Achieving Sustainable Construction in Affordable Housing

Mark P. Ternes

Michael K. Barcik
Associate Member ASHRAE

Dennis B. Creech

ABSTRACT

An energy-efficient design and construction checklist and information sheets on energy-efficient design and construction are two products being developed. These products will help affordable housing providers take the first steps toward a whole-house approach to the design and implementation of energy-efficient construction practices. The checklist presents simple and clear guidance on energy improvements that can be readily addressed now by most affordable housing providers. The information sheets complement the checklist by providing installation instructions and material specifications that are accompanied by detailed graphics. The information sheets also identify benefits of recommended energy-efficiency measures and procedures including cost savings and impacts on health and comfort. This paper presents details on the checklist and information sheets and discusses their use in two affordable housing projects.

INTRODUCTION

Inclusion of energy-efficient features in the construction of affordable housing offers many benefits to low-income homeowners, including reduced operating costs, improved comfort, reduced noise, and a healthier indoor environment. Current challenges to building energy-efficient affordable housing include overcoming the bias of considering just first cost rather than first cost and operating costs, incorporating energy-efficient features into construction designs and plans, and altering current construction practices in the field to achieve improved energy performance. Some immediate concerns of affordable housing providers regarding the energy efficiency of their plans and construction practices include:

- What are the important elements in constructing an energy-efficient home?
- What are the first steps we can undertake to improve the energy efficiency of our housing?
- Which energy improvements are less costly up front?
- How do I get my construction crew or contractor to follow the energy designs I have selected?
- Do energy-efficiency techniques require specially skilled laborers?

A whole-house "systems" approach to design and construction is generally becoming recognized as the appropriate method of developing energy-efficient and sustainable homes. A systems approach considers the interaction between the site, building envelope, mechanical systems, occupants, and other factors. The systems approach recognizes that features of one component of the house can greatly affect others. Such an approach is exemplified by the Building America design teams organized by the U.S. Department of Energy.

A checklist of energy features and information sheets on energy-efficient design and construction are two products being developed. These products will help affordable housing providers take the first steps toward a whole-house approach to the design and implementation of energy-efficient construction practices. These products are also needed to address the concerns expressed by affordable housing providers discussed above.

ENERGY-EFFICIENCY DESIGN AND CONSTRUCTION CHECKLIST

A first step to developing an energy-efficient home is to correctly perform current design and construction-related tasks that impact energy before considering more advanced

Mark P. Ternes is a research staff member at Oak Ridge National Laboratory, Oak Ridge, Tenn. **Michael K. Barcik** is a research engineer and **Dennis B. Creech** is executive director at Southface Energy Institute, Atlanta, Ga.

energy-efficient techniques. A checklist (see Appendix) presenting simple and clear guidance was developed to focus attention on energy improvements that can be readily addressed currently by most affordable housing providers.

The checklist is generic, and details will vary according to climate, house design, material selection, and other factors. However, most of the items are applicable to affordable houses built in most climates today. The checklist is not intended to provide detailed installation instructions or material specifications for each item. Such details are intended to be presented in the energy information sheets discussed later in this paper.

Foundation

Controlling moisture at the foundation is critical to maintaining the durability of the building as well as the health of its occupants. Groundwater is a common cause of moisture problems in homes. The checklist items focus on ensuring proper drainage around the home and preventing moisture from entering the home through the foundation.

Framing

Energy-efficient wood framing reduces the amount of wood framing used in the house so that more insulation can be installed. Since insulation reduces heat flow better than wood, this improves overall efficiency. Less framing also reduces the amount of cold interior surfaces that often occur at framing locations. Other sustainable benefits include less use of natural resources (wood) and reduced waste. In addition to saving energy dollars, energy-efficient framing can reduce material and labor costs as well. The energy-efficient framing techniques identified in the checklist focus on ensuring complete insulation coverage in the walls and attic and providing shading for windows in homes in hot and mixed climates.

Insulation

Insulation reduces heat flow through the building envelope and is routinely installed in any new house. The checklist emphasizes using the appropriate insulation levels for the climate by meeting or exceeding minimum insulation requirements specified in the climate-based *Model Energy Code* (CABO 1995).

While the amount of insulation installed is important, so is the quality of installation. Even small gaps and areas of compressed insulation can reduce insulating levels significantly. Gaps can also allow condensation to take place, which damages building materials and can cause growth of molds and other biological contaminants. Volunteers or unskilled workers can do a successful job if given proper instruction. The checklist addresses methods of ensuring complete insulation coverage, installing insulation flush against surfaces without overcompressing it, and means of increasing insulation levels without increasing costs.

It is important to seal air leaks before insulating. Commonly used insulation materials, such as batts and loose-fill products, do not stop air leakage. For most affordable house designs, materials other than insulation will form the air barrier (e.g., the interior dry wall or exterior housewrap), although there are some insulation products (such as exterior rigid insulation) that can reduce air leakage while insulating.

Air Sealing

Air leakage accounts for a significant portion of a home's heating and cooling costs. Problems can also originate from moisture-laden air leaking into the building envelope. Commonly used sheet materials, such as drywall, sheathing, and decking, are effective at stopping air leakage when they are installed to create a continuous air barrier.

Many homes built with standard construction practices have large gaps in the sheet goods. Although windows, doors, and outside walls contribute to air leakage, the biggest gaps are often hidden from view: under the bath tub, above dropped soffits for kitchen cabinets, or in mechanical room closets. Other holes in the building envelope are smaller but more numerous, such as holes drilled for electrical wires and plumbing pipes. The checklist identifies the important air leakage sites created during typical construction that need to be identified during design and sealed during construction. The checklist also identifies five key steps to correctly installing housewrap, which is recommended as a backup or contingency to caulking and sealing.

Although the air sealing items identified in the checklist are not overly sophisticated, they are sufficient to make a significant reduction in house air leakage compared to typical affordable housing construction practice. Builders of affordable housing are also more likely to implement these simpler approaches, most of which do not require any extended training.

Air sealing, although labor intensive, does not usually require expensive materials or special construction skills. Many affordable housing programs rely on volunteers for labor (Figure 1). These volunteers make excellent air sealers because they have the time and persistence to do a thorough job. The materials required (caulk, foam, housewrap tape, polyethylene plastic, rigid board insulation, other sheet goods such as plywood or drywall, etc.) are inexpensive and available from local building suppliers. However, air sealing must be done throughout the construction process: during framing, prior to insulating and installation of interior finish materials, and after installation of fixtures. The key is to identify the important sources of leakage, assign the responsibility for sealing the holes, and check to ensure the air sealing was done effectively.

Windows and Doors

While energy-efficient windows (i.e., wood or vinyl framed, low-e, etc.) cost more than standard models, they can

Figure 1 *Thorough air sealing, while labor intensive, does not require skilled workers and can easily be done by volunteers.*

cut energy bills significantly. The use of energy-efficient windows improves comfort by increasing surface temperatures and reducing drafts. They also limit window/frame condensation, which protects building materials and reduces mold growth. The checklist requires windows to be selected to meet or exceed requirements in the 1995 *Model Energy Code.* The checklist identifies backer rod (with caulk) as the preferred method for sealing windows and doors into their rough framing. The use of spray foam by inexperienced installers is not recommended because expanding varieties can warp frames, although training can alleviate this restriction.

Window orientation also affects energy use. The checklist focuses attention on facing major glass areas to the south for maximum winter heating and avoiding unshaded glass on east and west sides to reduce summer overheating.

Heating and Cooling System

The choice of energy source for heating equipment is often an important factor in determining cost. The checklist recommends comparing operating costs for all available fuel types during the design process so that short-term incentives do not dictate an expensive, long-term energy source.

Energy-efficient homes require less heating and cooling than standard homes. Therefore, smaller mechanical systems can be installed, which save the builder or housing provider money up front. It is common for mechanical systems to be oversized, which results in increased equipment costs, wasted energy, and reduced comfort and moisture control. Properly sized equipment will last longer, provide greater comfort, and save homeowners money on initial and operating costs. The checklist recommends that equipment sizing be based on calculation and selection methods using industry standard procedures (ACCA 1986, 1995) that consider insulation levels, window type and orientation, and air sealing measures.

Higher-efficiency equipment costs more up front than standard models but reduces long-term operating costs. The checklist requires energy calculations to be performed to determine when higher-efficiency equipment is justified. These calculations can often be performed by the heating and cooling contractor or local utility.

Many new homes built today rely on forced-air distribution of conditioned air through ductwork. Air leakage and heat losses and gains from poorly sealed and inadequately insulated ductwork can waste a considerable portion of a home's heating and cooling energy. Duct leakage also creates pressure imbalances in a home, which may endanger the health and safety of the occupants.

The checklist identifies one of the best solutions to cutting energy losses from ductwork—locate the ducts inside the conditioned space of the house. For example, some affordable home designs provide for ductwork in an airtight plenum located below the ceiling of an interior hallway. Air is distributed to individual rooms from registers mounted high on interior walls of adjoining rooms. Locating ducts between floors of multistory homes is another option as long as this interstitial space is sealed and insulated.

If ducts cannot be located in the conditioned space, then it is critical to properly seal and insulate them. The checklist identifies the critical areas that must be sealed with mastic and requires adherence to insulation requirements in the 1995 *Model Energy Code.*

Ventilation

The activities of the homeowner, such as respiration, cooking, bathing, and cleaning, generate moisture. It is important in energy-efficient homes to provide for controlled ventilation to remove this moisture. In simple designs, spot ventilation provided by bath and kitchen fans that are vented directly to the outdoors may be adequate and are identified in the checklist. Higher-quality fans that are quiet and move desired amounts of air should be used. For more complex designs and severe climates, heat recovery ventilation and other techniques may be appropriate.

Water Heating

The cost for water heating can be as great as for space heating or cooling. Fuel cost is often the prime consideration for water heating. The checklist recommends investigating fuel choice before selecting a system type and identifies other simple measures that can be employed to reduce hot water energy use.

Lighting

Energy-efficient lighting saves on electric bills, helps keep the home cooler during the summer by reducing internal loads, and lasts longer. The checklist highlights installation of fluorescent fixtures in high-use interior areas of the home and use of fluorescent or high-pressure sodium fixtures for exterior lighting.

ENERGY TECHNICAL BULLETINS

A series of four-page technical bulletins are being prepared to complement the checklist. Bulletins identify benefits of recommended energy-efficiency measures and procedures including cost savings and impacts on health and comfort. They provide installation instructions and material specifications, and they are accompanied by graphics. Each bulletin will be placed on a U.S. Department of Energy residential web page as it is completed. This web page is located at http://www.eren.doe.gov/buildings/residential/tools.htm.

Bulletins are being prepared that provide a general overview of items appearing on the checklist. Topics include why energy efficiency is important (completed), sealing air leaks, and energy-efficient construction. More detailed bulletins are also being prepared that focus on specific checklist items. One bulletin describes energy-efficient framing techniques, while another describes details of installing a whole-house fan (completed). A set of six bulletins discuss working with a heating and cooling contractor, selecting heating and cooling equipment, installing a furnace, installing a heat pump, designing a duct system, and installing ducts.

USE OF THE CHECKLIST AND BULLETINS

The energy-efficient checklist and energy technical bulletins are intended to be used during the design and construction planning phase to guide the house and site layout, identify energy-efficiency options and improvements, highlight construction and implementation issues that need to be coordinated and resolved, and ensure that selected equipment and necessary materials are specified and purchased.

The checklist and bulletins are also intended to be used during construction by workers and construction leaders. A version of the checklist developed for a specific project and that is less wordy can be used during construction to make sure all energy elements are performed as intended. Bulletins can serve as installation instructions.

HABITAT FOR HUMANITY CASE STUDIES

Two Habitat for Humanity (HFH) projects provide excellent case studies for the use of the checklist to ensure the construction of energy-efficient houses in an affordable housing context. HFH relies on volunteer labor to build and rehabilitate homes. Many HFH affiliates rely on specialized crafts and contractors to perform electrical, plumbing, heating and cooling, drywall, and cabinet work, so they are similar to other affordable housing providers in many ways.

1997 Jimmy Carter Work Project

The Jimmy Carter Work Project (JCWP) is an internationally recognized annual event in which Jimmy and Rosalyn

Figure 2 *Habitat for Humanity's 1997 Jimmy Carter Work Project provided a good test for the effectiveness of a design and construction checklist aimed at improving energy efficiency in affordable housing.*

Carter join HFH volunteers in a week-long "blitz-build." In a "blitz-build," houses are built in one week. During 1997's event in June, over 2,400 volunteers constructed 50 houses at seven rural areas in the Appalachian area of Kentucky and Tennessee (Figure 2).

A year before the actual construction of the houses, HFH's design committee began the development of a construction manual for the project. This manual identified the construction details of the several house plans to be built during the project and identified a daily schedule that had to be met to ensure that houses would be completed by the end of the week's building period. Material requirements were identified from the construction manual, and materials were obtained so that they would be on hand at each site before the start of construction.

Many of the concepts advocated in the checklist were used in the initial design for these houses: *Model Energy Code* insulation levels were being followed and exceeded; double-pane, low-e, wood windows had been selected; a large front porch was designed to provide shading to front windows; housewrap was to be installed on many houses; and ducts were to be insulated to R-6. Energy simulations confirmed that the energy features selected for these houses would allow their designs to meet the requirements of an Energy Star house if the air leakage rates of the houses were less than 0.35 natural air changes per hour ($ACH_{natural}$) following construction. Energy Star homes are equivalent to a Home Energy Rating System (HERS) Five-Star home, which is rated through an industry standard procedure (HERSC [no date]).

Because the primary design work had already been completed, some elements of the checklist (particularly those dealing with design issues such as framing and locating ducts inside the conditioned space) could not be included in the design. Therefore, a scaled-down version of the checklist was used that primarily focused on three construction-related, energy-efficiency details: air sealing, insulation, and duct installation. Air sealing details had not been addressed in the original construction plans and were critical if the houses were to meet Energy Star requirements. The challenge with insulation and duct installation details was to ensure that the design intent was achieved during construction by the volunteer labor crews.

Four steps were performed to finalize the energy-efficiency package and approach. First, energy-efficiency training sessions emphasizing the checklist items were provided to construction managers at the local HFH affiliates involved in the 1997 JCWP several months prior to the project. Second, the energy measures were incorporated into the day-to-day schedule provided in the construction manual for the project. This coordinated the energy measures with other construction activity for the house leaders and allowed conflicts and scheduling requirements to be thought out and resolved. Third, a poster (Figure 3) of the energy-efficiency checklist was developed to be hung at each of the 50 houses during the week of the blitz-build. The poster provided blocks next to each of the 34 items to be checked off as they were completed and also provided detailed installation diagrams for many of the items. Finally, an energy specialist was assigned to each house during the week-long construction of the homes. Specialists came from national laboratories, research facilities, building associations, and other HFH affiliates. The primary role of the energy specialist was to champion energy efficiency at the site by demonstrating an enthusiastic commitment to energy efficiency and making sure energy details were completed during construction.

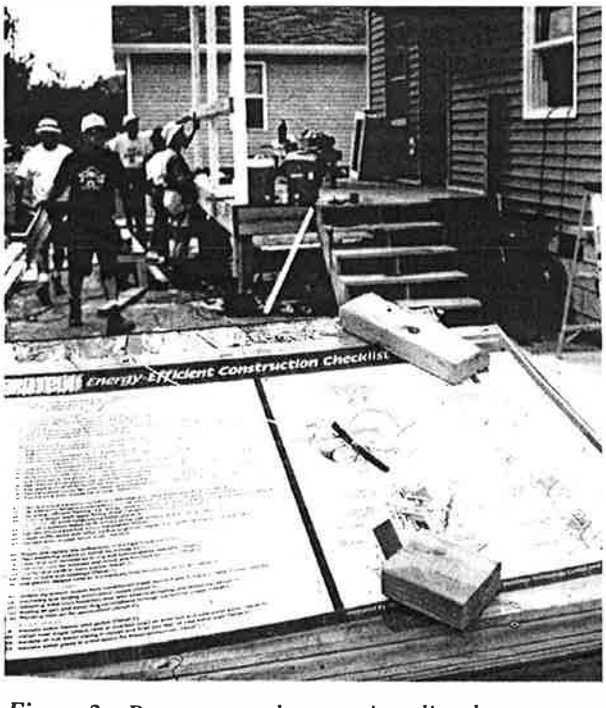

Figure 3 Posters used on site listed energy-efficiency measures to be performed during construction and provided graphics on correct installation techniques. (Photo courtesy of Habitat for Humanity International.)

Blower door tests revealed that tight houses were obtained from use of the checklist and on-site energy specialists, even when using volunteers and working in the time constraints of a week-long blitz-build. An air leakage rate of less than or equal to 0.35 $ACH_{natural}$ was measured by a blower door in 16 of 20 houses tested (Table 1). These houses were tighter by almost a factor of two compared to a typical HFH house, which has a leakage rate of 0.60 $ACH_{natural}$ or more based on previous measurements.

More advanced air sealing treatments can achieve an airtightness of less than 1.5 ACH measured at a 50 Pa pressure difference (ACH_{50}) (Mayo and Sinha 1996) compared to the average value of 6.2 ACH_{50} (see Table 1) achieved in these HFH houses. However, these HFH houses were as tight, if not

TABLE 1
Air Leakage Measurements—
1997 Jimmy Carter Work Project

House	House Air Leakage		Duct Leakage (cfm_{25})
	ACH_{50}	$ACH_{natural}$	
1	8.4	0.39	91
2	7.8	0.36	99
3	6.8	0.32	90
4	9.0	0.42	76
5[a]	5.3	0.25	-----
6[a]	6.1	0.28	-----
7[a]	5.6	0.26	-----
8[b]	5.6	0.27	112[c]
9[b]	4.6	0.22	35[c]
10[b]	4.3	0.20	25[c]
11[b]	3.7	0.17	45[c]
12[b]	6.3	0.30	22[c]
13[b]	10.2	0.49	6[c]
14[b]	3.9	0.19	32[c]
15[b]	6.9	0.33	41[c]
16[b]	6.0	0.30	32[c]
17[b]	6.6	0.31	80[c]
18[b]	7.3	0.35	-----
19[b]	4.5	0.21	264[c]
20[b]	4.4	0.21	64[c]
Average	6.2	0.29	70

[a]Data provided courtesy of the Florida Solar Energy Center.
[b]Data provided courtesy of the Energy Efficient Building Association.
[c]Data converted from cfm_{50} readings by multiplying by 0.637.

tighter, than new houses built in three other areas of the United States. Twenty of 100 new houses in North Carolina and South Carolina had an ACH_{50} of over 10, while only 1 of 100 had an ACH_{50} under 5 (Katz 1997). In comparison, only 1 of the 20 1997 JCWP houses had an ACH_{50} over 10, while 6 of 20 had an ACH_{50} under 5. The average air leakage rate of 0.29 $ACH_{natural}$ measured in the Habitat houses compares favorably with average rates measured in 135 new houses in Iowa (0.39 $ACH_{natural}$) and 200 homes in Vermont (0.38 $ACH_{natural}$) (Neme et al. 1996). Neme et al. mention that the values for Vermont and especially Iowa may actually be higher than these reported values because basement volume was included in the conditioned volume of the houses when, in fact, many of the basements were not conditioned.

Duct blower tests also revealed tight ductwork. The duct leakage in 16 tested houses averaged 70 cubic feet per minute at 25 Pa (cfm_{25}), with 14 of these 16 houses having a leakage rate of less than 100 cfm_{25} (Table 1). These houses are tighter than many other houses that have been tested across the country. An average duct leakage of 158 cfm_{25} was measured in 96 houses in Phoenix, Arizona (Kolb and Ternes 1995), and 182 cfm_{25} in 82 North Carolina homes (Vigil 1993). Proctor and Pernik (1992) reported that three studies showed 80% to 98% of 226 homes in California had duct leakage greater than 96 cfm_{25}. Although tighter houses and ducts have been achieved by other builders, the improvement seen in these affordable homes from use of the checklist remains significant.

Energy specialists proved to be essential to the success of the energy-efficiency initiative. The focus of many house leaders and workers was on completing construction of the house as scheduled within the week allotted. Efficiency measures would have been neglected or installed incorrectly if the energy specialist had not been present to make sure measures were installed as intended at the proper time during construction. For example:

- The specialist's role was critical during the first hours of construction when the bottom plate needed to be sealed to the subfloor—at a time when most everyone else's attention was directed at raising the pre-assembled exterior walls of the house. The specialist's role continued by being diligent in ensuring that all penetrations, gaps, and holes in the thermal envelope were sealed.
- A specialist in at least one house corrected volunteers who were installing floor insulation with the kraft paper facing the wrong direction.
- Specialists at numerous sites sealed return plenums and ducts following the guidelines in the checklist. At one construction site involving ten houses, energy specialists found a large duct leak in the first system installed even though the contractor was adhering to the checklist and sealing the ducts and return plenum with mastic. Alerting the contractor to this problem before other jobs were finished prevented this problem from being duplicated.

Sumter County, Georgia, Habitat for Humanity Affiliate

The HFH affiliate in Sumter County, Georgia, has received training on the energy-efficiency checklist on several occasions over the last two years. As a result, many of the concepts advocated in the checklist have been adopted. These include meeting *Model Energy Code* levels of insulation, using double-pane windows with a thermal break, building energy-efficient T-walls and insulated headers to improve insulation coverage, isolating the combustion closet from the house, replacing exterior sheathing with rigid board insulation, and sealing many of the important sites of air leakage.

In April 1998, the Sumter County HFH affiliate, in partnership with other community organizations, built 20 houses as part of the week-long Easter Morning Build. The Easter Morning Build represents the first phase of a 140-house subdivision of HFH houses.

The checklist was reviewed with the affiliate during the design phase for this project and additional energy features were added to these homes, with the primary emphasis placed on additional air sealing tasks and steps to ensure complete insulation coverage. As with the 1997 JCWP, the energy measures were incorporated into the project's planning schedule and construction manual. Additionally, members of HFH International's Green Team (volunteers from various affiliates with an expressed interest in advocating sustainable issues within their affiliate) were trained the two days before the blitz on the energy-efficiency features to be installed in these specific houses. One Green Team member was then assigned to each house to oversee the installation of energy measures during the build.

Measurements showed that the houses were tighter than those built during the 1997 JCWP: the average house air leakage was 4.6 ACH_{50} compared to 6.2 in the 1997 JCWP, and the average duct leakage was 49 cfm_{25} compared to 70 cfm_{25}. These results (Table 2) clearly show that houses can be built tighter than typical construction practice by following the checklist items.

A large part of the improvement in house and duct airtightness can be attributed to the presence of a Green Team member to oversee implementation of the checklist items. In several houses where the Green Team members were not continuously present, air sealing opportunities were missed, which led to higher air leakage values. This project reaffirmed that Green Team members should be dedicated and persistent in doing the energy tasks on the house or leading a crew in doing the tasks. In a blitz-build, they should not be expected to have time to help out on other major construction activities. The project also reaffirmed the need to consider interior duct work and other design-intensive energy features early in the design phase.

TABLE 2
Air Leakage Measurements—Sumter County, Georgia, Habitat for Humanity Affiliate

House	House Air Leakage (ACH_{50})	Duct Leakage (cfm_{25})	
		Total	To Outside
1	3.4	61	31
2	2.8	73	10
3	5.3	112	52
4	3.4	88	34
5	4.1	82	-----
6	4.9	67	15
7	5.9	145	78
8	6.6	163	90
9	5.7	78	40
10	3.8	125	65
11	3.5	90	43
12	5.3	118	45
13	4.6	158	77
14	3.8	125	66
15	3.5	135	50
16	3.5	76	50
17	5.3	112	70
18	5.2	61	51
19	4.3	100	20
20	6.4	104	-----
Average	4.6	104	49

CONCLUSIONS

A first step toward a whole-house approach to the design and implementation of energy-efficient construction practices can be achieved by improving current construction practices and focusing on energy measures that fit within the current skills of builders, workers, and construction volunteers. An energy design and construction checklist is a useful tool for affordable housing providers because it identifies important elements to be considered during design and steps to be completed during construction. Without such a tool, providers of affordable housing often lack the ability to identify the important elements to address first.

Energy technical bulletins that complement the checklist by providing more detailed information on the recommended items should also be useful in the future. Since technical assistance cannot be provided directly to all affordable housing providers, technical bulletins will help bridge this gap by providing the information builders and workers need to implement new concepts on their own and to realize that increasing the affordability of a home is not beyond their skill level.

Affordable housing programs that have successfully cut energy waste have a champion that understands the importance of a systems approach and the need for planning and quality control. The champion does not have to be an energy or construction expert, just someone who is committed to making housing truly affordable, safe, and durable.

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APPENDIX

Energy-Efficient Design and Construction Checklist

Foundation

❑ 1. Install **foundation drains**.

❑ 2. For houses with slabs, provide a **capillary break** *under* the slabs.

❑ 3. Establish **drainage swales** as needed, and grade slopes 5% or more *away* from the foundation *everywhere*.

❑ 4. For houses with crawlspaces:

- ❑ A. Install a 6 mil plastic **ground cover**—*overlap* seams 12 in. and *lap* the foundation wall 6 in.
- ❑ B. *Close* **crawlspace vents** after making sure crawlspace is dry.

Framing

❑ 5. Build **exterior walls** using two-stud corners, T-walls, and insulated headers to improve insulation coverage.

❑ 6. Limit the use of **blocking** in exterior walls to improve insulation coverage.

❑ 7. Use **raised heel or oversized (cantilevered) trusses** to allow for complete attic insulation coverage over the exterior walls.

❑ 8. Use 2 ft **soffits** to shade windows facing south, east, and west in mixed and hot climates.

❑ 9. Locate the **attic access hatch** in unconditioned parts of the house (e.g., carport, garage, gable end of the roof) rather than inside the house.

❑ 10. Ventilate the attic using **continuous soffit and ridge vents**.

Air Sealing

(Use caulk, foam, and other materials as identified below)

Before drywall is installed:

❑ 9. Seal between the **bottom plate** of exterior walls and subflooring *during* construction—use a double bead of caulk or durable gasket (sill seal).

❑ 10. Seal the inside edge of the **bottom plate** of exterior walls to the subflooring *after* the frame walls are erected.

❑ 11. Seal the **bandjoist** of multistory units—seal between the top plate and band joist and between the band joist and subflooring *during* construction, or seal all the seams between the band joist and top plate, subfloor, and floor joists *after* construction.

❑ 12. For **bathtubs** on an exterior wall, insulate the exterior wall (see Item 30 below), and then airseal *behind* and *around* the tub *before* setting it—use plastic sheeting stapled and caulked or taped to the wood framing.

❑ 13. Seal **windows** into their rough opening—use backer rod (*preferred*) or other insulating material with caulk; do NOT use spray foam.

❑ 14. Seal **exterior doors** into their rough opening—use backer rod (*preferred*) or other insulating material with caulk; do NOT use spray foam.

❑ 15. Seal between **door threshold** and subflooring.

❑ 16. Seal all **wiring, plumbing, and HVAC penetrations** between conditioned and unconditioned space—at the top and bottom plates, through the ceilings, floors, and exterior walls, and other framing locations.

❑ 17. Seal **wiring penetrations and knockout plugs** in all electrical boxes located on exterior walls.

After drywall is installed:

❑ 18. For houses with a crawlspace, seal the **bathtub drain** penetration *after* the tub is set and the plumbing is connected and *before* the floor insulation is installed—use rigid board insulation, plywood, or other sheet goods with caulk or foam.

❑ 19. Seal **electrical boxes** (receptacles, outlets, switches, light fixtures, and circuit breaker box) to the drywall—use caulk or drywall mud; if possible, provide a surface-mounted electrical service panel rather than inserting one into exterior wall framing.

❑ 20. Install **foam gaskets** on all electrical boxes behind the cover plates.

❑ 21. Seal **plumbing penetrations** through the drywall.

❑ 22. Seal the **bathroom ventilation fan** housing to the drywall—use caulk or drywall mud.

❑ 23. Seal **attic bypasses and chases** (open partition walls, dropped ceilings, duct and flue chases) *before* the attic insulation is installed—if possible, construct these framing features after the ceiling is installed to avoid air leakage sites.

❑ 24. Seal **exterior penetrations** (porch light fixtures, outside outlets, phone, cable, electric service holes, and faucet hose bib).

❑ 25. Weatherstrip the **attic access hatch** cover.

❑ 26. For a **whole-house** fan:

- ❑ A. Seal gaps around the whole-house fan **frame**—use foam (*preferred*) or housewrap tape.
- ❑ B. Fabricate a whole-house fan **cover**—use rigid board insulation or fibrous duct board.

❑ 27. For an **attic pull-down stair**, weatherstrip and provide a latch to hold the stair panel tightly against the weatherstripping.

Insulation

❑ 28. Select **insulation levels** that meet or *exceed* the 1995 *Model Energy Code.*

❑ 29. For a **slab foundation**, install rigid board insulation during slab construction around the perimeter of the slab using a code-approved method.

❑ 30. Insulate the exterior walls around the **bathtub** *before* setting the tub.

❑ 31. Insulate the exterior walls behind **stairwells** and cover with sheet material *before* setting the stair stringers.

❑ 32. *Cut* the **wall insulation** batts to the full length of the cavity to be insulated.

❑ 33. *Slit* the **wall insulation** batts to fit around wiring, wall outlets, and plumbing.

❑ 34. For cold and mixed climates, *carefully* staple the kraft paper facing of the **wall insulation** batts to the front of the studs (*preferred*) or sides of the studs (allow no more than ¼ in. compression) every 12 in. In other climates, the kraft paper may need to face away from the interior, or an unfaced batt may be used.

❑ 35. Use rigid board insulation in place of **structural sheathing** in non-corner areas, fastened with plastic-capped nails.

❑ 36. Use **cross bracing** to allow rigid board insulation to be used in place of structural sheathing in corners.

❑ 37. For houses with crawlspaces:

❑ A. Install **floor insulation** batts *flush* against house floor (vapor barrier is optional and, if present, should be installed following manufacturer's instructions).

❑ B. Use **insulation hangers (rods)** placed every 12 in. to 18 in. to hold the **floor insulation** in place *without compressing* the insulation more than 1 in.

❑ 38. Install **soffit dams and rafter guides** *before* ceiling drywall is installed when using blown insulation to provide clearance for soffit ventilation, and obtain maximum attic insulation coverage over the exterior walls—use commercial products, rigid board insulation, batt insulation, or felt paper.

❑ 39. Install **blocking** in the attic above the porch to prevent blown insulation spillage into the porch soffit area—use rigid board insulation or other sheet goods.

❑ 40. Install a barrier around the **attic access** opening in the attic to ensure full insulation coverage—use an insulation batt, rigid board insulation, or other solid sheet good.

❑ 41. Insulate the **attic access** hatch cover—*glue* 3-4 pieces of rigid board insulation and/or *staple* an insulation batt (R-15 or greater preferred) to the top of the cover.

Sheathing

❑ 42. Repair any deficiencies in the **exterior sheathing** or **exterior rigid board insulation.**

❑ 43. Tape or caulk the **sheathing seams** or install **housewrap** (*preferred*).

❑ A. Cover and *seal* the housewrap to the **top and bottom plates and sills**—use housewrap tape or caulk.

❑ B. Cut *diagonals* in the housewrap for **windows and doors**, fold back, and staple or nail to the inside.

❑ C. *Overlap* and *seal* housewrap **seams**—use housewrap tape or caulk.

❑ D. Seal *all* **cuts, penetrations, and openings** in the housewrap—use housewrap tape or caulk.

❑ E. Use **plastic capped nails or staples** to mechanically fasten the housewrap to the house.

Windows and Doors

❑ 44. Select **window and door types** that meet or *exceed* the 1995 *Model Energy Code.*

❑ 45. Maximize **glazing areas** on the south walls.

❑ 46. Minimize **unshaded glazing areas** on the east and west walls in mixed and hot climates.

❑ 47. Use shade screens and tinting on windows in southern climates that are not shaded by the roof, porch, or other means.

Ventilation

❑ 48. Make sure a **ventilation opening** is cut in the roof for the bathroom fan *before* shingling.

❑ 49. Vent the **bathroom exhaust fans** *directly* to the outside through the roof or sidewall.

❑ 50. Vent the **kitchen range hood fan** *directly* to the outside through the roof or sidewall.

❑ 51. Make sure the dampers in the **bathroom and kitchen fans** are operating properly—the damper should be free swinging and should seal when the fan is off.

❑ 52. Select a **bathroom fan** with a flow rate rating of *at least* 50-70 cfm at 0.1 in. of water gauge and a noise rating of *no more than* 1.5 sones.

Equipment Closet

❑ 53. If a gas furnace or water heater is being installed, isolate the **equipment closet** from the conditioned space by:

❑ A. Insulating and sealing the combustion **closet walls.**

❑ B. Installing a solid (non-louvered) **door** with weatherstripping and a threshold.

- ❑ C. Sealing all **gas and water line penetrations** through the equipment closet.
- ❑ D. Providing two **air inlets** for combustion and **venting** for flue gases following code requirements.

Heating and Cooling Equipment

- ❑ 54. Select **heating equipment type** after comparing operating and initial costs for all available fuel types.
- ❑ 55. Choose **equipment size** using ACCA Manuals J and S.
- ❑ 56. Use **higher-efficiency equipment** when cost justified (typically in larger homes in more severe climates where fuel costs are high).

Air Distribution System

- ❑ 57. Design an **air-distribution (duct) system** using ACCA Manual D.
- ❑ 58. Locate **ducts** *inside* the living area rather than the attic or crawl space.
- ❑ 59. Avoid using **building cavities** as part of the duct system.
- ❑ 60. Connect all **joints** in the ductwork with **mechanical fasteners**.
- ❑ 61. Seal all **joints** in the ductwork with mastic—do NOT use cloth duct tape.
- ❑ 62. Seal the drywall and any penetrations in the **return duct plenum**—use mastic (*preferred*) or caulk.
- ❑ 63. Seal **duct boots** to the floor or drywall.
- ❑ 64. Seal the return and supply duct connections (mastic *preferred*) and openings at the **air handler** (tape at access panels).
- ❑ 65. Select ductwork **insulation levels** to meet or *exceed* the 1995 *Model Energy Code.*

Water Heater

- ❑ 66. Consider **fuel cost** in selecting system type.
- ❑ 67. Use **higher-efficiency equipment** when cost justified (typically if hot water use and fuel costs are high).
- ❑ 68. Make sure the **hot and cold water pipes** are connected to the correct taps on the tank.
- ❑ 69. Insulate the water heater **tank** with a jacket following manufacturer requirements.
- ❑ 70. Install **heat traps** (inverted loops preferred or check valves) on both the hot and cold water pipes.
- ❑ 71. Insulate all **hot water pipes** in the closet and the first 2 ft of **cold water pipe** connected to the hot water tank.
- ❑ 72. For houses with a crawlspace (especially in cold and mixed climates), insulate the **water pipes** in the crawlspace for freeze protection.

Lighting

- ❑ 73. Install **fluorescent light fixtures** for lights that will be on for 4 hours or more each day—usually kitchens, hallways, and often bathrooms.
- ❑ 74. Install fluorescent or high-pressure sodium fixtures for **exterior lighting**.
- ❑ 75. Use **motion sensors or photo cells** on exterior security lighting.
- ❑ 76. If **recessed lights** are installed, use only UL-approved fixtures rated Insulation Cover (IC) that meet ASTM E283 requirements.