foundation type used (either slab-on-grade, crawlspace, or basement). If followed, the design packages should allow a builder to construct homes that will achieve a HERS score between 86 and 88. This represents a reduction in space-conditioning and domestic hot-water energy consumption of between 30% and 40%, compared to a similar home built to meet the 1993 Model Energy Code.

In this report, we will identify the appropriate climate, building type, energy performance level, and building systems addressed by the design packages recommendations. The benefits that have resulted from the use of the recommendations in Building America projects are also identified. We summarize the building-science knowledge and quality-control tools that are required to successfully implement system design recommendations. The report is written as a how-to manual for other builders to use to achieve similar energy savings in the same climate and building type.

Cold-Climate Performance Packages

Introduction and Methodology

Initial development of the performance design packages for the cold-climate zone included an examination of recommendations made in Building America pilot home activities with Farm Development in Albany (Poughquag), New York; Woodmont Builders, Parsippany, New Jersey; Montgomery and Rust Construction, Pittsburgh, Pennsylvania; Jayar Construction, Pittsburgh, Pennsylvania; Kacin Construction, Pittsburgh, Pennsylvania; Heartland Homes, Pittsburgh, Pennsylvania; Pulte Home Corporation, Grand Rapids, Michigan; Estridge Homes in Indianapolis, Indiana; Pink Panther Homes by Estridge in Cicero, Indiana; Calumet Management in Chesterton, Indiana; John Laing Homes in Denver, Colorado; and New Town Builders in Denver, Colorado. To develop the design packages further, comparative energy efficiency analysis based on basement and crawlspace foundations house designs were conducted in three representative locations: Denver, Grand Rapids, and Albany.

The three design packages summarized in tables 1, 2, and 3 outline different cost-effective approaches to constructing homes in a cold climate so that they will obtain a HERS score between 86 and 88, as defined by the Mortgage Industry National Home Energy Rating Standards (RESNET 2002 [Residential Energy Services Network]). Table 1 includes a summary of a design package with an alternative to insulated sheathing approach. Table 2 includes a summary of a design package with an alternative to insulated sheathing. Table 3 includes a summary of a design package with an 80% gas furnace system approach.

It is assumed that a house with an energy efficiency score between HERS 86 and 88 satisfies this goal. The different design packages give the builder flexibility in their design strategy by allowing them to choose the approach with the lowest overall construction cost (if so desired).

Each design package is separated into five system categories: process considerations; site; foundations; building envelope; and mechanical, electrical, and plumbing systems. Subsections within each category highlight the important approach or practice, or the minimum performance specification, that has to be done in order to achieve the energy efficiency goal. A detailed discussion of the design packages is included in the section entitled Discussion of Design Packages.

Table 1. Summary of Cold-Climate Design Package #1: Insulated Sheathing Approach

System	Approach or Practice	Minimum Performance Level
Process Considerations	• Determine approach for constructing foundation and building envelope • Develop HVAC strategy that defines HVAC system	
Site	• Consider orientation and solar impacts of house, site, and shading • Minimize north glazing; worst-case design orientation is most glazing facing north	
Windows	• Maximum window square footage is less than 21% of floor area	• U[a] = 0.35, SHGC[b] = 0.45
Foundation	• Unvented, conditioned crawlspace	• R-10 exterior wall insulation • Uninsulated slab
Building Envelope		
Roof and Attic		• R-38 attic insulation • R-30 vaulted ceilings
Exterior Walls		R-16 total wall insulation: • R-13 in wall cavity • R-3 exterior sheathing
Exposed Floors		• R-30 insulation over unconditioned space
Building Airtightness		• 0.35 natural air changes/hour
Mechanical, Electrical, Plumbing	• Detailed peak-load calculations as per ACCA Manuals D & J • Engineered HVAC system layout	(ACCA 1995 and 1996)
Heating and Cooling Equipment	• Equipment in conditioned space	• 90% AFUE[c] gas furnace • HSPF[d] 7 air source heat pump • 10 SEER cooling
Air Distribution System		• Ducts sealed. Duct leakage to the outside less than 10% of total system airflow • R-4 if in unconditioned space
Indoor Air Quality		• Continuous low-speed exhaust fan or balanced ventilation • Power vented or direct vented combustion appliances
Water Heating		• EF[e] = 0.56 gas • EF = 0.88 electric

[a] U = overall heat transfer coefficient
[b] SHGC = solar heat gain coefficient
[c] AFUE = Annual Fuel Utilization Efficiency
[d] HSPF = heating seasonal performance factor
[e] EF = energy factor

Table 2. Summary of Cold-Climate Design Package #2: Alternative to Insulated Sheathing Approach

System	Approach or Practice	Minimum Performance Level
Process Considerations	• Determine approach for constructing foundation and building envelope • Develop HVAC strategy that defines HVAC system	
Site	• Consider orientation and solar impacts of house, site, and shading • Minimize north glazing; worst-case design orientation is most glazing facing north	
Windows	• Maximum window square footage is less than 21% of floor area	• U = 0.35, SHGC = 0.45
Foundation	• Unvented, conditioned crawlspace	• R-10 exterior wall insulation • Uninsulated slab
Building Envelope		
Roof and Attic		• R-38 attic insulation • R-30 vaulted ceilings
Exterior Walls		• R-19 in wall cavity
Exposed Surfaces		• R-30 insulation over unconditioned space
Building Airtightness		• 0.35 natural air changes/hour
Mechanical, Electrical, Plumbing	• Detailed peak-load calculations as per ACCA Manuals D & J • Engineered HVAC system layout	
Heating and Cooling Equipment	• Equipment in conditioned space	• 90% AFUE gas furnace • HSPF 7 air source heat pump • 10 SEER cooling
Air Distribution		• Ducts sealed. Duct leakage to the outside less than 10% of total system airflow • R-4 if in unconditioned space
Indoor Air Quality		• Continuous low-speed exhaust fan or balanced ventilation • Power vented or direct vented combustion appliances
Water Heating		• EF = 0.56 gas • EF = 0.88 electric

Table 3. Summary of Cold-Climate Design Package #3: 80% Gas Furnace System Approach

System	Approach or Practice	Minimum Performance Level
Process Considerations	• Determine approach for constructing foundation and building envelope • Develop HVAC strategy that defines HVAC system	
Site	• Consider orientation and solar impacts of house, site, and shading • Minimize north glazing; worst-case design orientation is most glazing facing north	
Windows	• Maximum window square footage is less than 21% of floor area	• U = 0.35, SHGC = 0.45
Foundation	• Unvented, conditioned crawlspace	• R-3 exterior wall insulation • R-10 interior or exterior wall insulation • Uninsulated slab
Building Envelope		
Roof and Attic		• R-38 attic insulation • R-30 vaulted ceilings
Exterior Walls		R-24 minimum total wall: • R-19 in wall cavity • R-5 exterior sheathing
Exposed Surfaces		• R-30 insulation over unconditioned space
Building Airtightness		• 0.25 natural air changes/hour
Mechanical, Electrical, Plumbing	• Detailed peak-load calculations as per ACCA Manuals D & J • Engineered HVAC system layout	
Heating and Cooling Equipment	• Equipment in conditioned space	• 80% AFUE gas furnace or HSPF 7 air source heat pump • 10 SEER cooling

Table 3. Summary of Cold-Climate Design Package #3:
80% Gas Furnace System Approach (continued)

System	Approach or Practice	Minimum Performance Level
Air Distribution		• Ducts sealed. Duct leakage to the outside less than 10% of total system airflow • R-4 if in unconditioned space
Indoor Air Quality		• Continuous low-speed exhaust fan or balanced ventilation • Power-vented or direct-vented combustion appliances
Water Heating		• EF = 0.56 gas • EF = 0.88 electric

Discussion of Cold-Climate Design Packages

In a cold climate, the emphasis for improving a home's energy efficiency must be initially focused on keeping occupants warm and comfortable during the winter months. The priority for building system performance and durability has to be winter conditions, because this is the most extreme climatic period in this region. With the increased use of air conditioning in cold-climate homes, energy efficiency and building system performance in summer conditions becomes important as well. Homes in this climate zone need to be designed for both considerations.

Design Process: Determine Current Level of Energy-Efficient Construction

The starting point for the design of any home is making sure that it will meet local building code requirements. Some building code requirements give more attention to energy efficiency than others, particularly those that refer to or follow the 2000 International Energy Conservation Code. To achieve more energy savings than a house built to energy efficiency requirements of local code, a more proactive approach to house design must be taken.

A HERS 86 score for a house qualifies it to be certified an ENERGY STAR® home and is the most common energy efficiency target level established for new homes. This level is also assumed to be the minimum goal for the design packages and assumes that the base-case house was built according to the requirements of the 1993 MEC with a HERS score of 80 (average for a new home). If the base-case home scored an 82, then a score of 88 on a new home is needed to achieve a minimum of 30% energy savings.

To meet the HERS 86 to 88 goal (30% to 40% energy savings), a builder can choose to follow the prescriptive design packages outlined in Table 1, Table 2, and Table 3, or conduct an energy efficiency evaluation evaluation on their homes that will allow more flexibility in design. If the latter approach is chosen, the first step is to establish the current level of energy efficiency and quality that the builder is achieving as standard practice. This base level of construction performance will be used as a reference point for improvements. Determining the characteristics of the base-case home is necessary to determine how much more energy efficient the home must be to reduce energy consumption to the target level. The most common way to accomplish this is by using an energy-analysis software computer program such as REM/*Design*™ (see www.archenergy.com). This software program determines a home's energy efficiency based on the house characteristics and its climatic location. Having a rating program establish the score of current standard practice allows a builder to determine how much more energy efficient the home must be to reduce energy consumption to the target level.

It is usually at this point that most builders decide to solicit the services of a professional in the field of energy efficiency in housing to use the software program and make a proper evaluation of existing and new designs. One way to find a suitable professional is by referring to the Residential Energy Services Network's (RESNET 2002) Internet site: http://www.natresnet.org, selecting "Directories" and then "Accredited HERS Providers." The organization can also be reached at P.O. Box 4561, Oceanside, CA 92052-4561, (760) 806-3448. An accredited HERS provider can help a builder meet not only design goals, but also construction implementation goals because HERS provides inspection and testing services, as well. The provider has undergone training and, by being accredited by RESNET, is acknowledged as possessing knowledge in the construction of energy-efficient housing. Builders may choose to take on these services themselves, but homes cannot be certified as ENERGY STAR® unless an accredited HERS provider is used.

To conduct an energy efficiency evaluation for the base-case home, the evaluator (whether it's IBACOS or a local HERS rater) requires specific information on how the home was constructed. In particular, the evaluator will need to know the following:

- Insulation levels for exterior walls (including band joist and knee walls), floors exposed to the outside or garage space, ceilings (all flat and sloped areas), and exterior door components
- Insulation levels for foundation walls and floors
- Window performance values (U-value and Solar Heat Gain Coefficient)
- The airtightness of the building based on blower door testing and methods used to achieve airtightness.
- The fuel efficiency, capacity, venting, and all other performance specifications for heating, cooling, ventilation, and hot-water production system equipment. The number of units used and their location will also be required.
- The amount of air leakage in the air distribution system based on airtightness testing using a duct blaster™ testing method
- The ductwork materials used—whether flex, sheet metal, or fibrous glass duct board—their location (either conditioned or unconditioned space), insulation level of the duct system, and what materials, if any, are used to seal joints
- Performance and venting (if applicable), details on all other combustion appliances, and details on alternative energy technologies (e.g., solar) used.

In addition to the information needed as listed above, airtightness testing using a blower door will have to be conducted on the base-case home. If the builder wishes to gain credit for the tightness of the duct system, a duct airtightness test will also need to be performed. Site inspections at pre-drywall and final completion stages of home construction would be conducted to verify all given information, discover new information, and allow for a general assessment of the quality of construction. The latest set of construction drawings for the base-case home, including all details, cross sections, and any structural, mechanical, electrical, and plumbing portions will be needed. The energy efficiency evaluation for the base-case home will result in a HERS score for the home.

Design Process: Recommendations for Improvement

Once the current level of energy efficiency for the base-case home has been established, the process of designing the same home to meet a higher energy efficiency goal can begin. Increasing the energy efficiency of a home to obtain a HERS score between 86 and 88 in a cold climate requires a design approach to reduce the amount of energy used, particularly for heating (i.e., a reduction in heating loads). Making thermal performance improvements in the foundation and building envelope should be considered first. For more information, see the Foundation Design and Construction and the Building Envelope Design and Construction sections of this report.

We recommend a combined approach between the HVAC, foundation, and building envelope systems that weighs the costs and benefits associated with all the measures and their interactions with each other.

For example, making performance improvements to the HVAC system without improving the foundation and building envelope systems will not likely enable the home to meet the performance target. Uneven room temperatures, drafts, and occasions of high humidity may result from an inadequately insulated foundation and non-airtight building envelope. So, improving only the HVAC system may not increase the comfort of occupants in the home. In addition, this approach may not increase the energy efficiency of a home to the target level. Furthermore, this approach may result in HVAC system equipment that is constantly running as a result of conditioned air being lost at a fast rate because of a large amount of heat loss and air leakage.

It is equally ineffective to rely on improvements to the foundation and building envelope systems without improving the HVAC system. Increasing insulation levels in the foundation and building envelope systems reduces heating and cooling loads only to an extent. For example, increasing attic insulation from R-20 to R-30 represents approximately 33% reduction in heat transfer, whereas an increase from R-38 to R-48 only represents a 20% reduction. There is also a cost increase associated with each increase in insulation depth and a point where the cost for each improvement outweighs the energy efficiency return on the improvement. Based on our experience, we recommend that making improvements to all house systems (site, foundation, building envelope, and mechanical, electrical, and plumbing) results in a cost-effective method to meeting energy efficiency, construction quality, and homeowner comfort goals.

Increasing insulation levels in certain construction systems can be done more easily and economically than in others. These options should be explored, especially in relation to the cost and ease of application of the improvement. A residual effect of many insulation improvements is that cooling loads would also go down because insulation controls heat flow and the amount of heat flow in an attic in the summer, for example, can be reduced with higher levels of insulation in that area.

Builders can choose to increase the thermal performance of the foundation and building envelope system that they currently use or explore alternatives.

There are construction systems that are alternatives to wood framing, such as insulated concrete forms, pre-cast foundation systems, and structural insulated panels, all of which provide good thermal performance and should be considered as a way to meet performance requirements. The cost and availability of these alternate construction systems usually govern whether they will be used. Finding a subcontractor who is familiar with the installation of the alternate system is crucial if the system is to be implemented without sacrificing construction time and quality. The performance requirements for the foundation and building envelope systems are outlined in their respective sections and should be used as a guide for selecting a system no matter its composition. For more information, see the Foundation Design and Construction and the Building Envelope Design and Construction sections of this report.

An HVAC system strategy that focuses on how the home is to be heated and cooled is needed. As part of developing this strategy, the heating and cooling system technologies available for use should be examined. Market conditions, product availability, and public acceptance could affect fuel source and HVAC system choices. An energy efficiency evaluation that includes peak-load calculations and how often cooling is needed will determine if cooling equipment is necessary to maintain comfort throughout the summer. Many homes in cold climates only need cooling for a few weeks a year and a decision to design for cooling, based on market acceptance of the home, must be made. The design packages provided here assume that cooling will be provided.

The types and performance of heating and cooling equipment available, their associated systems, and their cost and efficiency need to be reviewed. Integration of heating and cooling systems with a mechanical ventilation system and/or the hot water heating system should be examined. Whatever the system chosen, homeowner comfort is paramount. Maintenance requirements for any HVAC system should also be considered. The efficiency of heating equipment is particularly important in meeting energy efficiency goals; choosing a high-efficiency furnace or boiler can negate more costly changes to the thermal envelope (such as using insulating sheathing) without sacrificing home energy efficiency. The location of heating and cooling equipment within the home affects equipment performance; recommendations on this matter should form part of the HVAC strategy.

Site Design

The number and performance of windows are a key element of site design and reaching energy efficiency goals. In the cold climate, the design should specify windows with a U-value of 0.35 or less and a solar heat gain coefficient (SHGC) of 0.45 or less. This design requirement can be achieved with a double-glazed low-emissivity window with argon fill, which controls heat loss and reduces the likelihood of uneven temperatures near windows. Low-emissivity windows also limit solar gains, which is a benefit in hot weather situations. The square footage of all windows should amount to less than 21% of total floor area, with no more than 15% preferred. Windows facing north should be used sparingly with less window square footage used there than other orientations.

For a production builder, it may be hard to maximize solar contributions and minimize heat loss into a home's design by increasing or decreasing window size. This is because the house plan may be situated in all possible directions on a lot, and any attempts to alter heat loss and solar contributions would be wasted. Therefore all new homes should be evaluated for energy efficiency based on their worst-case orientation. For homes in the cold-climate zone, worst-case orientation would assume that the north side is the one with the most glazing. Standard 1-ft roof overhangs and no permanent shading devices should be assumed to exist as part of the energy efficiency evaluation.

Although reducing heating loads is the primary design consideration for this climate zone, an energy efficiency evaluation based on glazing orientation should be conducted for reducing cooling loads as well. The worst-case orientation for high solar contributions would be with most glazing facing west.

Foundation Design and Construction

In cold-climate homes, basements and crawlspaces are the most common foundation types. Basement walls should be designed and constructed for a minimum thermal performance of R-10 either on the interior or exterior. If the 80% efficiency furnace performance package 3 is used (Table 3) a minimum of R-3 exterior insulation is needed in addition to the R-10 requirement. If the basement receives conditioned air, temperature and humidity levels of an insulated basement are similar to the first floor. The result is a more comfortable, habitable basement.

It is preferred that the insulation be placed on the exterior side of the foundation wall. Exterior insulation will make that wall warmer during cold weather, thereby limiting the amount of condensation that can occur on the wall's inside face. Semi-rigid fiberglass board insulation or rigid extruded or expanded foam board insulation products are preferred in exterior insulation and can be applied in the appropriate thickness to achieve the R-10 performance level (Figure 1). These products also provide protection against potential water intrusion in the foundation and can help to divert water to a perimeter exterior drainage system. Careful detailing, and the use of a protection system such as parging or an exterior cladding, is needed to ensure that the top of the insulation is not exposed to water or soil penetration either through the material or between it and the wall.

On sites where the potential of a high water table or poor-draining soil exists, insulating on the exterior side of the foundation wall should be the only system considered. To keep the foundation wall dry, the following should be used for all basements and crawlspaces:

- Exterior dampproofing on the foundation wall
- A capillary break either above or below the footing (either a bituminous coating or a layer of polyethylene) to prevent moisture transfer from the ground
- An exterior perimeter drainage system.

For best results, the basement area should be conditioned and dehumidified.

Figure 1. The semi-rigid fiberglass board insulation, 2-3/8 in. thick, provides R-10 thermal performance and water drainage at the exterior of the foundation wall. It was applied over a dampproof coating to the height of the sill plate. The exterior edge of the brick or wall sheathing above the board was designed and installed so that the edge would lay flush with the foundation wall, thereby protecting the top edge of the insulation board.

While not the preferred option, basements can be insulated on the inside, as well. When using interior insulation, it's important to consider interior moisture diffusion control, the flame-spread rating of the product exposed to the interior, and the compatibility of the product with moisture. Extruded or expanded foam board insulation products can be placed on the inside of the wall and then strapped with a framing material to allow the placement of drywall over an air space. Blanket insulation with a perforated facing (to allow drying of the wall to the inside) can also be used on the inside face, but it is preferred that it be used in conjunction with an exterior insulation product and in conditioned basements. Because many foundations are restricted from drying to the outside when wet because of dampproofing, drying to the inside is necessary. An example of a suitable exterior insulation product is semi-rigid fiberglass board insulation with R-3 thermal performance. This product could be used on the exterior to reduce the condensation potential of the inside portion of the wall and limit moisture movement into it (package 3 recommendation, Table 3). The blanket insulation needs to be applied so that the facing is airtight; this way moisture-laden air does not reach the foundation wall from the inside. Insulated and drywalled wood-framed walls offset from the foundation are a popular choice because this type of wall construction can be used to finish a space. But this approach should be used with caution because basements often contain moisture. If wood is exposed to extended periods of moisture and warm temperatures, mold growth can occur.

There are pre-cast concrete foundation systems available that include R-5 rigid foam board insulation on the exterior side of the assembly. The system panel is manufactured to include cavities open to the inside where insulation can be placed.

Crawlspaces also require a minimum of R-10 insulation on the interior or preferably on the exterior side of the foundation wall. Approaches and systems for accomplishing this are similar to those used in basements. In addition, insulation placed on the interior side of a crawlspace wall must extend down the wall at least 2 ft below grade level. If the crawlspace wall extends less than 2 ft below grade level, then the remaining insulation must be placed horizontally along the ground (at the bottom of the wall). We recommend that all crawlspaces be built without venting, receive conditioned air, and have airtight and insulated foundation walls, together with the previously mentioned measures of keeping a foundation wall dry. The ceilings of crawlspaces do not need to be insulated in this type of crawlspace construction.

Basement or crawlspace slabs do not usually need to be insulated in order to achieve a 30% energy consumption savings. However, insulating the slab will make it less cold in the heating season and, therefore, the basement or crawlspace would be more comfortable.

Building Envelope Design and Construction

Whether the construction system chosen for the building envelope is insulated wood frame, insulated panels, insulated forms, or another system, its thermal performance is critical for energy efficiency goals to be realized.

Exterior walls should have a minimum nominal insulation value of R-16 (package 1, Table 1). In wood-frame construction, this level of thermal performance could be achieved with a 2x4 wall with R-13 cavity insulation (either fiberglass or cellulose) and R-3 insulating sheathing on the exterior face. SIPs, ICFs, or other construction systems that meet this minimum insulation value are suitable alternative choices to wood-frame construction.

If a wood-framing design without insulating sheathing is the preferred approach to building envelope construction, it should have a minimum nominal insulation value of R-19 (package 2, Table 2). An exterior wall constructed of 2x6 framing with full depth cavity insulation can meet this insulation level.

If package 3 is chosen (80% efficient furnace), R-24 thermal performance in the exterior wall is needed. In a wood-frame wall, this level of thermal performance could be achieved with a 2x6 wall with R-19 cavity insulation (either fiberglass or cellulose) and R-5 insulating sheathing on the exterior face.

Batt insulation in wall cavities should completely fill up the cavity, not be compressed, and encase or surround electrical or plumbing fixtures or wires. If kraft-faced batts are used, they should be face stapled, not inset stapled, to the studs. Insulation systems that are blown (cellulose or fiberglass) or sprayed (polyicynene or polyurethane) into a wall do a good job of filling the entire stud cavity, which can help increase the thermal performance and airtightness of the exterior wall. Unless specifically required by local building code, a polyethylene vapor retarder (between the framing and the drywall) is not recommended because it can limit a wall's ability to dry to the inside. In a wood-frame wall with batt insulation, the kraft facing on the batt would provide the necessary protection against vapor diffusion from the inside for this climate. In the case of other exterior wall constructions, drywall painted with a latex product suffices.

The design of any flat attic spaces should include a minimum of R-38 insulation. In wood-frame construction, this is usually achieved by using fiberglass batts, blown cellulose, or fiberglass. If a blown product is used, baffles should be used at the perimeter of the attic to ensure that insulation depth is kept as uniform as possible (Figure 2). High heel trusses, which allow for easier full height placement of insulation at the attic perimeter are recommended, and should allow the placement of insulation between 10 in. (cellulose) and 16 in. (fiber glass) in height as shown in Figure 3. Vaulted or sloped ceilings should include a minimum of R-30 insulation. In these situations, it is important that clearance for an air space be maintained between the top of the insulation (in the roof rafter) and the bottom of the roof sheathing. The ceilings of overhangs, built for fireplaces and bay windows for example, need to be insulated to the same level as a flat or vaulted ceiling, depending on their configuration. Floors over unconditioned space, such as floors above a garage, and window or fireplace overhangs that protrude outside, should include a minimum of R-30 insulation. Care must be taken to ensure that the perimeter of the overhang is insulated entirely.

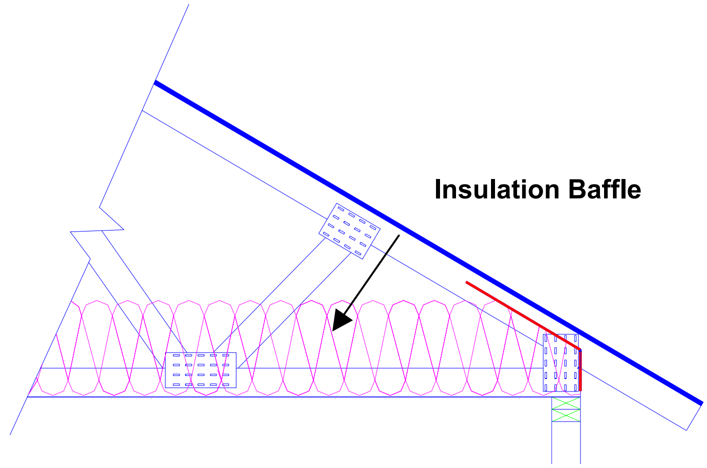

Figure 2. A baffle attached to the top plate at the roof perimeter prevents insulation from entering into the soffit. It should be used between every roof truss if blown insulation is used in the attic.

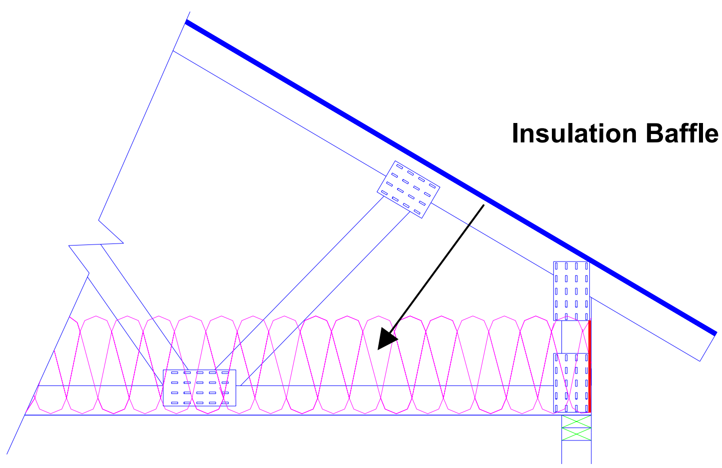

Figure 3. A high-heel roof truss allows for a uniform height of insulation to be placed over the entire ceiling, thereby avoiding a potential cold spot at the perimeter of the wall.

If wood framing is to be used in exterior walls, the amount should be optimized to facilitate a larger amount of insulation placement in the wall without sacrificing structural sufficiency of the home. This would result in a higher effective R-value for the wall and fewer cold spots, which often lead to comfort complaints and mold growth because moisture is more likely to condense on such surfaces. Common approaches to accomplish this are based on Optimum Value Engineering (OVE) framing techniques, such as keeping exterior wall corners open to the inside, the elimination of wood framing members not required for structural purposes, and spacing studs at 24-in. intervals instead of 16-in. intervals. The increased thermal performance effects of these measures in exterior walls and alternative construction systems can be accurately accounted for in the energy efficiency evaluation.

The design goal for building airtightness should be an annual air infiltration rate less than 0.35 natural air changes per hour. This can be verified with a blower door test. At this level of airtightness, home occupants should experience few drafts or uneven temperatures due to air leakage. If package 3 is chosen (Table 3), the building must be more airtight to compensate for the lower efficiency furnace and have an annual air infiltration rate less than 0.25 natural air changes per hour based on the blower door test.

To achieve this level of building airtightness, it is critical that a continuous air barrier for the home be established. The most common air barrier whether the house's structure is wood frame, SIPs, or ICFs, is the interior drywall because it covers most of the shell of the building including walls and ceilings. Where interior drywall is not present on exterior walls in living spaces, such as wall and ceilings areas adjacent to fireplaces, at bathtubs, shower enclosures and chases, draftstopping must be placed to provide air barrier continuity. In exterior walls, the exterior sheathing can also be considered as a component of the air barrier and should be installed without gaps and openings. House wraps, when installed with taped seams and sealed to the top and bottom of the wall assembly and around openings, also help to reduce air leakage in homes. The undersides of floors exposed to unconditioned space require an air barrier, as well. A sheathing product with joints sealed or taped would form a good air barrier in this application. The foundation wall, together with the band joist framing, is also considered as part of the air barrier system and needs to be well sealed.

Penetrations through the air barrier—whether they are large, like windows or doors, or small, like gas lines and electrical service—need to be sealed to the air barrier to prevent air leakage occurring through the hole or gap that results from the penetration. Foam sealants and caulking can be used to remedy air leakage penetrations.

Mechanical, Electrical, and Plumbing Design and Construction

Once an HVAC system strategy is established that outlines the heating and, if necessary, cooling and ventilation system technologies to be used, an engineered HVAC system design and layout should be performed. The engineered design, based on ACCA Manual J (1986), would accurately reflect the heating and cooling peak-load requirements for the house and individual rooms based on specifications obtained from the energy efficiency design package. Selection of HVAC equipment would be based on the determined loads and optimized so that energy is not wasted to condition and ventilate the home.

For homes with forced air distribution, zoning practices do not need to change to meet energy efficiency goals. However, an equipment optimization strategy, where one larger capacity HVAC system with a zone dampering system is used instead of two smaller capacity systems, is preferred because it is more energy efficient, less costly to purchase, and easier to maintain without sacrificing comfort and temperature preferences for different rooms.

Energy can be saved by installing higher performance heating and cooling equipment. Furnaces should have a minimum Annual Fuel Utilization Efficiency (AFUE) of 90%, boilers should have a minimum AFUE of 84%, and air conditioning condensing units and coil combinations should have a minimum Seasonal Energy Efficiency Ratio (SEER) of 10. If package 3 is chosen (Table 3), a furnace with a minimum AFUE of 80% can be used, but this choice will require more improvements to the building envelope. Direct-vent or sealed-combustion boilers or furnaces are recommended because the back drafting of combustion products is less likely to occur with these systems and, therefore, indoor air quality is less likely to be compromised. In addition, programmable thermostats are recommended so that occupants can control furnace operation. This would help them save energy during periods of low occupancy.

Air-source electric heat pumps can be used in the cold-climate zone, but they do not perform well over extended periods of sub-freezing temperatures. Thus, the greater the frequency of sub-freezing temperatures, the more often supplementary (resistance heat) will be running. This would result in reduced overall efficiency of the system. Units with SEERs of 10 or greater and heating season performance factors (HSPF) of 7 or larger are recommended. The efficiency of gas-fired air-source heat pumps should have a minimum heating efficiency or coefficient of performance (COP) of 1.2 and a cooling efficiency of 1.25 COP or more. Ground-source and water-source heat pumps with a heating COP of 2.8 or more and an energy efficiency ratio (EER) of 10 or more are recommended. The latter technologies have a greater initial cost than the air-source heat pumps, but operate much more efficiently through prolonged periods of cold weather.

If a forced-air system is used to provide heating and cooling, an engineered duct design, based on ACCA Manual D (1995), should be conducted based on HVAC equipment selection, optimum air distribution performance, and HVAC system airtightness. This design would include layout and ductwork sized for good air distribution. The duct design may result in changes to the HVAC equipment selected in order to facilitate better air distribution. Boilers that provide hot water that is circulated through baseboard convectors or a radiant floor or ceiling system should be designed to provide adequate heating for the home based on calculated heating loads.

Although furnaces are usually placed in the basement or crawlspace in cold-climate homes, they occasionally appear in the attic as well. Placement of the furnace or air handler in unconditioned space, whether in an attic, crawlspace, or basement should be avoided. Some of the heated air being moved by a furnace operating in a cold and dry unconditioned space may not make it to the living space if the supply system exhibits air leakage. Similarly, leaks in return air ductwork in an unconditioned space can draw cold and dry air, which ultimately lowers the temperature of the heated air being delivered to the home and can result in comfort complaints. Therefore, ductwork running through unconditioned space is not preferred, and we recommend that ductwork be kept within conditioned space where possible, although moving all ductwork into conditioned space is not required to meet the current energy efficiency goal. Ductwork traveling through unconditioned space should be insulated to R-4 and it is preferred that ductwork be covered with attic insulation if located in that space.

All ductwork, whether it is made of sheet metal, flexible plastic, or glass fiberboard must have all joints and openings sealed with a UL181-approved water-based mastic sealant or UL181-approved tape (for fibrous glass duct board applications). The ductwork that connects to the furnace or air-handling unit must also be sealed, along with any joints in the unit. The airtightness of the HVAC system must be tested by using a duct blaster™ and should not have air leakage to the outside greater than 10% of total system airflow. For example, a furnace that has total system airflow of 1,600 cfm, must not exhibit more than 160 cfm of air leakage to the outside of the house as a result of the air distribution system.

Registers for a forced-air system should be positioned in walls, floors, and ceilings according to local practice (which is assumed to offer the best air delivery for the particular locality). For many cold-climate locations, registers serving the first and second floors are placed in the floor to allow warm air to wash the walls and windows from below during the heating season. In other cold-climate locations, second floor registers are placed in high wall or ceiling locations to facilitate better delivery of cooled air. The layout of hydronic systems should follow manufacturer's specifications.

With building envelope airtightness increased, there is less outdoor air coming into and out of the home by uncontrolled means (i.e., air leakage). To ensure that the occupants of the home continue to receive an adequate amount of outdoor air, a mechanical ventilation system, a controlled method for the introduction of outdoor air, is needed. A two-speed exhaust fan set to run continuously at low speed and located in a bathroom can be used as a mechanical ventilation system. A heat-recovery ventilator can also be used. A heat-recovery ventilator draws outdoor air and heats it with house air before delivering it to the furnace or air handler or directly to the rooms, while exhausting stale indoor air.

Hot-water tanks with an energy factor (EF) greater than 0.56 for gas-fired units and 0.88 for electric units are recommended. Power vented-gas hot-water tanks are less susceptible to combustion product back drafting because they force combustion gases out the flue; this lessens the chance of detrimental indoor air-quality situations.

Mixed-Humid Climate Performance Packages

Introduction and Methodology

Initial development of the performance design packages for the mixed-humid climate zone included an examination of recommendations made in Building America pilot home activities with Washington Homes (a K. Hovnanian company) Manassas, Virginia; Fortis Homes in Greensboro and Raleigh (a K. Hovnanian company), North Carolina; Hedgewood Properties in Atlanta, Georgia; Venture Homes in Atlanta, Georgia; and John Wieland Homes and Neighborhoods in Atlanta, Georgia. To develop the design packages further, comparative energy efficiency analysis based on basement, crawlspace, and slab-on-grade foundations house designs were conducted in five representative locations: Washington, D.C.; Raleigh, North Carolina; Atlanta, Georgia; Dallas, Texas; and Seattle, Washington.

To produce the most representative and cost-effective design packages, the mixed-humid climate zone has been separated into a Western region that consists of areas in the states of California, Washington, and Oregon, and an Eastern region that consists of all other states in this climate zone. Areas in the Western mixed-humid climate zone region generally have greater heating load requirements and far lower cooling load requirements than mixed-humid climate zone areas in the Eastern region.

The three design packages that follow, summarized in tables 4, 5, and 6, outline the most cost-effective approach for constructing homes in each mixed-humid climate region so that they use between 30% and 40% less energy for space conditioning. Table 4 includes a summary design package for the Western mixed-humid climate region. Table 5 includes a summary design package for the Eastern mixed-humid climate region with basement and crawlspace construction. Table 6 includes a summary design package for the Eastern mixed-humid climate region with slab-on-grade construction.

It is assumed that a house with an energy efficiency rating between HERS 86 and 88 satisfies this goal. The design package for the Western region is for all foundation types. Two design packages were developed for the Eastern region, one for basement and crawlspace construction, and one for slab-on-grade construction.

Each design package is separated into five system categories: process considerations, site, foundations, building envelope, and mechanical, electrical, and plumbing systems. Subsections exist within each category and highlight the important approach or practice, or the minimum performance specification, which has to be done to achieve the energy efficiency goal. A detailed discussion of the design packages is included in the Discussion of Mixed-Humid Design Packages section of this report.

Table 4. Summary Design Package #1 for Western Mixed-Humid Climate Region

System	Approach or Practice	Minimum Performance Level
Process Considerations	• Determine approach for constructing foundation and building envelope • Develop HVAC strategy that defines HVAC system	
Site	• Consider orientation and solar impacts of house, site, and shading • Minimize north glazing; worst-case design orientation is most glazing facing north	
Windows	• Maximum window square footage is less than 21% of floor area	• U = 0.35, SHGC = 0.35
Foundation	• Unvented, conditioned crawlspace	• R-10 exterior wall insulation • R-10 insulation 2 ft wide under slab perimeter (slab-on-grade only)
Building Envelope		
Roof and Attic		• R-38 attic insulation • R-30 vaulted ceilings
Exterior Walls		• R-13 in wall cavity
Exposed Surfaces		• R-30 insulation over unconditioned space
Building Airtightness		• 0.35 natural air changes/hour
Mechanical, Electrical, Plumbing	• Detailed peak-load calculations as per ACCA Manuals D & J • Engineered HVAC system layout	

Table 4. Summary Design Package #1 for Western Mixed-Humid Climate Region (continued)

System	Approach or Practice	Minimum Performance Level
Heating and Cooling Equipment		• 90% AFUE gas furnace or HSPF 7 air-source heat pump • 10 SEER cooling
Air Distribution		• Ducts sealed. Duct leakage to the outside less than 10% of total system airflow • R-4 if in unconditioned space
Indoor Air Quality		• Positive or balanced pressure mechanical ventilation system • Power-vented or direct-vented combustion appliances
Water Heating		• EF = 0.56 gas • EF = 0.88 electric

Table 5. Summary Design Package #2 for Eastern Mixed-Humid Climate Region with Basement and Crawlspace Construction

System	Approach or Practice	Minimum Performance Level
Process Considerations	• Determine approach for constructing foundation and building envelope • Develop HVAC strategy that defines HVAC system	
Site	• Consider orientation and solar impacts of house, site, and shading • Minimize south and west glazing; worst-case design orientation is most glazing facing west	
Windows	• Maximum window square footage is less than 21% of floor area	• U = 0.35, SHGC = 0.35
Foundation	• Unvented, conditioned crawlspace	• R-10 Wall insulation • Uninsulated slab
Building Envelope		•
Roof and Attic		• R-30 attic insulation • R-30 vaulted ceilings
Exterior Walls		• R-13 in wall cavity
Exposed Surfaces		• R-30 Insulation over unconditioned space
Building Airtightness		• 0.35 natural air changes/hour
Mechanical, Electrical, Plumbing	• Detailed peak-load calculations as per ACCA Manuals D & J • Engineered HVAC system layout	

Table 5. Summary Design Package #2 for Eastern Mixed-Humid Climate Region with Basement and Crawlspace Construction (continued)

System	Approach or Practice	Minimum Performance Level
Heating and Cooling Equipment		• 80% AFUE gas furnace or HSPF 7 air source heat pump • 12 SEER cooling
Air Distribution		• Ducts sealed. Duct leakage to the outside less than 10% of total system airflow • R-4 if in unconditioned space
Indoor Air Quality		• Positive or balanced pressure mechanical ventilation system • Power vented or direct vented combustion appliances
Water Heating		• EF = 0.56 gas • EF = 0.88 electric

Table 6. Summary Design Package #3 for Eastern Mixed-Humid Climate Region with Slab-on-Grade Construction

System	Approach or Practice	Minimum Performance Level
Process Considerations	• Determine approach for constructing foundation and building envelope • Develop HVAC strategy that defines HVAC system	
Site	• Consider orientation and solar impacts of house, site, and shading • Minimize south and west glazing; worst-case design orientation is most glazing facing west	
Windows	• Maximum window square footage is less than 21% of floor area	• U = 0.35, SHGC = 0.35
Foundation		• Uninsulated slab
Building Envelope		
Roof and Attic		• R-30 attic insulation • R-30 vaulted ceilings
Exterior Walls		• R-13 in wall cavity
Exposed Surfaces		• R-30 insulation over unconditioned space
Building Airtightness		• 0.35 natural air changes/hour
Mechanical, Electrical, Plumbing	• Detailed peak-load calculations as per ACCA Manuals D & J • Engineered HVAC system layout	

Table 6. Summary Design Package #3 for Eastern Mixed-Humid Climate Region with Slab-on-Grade Construction (continued)

System	Approach or Practice	Minimum Performance Level
Heating and Cooling Equipment		• 90% AFUE gas furnace • HSPF 7 air-source heat pump • 12 SEER cooling
Air Distribution		• Ducts sealed. Duct leakage to the outside less than 10% of total system airflow • R-4 if in unconditioned space
Indoor Air Quality		• Positive or balanced-pressure mechanical ventilation system • Power vented or direct-vented combustion appliances
Water Heating		• EF = 0.56 gas • EF = 0.88 electric

Discussion of Mixed-Humid Design Packages

In a mixed-humid climate there is a lot more emphasis on keeping occupants cool and comfortable than there is in cold-climate homes because of the extended periods of hot and humid weather. This is especially true in the Eastern mixed-humid climate zone region. To improve a home's energy efficiency in this climate-zone region, the priority for building system performance and durability is designing for summer conditions because it is the most severe climatic period. In addition, homes in the Western region face significant periods of cold weather, as do homes in the northern sections of the Eastern region, and so energy efficiency and building system performance in times of colder weather also become important. Consequently, homes in the entire mixed-humid climate zone need to be designed for both heating and cooling considerations.

Design Process: Determine Current Level of Energy-Efficient Construction

The starting point for the design of any home is making sure that it will meet local building code requirements. Some building code requirements give more attention to energy efficiency than others, particularly those that refer to or follow the 2000 International Energy Conservation Code. To achieve more energy savings than a house built to energy efficiency requirements of the local code, a more proactive approach to house design must be taken.

A HERS 86 score for a house qualifies it to be certified as an ENERGY STAR® home and is the most common energy efficiency target level established for new homes. This level is also assumed to be the minimum goal for the design packages and assumes that the base-case house was built according to the requirements of the 1993 MEC with a HERS score of 80 (average for a new home). If the base-case home scored an 82, then a score of 88 on a new home is needed to achieve a minimum of 30% energy savings.

To meet the HERS 86 to 88 goal (30% to 40% energy savings), a builder can choose to follow the prescriptive design packages outlined in tables 4, 5, and 6 or conduct an energy efficiency evaluation on their homes, which will allow for more flexibility in design. If the latter approach is chosen, the first step is to establish the current level of construction with respect to energy efficiency and quality. Determining the characteristics of the base-case home is necessary to determine how much more energy efficient the home must be to reduce energy consumption to the target level. The most common way to accomplish this is by using an energy-analysis software computer program, such as REM/*Design*™. This software program determines a home's energy efficiency based on the house characteristics, which are input into the program, and its geographic location.

It is usually at this point that most builders decide to solicit the services of a professional in the field of residential energy efficiency to use the software program and make a proper evaluation. One way to find a suitable professional is by referring to the Residential Energy Services Network's (RESNET [2002] Internet site: http://www.natresnet.org, selecting "Directories" and then "Accredited HERS Providers.") The organization can also be reached at P.O. Box 4561, Oceanside, CA 92052-4561, (760) 806-3448. Accredited HERS raters can help builders meet not only design goals, but also construction implementation goals because HERS provides inspection and testing services, as well. The rater has undergone training and, by being accredited by RESNET, is acknowledged as possessing knowledge in the construction of energy-efficient housing. Builders may choose to take on these services themselves, but homes cannot be certified as Energy Star® unless an accredited HERS rater or provider (such as IBACOS) is used.

To conduct an energy efficiency evaluation for the base-case home, the evaluator (whether it's IBACOS or a local HERS rater) requires specific information on how the home was constructed. In particular, the evaluator will need to know the following:

- Insulation levels for exterior walls (including band joist and knee walls), floors exposed to the outside or garage space, ceilings (all flat and sloped areas), and exterior door components.

- Insulation levels for foundation walls and floors
- Window performance values (U-value and SHGC)
- The airtightness of the building based on blower door testing and methods used to achieve airtightness
- The fuel efficiency, capacity, venting, and all other performance specifications for heating, cooling, ventilation, and hot water production system equipment. The number of units used and their location will also be required
- The amount of air leakage in the air distribution system based on duct blaster™ testing
- The ductwork materials used, whether flex, sheet metal, or fibrous glass duct board, their location (either conditioned or unconditioned space), and what materials, if any, are used to seal joints
- Performance and venting (if applicable), details on all other combustion appliances, and details on alternative energy technologies (e.g., solar) used.

In addition to the information needed above, blower door and duct blaster™ testing will have to be conducted on the base-case home to determine airtightness values. Site inspections at pre-drywall and final completion stages of home construction should be conducted to verify all given information, discover new information, and allow for a general assessment of the quality of construction. The latest set of construction drawings for the base-case home, including all details, cross sections, and any structural, mechanical, electrical, and plumbing portions, will be needed. The energy efficiency evaluation for the base-case home will result in a HERS score for the home.

Design Process: Recommendations for Improvement

Once the current level of energy efficiency for the base-case home has been established, the same home plan can be designed to meet a higher energy efficiency goal. To achieve a HERS score of 86 or more in a mixed-humid climate requires a design approach to reduce the amount of energy used for cooling and heating (i.e., a reduction in cooling and heating loads). The Eastern region requires a greater emphasis on cooling-load reduction, while the Western region requires a greater emphasis on heating-load reduction. For more information, see the Mechanical, Electrical, and Plumbing Design and Construction section of this report.

Builders are sometimes tempted to make only performance improvements with the HVAC system and not with the foundation and building envelope systems. However, uneven room temperatures, drafts, and occasions of high humidity may result from an uninsulated foundation and building envelope that isn't airtight. So, improving only the HVAC system does not increase the comfort of occupants in the home. In addition, this approach may not increase the energy efficiency of a home to the target level. This approach may result in HVAC system equipment that is constantly running as a result of conditioned air being lost at a fast rate because of air leakage and poor thermal envelope performance.

Alternatively, a builder may choose to not make any improvements to their HVAC system and rely only on improvements to the foundation and building envelope systems as a means to meet energy efficiency goals. In the mixed-humid climate, the energy efficiency gains from only increasing insulation levels in foundation and building envelope systems and improving building airtightness to an economical point will not be great enough to result in a 30% reduction in space conditioning needs.

An HVAC system strategy that focuses on how the home would be cooled and heated is needed. As part of developing this strategy, the cooling and heating system technologies available for use should be examined. Market conditions, product availability, and public acceptance could affect fuel source and HVAC system choices.

The types and performance of cooling and heating equipment available, their associated systems, and their cost and efficiency should be reviewed. In the mixed-humid climate zone, the approach to providing cooling, whether through an air handler/condensing unit or a heat pump system, is a key decision. Whatever the system chosen, homeowner comfort is paramount. Maintenance requirements for any HVAC system should also be considered. The efficiency of cooling equipment is particularly important in meeting energy efficiency goals. In the Eastern region, choosing a high-efficiency condensing unit is an appropriate step. The location of heating and cooling equipment within the home affects equipment performance. Recommendations on this matter should form part of the HVAC strategy.

A builder can choose to increase the thermal performance of the foundation and building envelope system that they are currently using or explore alternatives.

There are construction systems that are alternatives to wood framing, such as insulated concrete forms, pre-cast foundation systems, and structural insulated panels, which provide good thermal performance and should be considered as a way to meet performance requirements. The cost and availability of these alternate construction systems usually govern if they will be used or not. Finding a subcontractor who is familiar with the installation of the alternate system is crucial if the system is to be implemented without sacrificing construction time and quality. The performance requirements for the foundation and building envelope systems are outlined in their respective sections and should be used as a guide for selecting a system no matter its composition. For more information, see the Foundation Design and Construction and the Building Envelope Design and Construction sections of this report.

Site Design

The number and performance of windows are a key element of site design and reaching energy efficiency goals. In the mixed-humid climate, the design should specify windows with a U-value of 0.35 or less and a SHGC of 0.35 or less. This design requirement can be achieved with a double-glazed window with a spectrally selective coating that minimizes the amount of solar heat gain and, thus, reduces cooling loads. A high-performance window meeting these characteristics needs to be used in both mixed-humid climate regions. Windows that meet this performance specification also have reduced heat loss. The square footage of all windows should amount to less than 21% of total floor area, with no more than 15% preferred. In the Eastern region, windows facing south and west orientations should be used sparingly, with glazing area limited, if it all possible. In the Western region, windows facing north should be used sparingly with less window square footage used there than other orientations.

It may be difficult for production builders to minimize solar contributions in a home’s design by decreasing window size toward a particular orientation because the house plan may be situated in all possible directions on a lot. So, any attempts to alter solar contributions would be wasted. Therefore, all new homes should be evaluated for energy efficiency based on their worst-case orientation. For homes in the Eastern region, worst-case orientation would assume that the west side is the one with the most glazing. In the Western region, worst-case orientation would assume that the north side is the one with the most glazing. Standard 1-ft roof overhangs and no shading devices should be assumed to exist as part of the energy efficiency evaluation, unless specific solar minimizing techniques are part of the design.

Foundation Design and Construction

In mixed-humid climate homes, basements, crawlspaces, and slab-on-grade are the most common foundation types. Basement walls should be designed and constructed for a minimum thermal performance of R-10, either on the interior or exterior. If the basement receives conditioned air, temperature and humidity levels of an insulated basement are similar to the first floor. The result is a more comfortable, habitable basement.

It is preferred that the insulation be placed on the exterior side of the foundation wall. Exterior insulation will make that wall warmer during cold weather, thereby limiting the amount of condensation that can occur on the wall's inside face. Semi-rigid fiberglass board insulation or rigid extruded or expanded foam board insulation products are preferred for exterior insulation. These products can be applied in the appropriate thickness to achieve the R-10 performance level. They also provide protection against potential water intrusion in the foundation and can help divert water to a perimeter exterior drainage system. Careful detailing and the use of a protection system such as parging or an exterior cladding is needed to ensure that the top of the insulation is not exposed to water or soil penetration, either through the material or between it and the wall.

On sites where the potential of a high water table or poor-draining soil exists, insulating on the exterior side of the foundation wall should be the only system considered. To keep the foundation wall dry, the following should be used for all basements and crawlspaces:

- Exterior dampproofing on the foundation wall
- A capillary break either above or below the footing (either a bituminous coating or a layer of polyethylene) to prevent moisture transfer from the ground
- An exterior perimeter drainage system.

For best results, the basement area should be conditioned and dehumidified.

While not the preferred option, basements can be insulated on the inside, as well. When using interior insulation, it's important to consider interior moisture diffusion control, the flame-spread rating of the product exposed to the interior, and the compatibility of the product with moisture. Extruded or expanded foam board insulation products can be placed on the inside of the wall and then strapped with a framing material to allow the placement of drywall over an air space. Blanket insulation with a perforated facing to allow drying of the wall to the inside can also be used on the inside face, but it is preferred that it be used in conjunction with an exterior insulation product and in conditioned basements. Because many foundations are restricted from drying to the outside when wet because of dampproofing, drying to the inside is necessary. An example of a suitable exterior insulation product is semi-rigid fiberglass board insulation with R-3 thermal performance. This product could be used on the exterior to reduce the condensation potential of the inside portion of the wall and limit moisture movement into it. The blanket insulation needs to be applied so that the facing is airtight so that moisture-laden air does not reach the foundation wall from the inside. Insulated and drywalled wood-framed walls offset from the foundation are a popular choice because these types of walls can be used to finish the space. However, this approach should be used with caution because basements often contain moisture. If wood is exposed to extended periods of moisture and warm temperatures, mold growth can occur.

There are pre-cast concrete foundation systems available that include R-5 rigid foam board insulation on the exterior side of the assembly. The system panel is manufactured to include cavities open to the inside where insulation can be placed.

Crawlspaces also require a minimum of R-10 insulation on the interior or preferably exterior side of the foundation wall. Approaches and systems for accomplishing this are similar to those used in basements. In addition, insulation placed on the interior side of a crawlspace wall must extend down the wall at least 2 ft below grade level. If the crawlspace wall extends less than 2 ft below grade level, then the remaining insulation must be placed horizontally along the ground at the bottom of the wall. We recommend that all crawlspaces be built without venting receive conditioned air (Figure 4), and have airtight and insulated foundation walls, together with the previously mentioned measures for keeping a foundation wall dry. The ceilings of crawlspaces do not need to be insulated in this type of crawlspace construction.

Slab-on-grade foundations need to be insulated in the Western region to achieve a 30% energy consumption savings. A minimum of R-10 insulation in a 20-ft width under the slab at its perimeter is needed (Figure 5). By insulating this portion of the slab, there will be less heat loss from the house. In the Eastern region, although the slab can remain uninsulated as long as a 90% efficient furnace is used, homes in warmer areas of the region should be able to substitute slab perimeter insulation as mentioned above for a high efficiency furnace. An energy efficiency evaluation would confirm that the substitution is warranted.

Figure 4. Unvented and conditioned crawlspaces with insulated walls are recommended. Because foundation walls of a crawlspace are usually at least partially above grade, insulating the exterior side of the walls requires detailing to ensure that the insulation is not exposed to the elements. Consequently, builders often choose to insulate on the interior side of the wall. The insulation on the inside must meet flame-spread requirements and should not have an impermeable face, so that moisture is not trapped within the wall assembly.

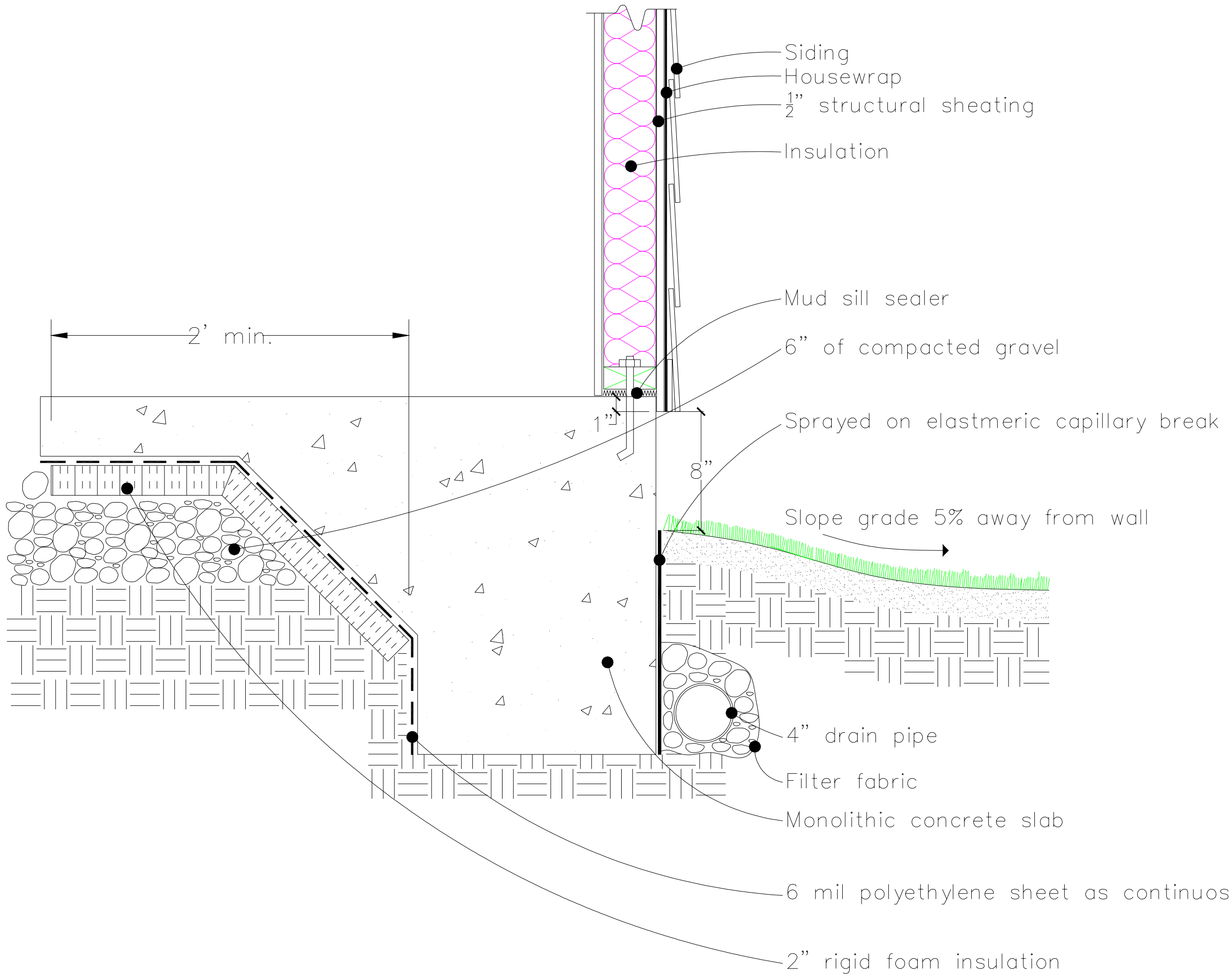

Figure 5. Insulating below a slab-on-grade foundation at the perimeter prevents heat loss in the slab area where it is most likely to occur

Building Envelope Design and Construction

Whether the construction system chosen for the building envelope is insulated wood frame, insulated panels, insulated forms, or another system, its thermal performance is critical for energy efficiency goals to be realized.

Exterior walls should have a minimum nominal insulation value of R-13. In wood-frame construction, this level of thermal performance could be achieved with a 2x4 wall with R-13 cavity insulation (either fiberglass or cellulose). SIPs, ICFs, or other construction systems that meet this minimum insulation value are suitable alternative choices to wood-frame construction.

Batt insulation in wall cavities should completely fill up the cavity, not be compressed, and encase or surround electrical or plumbing fixtures or wires. If kraft-faced batts are used, they should be face stapled, not inset stapled, to the studs. Insulation systems that are blown (cellulose or fiberglass) or sprayed (polyicynene or polyurethane) into a wall do a good job of filling the entire stud cavity, which can increase the airtightness of the exterior wall. Unless specifically required by local building code, a polyethylene vapor retarder (between the framing and the drywall) is not recommended because it can limit a wall's ability to dry to the inside. Painted drywall should provide enough vapor diffusion protection to minimize moisture movement from the inside.

The design of any flat attic spaces should include a minimum of R-38 insulation. In wood-frame construction, this is usually achieved by using fiberglass batts or blown cellulose or fiberglass. If a blown product is used, baffles (Figure 2) should be used at the perimeter of the attic to ensure that insulation depth is kept as uniform as possible. High heel trusses (Figure 3), which allow for easier full height placement of insulation at the attic perimeter are recommended, and should allow the place of insulation between 10 in. (cellulose) and 16 in. (fiber glass) in height.

Vaulted or sloped ceilings should include a minimum of R-30 insulation. In these situations, it is important that clearance for an air space be maintained between the top of the insulation in the roof rafter and the bottom of the roof sheathing (Figure 6). The ceilings of overhangs, built for fireplaces and bay windows, for example, need to be insulated to the same level as a flat or vaulted ceiling depending on their configuration. Floors over unconditioned space, such as room floors above a garage, and window or fireplace overhangs that protrude outside, should include a minimum of R-30 insulation. Care must be taken to ensure that the perimeter of the overhang is insulated entirely.

If wood framing is to be used in exterior walls, its amount should be optimized so that a larger amount of insulation can be placed in the wall without sacrificing structural sufficiency of the home. This would result in a higher effective R-value for the wall and would also result in fewer cold spots. Such cold spots often lead to comfort complaints and mold growth, because moisture is more likely to condense on such surfaces. Common approaches to prevent cold spots are based on OVE framing techniques such as

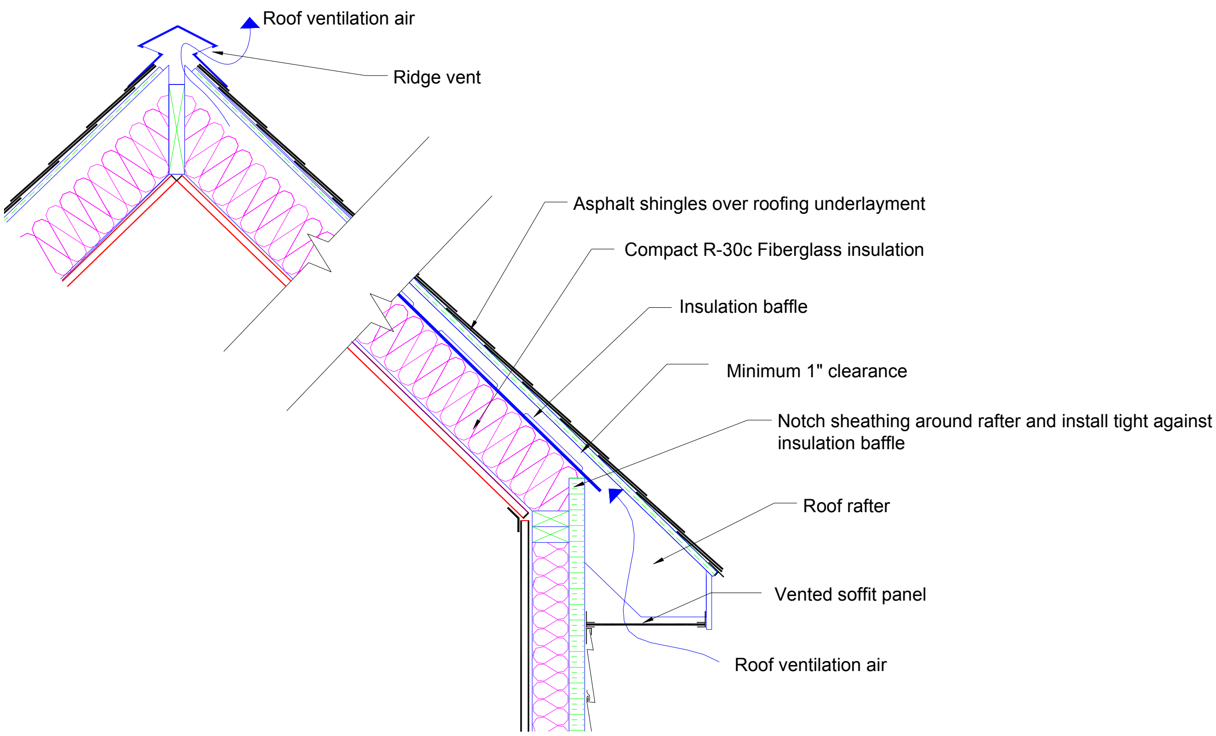

Figure 6. Correct method for insulating a vaulted ceiling

keeping exterior wall corners open to the inside, eliminating wood-framing members not required for structural purposes, and spacing studs at 24-in. intervals instead of 16-in. intervals. The increased thermal performance effects of these measures in exterior walls and alternative construction systems can be accurately accounted for by energy-analysis software.

The design goal for building airtightness is an annual air infiltration rate less than 0.35 natural air changes per hour. This can be verified with a blower door test. At this level of airtightness, home occupants should experience few drafts or uneven temperatures as a result of air leakage.

To achieve this level of building airtightness, it is critical that a continuous air barrier for the home be established. The most common air barrier is the interior drywall because it covers most of the shell of the building, including walls and ceilings, whether the house's structure is wood frame, SIPs, or ICFs. Where interior drywall is not present on exterior walls in living areas, draftstopping must be placed to provide air barrier continuity. Such areas include wall and ceilings, areas adjacent to fireplaces, and at bathtubs, shower enclosures, and chases. In exterior walls, the exterior sheathing can also be considered as a component of the air barrier and should be installed without gaps and openings. House wraps, when installed with taped seams and sealed to the top and bottom of the wall assembly and around openings, also help to reduce air leakage in homes. The undersides of floors exposed to unconditioned space require an air barrier as well. A sheathing product with joints sealed or taped would form a good air barrier in this application. The concrete or block foundation wall, together with the band joist framing, is also considered part of the air barrier system.

Penetrations through the air barrier—whether they are large, such as windows or doors, or small such as gas lines and electrical service—need to be sealed to the air barrier to prevent air leakage occurring through the hole or gap that results from the penetration. Foam sealants and caulking can be used to remedy air leakage penetrations.

Mechanical, Electrical, and Plumbing Design and Construction

Once an HVAC system strategy that outlines the heating, cooling, and ventilation system technologies to be used is established, an engineered HVAC system design and layout should be developed. The engineered design, based on ACCA Manual J (1986), would accurately reflect the heating and cooling peak-load requirements for the house and individual rooms based on specifications obtained from the energy efficiency design package. Selection of HVAC equipment would be based on the determined loads and optimized so that energy is not wasted to condition and ventilate the home.

For homes with forced air distribution, zoning practices do not need to change to meet energy efficiency goals. However, an equipment optimization strategy, where one larger capacity HVAC system with a zone-dampering system is used instead of two smaller capacity systems, is preferred because it is more energy efficient, less costly to purchase, and easier to maintain without sacrificing comfort and temperature preferences for different rooms.

Energy can be saved by installing higher performance heating and cooling equipment. In the Eastern mixed-humid climate zone region, it is important that condensing units should have a minimum SEER of 12 (when matched with condensing coil used). It is critical that the condensing unit be sized according to the engineered design so that it has enough capacity to meet cooling-load requirements, but not be too large so that it becomes prone to short-cycling. Condensing units that short-cycle do not have enough time to dehumidify indoor air, and "clammy" interior conditions can result. Furnaces in this region can have a minimum AFUE of 80% if installed in basement or crawlspace construction. A higher performance furnace of 90% AFUE or greater is required for homes with slab-on-grade construction. Direct-vent or sealed-combustion boilers or furnaces are recommended because the back drafting of combustion products is less likely to occur with these systems. Therefore, indoor air quality is less likely to be compromised.

In the Western mixed-humid climate zone region, it is important to increase the efficiency of the furnace to a minimum AFUE of 90%. Boilers require a minimum AFUE of 84% and condensing units should have a minimum SEER of 10 (when matched with condensing coil used). In all homes in this climate zone, programmable thermostats are recommended so that occupants can control furnace operation. This would help them save energy during periods of low occupancy.

Air-source electric heat pumps are a suitable option in both mixed-humid climate zone regions because outdoor temperatures often do not reach below freezing. Consequently, supplementary (resistance) heat is not used often and the overall efficiency of the system is maintained. Units with SEERs of 12 (10 SEER in the Western region) and HSPF of 7 or larger are recommended. The efficiency of gas-fired air-source heat pumps should have a COP of 1.2 and a cooling efficiency of 1.25 COP or greater. Ground-source and water-source heat pumps with a COP of 2.8 or greater and an EER of 10 or greater are recommended. The latter units have a greater initial cost.

If a forced-air system is used to provide heating and cooling, an engineered duct design, based on ACCA Manual D (1995), should be conducted based on HVAC equipment selection, optimum air distribution performance, and HVAC system airtightness. This design would include layout and ductwork sized for good air distribution. The duct design may result in changes to the HVAC equipment selected to facilitate better air distribution. Boilers that provide hot water that is circulated through baseboard convectors or a radiant floor or ceiling system would be designed to provide adequate heating for the home based on calculated heating loads.

The furnace, air handler, or heat pump should not be placed in an unconditioned attic, crawlspace, or basement (Figure 7). Some of the cooled air being moved by an air handler operating in a hot and humid unconditioned space may not make it to the living space if the supply system exhibits air leakage. Similarly, leaks in return air ductwork traveling through unconditioned space can draw hot and humid air, which ultimately raises the temperature of the cool air being delivered to the home and can result in comfort complaints. Therefore, ductwork running through unconditioned space is not the preferred approach, and we recommend that ductwork be kept within conditioned space, although moving all ductwork into conditioned space is not required to meet the current energy efficiency goal. Ductwork traveling through unconditioned space should be insulated to R-4. It is preferred that ductwork be covered with attic insulation if located in that space.

All ductwork, whether it is made of sheet metal, flexible plastic, or fibrous glass must have all joints and openings sealed with a UL181-approved water-based mastic sealant or UL181-approved tape (for fibrous glass ductwork applications). The ductwork connecting to the furnace or air-handling unit must also be sealed along with any joints in the unit. The airtightness of the HVAC system must be tested by using a duct blaster™ and should not have air leakage to the outside greater than 10% of total system airflow. For example, a furnace that has total system airflow of 1600 cfm must not exhibit more than 160 cfm of air leakage to the outside of the house as a result of the air distribution system.

Figure 7. Locating mechanical equipment responsible for air movement in a conditioned space, such as this conditioned crawlspace, means that it is not subject to the cold and extreme hot and humid circumstances that it would experience if it was located in an attic, vented crawlspace, or the outdoors.

Registers for a forced-air system should be positioned in walls, floors, and ceilings according to local practice, which is assumed to offer the best air delivery for the particular locality. For many mixed-humid climate locations, registers serving the second floor are placed in the ceiling to allow cool air to fall to the floor during the cooling season. Registers placed in second-floor locations high on the walls also work well as a substitute to ceiling registers and make it possible to keep ductwork within conditioned space. Registers on the first floor are typically placed in the floor, resulting in air being delivered upward into the room. The layout of hydronic systems should follow manufacturer's specifications.

With building envelope airtightness increased, there is less outdoor air coming into and out of the home by uncontrolled means (i.e., air leakage). To ensure that the occupants of the home continue to receive an adequate amount of outdoor air, a controlled method for the introduction of outdoor air, such as a mechanical ventilation system, is needed. A positive or balanced pressure ventilation system is recommended in this climate zone. Running a 6-in.-diameter piece of ductwork from a hood mounted to the exterior wall to the return plenum of the air handler provides outdoor air when the unit is operating. This positive-pressure system can include an air-handler fan controller to regulate outdoor air intake. An energy-recovery ventilator is an example of a balanced pressure system. An energy-recovery ventilator draws outdoor air and removes moisture from it before delivering it to the furnace/air handler or directly to the rooms, while removing an equal quantity of indoor air.

Hot-water tanks with an EF greater than 0.56 for gas-fired units and 0.88 for electric units are recommended. Power-vented gas hot-water tanks are less susceptible to combustion product back drafting because they force combustion gases out the flue, which lessens the chance of detrimental indoor air quality situations.

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13. ABSTRACT *(Maximum 200 words)*

This report presents system design packages for cold and mixed-humid climates. Builders and contractors can use these design packages to construct homes that achieve a Home Energy Rating System (HERS) score between 86 and 88. This represents a reduction in space-conditioning and domestic hot-water energy consumption of between 30% and 40%, compared to a similar home built to meet the 1993 Model Energy Code. The six different design packages, three for each climate zone, give the builder flexibility in their design strategy by allowing them to choose the most cost-effective approach. The recommendations presented in these design packages are based on more than 10 years of experience that IBACOS has had working with builders throughout the United States on Building America projects.

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