Chapter Eight

Air Sealing

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Air Sealing

Residential homebuilders today construct most homes, Habitat and others, with no understanding of air pressure and the forces acting to move air in a home. The understanding of stack effect and effects of heating and cooling systems on the pressurization of the home are rarely incorporated into the construction process. In fact, homes today are often intentionally built “leaky.” There exists a strong belief among homebuilders that homes “need to breathe” for effective operation, and holes and gaps are left in the building envelope for this purpose.

Is this belief that homes “need to breathe” and be built leaky correct? According to Lstibruke (1999, p.31), a home should be built as tight as possible and then ventilated mechanically. The mechanical ventilation controls the leakage and the change of air in the home. Remember that air change is necessary to rid a home of many harmful toxins and pollutants. Leaky homes, with no controlled ventilation allow for heated air to leave the house at any rate. Mechanical ventilation balances the need to change air and to keep air (which has been heated) inside the building envelope.

Building a truly tight home is impossible. Since homes are moving objects, no matter how tight the materials are at construction time, they will move. Because of this fact, air sealing the cracks and holes in the building envelope with flexible material such as urethane foam is very important to maintaining a safe, comfortable home that is not allowing conditioned air (which costs money) to leave the home (Illustration 8.1).

Many places in the building envelope require air sealing. The juncture of foundation to ribbon joist, the point of contact between bottom wall plate and subfloor, and the area around fan boxes and light switches are all areas that must be addressed (Illustration 8.2).
shows even more areas). The rationale for air sealing the home and detail a process for air sealing implementation is included in this section. However, the mechanical ventilation issue is not addressed. Further exploration can be made by referencing *A Builder’s Guide to Cold Climates* (Lstibruek, 1999).

Air sealing is often met with skepticism in the residential construction world. First, air sealing is not seen as a needed additional step in the construction process. For each additional step that a contractor has to perform, there is an additional cost. Air sealing does take some time and, therefore, cost. The second, air sealing stops something that cannot be tangibly seen, air. Few homeowners can complain about something that cannot be seen until well into the life of the home. The “picture” of air loss only shows itself when bills from winter heating losses hit the homeowner’s pocketbook and when the warm air leaving the house condenses on the roof deck causing moisture damage.

According to the Southface Institute (1999), air leakage can account for over 50 percent of a home’s heating and cooling costs and can contribute to problems with moisture, noise, dust, and entry of pollutants, insects, and rodents. Habitat International’s own calculations show that as much as $100 annually can be saved by proper air sealing (Habitat for Humanity International, 1999).

Additionally, air sealing has many other benefits. First, air sealing reduces the potential for harmful contaminants to come into a house, as seen in Illustration 8.4. Air sealing, however, is only effective and safe when combined with an HVAC system that ventilates the home properly. Second, comfort is improved in the home with proper air sealing. Air moves through any hole, large or small. By stopping airflow you effectively cut the potential for drafts that cause discomfort in a home. Finally, air carries moisture. Reducing the movement of moisture from the inside of the home into the wall assemblies reduces the chance for building durability failures because of moisture problems.

The practice of air sealing in the building envelope makes especially good sense in Habitat homes. Being a labor-intensive practice that requires almost no training, air sealing can fit the needs of most Habitat construction sites -- that is, finding work for lots of volunteers. Lots of workers equal lots of air sealers. But, in order for air sealing to be...
effective we must understand which holes are most important. To do that, we need to understand the process of air movement and house pressurization.

The science of air movement and pressurization

Most building materials, especially drywall, are effective airflow barriers. The key to effective air sealing is to seal the holes and cracks that exist in between these building materials. Before doing this, we must understand the concept of the “stack effect” to really understand how air moves in the home. As the warm air in a house rises, a natural pressure system is created. This system creates negative pressure at the bottom of the house and positive pressure at the top of the house (Illustration 8.5). Air pressure is neutral at the window level. Because of this, the windows are under the least pressure for air to flow in and out of the house. Ironically, this is where most air sealing occurs. Home improvement stores advertise weather-stripping for the windows and caulk for the window joints, but air is not under great pressure at this point in the house.

Air movement can also be caused by forced air heating systems. These systems are common in Habitat homes and therefore should be a concern of Habitat affiliates. The potential for poor heating system installation and operation can cause air movement and pressure changes when the ducts (which transport the air) are leaky. These pressure differences are different than those caused by the stack effect. Because of this, careful attention must be paid to the heating system of the house.

Because of stack effect, air-sealing efforts should be focused on the attic and crawl space area. According to David Keefe (1995, p.1),

The best opportunities for reducing overall leakage are often found at the top and the bottom of the house. These areas experience pressures from warm air rising [stack effect]. They also tend to have problems other than heat loss. Leaks at the top of the building, where air usually goes out, often cause condensation problems. Leaks at the bottom of the house can carry moisture, radon, or whatever else is in the soil gas, into the house. Another reason to look at the top and bottom is that
the rough areas bordering the living space tend to have large holes that can be fixed relatively cheaply.

Some might argue that the floor stops air movement. This is not correct. The floor stops some air movement but not all. In fact, according to Lstibrueck (1999, p.28), the crawl space should be treated as part of the conditioned area of the building envelope. Keefe (1995, p.1) adds that crawl spaces also can leak even though it is often assumed that they can’t leak because they are covered with dirt. Keefe (1995, p.4) states, “Crawl spaces can leak – and do. When they leak, they bring in not plain air, but soil gas. At the very least, this air is wet [potential moisture control issue]. At worst, it can contain radon, sewage gases, or pesticides.”

But the crawl space and attic are two of the places that are least likely to get air sealed. They are dirty, cramped spaces and very few people like to work in these spaces. According to Keefe (1995, p.5), “Whoever worked in those areas was probably not too concerned with being meticulous; he or she just wanted to get out quickly. The good news is that a worker with a healthy attitude [most Habitat volunteers] can get good job satisfaction by attacking such a challenge. It usually turns out not to be as bad as imagined and helps to foster a “can do” attitude that helps elsewhere. Getting dirty is a fact of life for effective air sealers.”

Once the effort is made to enter these areas, an understanding of potential air leaks is necessary to effectively air seal. Places where air can move in the attic and crawl space include:

**Attic**

- Joints of two pieces of drywall
- Connections of ceiling and wall as observed from the attic
- Holes cut in the drywall for electrical outlets and ceiling fan boxes
- Gaps around attic access doors and openings
- Gaps around return or supply ducts (if present)
- Holes in wall assemblies for electrical wiring
- Plumbing penetrations and rough-in cuts in wall assemblies
**Floor and Crawl Space**

- Crawlspace vents
- Connection of bottom wall plate to subfloor
- Joint of subfloor to band joist and band joist to ribbon joist
- Connection of ribbon joist to top of foundation
- Gaps that may exist along the perimeter of the crawl space access door
- Wire and plumbing penetrations through the band joist

Once these areas have been identified, a material for air sealing implementation must be chosen. According to Keefe (1995, p.4), “The criteria for selecting an air sealing material are straightforward. First, it must actually stop air. The frequency with which fiberglass insulation is used as an air barrier points out the need to remember this fact. Second, it must be relatively permanent for the life of the building. Third, it should be safe for both installers and occupants.” The best choice for air sealing cracks and small holes is urethane foam (Illustration 8.6). While the initial costs of a foam gun purchase make the first application seem more costly than caulk, this cost is quickly recovered after several applications.

**Air Sealing practices in Central Indiana Habitat Affiliates**

Few of the Central Indiana Habitat affiliates have implemented the air-sealing techniques mentioned above. When inspecting attics and crawlspace it was rare to find any signs of air sealing with any caulk or urethane foam. Most work was done around the window areas in the form of weather-stripping and caulking.

Many of the construction coordinators of these homes were under the misconception that air leakage occurred around the windows of a house. While a source of air leakage, they usually are not the largest source in the house. Few of the homes had air-sealed fan boxes, light fixtures, or holes caused by electrical work in top and bottom plates of the framing. Air sealing was done around wall outlets and light switches, effectively
covering up large gaps but missing other, smaller areas that easily could continue to let air flow through (Illustration 8.7).

Another common misconception in the field was the thought that “housewrap” was the answer to air sealing problems. This engineered “paper” is used to “wrap” the house and prevent air leakage. However, the effectiveness of this “wrap” remains dependent on the installation of the product. Poor installation results in missed air leakage sites, effectively rendering the product useless as an air barrier. Habitat affiliates should not continue to believe that this product is the only action needed in the process of air sealing.

**Recommendations for Habitat affiliates**

**Developing an air sealing strategy**

The scheduling of the house’s construction has a major role in the preparation for effective air sealing in these areas. Many homes have large gaps in the building envelope that are hidden from view. The space under the bathtub, dropped ceilings, and mechanical room closets, not to mention all of the attic and crawl space areas, are places subject to air leakage. Stopping these potential air leaks is a function of effective planning in the construction process. Looking at design blueprints to identify sites of “covered” air leakage and assigning team members the responsibility for air sealing are two effective means of tackling air sealing concerns. Regardless, air sealing must be done throughout the home construction process. It is not something that can be done at one time during the construction cycle of the home.

An effective process for Central Indiana Habitat affiliates follows:

**Create an air leakage checklist.** By creating an air leakage checklist, construction coordinators and volunteer leaders can effectively maintain a consistent air sealing strategy. Consulting the Habitat/Southface Institute (1999) “Guide to Air Sealing,” found in appendix A of this thesis, should make the initial development of this checklist much easier. This guide has an excellent listing of potential air leakage sites and “trouble” spots.
Purchase and maintain one or several urethane foam guns. There are currently many companies producing products for urethane foam sealing in residential applications. Each of these companies has several foam gun options. The key to selection is to find a product that is easy to use and can be used repetitively with little clogging or foam stoppage. Some of this responsibility lies with the Habitat affiliate. Maintaining a clean foam gun is important to long term use.

Buy urethane foam in bulk. Bulk purchases of foam make for individual product cost savings. Consider teaming up with other area Habitat affiliates to reduce the overall cost of air sealing even more. As a word of caution however, most urethane foams have a shelf life. Reading and following manufacturers’ recommendations will result in less wasted product because of shelf life failures.

Create an “Air Sealing Team” on site. Volunteers always want a special job. Air sealing is a very special job for all the reasons mentioned above. Dedicate several members as air sealers. Point out areas of concern and give them the checklist developed above. Remind them that over sealing is almost never a problem, but the foam is not free. After the team is done with air sealing, make a quick inspection for holes and gaps in the building envelope.

Conduct a Blower Door test. According to Keefe (1995, p.3), “Blower doors offer a way to quantify air sealing results and make it much easier to determine which areas of the house deserve (air sealing) treatment. Blower doors work (Illustration 8.8 and 8.9) by measuring the relationship between air flow (the fan in the door) and house pressure (measured on the pressure gauge with the blower door unit) to determine the size of the holes between the indoors and outdoors. This process is collectively known as pressure diagnostics.” Blower door tests are not common in Habitat homebuilding. A potential option to change this fact is for the affiliate to determine an individual or company willing to conduct blower door and other pressure diagnostics as pro bono work. The results could lead to improved air sealing and overall energy savings.
Optimal Value Engineering (OVE)

All the Habitat affiliates in this study are currently using dimensional lumber for framing members in their homes. Using wood to frame a house (Illustration 9.1) has been standard in Central Indiana for many years. But, the price and quality of dimensional lumber is not the same as in years past. Prices in dimensional lumber have increased faster than inflation, while there has been a decrease in overall quality. This presents organizations like Habitat with a problem. How does it continue to provide low cost, quality housing when the product that is used to frame our homes continues to rise in price and decrease in quality?

One possible solution to this situation would be to change building materials. Steel studs and engineered wood products are being sold in the home construction market at competitive prices. These products have better structural integrity, last longer and have less waste. However, Habitat affiliates in Central Indiana are committed to continuing the tradition of wood frame construction. Therefore, this study focuses on ways to improve wood framing through reduction of material and improved technique.

One possible technique that might be used to reduce the need for dimensional lumber is called Optimal Value Engineering or OVE. According to the Southface Institute (1999), “Building experts have performed considerable research on ways to reduce the amount of framing in our homes. This process is called Optimal Value Engineering or OVE. When installed correctly there is no loss of structural integrity to the home.” The goals of OVE follow:

- To reduce framing time and lower construction costs.
- To save on increasingly scarce dimensional framing lumber.
- To increase energy efficiency, thus reducing annual energy costs.

All of these goals are important to Habitat homes. Since the resources of Habitat affiliates are scarce, opportunities for improved design that save money are important. OVE should be looked at as a way for affiliates to reduce costs. These cost savings can then be transferred into the better heating and cooling systems, perimeter drains, and air sealing techniques described above. This section of the thesis is an opportunity to
Chapter Nine

Optimal Value Engineering
The science of Optimal Value Engineering

The basic concept of OVE is to use less lumber to frame a house without losing structural integrity. Often, this concept has been met with opposition from homebuilders because of the fear that using less lumber will compromise structural integrity. According to the Southface Institute (1999) and many other independent research initiatives, this is not the case, assuming that installation is performed correctly.

There are several techniques within the practice of implementing OVE. According to the Southface Institute (1999), some of the common approaches to saving lumber in construction with OVE include:

- Less corner framing.
- Less framing around partition walls.
- More energy efficient headers with less material.
- Eliminating cripples under windows.

Corner framing is included more for installation of drywall later in the home building process than for the structural needs of the frame corner. The traditional corner (Illustration 9.2) has additional studs that are not needed for structural support (Southface, 1999). The purpose for these additional studs is to create a "nailing surface" for the drywall at the corner. If we use drywall clips or some other form of drywall support (Illustration 9.3) in the corner, we can eliminate the need for that additional lumber material and therefore create a cost savings.

The partition walls (those that make the hallways and rooms; not load bearing) of most Habitat homes in Central Indiana contain too much lumber according to the principles of OVE. Using OVE technique, the number of studs can be reduced without losing the structure of the frame. The key to implementation of this technique is the planning and design of the frame assemblies well before the home is being built in the field. Illustration 9.4a shows a common wall in Central Indiana Habitat homes. This wall has studs
placed on 16" centers with windows placed arbitrarily in the wall cavity. This arbitrary placement creates the need for additional framing for drywall nailing and window support. Additionally, all walls contain a "top plate" made of 2x4 material across the top of every wall in the home. With proper engineering, this top plate is not needed (Southface, 1999).

The OVE wall in diagram 9.4b shows an OVE approach to the wall assemblies. Studs are spaced on 24" centers with no top plate. This can be accomplished by aligning the wall studs with the rafters and ceiling joists of the roof assemblies which are also on 24" centers (Illustration 9.5). The window cavities are also included within the design of the OVE wall reducing additional need for "cripples" and other supports (Illustration 9.6). This system,
Ten Chapter

Recommendations

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Barriers to Implementation in Central Indiana Habitat Affiliates

The purpose of this research has been to identify whether or not building science principles are understood and being applied in Habitat affiliates in Central Indiana. As described in the literature review chapter, there are many categories that implementation barriers can fall under. In review, these barriers include:

- Institutional barriers
- Economic barriers
- Organizational barriers
- Behavioral barriers

In this chapter, I address each of these barriers in relation to Habitat and the four areas of focus that I have chosen for this thesis, exploring the unique situations that exist in Habitat for Humanity affiliates and suggesting potential alternatives.

Institutional Barriers

The instance of a construction coordinator challenging a building code inspector is rare. Most Habitat affiliates are not looking to “challenge” codes with the local officials. In fact, nearly all of the construction coordinators working in Central Indiana are not building professionals by trade. Rather than “making waves,” they are looking to have the building inspectors and planning and zoning departments on their side when building new homes that need inspections. In the mind of most Habitat construction coordinators, challenging the knowledge of a building inspector can only lead to delayed or stopped projects and hurt feelings.

Since challenging building codes is not an option to most Habitat affiliates, most simply follow the codes to what an inspector desires. What occurs however, is that most of the codes themselves and the inspectors that enforce them do not understand basic building science principles and techniques. While there are many different codes for different aspects of homebuilding (plumbing, electrical, framing), there is reluctance among building code inspectors to take advantage of education learning opportunities. This fact creates a significant barrier for Habitat affiliates. Codes are the law (even though they have some building rules that do not follow building science). This fact creates a “perceived” rule of Habitat that, “We are a Christian organization and we are not going to break laws (building codes), regardless of whether the codes are right or not.”
As mentioned above, the institutional barrier of building codes and their content is not the only problem for building science implementation in Habitat affiliates. Enforcement or inspection of those codes is also of concern. Many Habitat affiliates experience little or no detailed code enforcement. Therefore, if a code violation is not detected it cannot be solved. We then have a two-pronged negative effect of codes. First, assuming that the codes regulate construction methods incorrectly (especially in the areas of moisture control and health and safety), following them makes for a house that does not meet its potential as a quality home. Second, with poor inspection, even the basic content of the codes may not be met, further harming the quality of the home.

This thesis looks to only alert the reader that codes and their enforcement are a concern. There currently is research that is being conducted to reform model building codes on a national level by several organizations. Information about this process can be obtained at http://www.hud.gov/fhe/modelcodes/. An analysis of this research falls outside of the scope of this thesis. Regardless of this fact, I want to point out that Habitat affiliates can often face a tough institutional barrier to building science implementation in code administration.

**Economic Barriers**

The discussion at Habitat affiliate's board meetings is rarely about construction techniques. Rather, the topic of most concern is the cost of the home. As pointed out in this thesis, building science implementation is not free. It is, however, cost effective when analyzed over the life of the home. Unfortunately, very few Habitat boards look at these life cycle costs. This short-sightedness creates a tremendous barrier to building science implementation. Since Habitat is mostly concerned with getting the homes to their potential buyers at the lowest cost possible, the long term costs (health and safety, durability, comfort and affordability) are often lost in the discussion. Unfortunately this perspective runs counter to the creed of Habitat. The affiliate provides a simple, affordable home to those in need, but that home may not be safe or may have durability problems in a few years because of poor building science implementation.
Building science implementation suffers when Habitat boards are unwilling to look at these long-term costs. Many do not view opportunities to save resources such as OVE framing as viable options to make up for the difference in cost between the no building science changes to a home that has some "new" ideas. The crux of the problem exists in the need to look at the house as a whole and find areas that can be constructed more efficiently (e.g. framing) and those that must be improved (e.g. heating system).

A possible analogy is an average company budgeting process. To survive in the marketplace, companies are forced to eliminate areas of their operations that are wasting resources. This is similar to how lumber is often wasted in home construction. In the same fashion, these businesses dedicate those savings to the portions of their budget that they see as creating benefit for the long term. This might be similar to air sealing and improved moisture control in home construction. What this analogy shows is that the Habitat affiliate must review the "true" cost of the home, finding areas for savings (i.e. framing) and areas that require more resources (i.e. heating system).

Many board members see rethinking the costing of a house as a step back from the success (quantity of homes) that Habitat has enjoyed since its inception. The thought prevails, "We have made strides in providing affordable housing. What is wrong with our construction techniques and house model?" The answer to that question can be found in looking at the amount of time that most affiliates (and therefore homes) have been in existence. With most affiliates in Central Indiana being only 10 to 15 years old, there has been little time to see failure in the buildings that they have constructed. It takes time to "see" the costs of high-energy bills, poor durability because of little moisture control and health concerns.

Another economic factor that illustrates this point is that Central Indiana has low energy costs compared to the rest of the country (Hill, 1999). Energy efficiency therefore does not translate into big savings in this region and does not create a pressing need for implementation in home building. Without homeowner complaints about bills and limited intervention from the International level, local affiliates have no "check" on their quality of service to homeowners.
Organizational Barriers

When Habitat for Humanity was founded, the plan was for most of the work to be done at the affiliate level. Because of this, the local affiliates have enjoyed a certain level of autonomy within the organization. While Habitat for Humanity International advises affiliates, there is little direct influence in local decisions of building construction practice. Guides to building construction are published (see appendix A) and consultation is provided. But, the decisions on how to build still rest in the hands of the affiliate.

Because of the local affiliate tradition of autonomy, most affiliates do not want to change their building practices. This creates a barrier to learning anything from the materials that come from the International level. “We build how we build,” is often the mentality. This mentality effectively “shuts out” new suggestions and change.

What is really happening at the local level? Habitat International requests general consistency (one bathroom, no garage, etc.) in most homes to meet the mission of providing a simple, affordable house. However, those requirements can be “bent” with special request. They are appearance and design issues. Rarely is the issue of how a house is built recommended to the affiliate level. Telling affiliates how to build would be breaking that sacred “autonomy” of the Habitat grassroots spirit.

So, the decisions are made by the local affiliate. What then are they doing? Most Central Indiana affiliates’ building committees are not dealing with building science issues. They are looking at the issues of design and finish work, the details that are seen. The aspects of building science are left up to the knowledge of the construction coordinators. Unfortunately, these coordinators also have little concern with the building science aspects because, as is the reason for the committee, they cannot be seen (and therefore not heard).

Habitat International has begun efforts to focus the attention on building science issues in Habitat homes. In 1994 they started the Habitat environmental initiative which focused on creating sustainability in Habitat homes. According to Habitat (Habitat for Humanity, 1999),

Habitat’s Environmental Initiative promotes energy-efficient, environmentally friendly construction, encouraging good
stewardship of natural resources and raising awareness of the environmental impact of house building. The Environmental Initiative embraces the concept of sustainable building: meeting the needs of the present without compromising the ability of future generations to meet their own needs.

Developed by HFHI's Construction and Environmental Resources department, the initiative provides education and training to volunteers working with Habitat's many local affiliates. Emphasizing resource efficiency, construction materials conservation, energy efficiency and environmental sensitivity, the initiative helps affiliates achieve higher levels of sustainable building practices.

The HFHI Green Team, a network of local volunteers across the United States, is a primary force in accomplishing these goals. Green Team members champion sustainable building practices in their area, learning resource-efficient construction techniques through training sessions, newsletters and technical bulletins.

Noting that the International level has begun efforts to establish building science as a priority in home building, we must then shift our attention to how that information is sent to the local affiliates. Let's revisit the typical Habitat affiliate of Central Indiana:

- Concerned to build homes to help those in need by making them as affordable as possible.
- Have little time to learn new techniques and often are unwilling to learn because of behavioral barriers.
- Are very conservative by nature in this part of the country and are often not in total understanding of "environmentalist" concerns.
- See involvement from the International level as a intrusion to the "way that things have always been."
- Often resistant to change.
Because of these factors, it is possible to see why Habitat’s “Environmental Initiative” and “Green Team” have not been accepted into common building practices. Some board members may view them as radical ideas that are better suited for the “coasts” or other more “environmentally” aware parts of the country. The naming of the “initiatives” themselves and the “environmental terminology” that they use, has the potential to shut off potential benefactors (the affiliates and construction coordinators) before they even look at materials on building science.

Habitat International should re-think the terminology that it uses when promoting their building science materials. Instead of approaching the changes from an environmental and energy-efficiency standpoint, they should address health and safety and durability concerns. Put bluntly, having “people in need” getting sick or having a home “fail” is a far more important issue than energy efficiency.

Additionally, the international level of Habitat must start promoting their materials on building science not just as “recommendations.” Some teeth for implementation must be developed. These practices need to become standard, not just options.

**Behavioral Barriers**

Regardless of all the barriers that have been mentioned above, the one that offers the most difficult challenge to Central Indiana Habitat affiliates is that of changing the personal behaviors of the “players” (construction coordinators, construction committees, affiliates) involved with the house building process. By behavioral barriers I mean the ability of a person or persons to take on new ideas by allowing new building practices to take place within the Habitat house.

In order to address this issue, we must look first at the current model for building in Central Indiana. Most affiliates:

- Have a construction coordinator who is working for Habitat out of love for the affiliate and the mission of Habitat, not the reward of financial success. In some cases construction coordinators are not even paid or are only paid per job.
- Use volunteers who are usually unskilled, but are very eager to learn. They also come on the weekends and want to do tangible work such as framing or roofing that shows some level of completion following the day.
• Use more permanent volunteers, who often are retired individuals who have worked with some form of construction in the past. They hold tight to their “training” in the past and are reluctant to change. They are often uninformed about the world of “environmentalism” and energy conservation.

• Have construction committees consisting of local contractors and building professionals. As established earlier in this research, many of these professionals are not building using building science principles either. Therefore, their advice as a committee to the construction coordinators is often incorrect in terms of building science. The members of the committee are also often older and lack an understanding and appreciation of “environmentalism” and resource conservation that was mentioned in regard to the permanent volunteers.

• Are under the watchful eye of a Board of Directors, which is trying to stretch each dollar farther for more homes to be built.

Under these conditions, it is evident that change in this model of building can be difficult. One example was found in the construction of a house by a university in conjunction with a local affiliate. The university group made the effort to try innovations in building science and develop a better home. They were conscious of costs and tried to use the house as a learning tool for future homebuilding activities by Habitat. The local affiliate saw this effort by the university group to implement building science as an attack against the construction knowledge of their organization. The affiliate collectively shut out the effort and missed a great deal of the learning opportunities that might have existed in the construction of the house. When the project hit some administration problems and some “new” techniques came in over cost, the affiliate immediately dismissed the idea of building anything that might be a break from their normal home model. A “told you so” mentality developed and the benefits of the project were then missed.

The point of this example is to showcase the behavioral barriers that exist with Habitat affiliates. Is this changing this short-term mentality a possibility in Habitat affiliates? In order each affiliate to rethink their perspective home cost and changing construction practices, the link must be established between Habitat’s “mission” and the additional “burden” of new building science practices. The case must be made that it is the “responsibility” (in light of the Habitat mission) that an affiliate provides new homeowners with a home that is safe, durable, comfortable and affordable. If they do not provide this home, they are not fulfilling their mission.
Afterward
A study of this magnitude certainly will show many deficiencies in an organization such as Habitat for Humanity. Building a house is a very complicated project and one that requires a great deal of time, money, and coordination. I know, I have tired it in the past. However, the benefit that Habitat for Humanity brings to the world cannot be understated. There is room for improvement. That is to be expected. Continuing to open up to new ideas is the key to maintaining the goals of Habitat.

When I started this thesis it was my hope to find out if there was any chance that building science information could be applied to Habitat activities. I believe that I have shown that to be true in the course of this work. I also believe that anyone can do it and building science can be effective in its implementation.

There are so many areas in which the study could have gone. In fact, references to other books and articles that will guide the reader to more knowledge on the subject are scattered in the thesis. There is knowledge out there! I have only chosen a few areas to quickly highlight. Hopefully, this work has shown that changes can be made. Areas that might be tackled in future research that I feel are important to Habitat affiliates:

- Mechanical ventilation
- Insulation
- Pressure diagnostics
- Windows and solar heating
- Duct work sealing
- Roofing and roof venting
- And about a hundred more....

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Adam D. Thies
Muncie, Indiana
April 27, 2000
Works Cited


Energy Efficiency Pays!

Some low-income families may spend over 15 percent of their income on energy to operate their homes. An Atlanta, Ga., community found that the annual energy bills for newly constructed, affordable homes averaged over $1,200. Increasing the energy efficiency of the homes saved over $400 a year and added less than $500 to construction costs.

Cutting energy waste saves money and builds community wealth

Simple energy efficiency improvements can cut energy costs by over 40 percent in most affordable housing. The money that families save on energy can help them make mortgage payments, and pay for food, clothing and other essentials.

Energy efficiency helps families and their communities. If the 900 affordable homes scheduled to be built or renovated in an Atlanta community are made energy efficient, the families will save over $7 million on energy costs over a 30-year mortgage period. Studies show that a dollar saved on energy stays within the community and generates more wealth.

Protect the health of families and the environment

All homes should provide a healthy indoor environment. Poor energy features can contribute to serious health concerns, especially for children, the elderly, and those suffering from illness. Energy-efficient homes can reduce health risks from mold, dust mites, radon, combustion byproducts and other contaminants. They offer fewer entry points for dust and pollen, insects, rodents and other pests.

Homes are not often thought of as causing pollution, but the electricity, fossil fuels and other energy sources they use contribute to global warming, acid rain, smog and other serious environmental problems. Wasted energy needlessly pollutes the environment. Energy-efficient homes protect the planet as well as the pocketbooks of homeowners.

Affordable for the future

To be affordable, housing must be designed and constructed to last and not require expensive maintenance. Energy-efficient construction improves building durability by reducing moisture-related problems. When families spend less on energy bills, they can better budget for maintenance and repairs.

While energy efficiency may modestly increase construction cost, it will help ensure that a house built today will be decent, safe and affordable in the future.
Energy Efficiency Makes Housing Rehab Affordable

In Greene County, Pa., the Habitat for Humanity affiliate closely monitored energy usage for remodeled homes. They discovered annual energy bills as high as $1,800. The data clearly showed that the highest energy consumption occurred where little attention had been given to energy improvements to the building envelope and HVAC equipment.

By incorporating proper planning and quality control during remodeling, HFH successfully reduced air leakage in the building envelope and duct system and improved efficiencies of the insulation, water heater and space-conditioning equipment.

The results were significant. Gas bills for heat and hot water dropped from between $50 to $110 per month to around $30. Electricity costs were reduced by improving lighting and certain "energy-hog" appliances, such as old refrigerators and dryers. Improvements in water efficiency reduced water and sewage costs.

HFH has lowered energy use in older homes to about the same levels as for new, energy-efficient homes. The key is a "systems" approach that considers all energy usage, including heating, cooling, hot water, lighting and appliances. It is also critical to educate homeowners on how to operate their homes in an energy-efficient manner.

Energy efficiency means quality and affordability

Many energy features offer additional benefits such as increased comfort, reduced noise and greater fire safety. Energy-efficient homes also experience less condensation, which protects framing, windows and finish materials. Better control of moisture and temperature means less movement of materials which reduces floor squeaks and drywall cracks.

While some energy features add to construction costs, others can reduce costs. For example, increasing insulation and sealing air leaks reduce heating and cooling needs, allowing the use of smaller equipment and ductwork. The savings on the mechanical systems can pay for the increased cost of insulation and air sealing. Energy-efficient framing techniques can reduce lumber costs over 15 percent and prevent mold growth in outside walls and ceilings.

Getting the most efficiency for the least cost requires careful attention throughout the design and construction process. Most energy-efficient homes have dozens of little improvements that individually add little to construction cost, yet together yield big savings.

Energy efficiency and homeownership

If home buyers pay less for energy, they can afford larger mortgages. Because energy-efficient homes have lower and more stable utility costs, there is less risk of foreclosure. Some areas have energy-efficient mortgages which help offset any added construction costs due to energy improvements.

Energy efficiency is a great investment for homeowners. When added to a mortgage, energy improvements usually cost less than the savings they offer on utility bills. Increasing the value of a home is a great investment — paying high energy bills is not!

Energy codes

Many state and local governments have mandatory energy codes. Federal housing programs require that homes comply with the Model Energy Code. Developers of affordable housing can be held liable if homes do not comply with energy codes. While energy codes set minimum standards, it is often wise to exceed code requirements. The results will be more efficient, healthy, durable, comfortable and affordable homes.

Average household energy expenditures

The average American family spends $1,291 on home energy per year. Energy use varies according to home characteristics, occupant lifestyle and climate.

<table>
<thead>
<tr>
<th>Region</th>
<th>Amount</th>
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<tbody>
<tr>
<td>Northeast</td>
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<tr>
<td>West</td>
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What Makes a Home Energy Efficient?
Increasing the energy efficiency of affordable homes does not have to add greatly to construction costs, nor require special materials or construction skills. However, cutting energy waste; ensuring occupant health, safety, and comfort; and improving building durability does require careful planning, training and quality control during construction.

HVAC
Poor design and installation of heating, ventilation and air conditioning (HVAC) equipment commonly increase energy costs 10 - 30 percent in affordable housing. This wastes money and can endanger the health of families. Proper design and installation of HVAC equipment is usually the top priority for cutting energy bills.

☐ Equipment size
Equipment that is too big (excess capacity) costs more to buy and operate, and leads to poor comfort, excess noise and greater pollution. Do not allow rules of thumb, such as so much heating or cooling per square foot of living area, to be used to determine equipment size. To size equipment, require exact calculations that consider insulation levels, window type and orientation, and air-sealing measures.
Calculating equipment size should take less than an hour for most affordable home designs, and will prevent the purchase of costly, oversized equipment and provide significant savings to home owners for years to come.

☐ Equipment efficiency and energy source
The professional that calculates the size of the HVAC equipment should also be able to determine estimated operating costs for various equipment efficiencies and energy sources. Smaller, high-efficiency models may not cost considerably more than standard equipment. While future prices can vary, it is important to consider the cost of energy sources when selecting equipment. Saving a few dollars on equipment is no bargain if families will pay hundreds more because the equipment uses an expensive energy source.

☐ Ductwork
Improving the efficiency of ductwork is the single most important energy measure for most affordable homes. Poor ductwork can waste hundreds of dollars each year and cause serious health and safety problems. It is best to locate ducts inside the living area — not in attics or crawl spaces. Do not use building cavities, such as closet returns, as part of the duct system. Make sure all joints in the ductwork are sealed permanently with mastic, a thick paste that provides a durable seal for all types of duct. Duct tape does not provide an effective seal for ductwork.

After ducts are sealed, ensure they have adequate insulation. The Model Energy Code sets minimums, but higher levels are often cost effective. Do not rely on insulation to seal ducts — use mastic.

☐ Tapes do not provide a lasting seal. Mastic is economical, easy to apply and provides a durable seal.
Improve energy efficiency throughout the house

1. Ventilate attic.
2. Install adequate insulation with no gaps or compressed areas.
3. Specify efficient windows; consider orientation.
4. Seal all penetrations.
5. Locate ducts inside conditioned space; if not possible, ensure ducts are sealed with mastic and insulated.
6. Size heating and cooling equipment; choose efficient models.
7. Provide controlled ventilation.
8. Install efficient water heating.
9. Specify efficient lighting for fixtures used more than four hours daily.

Air leakage
Excess air leakage in homes can increase heating and cooling bills by 30 percent and reduce fire safety. Although windows, doors and outside walls contribute to air leakage, the biggest holes are usually hidden from view and connect the house to the attic, crawl space or basement. Reducing air leakage typically costs less than $200 for an average home and is required by the Model Energy Code.

Insulation
Affordable houses will not get the full benefits of their insulation if it is installed poorly. Gaps and compressed areas in the insulation can cut savings over 25 percent. Poor installation also leads to condensation and comfort problems. The Model Energy Code sets minimum requirements for insulation levels, but it is often cost-effective to exceed these levels.

Water conservation
A family of four can spend more for hot water than heating or cooling. Consider the cost of various fuels for heating water as well as the efficiency of the water heater. Simple conservation measures, such as low-flow showerheads, tank insulation jackets, and convection traps in hot and cold water lines, pay back quickly. Replacing inefficient plumbing fixtures in older homes can save families hundreds of dollars.

Windows
While energy-efficient windows cost more than standard models, they can cut energy bills significantly and lower other construction costs. High-performance windows can reduce heating and cooling needs enough to permit smaller, and cheaper, HVAC equipment and ductwork. The use of energy-efficient windows greatly improves comfort by increasing surface temperatures and cutting drafts. They also reduce condensation, which protects building materials and reduces mold growth.

Window orientation greatly affects energy use — as much as 25 percent for some designs. Major glass areas should face south for maximum winter heating. Avoid unshaded glass on east and west sides to reduce summer overheating. Use solar shade screens, roof overhangs, awnings, trees and other landscaping to provide shade.

Lighting
Energy-efficient lighting saves on electric bills, helps keep the home cooler by reducing waste heat, and lasts longer. Specify compact or tubular fluorescents for interior fixtures that will be on for four hours or more each day — usually in kitchens, hallways, and some living areas. Energy-efficient fluorescents provide excellent light quality and are long-lasting. Their extra cost is repaid in energy savings. Exterior security lighting can cost hundreds of dollars a year to operate if it is not energy-efficient. Install only compact fluorescent or high-pressure sodium fixtures for security lighting and consider motion sensors or photo cells to operate lights automatically.

Appliances
Appliance energy use is usually greatest for refrigerators, clothes washers and dryers, and dishwashers. Remember, the true cost of an appliance is the purchase price plus the cost for energy and water for operation. Providing a cheap, inefficient appliance will waste the money of low-income families for years to come. Federal law requires that most appliances have Energy Guide tags that compare estimated operating costs between energy-efficient and standard models.

It takes a champion!
Affordable housing programs that have successfully cut energy waste have a champion who 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 committed to making housing truly affordable, healthy, durable and comfortable.
Installing and using a whole house fan

Why use a whole house fan?
A whole house fan is a simple and inexpensive method of cooling a house. The fan draws cool outdoor air inside through open windows and exhausts hot room air through the attic to the outside. The result is excellent ventilation, lower indoor temperatures, and improved evaporative cooling.

What are the benefits?
A whole house fan can be used as the sole means of cooling or to reduce the need for air conditioning. Outside air temperature and humidity dictate times when the whole house fan would be favorable over air conditioning. If both methods of cooling are present, a seasonal use of the whole house fan (during spring and fall) may yield the optimum combination of comfort and cost.

- **First cost benefit**: Equipment cost for whole house fan = $150 - $250
  Equipment cost for window unit AC = $250 - $750
  Equipment cost for central AC = $2,000 - $4,000

- **Ventilation**: A whole house fan can be used to change the air in the house and vent odors quickly.

- **Economics of operation**: Operating a properly sized 1.5 ton (equivalent to 18,000 Btu/hr), central air-conditioning unit of the minimum required 10 SEER efficiency costs about $250 per cooling season in an area with 1,250 cooling hours, based on $0.05/kwh, or roughly 15 cents to 20 cents per hour run time. A 18,000 Btu/hr window unit of similar efficiency will cost about the same. The greatest variable in cost will be how the homeowner uses the AC to cool the house.

- By contrast, the whole house fan has a motor in the 1/6- to 1/8-hp range, uses 120 watts to 600 watts and costs around 1 cent to 5 cents per hour of use.

What are the drawbacks?

- **Temperature, humidity and dust**: A whole house fan has some drawbacks: the fan can only cool the inside of a house to the outside temperature; unlike an air conditioner, it does not dehumidify; and dust and pollen can be brought into the house.

Maximize your savings

During the winter months (and summer when air conditioning is used), a whole house fan represents a potential energy loss because it is essentially a large, uninsulated hole in the ceiling. Standard fan louver do not insulate or seal tightly.

- **Build and use fan covers**: See diagrams for construction details.

  Because the louver are leaky, a cover should be constructed to airseal and insulate this hole during the seasons when the fan is not in operation. The cover may be installed from the attic side if attic access is easily available or from the house side. Both covers could be included in excessively hot or cold climates.

  Homeowners must remember to remove cover(s) before operating the fan and to replace cover(s) during seasons when the fan is not in use.

Cooling strategies

In the summertime, the air inside a home is heated during the hot part of the day. At night especially, and during the morning and late evening, the outside air is often cooler and can be used to replace the inside air. It is important to open all or at least several windows, even if only partially, to provide adequate airflow. Closing windows in unused rooms will create higher velocity air movement in occupied rooms.

Running the whole house fan whenever outdoor temperatures are lower than indoor will cool the house. Operate the whole house fan throughout the evening to cool interior materials, walls, etc. An approximate rule of thumb would be to use the whole house fan whenever outdoor temperatures are below 85°F. As daytime temperatures rise, turn off the whole house fan.

The cool room materials (along with ceiling or circulating fans which create an additional cooling effect) will help keep the interior more comfortable.
Installing a whole house fan

Use house wrap tape, spray foam or caulk to seal fan frame to truss frame

Truss chord mounting bracket
Line up brackets
Do not cut truss chord

Airseal any gaps between fan box and truss frame so that when fan is running, no attic air is pulled across the fan.

Construct "H" brackets from 2X4's to create frame support for fan.

IMPORTANT:
Ensure louvers function properly (no binding or sticking)

-mount to louver section with VELCRO™ and bolt with washer and wing nut.

Caulk cracks and seams

Rigid board insulation (1/2" - 1" thick) covered with white contact paper.
How to build an attic-side box cover

A typical whole house fan has a 30" diameter blade with a sheet metal cowling of 31" to allow for blade clearance. An attic-side box cover may be constructed from a 4' x 4' piece of 1" rigid fiberglass duct board. The box will be 33" square with 1" thick walls (inside dimension of 31" x 31"). It will be 6½" deep. Adjust dimensions to actual fan size.

Use “H” brackets to provide proper support

When installing a whole house fan, be sure to provide proper support and seal the unit into the rough opening in the ceiling. Never cut a truss chord; wooden "H" brackets installed between the trusses create a framed box to raise the fan above the truss system. The louvers must be able to operate freely (open/close) and care must be undertaken to prevent binding or misalignment.

Helpful reminders

Attach labels to remind users to remove energy-saving covers.

- Label the attic-side box cover
  - “Whole house fan cover”
  - “Remove before operating fan”
  - “Replace when not using fan”
- Label the fan switch

WARNING! Do not operate fan without removing cover
Selecting a whole house fan

- **Fan speed**
  Two-speed fans permit the entire house to be ventilated quickly on high speed (such as when the occupants first arrive at home) and then provide gentle air circulation at the lower, quieter speed. Variable-speed units offer more flexibility in selecting the desired air movement.

- **Control options**
  Controls may be simple on/off pull or wall switches, multi-speed rotary wall switches, or a timer that automatically shuts off the fan at pre-selected time intervals.

- **Louvres**
  Dampers or louvers typically operate automatically whenever the fan operates. Motorized dampers are available but are not necessary if the louvers are correctly installed and maintained. Proper opening and closing of louvers is critical to a whole house fan's performance.

- **Motor mounts and noise**
  A direct drive unit has its fan blades attached directly to the motor’s shaft. It is usually less expensive and operates at higher rpm’s than its belt-driven counterpart. A belt-driven unit, which typically features a motor-driving a slower-moving, larger diameter fan with four or more blades, may be quieter but will require maintenance of the pulley and belt.

Sizing a whole house fan

Determining the amount of airflow in cubic feet per minute (cfm) that the whole house fan should provide involves a simple calculation. Multiply the total gross square footage of the house (include upstairs area) by the ceiling height (typically 8 feet). Select a fan that delivers between one half to one times that amount of cfm at 0.1” static pressure. For example, a 25’ x 40’, one-story home is 1,000 square feet and would need an 8 x 1,000 x 0.1 = 4,000 cfm fan or better. A manufacturer sells a two-speed unit that delivers 4,500 cfm at the high setting (240 watts) and 3,200 cfm at low (120 watts); this unit should be adequate.

Installation tips and concerns

- **Seal penetrations and vent attic adequately**
  Caulk all penetrations between the attic and living space, i.e., electrical boxes for ceiling light fixtures, loose attic hatches, large cutouts for plumbing vents, exposed beams and recessed lights. A whole house fan creates a positive pressure in your attic, and it is important that hot, dusty air from the attic is not forced back into the living space through cracks and gaps. See Air Sealing Energy Bulletin for why this is important.

  Guidelines for sufficient attic vent area is one square foot of net free vent area per 750 cfm of fan airflow, (4,500 / 750 = 6 square feet for the example above). Continuous ridge and soffit vents are usually more than adequate. Vents with insect screens may have a net free area equivalent to one half of the total open area depending upon the size of the holes in the screen area. Insulation should be installed directly against the fan box frame. Blown-in insulation may require the sides of the fan box to be raised (with baffles) to prevent interference.

- **Avoid backdrafts**
  Care should be taken to avoid backdrafting combustion appliances that are installed in the conditioned space. It is strongly recommended that combustion appliances not be installed in such a manner that they use room air for combustion. The whole house fan is capable of pulling large quantities of air from the home and, particularly if not enough windows are open, may easily backdraft a water heater located inside a louvered closet door. See Combustion Equipment Safety Energy Bulletin for why this is dangerous.

- **Label your switches**
  Controls should be placed higher on walls than light switches to avoid confusion and to keep them out of the reach of small children. Labels over switches are recommended to remind users to remove any energy-saving covers and to open at least two or more windows before using.
Energy-Efficient Construction

Building an energy-efficient home requires dozens of decisions by home designers, builders, and subcontractors. Many decisions affect the cost of construction and the profitability of the project. While energy efficiency requires careful planning and attention to details throughout the construction process, it offers substantial benefits to building professionals:

- fewer callbacks due to drywall cracks, nail pops, moisture damage, and other problems
- reduced liability from failure to comply with building, fire, and energy codes
- enhanced design and construction flexibility due to smaller and more simple mechanical systems
- increased markets due to "energy-efficient mortgages" and other incentives
- greater customer satisfaction because of improved comfort, less noise, reduced maintenance, increased durability, and lower operating costs
- recognition as a professional dedicated to quality and protecting the environment

House As A System

Successful design and construction professionals follow a "systems" approach to improving the energy efficiency of their 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.

For example, energy-efficient windows cost more than standard products. However, energy-efficient windows reduce heating and cooling needs, which reduces the size of the mechanical systems. The reduction in size saves money on the purchase and installation cost of the mechanical equipment which pays for the better windows.

Home design and construction has changed dramatically over the past 20 years. Most builders realize that today's homes have tighter envelopes, increased insulation levels, and higher efficiency mechanical systems and appliances. However, many building professionals do not realize that these improvements have not tapped the full potential for saving energy. When approached piecemeal and without consistency, some of these improvements can endanger the health, safety, and durability of the building.

For example, the increased insulation of today's homes slows heat flow, but also reduces the ability of the building envelope to dry. If the envelope is not thoroughly sealed against air leaks, moisture-laden air can enter and cause problems.

Air Barrier

Air leakage can account for over 50 percent of a home's heating and cooling costs, and contribute to problems with moisture, noise, dust, and entry of pollutants, insects, and rodents. Commonly used sheet materials, such as drywall, sheathing and decking, are effective at stopping air leakage. The key is to seal all holes and seams between sheet materials to create a continuous air barrier.

Many homes have large gaps in the sheet goods. These gaps are often hidden from view, under the bathtub, above dropped soffits for kitchen cabinets, or in mechanical room closets. Avoiding these gaps is inexpensive during construction. The key is to identify problem areas in the design process, assign the responsibility for sealing the holes, then check to ensure the airsealing was done effectively.

The first priority to airsealing should be no big holes in the sheet materials that form the air barrier.

Airsealing does not usually require expensive materials or special construction skills. Many affordable housing programs rely on volunteer labor. However, airsealing must be done throughout the construction process: during framing, prior to insulating and installation of interior finish materials, after installation of fixtures, and as a part of final punch-out. The materials that form the air barrier must be designed to provide a seal that will last, the life of the home or be easily reapplied by the homeowner.

Tighter homes means less infiltration of cold, dry outdoor air. Whereas many standard homes experience excessive dryness in winter and require a humidifier, tighter homes may have excess humidity and need controlled ventilation.

Testing the air tightness of a home using a variable-speed fan called a blower door can help ensure that airsealing work is effective. Blower-door testing is required by many energy efficiency certification programs. The test can usually be performed in less than an hour for simple floor plans and may be offered by utilities, weatherization agencies, and energy service companies.


For more information contact Energy Efficiency and Renewable Energy Clearinghouse (800) 733-8996. DOE-EREC, PO Box 2418, Martinsville, VA 22116-0121 www.eren.doe.gov or Sunstone Energy Institute, 241 Pine St., Atlanta, GA 30308; (404) 872-3049 www.sunstone.org
Air seal and insulate the building envelope

Insulation Barrier

Insulation reduces heat flow through the building envelope. Gaps in insulation waste energy and can lead to condensation which can damage building materials and cause growth of molds, dust mites and other biological contaminants.

The effectiveness of insulation is measured by its R-value—the resistance to heat flow. The higher the R-value, the greater the insulating value. The recommended amount of insulation depends on the building design, climate, price of energy, and cost of materials and labor. Consult the Model Energy Code for minimum insulation levels—remember, any construction project using federal dollars must comply with the MEC. Choose insulation materials based on the installed cost per R-value per square foot.

While the amount of insulation installed is important, so is the quality of installation. Even small gaps and compressed areas can reduce insulating levels significantly. A study of attic insulation found that just 5 percent voids in the insulation—typical in many homes—could reduce the overall R-value by more than 30 percent.

Many homes experience mold growth at the junction of the ceiling and exterior walls. The cause of the mold is often too little attic insulation at the eave. Warm room air hits the cold ceiling and moisture condenses in the drywall. The damp drywall is an ideal environment for mold growth.

It is important to seal air leaks before insulating. Commonly used insulation materials, such as batt and loose-fill products, do not stop air leakage. As air leaks through these materials, it lowers the R-value. For most affordable home designs, materi-
An energy checklist helps ensure a systems approach. The details will vary according to climate, site, house design, materials selection and other factors. The following checklist is for a home built in a temperate climate with an unconditioned crawl space, atmospheric combustion appliances, and kitchen and bath fans for ventilation.

**Foundation**
- Grade slopes minimum of 5 percent from foundation
- Install 6 mil plastic ground cover in crawl space, overlap and seal seams (if required)
- Provide radon vent stack
- Close crawl space vents

**Air sealing**
Before drywall is installed:
- Seal bottom plate of exterior walls during construction
- Seal inside edge of bottom plate after exterior walls are erected
- Air seal behind bathtub before sitting and after insulation is installed using plastic, drywall, or other sheet material
- Seal windows and exterior doors into rough opening using non-expanding spray foam or backer rod (recommended)
- Seal wing, plumbing and HVAC penetrations at top and bottom plates, ceilings and floors

After drywall is installed:
- Seal bath tub drain penetration after installation and before floor insulation installed
- Seal plumbing pipes and electrical boxes (e.g., receptacles, switches, lights, and circuit breaker box) to drywall
- Seal bathroom ventilation fan to drywall
- Seal attic bypasses and chases (e.g., open partition walls, dropped ceilings, and duct and flue chases)

**Sheathing**
- Caulk, glue or gasket drywall
- Seal duct boots to floor or drywall
- Verify that the HVAC contractor has sealed return and supply duct connections (mastic required)
- Seal exterior penetrations (e.g., porch light fixtures, outside outlets, and phone and electric service holes)
- Seal gaps around whole house fan frame (backer rod, tape or spray foam preferred)
- Fabricate whole house fan cover using rigid foam insulation, contact paper, and Velcro
- Weatherstrip attic access hatch cover

**Insulation**
- Use insulation hangers (rods) placed every 12 inches to hold floor insulation in place
- Use energy-efficient framing (e.g., energy corners, T-walls, insulated headers) to improve coverage
- Carefully staple kraft paper facing of wall insulation batts to side of stud or front (preferred) to avoid compressing batts
- Cut wall insulation batts to fit around wing, wall outlets and plumbing
- Install soffit dams and rafter baffles to provide clearance for soffit ventilation
- Insulate attic access hatch cover or construct cover for attic stairs from rigid foam insulation

**Water heater**
- Insulate water heater with jacket
- Install heat traps (check valve or inverted loop) on both hot and cold water pipes
- Insulate all hot water piping in closet and first two feet of cold water pipe
- Insulate water pipes in crawl space for freeze protection

**HVAC combustion closet**
- If using a gas furnace or water heater, isolate equipment closet from conditioned space
- Insulate and seal combustion closet walls
- Install solid (non-louvered) door with weatherstripping and threshold
- Seal all gas and water line penetrations through equipment closet
- Provide inlet air for combustion

**Moisture**
Controlling moisture is critical to maintaining the durability of a building as well as the health of its occupants. When moisture condenses it can damage finish materials, reduce the R-value of insulation, and lead to decay. High moisture levels are necessary for the growth of molds and dust mites which can endanger human health.

Ground water is a common cause of moisture problems in homes. Ensure proper drainage around the home—usually slope grade a minimum of 5 percent away from the foundation. Cover bare earth under crawl spaces with a ground cover. Provide a capillary break under slabs.

Problems can also originate from moisture-laden air leaking into the building envelope. Airsealing the envelope not only saves energy but can reduce these moisture problems. Moisture can diffuse through permeable building materials, such as drywall. Vapor barriers may be recommended in some climates to control diffusion of water vapor.

The activities of the homeowner, such as respiring, cooking, bathing and cleaning, generate moisture. In energy-efficient homes, it is important to provide for controlled ventilation to remove this moisture.
Heating & Cooling

Fuel choice
The choice of energy source for heating and cooling equipment is an important factor in determining cost. Compare operating costs for all available fuel types. Do not let short-term incentives dictate an expensive energy source.

Equipment size
Energy-efficient homes require less heating and cooling than standard homes. Therefore, smaller mechanical systems can be installed, which saves the builder money. Properly sized equipment will last longer, provide greater comfort, reduce noise, and save homeowners money. Require that equipment be sized using Manual J or similar procedure.

Equipment efficiency
High-efficiency equipment costs more than standard models; reducing equipment size through energy improvements to the building envelope offsets this extra cost.

AFUE (annual fuel utilization efficiency)—measures the efficiency of furnaces. Units range from a low of 78 percent to mid-efficiency of 80 + percent to high-efficiency of over 95 percent. AFUE does not measure the electrical consumption of the furnace blower. An inefficient blower can waste hundreds of dollars over its life. Use the manufacturer’s data sheets to compare blower efficiency as well as AFUE.

HSPF (heating season performance factor)—measures the efficiency of an electric heat pump in heating mode. Units range from a low of 6.8 to mid-efficiency of 7.2 to high-efficiency of 8.0.

SEER (seasonal energy efficiency ratio)—measures the cooling efficiency of an air conditioner or heat pump. Units range from a low of 10 to mid-efficiency of 12 to high-efficiency of over 14.

Reducing the size of heating and cooling equipment can help pay for energy improvements to the building envelope. Require Manual J calculation of equipment size.

Water Heating
The cost of water heating can be as great as for heating or cooling. Fuel cost is often the prime consideration for water heating. The right choice can save homeowners several hundred dollars each year on energy bills.

High efficiency water heaters typically pay for their extra cost in energy savings within a few years. Increase savings with simple conservation measures, such as a temperature setting of 120°F, anti-convection loops in hot and cold lines, and tank insulation.

Avoid locating atmospheric combustion water heaters within the conditioned space. Specify power vented models.

Ventilation
Houses need controlled ventilation. In simple designs, spot ventilation provided by bath and kitchen fans may be adequate. For more detailed designs and severe climates, other ventilation options may be appropriate.

Ductwork is sealed and insulated

Ductwork
Many homes rely on forced-air distribution of conditioned air through ductwork. Studies show that air leakage from poorly sealed ductwork can waste over 30 percent of a home’s heating and cooling energy. Duct leakage can also create pressure imbalances in a home which endanger health and safety.

The best solution to cutting energy losses from ductwork is to locate the ducts inside the conditioned space of the home. For example, many affordable home designs provide for ductwork in an air tight plenum located at the ceiling of an interior hallway. Air is distributed to individual rooms from registers or similar lines, or similar ducts cannot be located in conditioned space, then it is critical to properly seal and insulate them. The 1995 Model Energy Code mandates that all ductwork be sealed with mastic. Duct tape does not provide a lasting seal for ducts and should not be used. The code also sets minimum duct insulation levels based on climate.

Duct leakage can cause pressure imbalances which can draw in outside air and cause backdrafting of combustion appliances. Seal connections with mastic.
Seal air leaks and save energy!

What is Air Leakage?
Air leakage, or infiltration, is a major problem in both new and older homes. Besides wasting hundreds of dollars on energy bills, air leakage paths can cause building durability problems, increase the risk of fire spread, permit insect and rodent entry, and create unhealthy indoor air quality. Reducing air leakage usually adds little to the materials cost of a house and does not require specialized labor.

What is the building envelope?
The building envelope is the floor, exterior walls and ceiling that separate the inside conditioned space from the outside or unconditioned space. The building envelope should form a continuous insulated barrier and a continuous air barrier. These barriers are usually formed by different materials.

Standard insulation products, such as batt or loose fill products, do not seal against air leakage. For most affordable homes, the sheet goods that form the decking, sheathing, and finish materials are the primary air barrier. Seal holes in the materials with durable caulks, gaskets and foam sealants.

How does airsealing affect HVAC?
Reducing infiltration can significantly cut heating and cooling costs. Because infiltration can account for up to 50 percent of heating and a significant part of cooling loads, by tightening the building we can often decrease the size and first cost of the HVAC system.

Annual Energy Costs for 1300 sq. ft. house

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</tr>
<tr>
<td>Cooling</td>
<td>$178</td>
</tr>
</tbody>
</table>

* Estimated 12 air changes at 50 Pascal pressure difference
** Estimated 5 air changes at 50 Pascal pressure difference

An attic access is one of the biggest "intentional" holes between living space and non-conditioned space. Add weatherstripping and an insulated cover.

Can a house be too tight?
A leaky house that breathes in moldy, humid crawlspace air, or dusty attic air, is not healthy. It is unwise to rely on the weather for ventilation. During cold or windy weather the house may have too much air leakage, and during warm or calm weather, too little.

As houses need controlled ventilation. For simple designs, effective spot ventilation, such as kitchen and bath fans that exhaust to the outside, may be adequate. For complex designs or harsh climates, whole house ventilation may be appropriate. These systems may incorporate heat recovery, moisture control and air filtration.
What are the priorities for airsealing?

It just makes sense to first seal all the big holes, then the large cracks and penetrations, and finally the smaller cracks and seams. Many times unseen holes or pathways, called bypasses, occur at key junctures in the framing (such as an attic to kneewall transition) and permit large quantities of air to leak in and out of a home.

Where are these leakage sites?

Focus efforts on sealing the attic and floors first, as the walls represent a less serious problem. Dropped soffit ceilings, ductwork and plumbing chases, leaky recessed light fixtures, wire penetrations, and pull-down stairs represent connections between the attic and the conditioned space. Major leakage sites in the floor can be found under the tub drain and at the numerous plumbing, HVAC, and wiring penetrations. In walls, the bottom and top plates, fireplaces with chimney inserts, the band joint (for two-story houses), and the window and door rough openings are the primary culprits.
Airsealing materials
Use a combination of these different airsealing materials.

- Caulk: Use to seal gaps less than 1/2". Select grade (interior, exterior, high temperature) based on application.
- Spray foam: Expands to fill large cracks and small holes. It can be messy; consider new, water-based foams. NOT recommended near flammable applications (flue vents, etc.).
- Backer rod: Closed cell foam or rope caulk. Press into crack or gap with screwdriver or putty knife. Often used with caulk around window and door rough openings.
- Gaskets: Can be applied under the bottom plate before an exterior wall is raised, or used to seal drywall to framing.
- Housewrap: Installed over exterior sheathing. Must be sealed with tape or caulk to form an airtight seal. Resists liquid water but is not a vapor barrier.
- Sheet goods (plywood, drywall, rigid foam insulation): These are the solid materials which form the building envelope. Air will only leak at the seams or through unsealed penetrations.
- Sheet metal: Used with high-temperature caulk for sealing high-temperature components, such as flues, to framing.
- Polyethylene plastic: Inexpensive material for airsealing that also stops vapor diffusion. Must have all edges and penetrations sealed to be effective air barrier.
- Weatherstripping: Used to seal moveable components, such as doors and windows.
- Don’t rely on the insulation: The most common insulation, fiberglass, does not stop air leakage. In older houses, dirty fiberglass is a telltale sign of air movement (it simply acts as a filter). Certain types of insulation, such as dense-packed cellulose and urethane foams, can be effective at reducing air flow.
Airsealing checklist

Before drywall

- Seal bottom plate of exterior walls with caulk or sill seal; seal inside edge with caulk after walls are up.
- Seal band joist area with caulk, spray foam, or gasketing between top plate and band joist, and between band joist and subfloor.
- For bath tubs on outside walls, insulate the exterior wall and air-seal behind tub with sheet goods before tub is installed. After the drain is installed, seal the tub drain penetration with rigid foam insulation and spray foam.
- For dropped soffit cabinets and showers, use sheet material and sealant to stop air leakage from attic into soffit and then insulate. Alternately, frame and install drywall for the soffit area after the taped ceiling drywall is installed.
- Seal windows and exterior doors with backer rod and caulk or spray foam. Be cautious when using (non-Lautex) spray foam as it can expand and pinch jambs and may void some window warranties.
- Seal all electrical wire, plumbing and HVAC penetrations between any conditioned and unconditioned spaces.

After drywall

- Seal electrical switch and outlet boxes to drywall with caulk.
- Seal light fixture boxes to drywall with caulk or foam.
- Seal bath and kitchen ventilation fans to drywall with caulk or foam.
- Seal all duct boots to floor or drywall with caulk, foam, or mastic.
- Seal any plumbing penetration through drywall with caulk or foam.
- If not done before drywall, seal tub drain penetration (from crawlspace side) with plywood or rigid board insulation and caulk or foam.
- Seal gaps at whole house fan with spray foam or housewrap tape (ensure louvers function properly).
- Fabricate whole house fan cover (See Whole House Fan Energy Bulletin). If the fan is turned on while the cover is in place a fire may result from the motor over heating. A contact switch should be used with the cover that will not allow the fan to run while the cover is in place.
- For attic hatches, insulate top of board with at least two inches of rigid foam insulation or fiberglass batt; seal with weatherstripping. Use these same steps for short and full-size attic kneewall access doors and include a tight latch.
- For attic pull down stairs, use rigid foam cover kit; make stairs airtight using latch bolts and weather stripping.

Airseal exterior

- Seal all exterior penetrations, such as porch light fixtures, phone, security, cable and electric service holes, with caulk or spray foam.
- Repair or replace any missing sheathing.

If installing housewrap:

- Seal top and bottom edges past the plates with housewrap tape or caulk.
- Seal housewrap at windows and doors.
- Minimize cuts in housewrap and caulk or tape to seal all penetrations.
- Overlap seams and seal with caulk or housewrap tape.
- If not using housewrap, seal all sheathing seams with housewrap tape or caulk.

Diagnostic tools

A blower door is a variable-speed fan used to measure how tight a house is and locate air leakage sites. Often, an energy efficiency incentive program, such as the DOE/EPA Energy Star Program, requires a blower door test to confirm the tightness of the house.
**Wall Insulation**

**Keys to effective wall insulation**

Walls are the most complex component of the building envelope to insulate, air seal, and control moisture. The keys to an effective wall are:

- **Air-tight construction** — all air leaks sealed in the wall during construction and prior to insulation installation.

- **Moisture control** — exterior rain drainage system, continuous air barrier, vapor barrier located on the appropriate side of the wall.

- **Complete insulation coverage** — Optimum Value Engineered framing to maximize insulation coverage, no gaps or compressed insulation in cavity insulation, continuous insulated sheathing.

**Air sealing**

Air sealing reduces convective heat flow and prevents water vapor in the air from entering the wall. In a 100-square-foot wall, one cup of water will diffuse through drywall without a vapor barrier in a year, but 50 cups will enter through a ½" round hole. Thus, sealing air leaks is about 50 times as important as installing a vapor barrier.

**Moisture control**

Air sealing and moisture control make insulation more effective. It is a myth that installing vapor barriers is the most important step for controlling moisture in walls. Most moisture enters walls through either a fluid capillary action or as water vapor through air leaks.

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**Prevent rain penetration**

Causes of rain leaks through exterior walls include improper installation of siding materials; poor quality flashing, weatherstripping, or caulking around joints in the building exterior (such as windows, doors, and bottom plates); and wind-driven rain that penetrates the exterior finish. To enhance protection against rain penetration, create a drainage plane within the wall system of the home.

**Control moisture in walls**

Controlling moisture in all climates involves the following steps:

- **Install a polyethylene ground cover** on the earth floor of homes with crawl spaces and slope the earth away from the foundation of all houses.

- **Install a vapor barrier** which has a Perm rating of less than one. In most cold climates, vapor barriers should be placed on the interior (warm-in-winter) side of walls. However, the map shows that in some southern climates, the vapor barrier should be omitted, while in hot and humid climates, such as along the Gulf coast and in Florida, the vapor barrier should be placed on the exterior of the wall.

- **Place a termite shield or other vapor impermeable membrane** on the top of the foundation wall. This will prevent moisture from wicking into the framed wall from the concrete foundation wall by capillarity.

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Developed with funding from the U.S. Department of Energy and U.S. Environmental Protection Agency by the Southface Energy Institute. For more information contact Southface Energy Institute.

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Wall Framing with O.V.E.

Building experts have performed considerable research on ways to reduce the amount of framing in our homes. The U.S. Forestry Products Association and other organizations have devised a framing system using Optimum Value Engineering (O.V.E.) that reduces unnecessary framing, yet maintains structural integrity. The goals of O.V.E. are to:

- Reduce framing time and lower construction costs
- Save on increasingly scarce dimensional framing lumber
- Increase energy efficiency, thus reducing annual energy costs

Many builders have been resistant to adopt O.V.E. practices due to concerns about compromising structural integrity. With quality installations, the home’s framing strength should not be altered by O.V.E. Approaches include:

- Less corner framing
- Less framing around partition walls
- More energy-efficient headers
- Eliminating curtailed studs (cripples)
- Using single top plates via point loading

<table>
<thead>
<tr>
<th>Comparison</th>
<th>Standard</th>
<th>O.V.E.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insulation Voids</td>
<td>3%</td>
<td>0%</td>
</tr>
<tr>
<td>Framing factor</td>
<td>15-25%</td>
<td>10-15%</td>
</tr>
<tr>
<td>Batt R-value</td>
<td>R-13</td>
<td>R-13</td>
</tr>
<tr>
<td>Sheathing R-value</td>
<td>R-0.5 to 2.0</td>
<td>R-2.5</td>
</tr>
<tr>
<td>Effective Average R-value</td>
<td>R-11.1</td>
<td>R-14.6 (30% higher)</td>
</tr>
</tbody>
</table>

Standard Framing versus O.V.E. framing

2x6 Wall Construction

Many homes in the United States use 2x6’s for construction. In most code jurisdictions, 2x6’s can be spaced on 24-inch centers, rather than 16-inch centers used for 2x4’s (some locations permit 2x4, 24" O.C.). The advantages of using wider wall framing are:

- More space provides room for R-19 or R-21 wall insulation
- Thermal bridging through studs is reduced due to the higher R-value of 2x6’s. Plus, overall thermal bridging is reduced due to less stud area in wall
- Less framing reduces labor costs
- There is more space for insulating around piping, wiring, and ductwork

Disadvantages of 2x6 framing include: the interior finish or exterior siding may bow slightly between studs due to the wider spacing; the window and door jambs must be wider and can add $12 to $15 per opening; walls with substantial window and door area may require almost as much framing as 2x4 walls and leave relatively little area for actual insulation. Also, adding thicker insulated sheathing may be a less expensive way to increase overall R-value.
The economics of 2x6 wall insulation depend on the number of windows in the wall, since each window opening adds extra studs and requires the purchase of a jamb extender. Walls in which windows and doors occupy 10% or less of the total wall area should use 2x6's in areas with significant windows. However, in walls where windows make up over 10% of the total area, the economics become questionable because of the cost of jamb extenders and the minor improvement in average wall R-value.

<table>
<thead>
<tr>
<th>Thickness (inches)</th>
<th>R-value</th>
<th>Cost ($/sq. ft.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 1/2</td>
<td>11</td>
<td>12-16</td>
</tr>
<tr>
<td>3 3/4</td>
<td>13</td>
<td>15-20</td>
</tr>
<tr>
<td>3 1/2</td>
<td>15 (high density)</td>
<td>34-40</td>
</tr>
<tr>
<td>6 to 6 1/4</td>
<td>19</td>
<td>27-34</td>
</tr>
<tr>
<td>5 1/4</td>
<td>21 (high density)</td>
<td>33-39</td>
</tr>
<tr>
<td>8 to 8 1/2</td>
<td>25</td>
<td>37-45</td>
</tr>
<tr>
<td>9 1/2</td>
<td>30 (high density)</td>
<td>45-49</td>
</tr>
<tr>
<td>12</td>
<td>38</td>
<td>55-60</td>
</tr>
</tbody>
</table>

This chart is for comparison only. Determine actual thickness, R-value, and cost from manufacturer or local building supply.

What type of insulation should I use?
The home designer has an increasing array of insulation products from which to choose to insulate wood-framed walls. The wide variety of insulation materials often makes it difficult to determine which products and techniques are the most cost effective. Refer to the Model Energy Code (MEC) for R-value recommendations.

- Fiberglass and rock wool batts. 2x4 walls can use R-13 or R-15 batts; 2x6 walls use R-19 or R-21 products.

- Cellulose insulation, made from recycled newsprint, comes primarily in loose-fill form. It can be installed in walls via a dry-pack process and a moist-spray technique. It generally costs more than batt insulation, but offers reduced air leakage through the wall cavity plus improved sound deadening.

- Fiberglass and rock wool loose-fill insulation provide full coverage with a "Blown-In Blanket" System (BIBS) which involves blowing insulation into open stud cavities behind a net.

- Rigid foam insulation has a higher R-value per inch than fiberglass or cellulose and stops air leaks, but is considerably more expensive. It is manufactured in sheet good dimensions and is often used as the outer layer of insulation.

- Icynene foam can be blown into walls and has an environmental benefit - it is manufactured using carbon dioxide rather than more polluting gases such as pentane or hydro-chloro-fluoro carbons like other foams.

Wall Sheathings
Some builders use 1/2-inch wood sheathing (R-0.6) or asphalt-impregnated sheathing, usually called blackboard (R-1.3), to cover the exterior framing before installing siding. Instead, use 1/2-inch expanded polystyrene (R-2), extruded polystyrene (R-2.5 to 3), or polyisocyanurate (R-3.4 to 3.6) foam insulated sheathing. Sheathing thicker than 1/2" will yield higher R-values. Advantages of foam sheathing over wood or blackboard include:

- Energy savings and improved thermal comfort by providing a continuous layer of insulation — reduces framing shortcomings

- Easier to cut and install

- Protects against condensation by keeping the interior of the wall warmer

- Usually costs less than plywood

Ensure that the sheathing completely covers, and is sealed to, the top plate and band joist at the floor. Most sheathing products come in 9- or 10-foot lengths to allow complete coverage of the wall. Once it is installed, patch all holes, penetrations, and seams with caulk or housewrap tape. See Air sealing Energy Bulletin.

Because of its insulation advantages over plywood and oriented strand boards (OSB), foam sheathing is best when used continuously in combination with let-in bracing, which provides structural support offered by plywood or OSB. Some builders use two layers of sheathing — plywood or OSB for structure and support, and foam for insulation. When the total depth of the sheathing material exceeds 1/2 inch, make certain the window and door jambs are adjusted for the total wall thickness.

Let-In Bracing Opportunities for Wall Framing
Steps for effective wall insulation

1. Review the plans and specifications and identify all walls between conditioned (heated and cooled) spaces and unconditioned spaces (exterior, attics, crawl spaces, unheated garages, and mechanical rooms). Utilize O.V.E. framing to save energy and dimensional wood lumber.

2. Use diagonal corner bracing (let-in bracing) on exterior walls to substitute for corner plywood sheathing and allow continuous insulated sheathing. Let-in bracing can be 1x4 wood or a metal T-brace.

3. Seal all air leaks in walls before insulating, including under the bottom plate, around windows and doors, band joist area between floors and all electrical, plumbing, and HVAC penetrations.

4. Fixtures such as stairs, or shower/tub enclosures cover exterior walls and do not allow easy installation of insulation after the sheathing is attached, insulate behind these components in advance and cover with a weatherproof barrier.

5. Use caulk and backer rod, not insulation, to seal around window and door jambs. Use foam sheathing for insulating headers to reduce framing heat loss.

6. Face staple batts as side stapling creates channels for air flow and compresses the insulation, thus reducing the R-value. If face stapling is not an option, use unfaced batts or carefully side staple within ¼" of the stud face.

7. Obtain full coverage of batt, roll, or blown wall insulation. Cut insulation to fit snugly into non-standard stud spaces.

8. Silt the insulation around the back or front side of electrical wiring without compressing or tearing the insulation.

9. Notch out the insulation around electrical boxes, but leave sufficient thickness to insulate behind the box.

10. Use R-13 or R-19 batts for insulating areas during framing behind shower/tub enclosures and other hidden areas and use ½" drywall, plastic, or other sheet material for sealing behind shower-tub enclosures and other areas that cannot be reached after construction.

11. Once the interior drywall is in place, seal all penetrations with durable caulking.

Miscellaneous materials to have on-hand
In addition to standard framing lumber and fasteners, provide the following materials during construction:

- Cauk or foam sealant for sealing areas that may be more difficult to seal later
- Foam sheathing for insulating headers
- 1x4 wood or metal T-bracing for let-in corner bracing
- R-13 or R-19 batts for insulating areas during framing behind enclosures and other hidden areas
- ½" drywall or other sheet material for sealing behind shower/tub enclosures and other areas that cannot be reached after construction.
Combustion Equipment Safety

Combustion appliances are efficient
Fuel-fired combustion appliances are often the most efficient and cost-effective way to produce heat. Combustion appliances today commonly use natural gas, propane, oil, kerosene, and wood as their fuel. Examples include:
- furnaces
- space heaters
- water heaters
- ranges
- fireplaces
- wood stoves
- gas clothes dryers

Although combustion appliances have been used for many years and have been installed in millions of homes, careful installation is still required to ensure their safe and efficient operation, especially in today's more energy-efficient homes.

Problems posed by combustion equipment
During the combustion process, the appliances burn fuel using oxygen from the air and release exhaust gases such as carbon dioxide, water vapor, nitrogen oxides, and carbon monoxide. While most combustion appliances operate properly and create no ill health effects, occasionally a situation develops which can cause serious medical problems, and sometimes death. This occurs primarily from carbon monoxide poisoning when:
- Combustion appliances malfunction and exhaust high levels of carbon monoxide either directly into the home, into the ductwork, or into leaky exhaust flues;
- A negative pressure difference is created in a home that causes an appliance to backdraft — pull combustion gases down the exhaust flue and into the home.

What about fuel-burning stoves and ovens?
There is growing evidence that gas-fired stoves and ovens create high levels of carbon monoxide in homes. There are five precautions which should help prevent problems from stoves and ovens:
- Install a carbon monoxide detector in the living area near the kitchen.
- Always install a kitchen exhaust fan that is vented to the outside and operate the fan whenever cooking.
- Have the stove or oven, as with all major appliances, serviced regularly (every 2 years is recommended).
- Do not use a stove as a space heater.
- Buy a stove with pilotless ignition.

Are unvented gas space heaters safe?
Most energy and health experts advise against unvented combustion appliances. Even when operating properly, these units produce unhealthy exhaust gases such as nitrogen oxides and excess water vapor. If these units are present, do not weatherize the home and advise occupants to open windows a little to ensure ventilation whenever the units are operating.

Balance the air pressure in the house and provide spot ventilation for non-vented combustion appliances, such as gas stoves.

Negative house pressures affect combustion appliances
Pressure differences that backdraft an appliance limit the supply of oxygen to the burner, which causes it to produce increased levels of carbon monoxide. While clothes dryers and vent fans may cause negative pressures, a major cause is due to imbalances created by heating and cooling systems with duct leakage or poorly designed return ductwork. Forced-air heating and cooling systems should be balanced — the amount of air delivered through the supply ducts should be equal to that drawn through the return ducts. If the two volumes of air are unequal, pressure imbalances will occur in the home.

Leaks in the supply side of a duct system can create a negative house pressure by pulling less air into the house and pulling more air in through the return side — this increases air infiltration from the outside and the possible backdrafting of flues and exhaust vents because the house is attempting to equalize the pressure by pulling air in from other sources. Another shortcoming of leaky supply ducts is a general loss of efficiency and increased energy costs.
Positive pressures may be a problem too. Ductwork systems that are leaky on the return side have their own set of problems: the house becomes pressurized, generating air leakage out of the building envelope. Air from unconditioned sources, such as a crawl space, is pulled in through the leaky return system into the living space — air that may be contaminated with radon, mold, pesticides, or toxic chemicals. Positive pressures in cold climates may drive moisture through walls and cause deterioration. Hot, humid air is pulled into the ducts in summer — cold air is drawn into the ducts in winter. If leaky return ducts are located near combustion appliances, such as in an equipment closet or crawl space, the negative pressure could cause flues and chimneys to backdraft.

Pressure differences in the conditioned space of a home can affect indoor air quality and energy use.

Special issues with pressure differences
Pressure differences can also result in homes with tight ductwork if the home only has one or two returns. When interior doors are closed it may be difficult for the air in these rooms to circulate back to a central return duct. The pressure in the closed-off rooms increases, and the pressure in rooms open to the return decreases. Rooms with one supply and no return should have:

☑ a 1-inch gap under the door connecting to an area with a return.

Rooms with two or more supplies should use one of the following:

☑ a transfer grille installed either in the door or through the wall between the room and the area with a return (a wall-mounted transfer grille must be totally sealed from the rest of the wall cavity) and it may contain a sound baffle to lessen noise transmission between rooms; or

☑ a jumper duct that connects the two rooms; or

☑ a separate return.

Carbon monoxide hazards
Carbon monoxide (CO) is a colorless, tasteless, odorless gas that is poisonous. There are hundreds of deaths in the United States each year because of CO poisoning.

<table>
<thead>
<tr>
<th>CO [ppm]</th>
<th>Time</th>
<th>Symptoms</th>
</tr>
</thead>
<tbody>
<tr>
<td>35</td>
<td>8 hours</td>
<td>Maximum exposure allowed by OSHA in the workplace over an eight hour period.</td>
</tr>
<tr>
<td>200</td>
<td>2-3 hours</td>
<td>Mild headache, fatigue, nausea and dizziness.</td>
</tr>
<tr>
<td>400</td>
<td>1-2 hours</td>
<td>Serious headache — other symptoms intensify. Life threatening after 3 hours.</td>
</tr>
<tr>
<td>800</td>
<td>45 minutes</td>
<td>Dizziness, nausea and convulsions. Unconscious within 2 hours. Death within 2-3 hours.</td>
</tr>
<tr>
<td>1600</td>
<td>20 minutes</td>
<td>Headache, dizziness and nausea. Death within 1 hour.</td>
</tr>
</tbody>
</table>

Install a carbon monoxide detector
Carbon monoxide detectors are highly recommended in homes with fuel-burning appliances. The detectors signal homeowners via an audible alarm when CO levels reach potentially dangerous levels. Some models have digital readouts of current CO levels, which are useful to the homeowner to monitor household air quality, while some less-expensive models indicate varying levels of CO with differing alarms. CO detectors are either a plug-in variety or can be hard-wired and should be installed in rooms with direct connection to combustion appliances, such as kitchens with fuel-burning stoves and ovens, areas near combustion closets for fuel-burning heating systems, and rooms with fuel-burning space heaters. A low wall socket location is preferred for plug-in models since CO is heavier than air.
Sheel-system combustion closet

Warning: Do not store anything in this closet. Keep door shut.

Solid door (non-louvered) with child proof latch must seal tightly against weatherstripping at top, bottom, and sides.

Seal penetrations and under bottom plate of walls.

Sealed, ducted return (if the cavity is used as a plenum, carefully seal this area since it is a return duct).

A shelf-system installation with a closed combustion closet provides a compact and safe arrangement for an atmospheric gas furnace.

Combustion closet design issues

Too often, combustion equipment closets are connected to the occupied rooms of the home via air leaks or louvered doors — this can be dangerous and is not recommended. Carbon monoxide and other pollutants present in the combustion closet can leak into the rest of the home and create dangerous conditions for the homeowners. Also, using room air for combustion robs efficiency since that air must be replaced by infiltration. The combustion closet should be air sealed and isolated from the rest of the house and ventilated to the outside.

Combustion equipment closet features

Insulate the interior and exterior walls of the combustion closet, finish the walls and ceiling with drywall, seal all holes and leaks between the closet and the rest of the house, and install a non-louvered, weather-stripped door. In addition, provide outside air for combustion by installing two ducts in the closet that are sized for the specific combustion appliances. One duct should extend to within 12 inches of the floor of the closet, while the other extends to within 12 inches of the ceiling (check with local codes). The ducts should extend to the outside, to a ventilated crawl space, or to a ventilated attic.

The sizes of the outside air ducts depend on local mechanical and building codes. Typical sizing methods for appliances in a combustion closet require a given number of square inches of ductwork per 1,000 Btu/hour of fuel used by the appliances. Consult with local mechanical engineers to design the combustion air ducts.

Creating a combustion equipment closet serves to separate the combustion appliance from the living space of the house. With a guaranteed source of combustion air in the mechanical room isolated from the living area, the home will be better protected against backdrafting and carbon monoxide problems.
A closed combustion closet is "a little piece of the outside located in the middle of the home." Fresh air for combustion is provided from sources not connected with the living space.

**Furnaces and water heaters**

Common combustion appliances, such as furnaces and water heaters, require air for combustion and to vent exhaust gases. Most of these appliances are non-direct vent units — they use air surrounding the appliance for combustion and are more affected by pressure differences in the house. Others, known as direct vent furnaces, bring combustion air directly into the burner via sealed inlets connected to the outside.

Direct-vent combustion appliances can be installed within the conditioned area of a home since they do not rely on inside air for safe operation. Non-direct vent combustion appliances must receive adequate outside air for combustion and exhaust venting. The primary concern with non-direct vent units is that a malfunctioning heater may allow flue gases to enter the area around the furnace and be pulled into the living space.

Most new furnaces have forced draft exhaust systems, meaning a blower always propels exhaust gases out the flue to the outdoors, and are unlikely to backdraft. Atmospheric furnaces and water heaters do not have a forced draft fan. Atmospheric furnaces are less common today due to federal efficiency requirements but this venting method is still common in many water heaters.

Atmospheric furnaces and water heaters should be isolated from the conditioned space. Those units located in well-ventilated crawl spaces, basements and attics usually have plenty of combustion air and encounter no problem venting exhaust gases to the outside.

Combustion appliances located inside the house should be carefully installed in a combustion closet to ensure proper, efficient operation and prevent indoor air-quality problems. If there are concerns that poor equipment or pressure imbalances may cause backdrafting or other indoor air quality problems, consult with a qualified contractor.

**Air quality in air-tight homes**

While any home may encounter pressure imbalances, homes that are more air-tight generate pressure differences more easily. However, a few simple design measures can prevent these problems and still permit the virtues of a more air-tight home.

**Air tight homes ...**

- Reduce indoor air problems because they prevent pollutants from entering through the attic or crawl space (or even moist, unfiltered air from outside)
- Provide intentional ventilation for the occupants
- Save energy by reducing the cost normally required to heat, cool, and control moisture in outside air leaking to the inside by infiltration
- Require intentional air for combustion appliances

See Air Sealing Energy Bulletin for more information.
Ceiling and Attic Insulation and Ventilation

Insulating ceilings is one of the most cost-effective energy-efficiency measures. When planning and managing attic insulation projects, make sure:

- All air leaks through the top floor ceiling are completely sealed
- Insulation levels meet or exceed local building codes
- Insulation coverage is continuous
- Space is provided for both insulation and air flow from soffit vents at the eave
- Attic areas intended for storage have sufficient space underneath for full insulation value
- Attic access doors are insulated and sealed
- Knee wall areas have adequate insulation and an air-sealing barrier

Attics over flat ceilings are often the easiest part of the exterior building envelope to insulate. They are usually accessible and have ample room for insulation. However, many homes use cathedral ceilings or have attic kneewalls that present unique insulation requirements. It is important to insulate all types of ceilings properly.

Attic Ventilation

Most building codes require roof vents to expel moisture in winter which could deteriorate insulation or other building materials. In summer, ventilation may reduce roof and ceiling temperatures, thus saving on cooling costs and lengthening the roof’s life.

However, research studies are investigating whether attic ventilation is beneficial for all climates. For years, researchers have believed the cooling benefits of ventilating a well-insulated attic are negligible. Some experts also question whether ventilation is effective at moisture removal. Until the research results are available and accepted, builders should follow local code requirements, which usually dictate attic ventilation.

The vent opening combination of continuous ridge vents along the peak of the roof and continuous soffit vents at the eave provides the most effective ventilation. Common rules of thumb are 1 sq ft of net vent opening for every 150 sq ft of insulated ceiling or 1 sq ft for every 300 sq ft if the insulation has a vapor barrier. The vent area should be divided equally between the ridge and soffits.

Cap vents, turbines, and gable vents can supplement a roof design that has insufficient ridge vent area. Power roof ventilators are not recommended as they consume more energy than they save and create negative pressures that may pull room air into the attic.

Increasing the roof height at the eave

One problem area in many roof designs occurs at the eave, where there is often insufficient space for full insulation without blocking air flow from the soffit vents. If the insulation is compressed, its R-value is diminished. If using a truss roof, consider raised heel or cantilevered trusses that form elevated overhangs. These should provide clearance for both ventilation and full-height insulation.

In stick-built roofs, where rafters and ceiling joists are cut and installed on the construction site, an additional top plate that lays across the top of the ceiling joists at the eave will prevent compression of the attic insulation and allow for ventilation.

The raised top plate design also minimizes windwashing of the attic insulation — where air entering the soffit vents flows through the attic insulation. When installing a raised top plate, place a band joist at the open joint cavities of the roof framing. The band joist helps prevent windwashing, which can reduce attic insulation R-values on extremely cold days and can add moisture to the insulation.

A raised top plate increases the area for insulation and ventilation at the eaves.
Attic insulation techniques

Loose-fill or batt insulation is typically installed in an attic. For batts with attached vapor retarders, put the backing next to the ceiling finish. Although installation costs may vary, blowing loose-fill attic insulation — fiberglass, rock wool or cellulose — is usually less expensive than installing batts and provides better coverage.

Steps for installing loose-fill insulation:
1. Seal all attic-to-home air leaks, especially chases, bypasses, and furr-downs. Most insulation, such as fiberglass and rock wool, does not stop air flow (refer to Airsealing Energy Bulletin).
2. Follow clearance requirements for heat-producing equipment found in an attic, such as flues or exhaust fans. Other blocking requirements may be mandated by local building codes. Use metal flashing, plastic or cardboard bat flaps, or pieces of batt or rigid insulation for blocking.
3. Prior to hanging ceiling drywall, install rafter baffles, to preserve ventilation from soffit vents at eave of roof. To ensure full coverage and reduce spillage, use insulation dams at the soffit, porch and attic access.
4. Insulate over the attic access by attaching a piece of batt insulation or installing an insulated cover box.
5. Obtain complete coverage of the blown insulation at consistent depths. Follow the manufacturer’s specifications for accurate insulation quantity (# of bags per sq ft) and avoid fluffing the insulation.
6. As required by the 1995 Model Energy Code (MEC), make sure the installer:
   • Provides attic rulers to show proper blown depth (one for every 300 sq ft).
   • Provides an accurate attic “Report Card” showing that sufficient density was installed.

Steps for installing batt insulation
1. Seal all attic-to-home air leaks, especially chases, bypasses, and furr-downs. Remember, most insulation such as fiberglass and rock wool, does not stop air flow (refer to Airsealing Energy Bulletin).
2. Block around heat-producing devices.
3. Insulate the attic hatch or attic stair as described in Step 4 for loose-fill insulation.
4. Determine the attic insulation area, based on the spacing of the joists, order sufficient insulation for the attic. Refer to the MEC for the R-value for your area. It is important to cover the top of ceiling joists or bottom cord of truss with insulation.
5. Obtain complete coverage of full-thickness, non-compressed insulation. When installing the batts, make certain they completely fill the joist cavities. Shake batts to ensure proper loft. If the joist spacing is uneven, patch gaps in the insulation with scrap pieces. Do not compress the insulation with wiring, plumbing or ductwork (cut slits in the insulation if necessary).

Energy-efficient cathedral ceilings

Cathedral or vaulted ceilings have limited space for insulation and ventilation within the depth of the rafter. Fitting in a 10-inch batt (R-30) and still providing ventilation is impossible with a 2x6 or 2x8 rafter. The MEC may allow R-19 cathedral ceiling insulation for some house designs, depending on the climatic zone. For most areas, R-25 to R-38 insulation is recommended, if not required. Choose high density R-30 batts, since they are about the same thickness as R-25 batts, and follow the same installation practice.
HABITAT FOR HUMANITY INTERNATIONAL
Buildings for the 21st Century

U.S. Department of Energy: Ceiling and Attic Insulation and Ventilation

Ceiling insulation R-values

<table>
<thead>
<tr>
<th>HDD Zone</th>
<th>Ceiling R-value</th>
</tr>
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<tbody>
<tr>
<td>1 (0-500)</td>
<td>R-19</td>
</tr>
<tr>
<td>2 (501-3,000)</td>
<td>R-30</td>
</tr>
<tr>
<td>3 (3,001-5,000)</td>
<td>R-38</td>
</tr>
<tr>
<td>4 (5,001-6,000)</td>
<td>R-38</td>
</tr>
<tr>
<td>5 (6,001-10,000)</td>
<td>R-49</td>
</tr>
</tbody>
</table>

HDD=Heating Degree Days
(Consult local weather bureau for your city's actual heating degree day range)

Cathedral ceiling insulation techniques
Cathedral ceilings must provide space between the roof deck and ceiling for adequate insulation and ventilation. Cathedral ceilings built with 2x12 rafters have space for standard R-30 batts and ventilation. A vent baffle should be installed between the insulation and roof decking to ensure that the ventilation channel is maintained.

If roof framing provides insufficient space for required insulation, higher insulation values can be obtained, by either framing furring strips (that permit additional insulation to be installed) or by adding rigid foam insulation under the rafters. Both techniques offer a resistance to the thermal bridging effect of the wood rafter. The rigid foam insulation must be covered with a fire-rated material when used on the interior of the building. Half-inch drywall usually complies, but check with local fire codes for confirmation.

Knee walls
Knee walls are vertical walls with attic space directly behind them. Typically, builders insulate the knee wall and the attic floor in the attic space. Unfortunately, the knee wall often receives only R-13 insulation with no protective cover.

Heating and cooling systems and ductwork are often located in the spaces behind the knee wall. Mechanical equipment and ducts suffer leakage and efficiency losses due to the extreme temperature range found in this unconditioned space.

For energy-efficient renovation of an existing home, effort should be devoted to adding more insulation and air-sealing the knee wall. Knee wall insulation should be adequate (refer to chart); installing and sealing the seams of rigid insulation achieves this plus helps to prevent attic air from infiltrating into the house.

In new construction, a better approach is to insulate and air-seal the rafter space along the sloping ceiling of the knee wall attic space. The rafters should receive R-19 to R-49 insulation, depending on the MEC. They should be covered with a sealed air barrier, such as drywall or foil-faced hardboard. The barrier must be caulked to the top plate of the wall below the attic space and to the top plate of the knee wall itself. All other cracks and holes must be sealed as well. The advantage of this technique is that all ductwork is now located inside the conditioned space and benefits from the more even temperatures.
Attic access
Build an insulated attic access cover to provide continuous coverage.

Pull-down attic staircase
Cover box pushes up and out of the way for access
Rigid insulation box forms lid for pull-down attic staircase

Scuttle hole cover
Hatch lid pushes up and out of the way for access
Air seal gasket

Radiant heat barriers lower attic temperatures and may be beneficial in reducing air conditioning requirements.

Radiant heat barriers
Radiant heat barriers (RHB) are reflective materials that can reduce summer heat gain by the insulation and building materials in attics and walls. RHBs work two ways: first, they reflect thermal radiation well and second, they emit (give off) very little heat. RHBs should always face a vented airspace and be installed to prevent dust build-up. They are usually attached to the underside of the rafter or truss top chord or to the underside of the roof decking and may be cost-effective in hot climates.

Attic storage areas
Attic storage areas can pose a problem. If the ceiling joists are shallower than the depth of the insulation, raise the finished floor using 2x4's or other spacing lumber. Install the batts before nailing the flooring in place. If mechanical systems are located in the attic, be sure to elevate the equipment to allow for full-height insulation.

Additional wood can be toenailed to the ceiling joists to increase the available depth for insulation when adding flooring to an attic.

Powered attic ventilators
Create negative pressures in the attic. This can pull conditioned air from the living space as well as contami­nate the indoor air with crawl-space pollutants.

Powered attic ventilator problems
Electrically powered roof ventilators can consume more electricity to operate than they save on air conditioning costs and are NOT recommended for most designs. Power vents can create negative pressures in the home which may have detrimental effects such as:

- Removing conditioned air from the home through ceiling leaks and bypasses
- Pulling pollutants from the crawlspace such as mold, radon, and sewer gases into the home
- Backdrafting fireplaces, water heaters, and fuel-burning appliances
Insulating Foundation and Floors

General guidelines for foundations
The bottom level of a home, whether slab-on-grade, floor over a crawl space, or underground basement, is susceptible to moisture and deterioration problems due to contact with the earth. The best approaches for preventing these problems will depend on the local climate and style of construction, but the same general rules apply to all foundation systems:

- Keep all untreated wood materials away from the earth.
- Provide rain drainage, such as gutters, to conduct rain water away from the house in non-arid climates.
- Slope the earth away from the house for at least five feet at a minimum 5% grade (3 inches in 5 feet).
- Provide a water managed foundation drainage system at the bottom of the footing when the foundation floor (interior grade) is below the exterior grade.
- Insulate between the conditioned and unconditioned portions of the foundation system. In termite-prone areas, extra care should be taken to prevent termites from tunneling through the insulation.

Methods of insulating slab-on-grade floors
Slabs lose energy primarily due to heat conducted outward and through the perimeter of the slab. Insulating the exterior edge of the slab in most sections of the country can reduce winter heating bills by 10% to 20%. Slab insulation is recommended in many localities by the Model Energy Code or state energy codes.

Insulation approaches to termite-resistant, slab-on-grade foundations

- Insulated sheathing
- Copper termite flashing
- Foamed edge loss
- Rigid insulation encapsulated or covered with membrane to protect from termite and exterior damage
- Monolithic slab
- With stemwall slab

Water Managed Foundations
1. Damp-proof below-grade portion of foundation wall — this is to seal the wall against ground moisture penetration.
2. Install drainage plane material or gravel against foundation wall — this relieves hydrostatic pressure and channels water to the drain.
3. Cover perforated drain pipe with gravel and cover with filter fabric. Locate drain beside footing, not on top — this creates an underground gutter.
4. Add sill gasket membrane — this serves as a capillary break to reduce wicking of water from the concrete and provides air sealing.
5. When backfilling foundation wall, slope earth away from house 5%.
The controversy with slab insulation

Over the past decade, reports of termite infestations in homes with slab insulation have become more frequent. These pests tunnel undetected through the foam to gain access to the wood framing in the walls. Some insurance companies no longer guarantee homes with slab insulation against termite damage. Recent rulings by national code organizations prohibit installing foam insulation in contact with the ground in several Southern states.

An alternative to slab edge insulation is to create a contained or floating slab with interior foam insulation. This non-monolithic approach provides termite resistance since the insulation is sealed under and above the slab.

Preventing termite problems is a key goal of any building, especially where a visual inspection of the foundation is not possible. Providing effective moisture control systems will help. In addition, make sure to remove all wood from around the foundation before backfilling.

While termite shields are not generally 100% effective, they should be installed continuously under the sill plate of the building to further inhibit termite infestation. The termite shield should extend beyond other building materials to force termites into an exposed area where they can be detected.

Before construction, confer with a pest control company to approve the design regarding a termite contract.

Insulated Crawl Space Walls — 3 Options

**Crawl space insulation**

For years, standard building practice was to insulate underneath floors over unheated areas. However, studies performed in Tennessee several years ago found that insulating the walls in well sealed crawl spaces and unconditioned basements can be an effective alternative to underfloor insulation.

**Crawl space wall insulation considerations**

- Cover the entire earth floor with sealed 6 mil polyethylene (recommended for all crawl spaces).
- Eliminate or close the foundation vents.
- Provide outside air for combustion to furnaces or water heaters that are located in these areas via a direct inlet duct from the outside.
- Leave a four-inch gap at the bottom of the insulation to serve as a termite inspection strip.
- Insulate and air seal the band joist area.
- Seal exterior walls; insulate and seal crawl space access doors.
- Create effective site drainage, this keeps the crawl space dry—some insulation can easily wick water.
- Review plans for this method of foundation insulation with pest control and local building officials to ensure code compliance.

**Advantages of crawl space wall insulation**

- Less insulation required (around 400 square feet for a 1,000 square-foot crawl space with 3-foot walls).
- Piping and ductwork experience little temperature swing so they may not require insulation for energy efficiency or freeze protection.
- Air sealing between house and crawl space is less critical.
- Because the crawl space remains cool in summer, the home can conduct heat down into the space if there is no insulation under the floor.

**Disadvantages of crawl space wall insulation**

- The insulation may be damaged by rodents or pests.
- A radon mitigation system will require ventilation of the crawl space to the exterior. Not planning for radon-resistant construction may necessitate air sealing the floor in order to mitigate the radon through ventilation.
- If the crawl space has air leakage with the outside, the home will lose considerably more heat than standard homes with underfloor insulation.
Most floors in conventional homes use 2x10 or 2x12 wood joists, wood I-beams, or trusses over unconditioned crawl spaces or basements. Insulation is usually installed underneath the subfloor between the framing members. To meet the Model Energy Code, homes typically need R-11 to R-19 floor insulation, depending on climatic zone.

Before insulating floors, make certain to seal all air leaks between the conditioned (heated and cooled) area of the home and the unconditioned space (crawl space or unheated basement). High priority leaks include holes around bathtub drains and other drain lines, plenums for ductwork, framing for basement stairs, as well as penetrations for electrical wiring, plumbing, and ductwork.

Most builders use insulation batts with an attached vapor barrier for insulating framed floors. The batts should be installed upwards — flush against the subfloor — to eliminate any gaps which may serve as passageways for cold air to flow between the insulation and the subfloor.

The orientation of the vapor barrier depends on the home's location. In most of the country, the vapor barrier should face upwards. However, in certain regions of the Gulf states and other areas with mild winters and hot summers, it should face downward.

Steps in installing underfloor insulation
- During the early phases of construction, meet with the mechanical subcontractors (plumbing, electrical, and heating/cooling) to inform them of the importance of keeping the space between floor joists as clear as possible.
- Run drain lines, electrical wiring, and ductwork below the bottom of the insulation so that a continuous layer can be installed. Be certain to insulate all duct work in unconditioned spaces. For freeze protection, supply plumbing may be located within the insulation. The best approach is to run supply plumbing together in a few joist spaces. The insulation can be split and run around the piping.
- Install a sealed layer of 6-mil polyethylene on the floor to reduce moisture levels in the crawl space. Lap polyethylene 6" up walls, overlap sections 12", and tape seams.
- Seal all holes and penetrations between the crawl space or unheated basement and the house.
- Obtain insulation for the proper joist spacing of the floor being insulated. Complete coverage is essential — leave no insulation voids and be certain to insulate the band joist area.

Are Foundation Vents Necessary?
Most building codes require crawl space vents to aid in removing moisture from the crawlspace. However, ventilation in the winter is undesired in order to keep crawlspace warmer. Furthermore, warm, moist outdoor air brought into the crawl space through foundation vents is often unable to dehumidify a crawlspace in many summer conditions and, in fact, can lead to increased moisture levels in the crawlspace.

For example, a crawlspace kept cool by the ground in the summer may have a temperature of 65°F and 90% relative humidity (RH) — the dew point temperature of the air is 62°F. The dew point of outdoor air at 90°F and 60% RH is about 74°F. Thus, outdoor air brought into the crawlspace will actually increase the moisture level until water condenses out on cool crawlspace surfaces such as floor joists and foundation walls. As framing stays moist, mold grows and dry rot develops.

Venting crawlspace which have air-conditioning ducts is a particular concern. Typically, the ductwork is leaky, poorly insulated, and creates a cold surface below the air’s dew point that causes moisture in the air to condense. Often, water accumulates in the duct insulation. Many building professionals are now recognizing that an unvented crawlspace (or closing crawlspace vents after the crawlspace has had time to dry out after construction) is the best option in homes using proper moisture control and exterior drainage techniques. However, get local code approval before omitting vents.
Build in radon resistance
Radon is a radioactive gas that occurs in some soils. It can enter a home through the foundation and floor system. If it occurs in significant concentrations (greater than 4 picocuries per liter), it may pose a severe health risk to the home occupants. To guard against radon problems:

Slab-on-grade or basement
- Use a 4-6” gravel base.
- Install continuous layer of 6-mil polyethylene.
- Stub in Tee below polyethylene that protrudes through polyethylene and extends above poured floor height.
- Pour slab or basement floor.
- Seal slab joints with caulk.

Crawl space
- Install sealed, continuous layer of 6-mil polyethylene.
- Install Tee below polyethylene that protrudes through polyethylene.

All foundations
- Install a vertical 3-inch PVC pipe from the foundation to the roof through an interior wall.
- Connect the Tee to the vertical 3-inch PVC pipe for passive mitigation.
- Have electrician stub-in junction box in attic.
- Test the bottom conditioned room for radon with an EPA-listed radon test kit or hire a qualified technician.
- If the house has high radon concentrations, install an active radon mitigation system by attaching a small blower to the PVC pipe in the attic to expel the gasses to the outside.
- Contact the Environmental Protection Agency for more information.

Planned radon-resistant construction is an inexpensive first-cost. If needed, it can easily be upgraded if active mitigation is later required to cure a high-radon problem.