STEP 3

CREATE A SUPER STRUCTURE

We will now design the physical structure that encloses the space layout that you created previously. This structure is what protects you from the forces of nature. It largely determines your comfort and your energy costs. As we design your structure, we will stress energy efficiency, strength, and longevity.

Your super-home will be built using mostly conventional construction materials and practices, so we will start with a quick tour of conventional home construction. Then, we will introduce four important design advances that apply throughout the structure. Armed with that knowledge, we will optimize each part of the structure individually, from the foundation to the roof.

This Step is the longest of the Eight. That's because there are several good ways of building a house, and we will cover the best options for different situations that may exist at your home site. In addition, we will introduce a number of valuable innovations.

We will get through this Step easily because we break it down into bite sized pieces. Remember, it's not your job to become an expert builder, but to apply to your design the advanced features that turn a conventional house into a super-house.

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HOW HOUSES ARE BUILT: THE MINIMUM YOU SHOULD KNOW

The construction of your super-house will be mostly conventional. It will use well-proven materials and mostly standard construction methods. So, let's spend a few moments to get familiar with the fascinating subject of house construction.

Knowing about house construction will add to the fun of planning your dream house. It will build your confidence in dealing with your builder. If you decide to hire design assistance, understanding construction will help you to express your desires more effectively. And, you will save money by being an educated client.

House construction has become highly standardized. That is mostly good. It allows a small number of workers to erect the frame of a house within a few days, and it allows small teams of specialists, such as plumbers, electricians, and drywall installers, to install the interior components within a few more days. Standardization of components provides economy and reliability in construction, and it still allows almost unlimited variation in architectural style.

To get the most benefit from this overview, visit construction sites to observe how houses are built. If you can, follow the construction of a few houses from the foundation to completion, so you see how the pieces fit together. House construction is logical and easy to understand. You will be pleased at how quickly you learn the process.

We will introduce important innovations into the design of your structure. This quick tour will provide you with a baseline for understanding how your super-home differs from conventional homes. And, if your builder sees that you understand basic construction, he will be comfortable in making the changes to his own past practices that your design introduces.

Houses are built from the ground up, so let's begin our tour of construction practices at the bottom.

THE UNDERGROUND STRUCTURE

Today, most houses use concrete construction at grade level and below. ("Grade" is builder language that means the top of the finished soil level.) Concrete or stone is needed where the house contacts the soil to resist destruction by moisture and by insects.

If the climate allows the ground to freeze, the foundation usually must extend below the frost depth to prevent "frost heaving" (which we explain later). If the foundation supports a frame structure, the foundation is extended well above the surrounding soil level to protect the wood from contact with the soil.

The foundation must support the structure at every part of its footprint. This may be done with a continuous foundation that supports the outer walls of the house, with concrete or masonry piers, or with a combination of the two. For example, common North American practice is to support the outer walls with a continuous perimeter foundation, and to support interior load-bearing walls with columns and a center beam.

Soil has limited ability to carry the weight of a house. Therefore, unless the house is built on solid bedrock, the bottom of the foundation rests on a broadened concrete base that is called a "footing." Figure 3-1 shows how the soil is excavated in preparation for making the footings.

The main footing follows the outline of the outer walls. Individual footings are created for columns that support the structure inside the outer walls. Additional footings may be laid for exterior stairs, porches, and so forth. Figure 3-2 shows the completed footings for a house.

If the house has a basement, the basement walls are built next. A poured concrete wall resting on a good footing can produce an excellent foundation with great strength. Before the concrete is poured, wooden or steel forms must be erected to hold the concrete, as in Figure 3-3.

Figure 3-4 shows how concrete is pumped into forms using modern equipment. Figure 3-5 shows the completed foundation wall. Once the footings are completed, a well organized crew can erect a complex foundation in two or three days.

The thickness of underground walls is determined primarily by the need to resist buckling by soil pressure. The parts of the wall that are farther below grade need to be thicker. However, to simplify construction, poured concrete foundation walls typically have the same thickness from top to bottom.

Prior to the use of poured concrete foundations for houses, foundations commonly were built from stones. Later, concrete blocks or cinder blocks were used, and they are still used as a cheaper alternative to poured concrete. Concrete blocks have hollow cores, reducing the amount of material required. And, forms are not required. However, the resulting foundation is weak. It is prone to sidewise buckling from soil pressure. It is vulnerable to cracks at the mortar joints, which are caused by uneven settling of the soil under the footing. The cracks and the hollow cores of the blocks admit water, radon, and insects from the surrounding soil. Therefore, we consider concrete block house foundations to be obsolete and unsatisfactory.

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Figure 3-1. Excavation for foundation footings. The soil has been excavated and flattened to bring the entire lower floor below the frost depth. Trenches are then dug for the footings. In this loose soil, the trenches are lined with boards. Steel reinforcing rods are supported within the trenches to strengthen the footings. In addition, five holes have been dug to act as forms for individual footings for columns that will support the interior structure of the house.

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Figure 3-2. Completed footings. Grooves along the centers of the footings act as keyways to prevent the foundation walls from being pushed off the footings by soil pressure. This foundation also has four individual footings to support interior columns. Only one was poured when the picture was taken.

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Figure 3-15. "Platform" construction for a wood frame house.

has a basement, a strong horizontal beam, which may be steel or lumber, supports the inner portions of the ground floor platform, as we saw in Figures 3-9 and 3-10. The inner portion of the beam rests on columns in the basement. The columns transmit the weight of the center of the house to the earth through individual piers or footings, as shown in Figure 3-6.

After the floor joists and rim joists have been installed, the "subfloor" is laid over them, as in Figure 3-20. The subfloor is the top surface of the platform. It is called the "subfloor" or "underlayment" because the visible finished floor surface (carpet, tile, hardwood, etc.) is laid over it. The best subfloor material is real plywood. If a plywood surface is attached to straight joists with glue and nails (or screws), the resulting floor is strong, level, and quiet.

Unfortunately, chipboard and similar cheaper materials are being substituted to reduce cost. At the same time, subfloors are being made thinner, resulting in floor surfaces that are weak and yielding.

Once the floor platform is complete, the exterior and interior walls are erected on it. The subfloor is a large, flat surface, so it is ideal for assembling parts of the wall. Often, an entire wall is assembled on the floor, and the wall is then lifted into position, as in Figure 3-21.

Frame walls are made of vertical wooden members called "studs." The studs usually rest on horizontal members called "sole plates" or "bottom plates." The bottom plates hold the bottoms of the studs in position, they distribute the weight carried by the studs, and they provide a nailing surface for the interior and exterior wall sheathing. Similarly, the tops of the studs are joined by horizontal members called "top plates."

The walls are built with framed openings for the windows and doors, as in Figure 3-21. "Headers" are installed at the tops of these openings to carry the weight of the structure above the openings. The bottoms of window openings are horizontal timbers called "sills." Headers and window sills are supported by shortened vertical members called "jacks," "cripples," or "trimmers."

After all the wall panels are built, they are joined at the corners. When the next floor or the roof is added, the result is a rigid box that can be enormously strong. To achieve the potential strength of the structure, the connections between the wall panels, the floor platforms, and the roof must be as strong as these components. Strong connections are easy to make in frame construction, but they are often inadequate in practice, making the house vulnerable to wind, earth movement, and sagging.

After the wall frames are built, they are covered with rigid exterior sheathing, as in Figure 3-22. In addition to creating an airtight wall, the sheathing also is an important structural component. It provides rigidity to the wall, preventing it from tipping sideways. (You can see old frame houses and barns that have collapsed sideways because they lacked adequate diagonal bracing in their walls.)

The sheathing also reinforces the wall studs, adding to the load carrying capacity of the wall. And, the sheathing serves as the base for lightweight exterior finish surfaces, such as siding or shingles.

Plywood is the strongest and most reliable sheathing material, but it is being replaced in cheap construction by chipboard and similar materials. It is bad practice to use any kind of insulation board as sheathing, although this has become a common way of increasing the insulation value of walls.

The exterior sheathing may be attached to the wall frame before or after the wall is erected. Installing the sheathing beforehand adds rigidity to the wall segment as it is being erected, improving safety and keeping the

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Figure 3-16. A "sill plate" being installed on the foundation. This is the first step in platform frame construction. The sill plate is anchored to the foundation with bolts that are embedded in the concrete. The pink strip between the sill plate and the foundation is "sill sealer." It prevents air leakage through the gap between the lumber and the concrete.

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Figure 3-17. The floor joists being installed on the foundation. The outer ends rest on the sill plates. The inner ends rest on beams and/or load bearing walls that were built as interior parts of the foundation. These floor joists are made of composite "I-joist" material, which is now prevalent. However, some houses still use the older style of solid timbers, which have both advantages and disadvantages.

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INSULATION MATERIALS FOR HOUSES

"Insulation" is anything that blocks the movement of heat.

Okay, what is "heat"? It is the random thermal jiggling of the molecules in matter. Heat flows through matter when molecules with more energy bump into molecules with less energy. This process of heat movement is called "conduction."

It is possible to block all heat conduction by creating an empty zone that has no matter. This is the principle used in a thermos bottle, which has a double-walled shell with vacuum inside. Unfortunately, nobody has yet invented a cheap and reliable vacuum container for large surfaces, such as the walls of a house.

The next best thing to vacuum is a gas, in which the molecules are far apart and don't bump into each other very often. Virtually all home insulation uses a gas as the insulating material. Air is the most common gas used in insulation, because it is everywhere. The big limitation of using air for insulation is that it moves easily, and it carries heat when it moves.

Fortunately for insulation, air has a tendency to form a thin, sticky layer on the surfaces of solid materials. Common porous insulation exploits this stickiness to keep air from moving. Such insulation has a lot of surface area with small air spaces, so that all the air inside the insulation can stick to a nearby surface. The shape of the solid material does not matter much. For example, some insulation is made from fibers, other types are made from granules, some is made from shreds of paper. However, the sticky forces that hold air in porous insulation are weak. For this reason, all porous insulation must be protected from wind and drafts.

Another method of keeping an insulating gas from moving is to enclose it in bubbles. This is the principle of plastic foam insulation, as well as some less common materials, such as foam glass and neoprene insulation. Using closed bubbles offers an additional advantage, which is the ability to use gases that have better insulation value than air.

Good insulation contains so little solid material that most heat conduction occurs through the gas. Still, heat loss through the solid material is significant. For this reason and to reduce cost, manufacturers minimize the amount of the solid material. That's why all good insulation is light in weight.

There is another way that heat moves, which is by radiation. When the molecules in solid matter bump into each other, they get excited and radiate energy. This radiated energy is another form of heat. Heat radiation inside insulation is not a big factor, because the radiation is captured inside the insulation itself. However, heat radiation between windows and the inside of a house is more important, as we will learn when we select your windows.

Now that we understand the concept of insulation, let's look at the types of insulation that are used in houses.

Glass and Mineral Fiber Insulation

"Glass" fiber insulation is made from melting a mineral, such as silica sand, and spinning it into fine fibers. Glass fiber insulation is presently the dominant type for wood frame buildings. Its overwhelming advantage is fire safety. The material itself will not sustain a fire, and if it is installed properly, it will deter the spread of fire through a wooden structure. Beyond that, it has reasonably good insulation value and it is relatively inexpensive. It is fairly easy to install, but installation requires more care than it usually gets.

"Mineral wool" or "rock wool" is similar to fiber glass, but it is made from a broader range of materials, such as basalt rock, limestone, or boiler slag. Its insulation value is similar to that of fiber glass. Typically, it looks dirtier. The choice between the two is mainly a matter of availability and price.

All fiber insulation has one big disadvantage, a lack of resistance to the flow of air or water vapor. To keep wind and drafts from blowing heat through fiber insulation, it must be enclosed. To block the flow of water vapor into fiber insulation, it must be supplemented with a separate "vapor barrier."

The hard, brittle glass or mineral fibers are a safety hazard during handling. They can penetrate eyes and skin, and there is suspicion that they may cause lung disease if they are inhaled. After installation in the house, the material is harmless unless it is disturbed.

Fiber insulation is available in the form of batts, loose fill, and semi-rigid boards. Each type is applied in different way.

■ Batts

A "batt" is a blanket of glass or mineral fibers that is made to a controlled width and thickness. The fibers are held together by a small amount of adhesive. Batt insulation is available in a variety of widths to accommodate common joist and stud spacings. Batts are also available in a wide range of thicknesses.

In most locations, glass and mineral fiber batts are the best all-around insulation for frame walls, floors, and ceilings. Batt insulation is also a prime choice for insulating the interior of masonry walls, as we will explain. The material usually is packaged in compressed rolls, as in Figure 3-35. Batts can easily be cut to the desired length with scissors, an electric carving knife, or similar tools.

Owens Corning

Figure 3-35. Glass fiber batt insulation, as usually packaged.

Johns Manville

Figure 3-36. Glass fiber batt being installed in a frame wall. Note that the tabs of the backing sheets are overlapped properly, creating an unbroken vapor barrier.

Batts are available in three styles. One is without a backing sheet, as in Figure 3-35. Another has a paper backing sheet that is impregnated with a tar-like moisture retardant, as in figure 3-36. And, a third type adds an aluminized coating to the backing sheet. Each of these types has its proper application, and it is important to know where to use each kind. Using the wrong kind can cause serious moisture trouble.

The backing sheets on batts have two functions. One is to hold the batt securely in place between wall studs, roof rafters, or floor joists. The other function is to serve as a vapor barrier.

The paper backing sheet has tabs on each side, about one inch (25 mm) wide. The tabs should be stapled to the face of studs, rafters, and joists, as in Figure 3-36. This provides secure positioning and a well overlapped vapor barrier. Unfortunately, builders often fail to use this valuable feature, so you need to discuss it with your builder.

Aluminum foil backing is also supposed to improve insulation value during cold weather by reflecting heat radiation from the interior of the house back into the house. For reasons that are rather technical, foil backing provides no significant benefit in a wall that is completely filled with insulation.

Certainteed

Figure 3-37. Proper installation of batt insulation in an attic. The upper layer or layers must have no vapor barrier, so that moisture can vent into the attic space. The crisscrossed arrangement of the batts provides optimum resistance to heat leakage along the joists and between the batts.

Plain batts, without a backing sheet, are needed where moisture must vent through the insulation. This includes the upper layers of attic insulation, as in Figure 3-37, and basement wall insulation.

In the United States, the width of batts is determined by the common spacings for studs and joists, which are 16" (400 cm) and 24" (600 mm). The thickness of common timber studs and joists is 1½" (38 mm), so most batts are made narrower than the stud spacing

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If your house will have concrete block walls above grade, the top of the basement wall (not including any brick shelf) should be at least as wide as the concrete blocks.

However, it is not necessary to make the foundation wall as thick as a super-insulated frame wall. That's because only the outer part of our super-insulated wall design carries the weight of the structure. (We will explain this under the heading, *Fabricated Wall Studs for Colder Climates*.)

How should the rebar be installed? The key to resisting soil pressure is to give the wall tensile strength on its inside surface. Remember that concrete itself is strong only in compression, and steel reinforcement is needed to resist tension. The stress that tends to break the wall occurs at the inner surfaces of the large, flat central portions of the wall, and at the top edge. Therefore, in these areas, ***the concrete contractor should place the rebar toward the inside surface of the wall***.

The rebar that is located in the central portions of the wall should be installed diagonally, for the reasons explained when we discussed shear wall foundations. The diagonal orientation braces the wall both vertically and horizontally. To resist buckling from soil pressure, the wall needs vertical bracing. To resist bowing, the wall needs horizontal bracing.

At the bottom of the wall, the builder should install horizontal rebar near the center of the wall thickness. This is to strengthen the wall against settlement of the soil underneath the footing. The rebar in the footing performs the same function. However, if the wall is poured separately from the footing (the usual practice), the wall itself needs reinforcement along its bottom edge.

At the corners, bend rebar into right angles and place it horizontally inside the wall to keep the corners intact.

Some concrete contractors know how to exploit the strength of rebar most effectively, and some don't. The main point is to locate the rebar strategically at the places where the tensile load on the concrete is greatest.

Does the distance between corners matter? Yes, it does. A wall cannot tip inward at a corner, but it can do so between corners. So, the top of the wall tends to bow inward horizontally between the corners. This tendency increases with the distance between the corners.

One solution is to make the wall thicker for greater distances between corners. Unfortunately, the *International Residential Code* does not seem to recognize this issue, so it does not relate wall thickness to the distance between corners.

Another solution is to add more corners to the basement wall. We'll discuss that next.

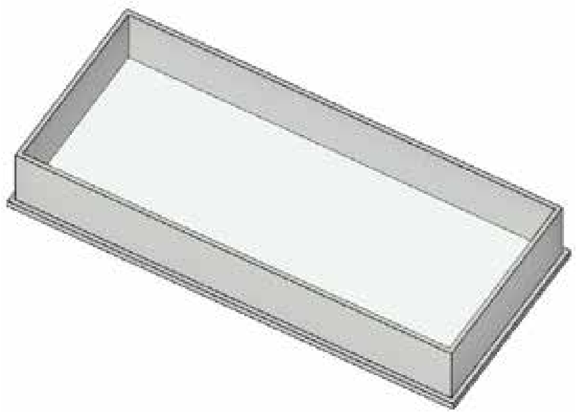

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Figure 3-104. A rectangular shear wall foundation provides excellent protection against irregular settling of soil under the footing. However, the long walls are susceptible to toppling by soil pressure from the side.

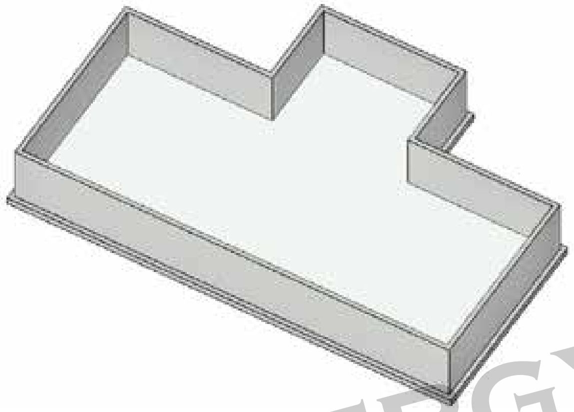

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Figure 3-105. Adding corners shortens the length of the wall segments and buttresses them against both toppling and buckling. However, the wall is no longer a continuous beam from one end of the house to the other, which somewhat increases susceptibility to soil settling under the footing.

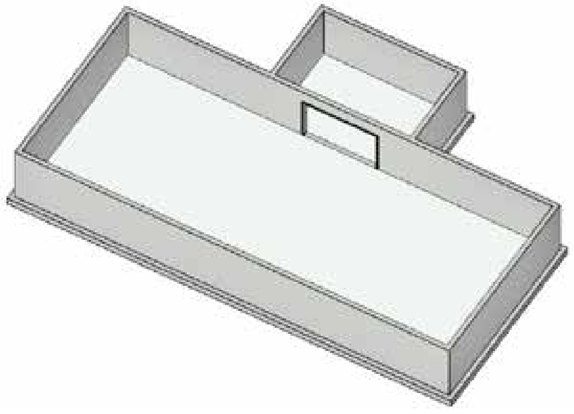

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Figure 3-106. A basement wall design that combines the strengths of the previous two designs. The long wall is still a continuous beam, with a continuous footing below the opening and a header above it.

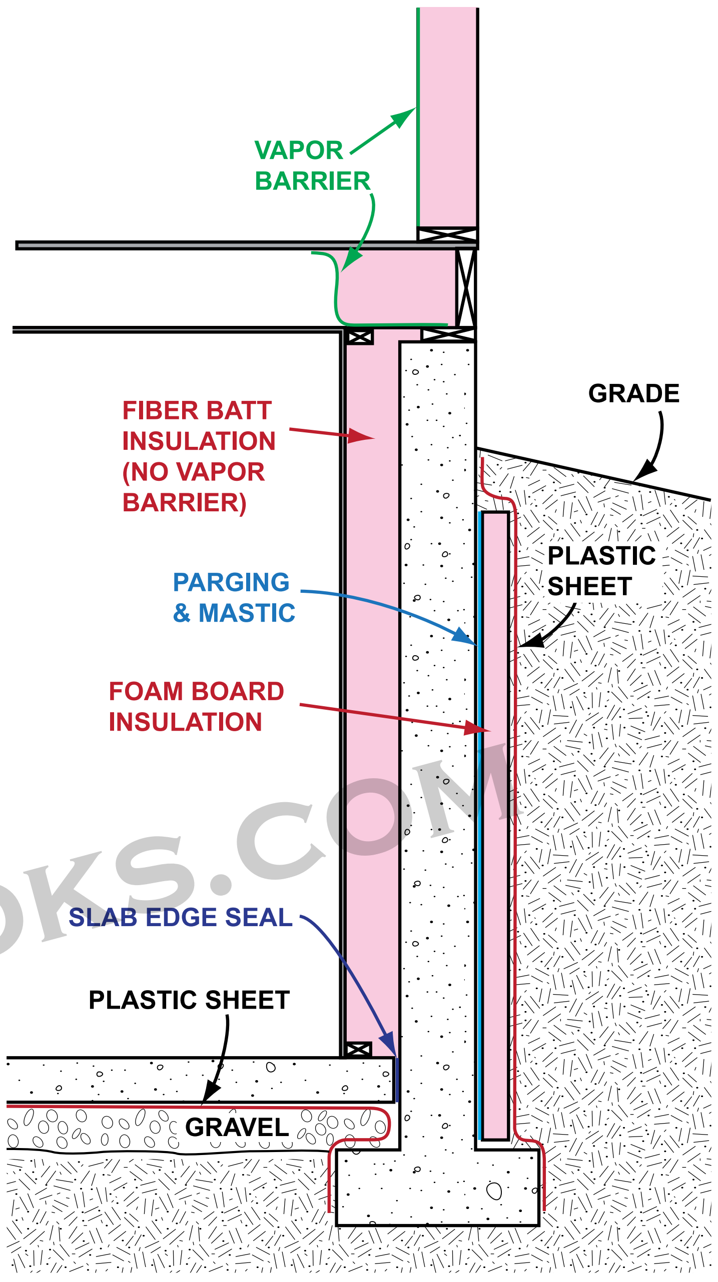

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Figure 3-107. Protection of a basement from water and radon in the soil, in a location where ground water is not a problem. The exterior and interior basement wall insulation is appropriate for a cold climate.

■ Add Corners to Strengthen Basement Walls

Previously, we observed that soil pressure may cause a basement wall to fail by tipping the wall inward or by pushing through it (buckling). You can strengthen your walls against both kinds of failure by adding more corners to the walls.

A basement wall is flat, which is a shape that does not resist soil pressure efficiently. By building corners into the footprint of the house, we can stiffen the basement walls, as shown in Figures 3-104, 3-105, and 3-106. The additional corners strengthen a wall in two ways. They brace the wall, and they reduce the length of the individual wall segments.

To see how well this works, use a sheet of paper as a model for a basement wall. Make some folds in the paper, as in Figure 3-105, and you will see how dramatically the corners stiffen the sheet.

Corners may also provide an appearance enhancement for the house by breaking up large, flat wall surfaces, as we recommended in Step 1.

Can you make a basement wall thinner if you add corners or other kinds of buttressing? We don't know. The *International Residential Code* does not recognize corners as a factor in wall thickness. If a basement wall is exceptionally long, buttress it in some reliable fashion, preferably with corners. Otherwise, simply follow the thickness requirements of the building code.

KEEP OUT WATER AND RADON

As we discussed previously, under *Water in the Soil*, basements need protection from water in the surrounding soil. The water comes from rain that soaks into the soil and from underground sources ("ground water").

The goal is not just to keep water out of the interior of the basement, but to keep the entire underground structure dry. Water that penetrates the wall can freeze and crack the concrete. Water will rust the steel reinforcements, causing them to swell and crack the concrete. If water continually seeps through a wall and then evaporates, the concrete will become powdery and weak in the wet areas.

Homebuilders should know how to protect basements from underground water, but actual building practice often is deficient. The principles and methods are easy to understand. The key points are:

1. ***Make your walls, foundation, and floor slab resistant to water penetration.***
2. ***Grade the soil around the house to shed rainwater and snowmelt away from the house.***
3. ***If there is underground water near the basement level, drain it away from the foundation.***

Blocking water entry into your basement also blocks radon. Coordinate your moisture protection features with the "radon mitigation" features that we covered earlier.

Figures 3-107 and 3-108 summarize the main features that we will discuss for protecting your basement against water and radon. The Figures also show the basement insulation, because water protection and insulation are done together.

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COOL ROOFS FOR WARM CLIMATES

If you touch a roof surface that is exposed to the sun, you may be surprised by how hot it is. Hot surfaces are one of the hallmarks of modern roofs. Common roofing materials absorb a majority of the solar heat that falls on them, and their impermeable nature prevents cooling by circulation of air through them. In contrast, traditional roofing materials, such as wooden shingles, remained relatively cool.

As air conditioning has become a major cost in warm climates, awareness that modern roofs are hot has made "cool roofs" a hot topic. But, just how important are they? If your roof is super-insulated, why should you care about the roof temperature?

The answer is that heat flow through insulation is proportional to the temperature difference across the insulation. If the average temperature difference doubles, it's like eliminating half your insulation. In fact, a hot roof can double or triple the daytime temperature difference across the ceiling insulation. Keeping your super-insulation as cool as possible can reduce your air conditioning energy consumption during a hot day by a few hundred watts. Also, a cool roof will improve your comfort when you are not using air conditioning.

But, let's be clear about this. ***The insulation is by far the most important feature that blocks solar heating through the roof.*** All the other features of a "cool roof" serve only an auxiliary function, which is to reduce the temperature difference across the insulation. An effective "cool roof" keeps the temperature of the outer surface of the roof insulation near to the temperature of the outside air. A super-insulated roof that is "cool" offers a relatively small advantage compared to a super-insulated roof that is not "cool," and it offers that advantage only during warm weather.

If a "cool roof" lowers your cooling cost during warm weather, will it increase your heating cost during cold weather by depriving your home of solar roof heating? Yes, but very little. Solar heating of roofs is not a big factor in winter, when the days are short and the sun remains low in the sky. And, heat radiates from the roof deck to the insulation only weakly when the roof deck is at winter temperatures.

So, tailor the "coolness" of your roof to the location of your home. In a predominantly warm climate, design a "cool roof" using techniques that are economical and reliable, which we will learn. If your home is located in a climate that is primarily cool or cold, there is no value in a cool roof.

If you live in a climate that has both warm and cold seasons, limit your cool roof design to the most economical techniques. In that climate, you don't have to agonize about fine tuning the coolness of the roof, because the super-insulation under the roof minimizes both cooling and heating requirements.

Bear in mind that some roof warming is always good. Many buildings that are centuries old have their original roof structures, even though the surface materials may have been replaced many times. This remarkable endurance owes largely to warming of the roof surface by the sun, which lowers the relative humidity throughout the roof structure.

Warming the roof deck by only a few degrees above the outside air temperature is sufficient to banish condensation. In addition, solar warming helps to evaporate water that enters from small leaks, so the wetness does not linger long enough to cause rot. Fortunately, almost any roof surface – even a "cool" surface – is warmed enough by daytime sunlight to provide this protection.*

Finally, remember that heavy shading of the roof, especially by trees, is the most effective method of keeping a roof cool. Shading of your entire house will keep the roof temperature close to the outside air temperature. But, before committing to tree shading, go back to Step 2 and review its limitations and challenges.

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ELEMENTS OF A COOL ROOF

A "cool roof" is not a specific design, but a design goal, which is to keep the top of the ceiling insulation as cool as possible. Your design can approach that goal by using one or more of these three techniques:

1. ***Select a roof surface that stays cool in direct sunlight.*** The technique offers a significant benefit with all roof types, and it may cost nothing. The effect of roof surfaces on cooling is poorly understood at present. We will learn how to make the most effective choices.
2. ***Ventilate the space between the roof surface and the insulation.*** This technique affects the structural design and appearance of the roof structure. It has the greatest potential in a truss roof. Roof ventilation has long been used for cooling, but rarely to its full potential.

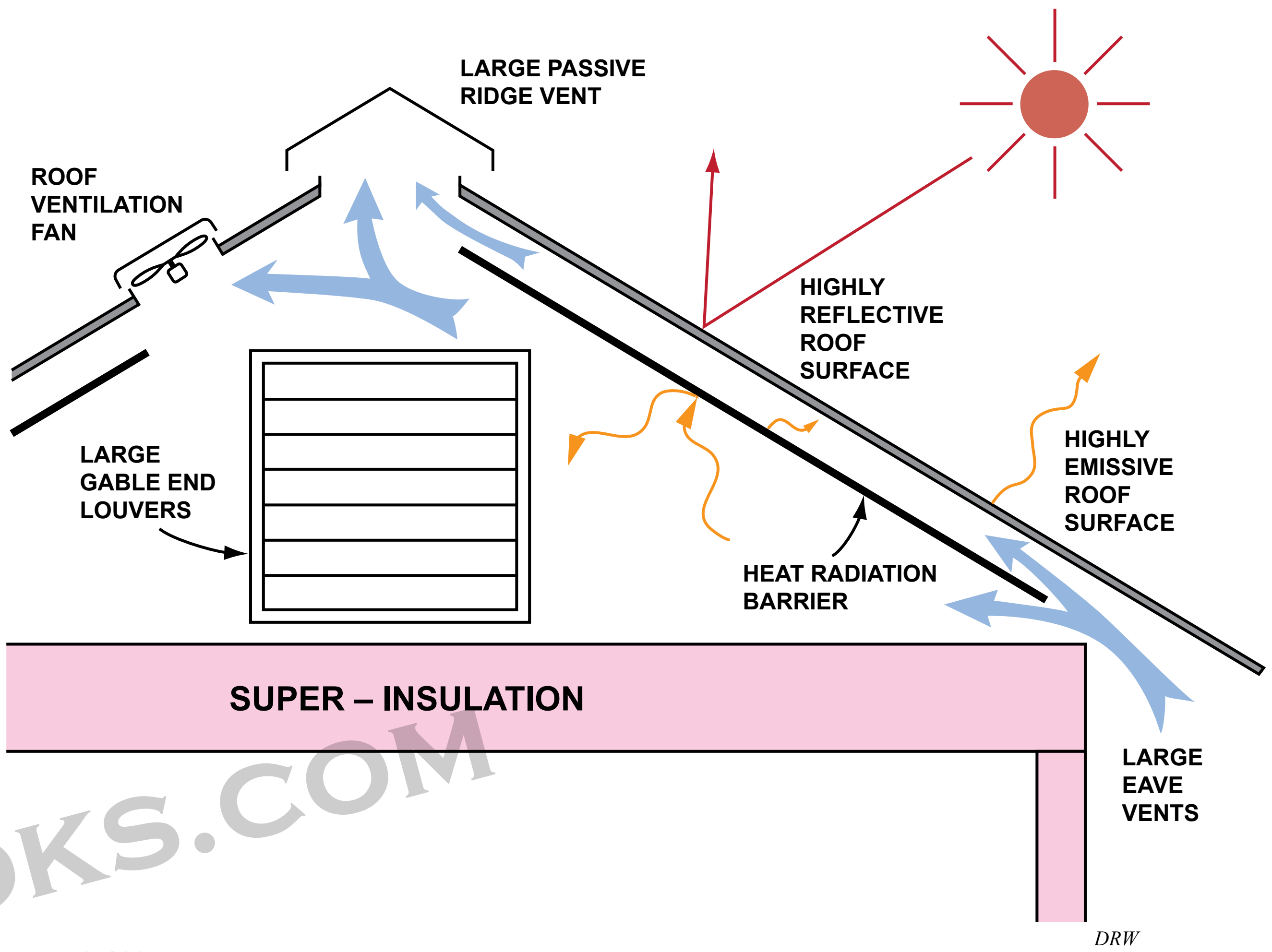

Figure 3-189. The elements of a "cool roof."

3. ***Block heat radiation from the underside of the roof surface to the ceiling insulation.*** This technique is relatively new and unproven, using a heat barrier material that is installed under the roof deck. The material is inexpensive. Installation is easy in a truss roof. It may interfere with insulation and cooling air flow in a beam or triangle-frame roof.

The elements of a cool roof are illustrated in Figure 3-189. Let's examine them at a level of detail that will allow you to design an outstanding "cool roof."

COOL ROOF SURFACES

The roof surface is the hottest part of the roof because it is directly exposed to the sun's heat radiation. It is the front line of defense against solar heat because a majority of solar energy can be blocked here. The color and other properties of your roof's surface material determine how far the roof's temperature can rise. By paying attention to your options when selecting your roof's surface, you can lower the roof temperature over a wide range, at no additional cost.

The temperature of a roof surface is the net result of three competing forces, (1) heating by sunlight, (2) cooling by radiation of the roof's heat into the sky, and (3) conduction of heat between the roof and the surrounding air.

At the beginning of a clear day, heating by the sun greatly exceeds radiation from the roof, so the roof temperature rises. Later in the day, the roof temperature reaches the point that the heat input from the sun is balanced by the combination of heat radiation from the roof and heat conduction to the surrounding air.

Table 3-5, *Maximum Solar Temperature Rise of Roofing Materials*, shows how hot a roof can become if it is heated by maximum sunlight and if there is no wind. The numbers represent a worst case that does not occur often. However, the relative sizes of the numbers are a valuable guide for selecting your roof surface materials.

If direct sunlight is blocked, the heating effect of the sun is reduced to a small fraction of the heating by direct sunlight. This happens if the house is heavily shaded by trees. Cloud cover also greatly reduces roof heating. So, don't go to extremes to achieve a cool roof if you will have tree shading, or if your climate is usually cloudy during warm weather.

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* For example, consider damp weather when the outside air temperature is 68 °F (20 °C) and the relative humidity is 100%. If solar heating increases the temperature of the roof deck by 9 °F (5 °C), it lowers the relative humidity on the underside of the roof deck to 74%. This is more than adequate to prevent condensation.

WINDOW SELECTION GUIDE

USAGE ISSUES

Let's begin our selection of the windows with the characteristics that matter to the people who will use them, including the people who will clean them and the people who will see them as part of the house's appearance.

☐ Size and Shape

Windows that open are rectangular, unless you can spend a fortune for a custom shape. If you have a wall where you want to install a non-rectangular window, you can combine a rectangular openable window with a fixed window of another shape.

Manufacturers offer some standard fixed windows with non-rectangular shapes, especially involving half circles (called "fanlights"). Be careful about using such shapes. One or two may be a nice accent, but don't overdo it. They complicate the wall framing, and they may be difficult to replace or to repair in the future.

All or most of your windows will be standard items that have prefabricated frames. For those, it is important to know the exact dimensions of the part of the frame that fits inside the wall opening. The gap between the window frame and the wall opening should be less than one half inch (12 mm or less) in width and height. This is necessary for easy installation, strong support of the window, and reliable sealing against air leakage.

In the past, window dimensions were fairly standard, so carpenters could build the window openings before the windows were bought. Unfortunately, this is no longer true. After you identify the window models you want, check the catalogs for a drawing that shows the exact dimensions. Or, order the windows before you build the walls, if you have a safe place to store them during construction.

Fixed windows without frames are made on a custom basis, so you can get almost any dimensions or shape that you want. Polygon shapes are especially easy to make because they have all straight edges. But, avoid acute angles, which are vulnerable to breaking off. Segments of circles and other curves can be made by glass shops having the appropriate equipment. To reduce cost, talk to the fabricator about designing the shapes and sizes of your windows to minimize waste of glass when the window is made.

Openable windows are limited in size by the weight of the glazing. Triple-glazed and intrusion-resistance glazing is heavy, limiting openable windows to smaller sizes. The maximum practical size depends on the method of opening.

☐ Fixed or Openable?

Should your windows be fixed or openable? Make this decision for each window individually, but avoid an unattractive patchwork of different window types. Common reasons to select ***openable windows*** are:

- Cooling ventilation during warm weather. This requires fairly large openings.
- Ventilation for air quality. This requires only a small opening.
- During warm weather, openable windows can quickly vent moisture from a damp space, especially a shower room or a toilet room.
- Occupants can talk to people outside the house through an opened window.

Common reasons to select ***fixed windows*** are:

- Fixed windows costs less, because the frames are much simpler. However, a mass market openable window may cost less than a custom fixed window.
- Double and triple glazing is practical in much larger sizes than in openable units.
- Fixed glass without a frame can be made in non-rectangular shapes at modest cost.

In the past, openable windows were a major path for heat loss during cold weather. But today, the best windows have little air leakage, typically less than the ventilation needed for good air quality. Sealing against air leakage is achieved with effective seals (weatherstripping), well designed latches, and rigid frames.

So, make a window openable if it is useful for ventilation or for communication to the outside. Otherwise, use fixed glazing. For example, fixed glass may be best for clerestories and for other glazing that is used primarily for daylighting and passive heating.

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☐ Styles of Openable Windows

For your openable windows, you have a range of style options, which are summarized in the following chart, along with the issues to consider in making the choice.

Air leakage has been a major comfort and energy efficiency issue with windows for as long as openable windows have existed. Today, most styles of openable windows are capable of sealing tightly when they are closed, but this quality comes at a cost premium with some designs. Double-hung windows are especially difficult to seal reliably.

Any kind of window in which more than one pane or sash is moved by a single actuator invites air leakage. The extreme case is a jalousie window, which is limited to climates and applications where air leakage matters little.

Beware of windows that require actuators with gears and linkages. These are usually made of cheap metal that wears out quickly. If your window style requires an actuator, select a window model that allows the actuator to be replaced easily. Even so, replacement parts won't be available throughout the life of the house.

An important innovation that we suggest for colder climates is installing two complete window assemblies in a wall opening, one inside the other. (See *Tandem Windows: a Big Energy Saver*, in Step 3.) If you use that technique, you need to select opening styles that work well together. It is not necessary for both windows to be the same type. For example, the inner window could be a slider model, and the outer window could be an awning model. To avoid condensation on the outer window, the inner window must be able to maintain tighter sealing against air leakage than the outer window.

☐ Ease of Cleaning

Unless the windows are easily accessible for cleaning from the outside, favor window styles that allow you to clean the outer surfaces from inside the room.

Hopper, inward-swinging casement, and tilt-turn windows are easy to clean from the inside,

It is virtually impossible to clean an outward-swinging casement window or an awning window from the inside.

If you install horizontal or vertical slider windows, select models that make it easy to remove the moving sash, or to tilt it inward. Otherwise, you won't be able to clean the outside surface of the moving sash from inside the room.

If you plan to clean your windows from the outside, arrange the landscaping around your home for easy access to the windows.

☐ Internal Shading Devices

Some windows with double glazing include adjustable shading louvers between the panes of glass. Reject this feature. In principle, it provides slightly more efficient shading than a separate shade installed inside the window. However, the internal shading mechanisms will fail long before the rest of the window. Repair will be difficult or impossible. The linkage that operates the louver must pass through the frame, making it impossible to fill the window with insulating gases.

Window Lingo

Here is some window language that we will be using.

- A "pane" is an individual sheet of glass in a window. It may also be called a "light."
- A "sash" is a part of a window assembly that consists of one or more "panes" or "lights" that are held by top, bottom, and side pieces.
- If a "sash" contains several panes, the pieces that join the panes are called "mullions."
- The complete window assembly consists of one or more "sashes" that are held in a "frame," which is attached to the wall opening.
- In a fixed window, the "sash" and the "frame" usually are the same. In a window that can open, the movable glass is held in one or more separate "sashes" that slide or are hinged within the "frame."

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Champion Windows

Figure 3-201. Horizontal Slider (Glider)

Two sashes, one of which slides horizontally to overlap the other. Provides straight-through ventilation. Popular in North America.

PRO: Easy to manipulate. Easy to position for minimum ventilation during cold weather. Movable sashes can be removed for cleaning from inside the room.

CON: Window usually has unsymmetrical appearance because the movable sash has slightly smaller glass area.

Pella Windows

Figure 3-202. Vertical Slider (Single-Hung)

Two sashes, a movable lower sash that slides up past a fixed sash. Provides straight-through ventilation.

PRO: Appearance somewhat similar to historic double-hung windows. The narrower shape allows windows to be installed within one or two stud spaces, and in narrow dormers.

CON: The weight of the movable sash is held in place by friction, making the sash difficult to manipulate. Or, balancing hardware is used, which invites trouble. Weatherstripping is prone to greater leakage and wear than with horizontal sliders. The outer surface of the movable sash cannot be cleaned from the inside. The appearance may be unsymmetrical because the movable sash has slightly smaller glass area.

Nu-Prime of Memphis

Figure 3-203. Double-Hung

Two movable sashes, each of which can slide vertically, overlapping each other. Provides straight-through ventilation. Generally obsolete, except where historic appearance is needed.

PRO: Historic appearance. Able to draw ventilation air through the top and/or bottom of the window. The narrow shape allows window to be installed within one or two stud spaces, and in narrow dormers.

CON: Complex weatherstripping is prone to air leakage and wear. The weight of the movable sashes is held in place by friction in frame, making the sash difficult to manipulate. Or, balancing hardware is used, which invites trouble.

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deedsdesign

Figure 3-204. Casement (Outward Swinging)

Sash is hinged on the side, and swings outward. Blocks wind coming from hinge side. Requires an actuator to hold the window in position. Sashes may be installed in facing pairs, or as side units with larger fixed windows.

PRO: Entire window area is openable.

CON: Difficult to adjust for minimum ventilation during cold weather. Outer surface cannot be cleaned from inside. The actuator eventually wears out. Prone to air leakage unless the frame is very stiff and the weatherstripping is well designed.

Home Crafts Inc

Figure 3-205. Casement (Inward Swinging)

Sash is hinged on the side, and swings inward. Does not require an actuator. Sashes are often installed in facing pairs to reduce their width.

PRO: Entire window area is openable. Easy to clean from inside.

CON: Intrudes into room. Conflicts with blinds and curtains. Without actuator, cannot hold position for minimum ventilation during cold weather.

DRW

Figure 3-206. Awning

Sash is hinged on top, and swings outward. Partially blocks wind. Requires an actuator to hold window in position. Often installed as a lower unit in combination with a larger fixed window.

PRO: Provides partial protection from rain when open.

CON: Outer surface cannot be cleaned from inside. The actuator eventually wears out.

DRW

Figure 3-242. Louvered doors between a bedroom and a dressing room.

DRW

Figure 3-243. A pocket door that isolates a bedroom wing from the rest of the house. This style of door mounting avoids interference with the bedroom hallway and with the entrance door on the left.

(called an "astragal") attached to one of the doors. This is awkward because it requires the two doors to be opened and closed in sequence. Modern doors offer a flexible rubber seal to avoid this annoyance.

Louvered doors provide a visual screen while allowing free flow of air and moisture. They can be hinged, as in Figure 3-242, or they can slide on a track.

Louvered doors do not block sound, and they are only partially effective in blocking dust. In appropriate applications, they help to avoid mildew in closets. They can also be used for visual privacy doors between related rooms, such as a bedroom and an adjacent dressing room, as in Figure 3-242.

In the days before air conditioning, louvered bedroom doors were used in warm climates to allow ventilation for cooling at night. They can still be used this way, in combination with a night ventilation fan, as we will explain in Step 4.

Pocket doors are doors that slide into a cavity ("pocket") in the wall, rather than swinging on hinges. A pocket door is a method of installation, in which any desired style of interior door (including a glazed door) is suspended from an overhead track with rollers.

A pocket door is commonly used in a location where a swing door would interfere with movement or where a swing door would take up desirable wall space. Figure 3-243 shows a good application for a pocket door. Another benefit is that pocket doors do not interfere with carpeting on either side of the opening. And, a pocket door saves a few square feet (a fraction of a square meter) of floor space because it does not sweep over any floor space around the door. A double pocket door, with wall cavities on both sides of the opening, can provide a very wide opening.

The wall that encloses a pocket door requires special design. The pocket must be slightly deeper than the width of the door, so it must extend into two or three normal stud spaces. This requires special wall framing. The sides of the pocket are weak, so this part of the wall cannot carry a structural load.

Pocket doors allow more air leakage than hinged doors because the clearances around the door cannot be sealed very well. They are somewhat awkward to use, requiring fingertips to pull the door out of the pocket. Removing a pocket door for maintenance or replacement may require removing some woodwork around the door opening.

Sliding doors are suspended from an overhead track, similar to the track used for pocket doors. The difference is that the door is mounted on the outside of the wall, so that no special wall framing is required. Any style of door can be used. Figure 3-244 shows a nice example.

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DRW

Figure 3-244. An interior sliding door with glazing.

Avoca Ridge Ltd

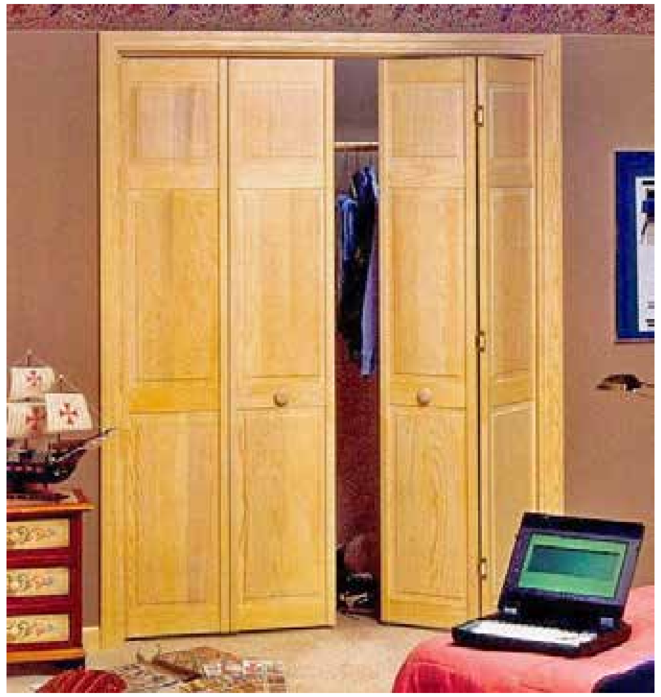
Figure 3-245. An attractive set of sliding doors for a closet.

A sliding door of any width can be used, and double doors can slide in both directions. The opening width is limited only by the amount of wall space available for stowing the opened doors. The track typically is hidden by a valance.

On the negative side, this method of installation allows a relatively large amount of air leakage. And, it provides only minimal security.

Panelfold Doors

Figure 3-246. A folding door used as a partition between spaces. When the door is closed, glass panels maintain a visual connection between the spaces.



LTL Home Products

Figure 3-247. An attractive folding closet door.

Sliding closet doors use several overlapping panels that are installed inside the wall opening, as in Figure 3-245. They do not intrude into the closet or into the room, so they are useful in rooms that are cramped by furnishings. This method of installation keeps the panels inside the door opening, so that no extra wall space is needed alongside the opening. However, the individual panels must be shuffled to get from one part of the closet to another. Closet doors typically use lightweight panels, but any type of door may be used, such as ordinary interior doors or louvered doors.