11

FINISHING THE ROOF

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A building's roof is its first line of defense against the weather. The roof protects the interior of the building from rain, snow, and sun. The roof helps to insulate the building from extremes of heat and cold and to control the accompanying problems with condensation of water vapor. Like any front-line defender, it must itself take the brunt of the attack. A roof is subject to the most intense solar radiation of any part of a building. At midday, the sun broils a roof with radiated heat and ultraviolet light. On clear nights, a roof radiates heat to the blackness of space and becomes colder than the surrounding air. From noon to midnight of the same day, it is possible for the surface temperature of a roof to vary from near boiling to below freezing. Rain falling on a roof causes abrasion on impact and then washes over the surface, causing further erosion. In cold climates, snow and ice cover a roof after winter storms, and cycles of freezing and thawing gnaw at the materials of the roof. A roof is vital to the sheltering function of a building, yet it is singularly vulnerable to the destructive forces of nature.

The roofing is generally applied to a house as soon as the framing has been completed so as to protect the framing from the weather. A dry working environment is also required for plumbing, heating, and electrical subcontractors, who will be scheduled to begin work inside the structure as soon as the roofing is in place.

Roofing is measured and sold by an area of coverage called a *square*, which is equal to 100 square feet of roof area. The roofing is generally installed by a roofing subcontractor.

Preparation for Roofing

Historically, roofs were surfaced with a single roofing material. Thatched cottages were roofed with thatch alone, and barns might be covered only with hand-split shakes. Today, roofs often include such complexities as dormers, skylights, and chimney penetrations, which require underlayment and flashing as well as the primary roofing material.

Underlayment

Before any roofing material is installed, the roof sheathing is generally covered with a layer (or two) of 15- or 30-pound building felt. Called *underlayment,* this layer serves to protect the building from precipitation before the roofing is applied. It also provides a permanent second layer of defense to back up the roofing. This flexible layer can be installed rather quickly, and when it is in place, the building is said to be "dried in" (Figure 11.1). In very cold climates, a special underlayment called an *ice-and-water shield* is required at the

Figure 11.1
The roof framing has been completed and underlayment applied to the roof of this residence even before the walls are sheathed. The temporary boards nailed to the steeper part of the roof allow workers to walk safely on the inclined surface.
(Photo by Rob Thallon)

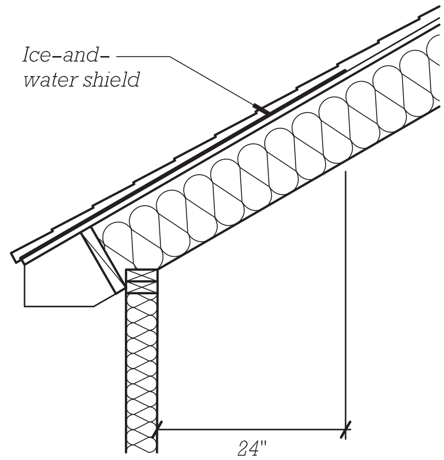


Figure 11.2
Code requires an ice-and-water shield in very cold climates. The shield must extend 24 inches (610 mm) over the insulated portion of the building.

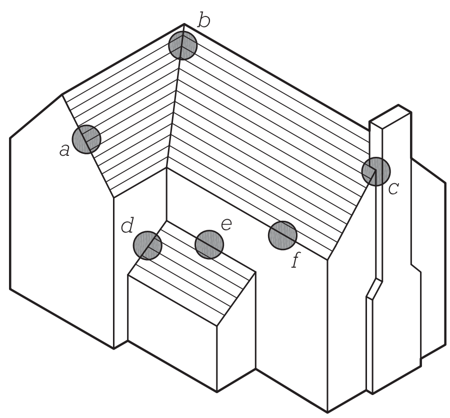


Figure 11.3
Typical flashing locations: (*a*) rake, (*b*) valley, (*c*) chimney and other roof penetrations, (*d*) sloped edge of roof at wall, (*e*) level edge of roof at wall, and (*f*) eave. Code roof flashing requirements vary according to the type of roofing.

eaves in order to prevent damage to the structure as a result of ice dams (Figures 11.2 and 11.13). Ice dams are discussed in Chapter 17.

Flashing

Roof flashing comprises metal sheet materials that are used to protect against water leakage at the junctions and edges of roof surfaces. The earliest flashings were made of lead or copper. Today, galvanized sheet steel and aluminum are the principal flashing materials, although enamel-coated sheet steel, copper, and stainless steel may also be used (Figure 11.3).

Some roof flashing materials, such as edge flashing, are readily available in standardized forms that work in a variety of situations. However, many roof flashings must be custom-made to fit a particular roof slope, a particular roofing material, or a special roof form. Standard flashings are made in large factories and purchased in bulk by roofing contractors, while custom flashings are fabricated in local sheet metal shops (Figure 11.4). The roofing subcontractor usually confers with the sheet metal subcontractor to determine the size and configuration of custom flashing, while the designer specifies the material of which it is made and may also recommend a specific shape.

Figure 11.4
Sheet metal shops such as this stay busy manufacturing custom flashings and gutters for both residential and commercial projects. Most of the work takes place on waist-high tables where sheet metal is measured, cut, formed, and soldered.
(Photo by Rob Thallon)

Figure 11.5
A steep roof can be made waterproof with any of a variety of materials. This thatched roof is being constructed by fastening bundles of reeds to the roof structure in overlapping layers in such a way that only the butts of the reeds are left exposed to the weather.
(Courtesy of Warwick Cottage Enterprises)

Roof Slope

Roofs are classified according to their steepness or *slope*. The slope of a roof is the ratio of the (vertical) rise to the (horizontal) run of the roof. In the United States, the ratio is given in inches of rise per 12-inch run. A 6 : 12 roof, for example, rises 6 inches for every 12 inches of horizontal distance. In Canada, slope is expressed as a ratio of 1 : *x*, so that a Canadian roof that slopes 1 : 2 is the equivalent of a 6 : 12 roof in the United States.

Roofing materials can be organized conveniently into two groups: those that work on *steep roofs* and those that work on *low-slope roofs,* which are nearly flat. The distinction is important: A steep roof drains itself quickly of water, giving wind and gravity little opportunity to push or pull water through the roofing material. Therefore, steep roofs can be covered with roofing materials that are fabricated and applied in small, overlapping units—shingles of wood, slate, or artificial composition; tiles of fired clay or concrete; or even tightly wrapped bundles of reeds, leaves, or grasses (Figure 11.5). There are several advantages to these materials: Many of them are inexpensive. The small, individual units are easy to handle and install. Repair of localized damage to the roof is easy. The effects of thermal expansion and contraction, and of movements in the structure that supports the roof, are minimized by the ability of the small roofing units to move with respect to one another. Water vapor vents itself easily from the interior of the building through the loose joints in the roofing material. Finally, a steep roof of well-chosen materials skillfully installed can be a delight to the eye.

Low-slope roofs have none of these advantages. Water drains relatively slowly from the surfaces, and small errors in design or construction can cause them to trap puddles

Material	Sheathing	Lowest Allowed Slope	Requirements below 4 : 12 Slope
Asphalt shingles	Solid	2 : 12	Double underlayment
Wood shingles	Solid or spaced	3 : 12	
Wood shakes	Solid or spaced	3 : 12	
Clay tiles	Solid or spaced	2½ : 12	Double underlayment
Concrete tiles	Solid or spaced	2½ : 12	Double underlayment
Slate	Solid	4 : 12	
Metal panel	Solid or spaced	3 : 12	
Roll roofing	Solid	1 : 12	
Membrane	Solid	¼ : 12	

Figure 11.6
Common residential roofing materials with required slopes, sheathing, and underlayment. The table is derived from Chapter 9 of the 2009 International Residential Code.

of standing water. Slight structural movements can tear the membrane that keeps the water out of the building. Water vapor pressure from within the building can blister and rupture the membrane. Low-slope roofs also have advantages: A low-slope roof can cover a building of any horizontal dimension, whereas a steep roof becomes uneconomically tall when used on a very broad building. And, when appropriately detailed, low-slope roofs can serve as balconies, decks, patios, and even landscaped parks.

Figure 11.7
This very steep roof is being reroofed with cedar shingles. Steel roof jacks nailed to the structure hold horizontal boards that allow workers access to the roof surface. After the job has been completed, the jacks are removed, but the nails that hold them remain in the structure. Roof jacks are generally required on roofs with 8 : 12 or steeper pitch. *(Photo by Rob Thallon)*

Steep Roofs

A roof with a pitch of 4 : 12 or greater is referred to as a “steep roof” by the National Roofing Contractors Association. There are numerous roof coverings in this category, and many can be used on roofs with a slope lower than 4 : 12 by increasing the number of layers of underlayment (Figure 11.6). As the roof slope increases, the performance of roof coverings generally improves, but at slopes steeper than about 7 : 12, workers cannot move easily without slipping, and roofing contractors increase their prices to allow for the installation of *roof jacks* or other safety devices (Figure 11.7).

Sheathing for Steep Roofs

Most steep roofs are constructed with *solid sheathing* made of oriented strand board (OSB) or plywood panels similar to wall and subfloor sheathing. The sheathing supports the underlayment over which the roofing material is laid. *Sheathing clips* may be used to maintain the alignment of panel edges between rafters, permitting thinner sheathing to be used. At eaves or rakes that are exposed from the underside, panel sheathing must be rated for exposure to the weather or tongue-and-groove boards may be used instead (Figure 11.8).

Figure 11.8
This roof is being sheathed with solid sheathing because it will be roofed with asphalt shingles, the most common roofing material in North America. The eaves, because they will be exposed from below, must be sheathed with a weather-resistant material—in this case, tongue-and-groove boards. *(Photo by Rob Thallon)*

FIGURE 11.9
The roof on this new residence is being sheathed with spaced boards because it will be roofed with cedar shingles, which have the strength to span between sheathing boards and last longer when allowed to breathe from beneath. *(Photo by Donald Corner)*

Many steep roof coverings have structural integrity of their own and thus can be supported intermittently on *spaced sheathing* (also called *open* or *skip sheathing*) made of 1 × 4 or 1 × 6 boards nailed across the rafters with open spaces between (Figure 11.9). Materials such as wood shingles last longer when they are installed over spaced sheathing, which allows them to dry from the underside between storms.

Insulation and Vapor Retarder for Steep Roofs

The *thermal insulation* and *vapor retarder* in most steep roofs are installed below the roof sheathing. Typical details of this practice are shown in Chapter 17. In places where the underside of the sheathing is to be left exposed as a finish ceiling, a vapor retarder and rigid insulation panels should be applied above the sheathing, just below the roofing (Figure 11.10). A layer of plywood or OSB is then nailed over the insulation panels as a nail base for fastening the shingles or sheet metal. There are also special composite insulation panels that include an integral nail-base layer on top.

Steep Roof Materials

Common roof coverings for steep roofs fall into four general categories: shingles, tiles, architectural sheet metal, and roll roofing. *Shingles* are small, lightweight units applied in overlapping layers with staggered vertical

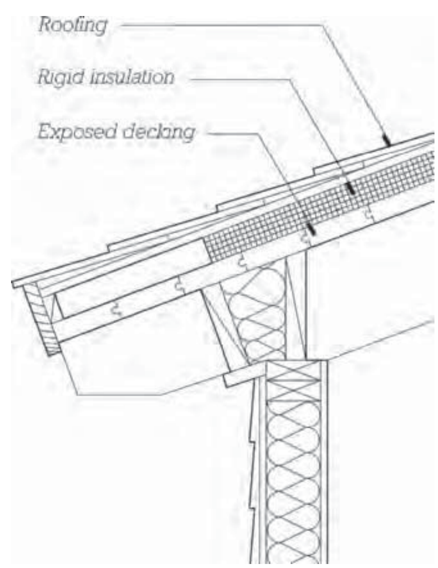


FIGURE 11.10
Section of a roof with sheathing exposed to an interior room. Ventilation of this roof is not required because the rigid insulation does not allow air to be trapped in the assembly. Some roofing manufacturers will not warranty their products on such a roof because roof surface temperatures are not moderated by ventilation.

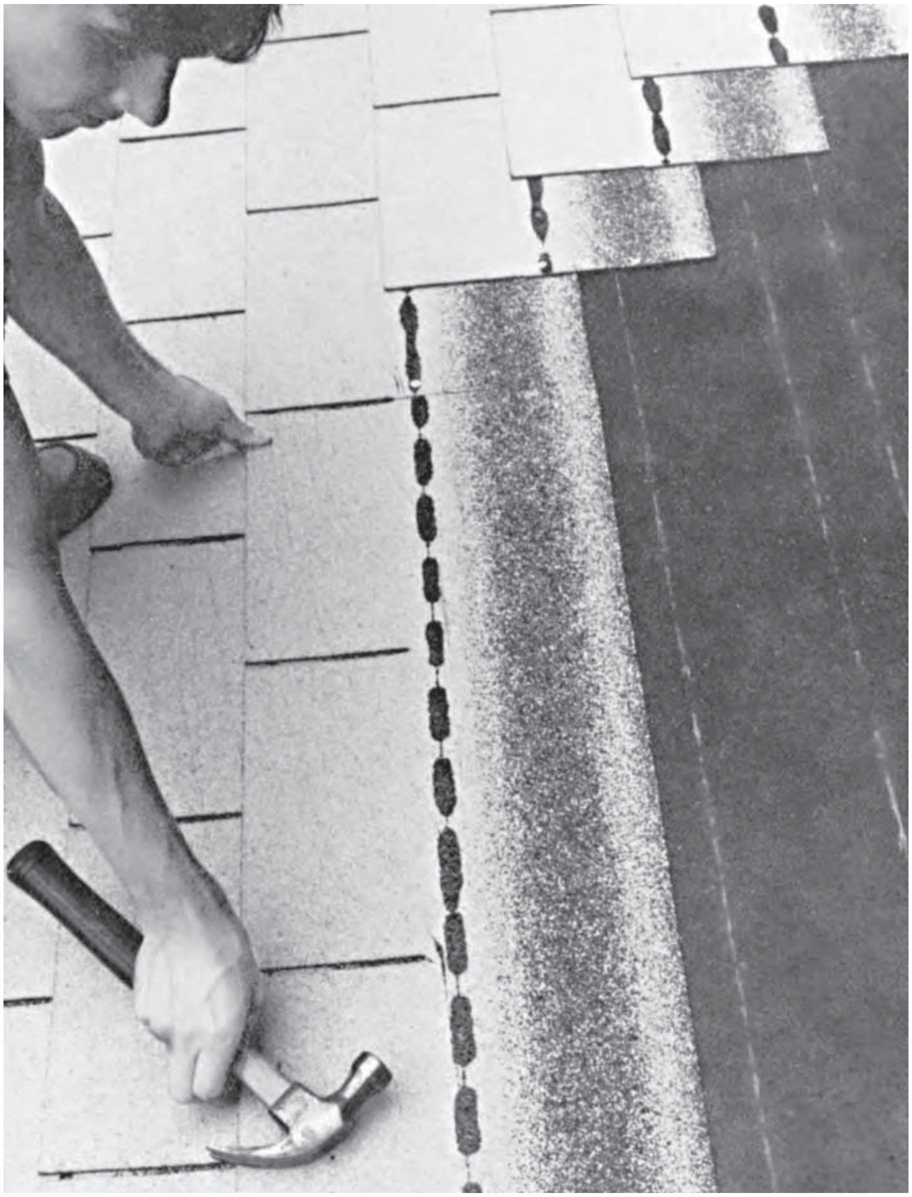


FIGURE 11.11
Installing asphalt shingles. To give a finer visual scale to the roof, the slots will make each shingle appear as if it is three smaller shingles when the roof is finished. Many different patterns of asphalt shingles are available, including ones that do not have slots. The dark strips running the length of the shingles are adhesive to seal the lower edges of the shingles against uplift from wind. *(Photo by Edward Allen)*

joints. The overlap between courses is such that the entire surface of the roof is covered by a minimum of two layers of roofing. *Roof tiles* are small but heavy units of concrete or fired clay. They overlap and interlock so that the roof surface is covered by only one layer. *Sheet metal roofing* is made of very lightweight metal panels that overlap slightly or are seamed, so that the roof is covered by one layer of roofing. *Roll roofing* is a flexible asphalt-impregnated felt that comes in rolls 36 inches (915 mm) wide that may be applied to provide single or double coverage. A wide variety of shingle, tile, and sheet metal roofs are available and range in price from economical to expensive.

Each type of material must be laid on a roof deck that slopes sufficiently to assure leakproof performance. The manufacturer specifies minimum slopes for each material. Slopes that are greater than the minimum should be used in locations where water is likely to be driven up the roof surface by strong storm winds.

Asphalt Shingles

Asphalt shingles are the most widely used roof covering in North America and are employed on approximately 90 percent of single-family houses. They are inexpensive to buy, quick and easy to install, moderately fire resistant, and have an expected lifetime of 15 to 25 years, depending on their exact composition. Asphalt shingles are die cut from heavy sheets of asphalt-impregnated felt. Most felts contain glass fibers for strength and stability, but some have an older composition that consists primarily of cellulose. The sheets are faced with mineral granules that act as a wearing layer and decorative finish. The most common type of asphalt shingle is 12 by 36 inches (305 by 914 mm) in size. (A metric shingle 337 by 1000 mm is also widely marketed.) Each shingle is slotted twice in the center and has a half-slot at each end to produce a roof that looks as though it were made of smaller shingles (Figure 11.11). Many other shingle styles are also available, including hexagonal patterns and thicker shingles that are laminated from several layers of material.

Asphalt shingles are flexible, which allows them to be used in unique ways. For example, asphalt shingles can bend across a valley or a ridge—eliminating the need for flashing at these locations. Because asphalt shingles have no stiffness, they must be applied over solid sheathing that has been covered with underlayment (Figures 11.12 to 11.14).

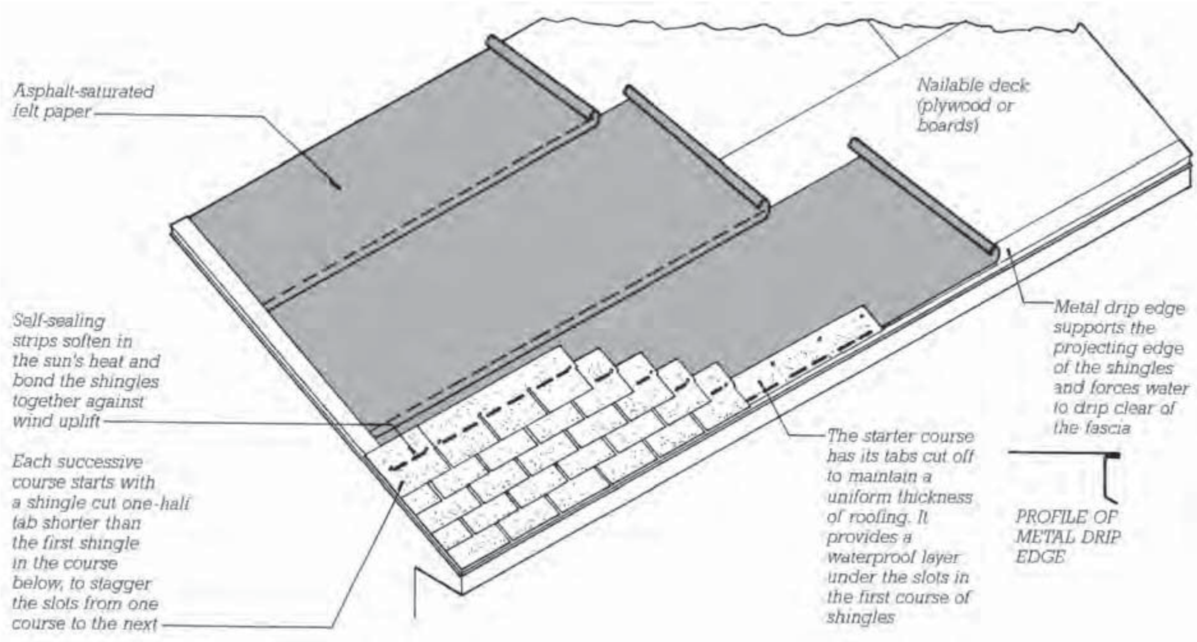


FIGURE 11.12
Starting an asphalt shingle roof. Most building codes require the installation of an ice-and-water barrier beneath the shingles along the eave in regions with cold winters; its function is to prevent the entry of standing water that might be created by ice dams. The most effective form of barrier is a 3-foot-wide (900-mm) strip of modified bitumen sheet that replaces the lowest course of asphalt-saturated felt paper. The bitumen self-seals around the shanks of the roofing nails as they are driven through it.

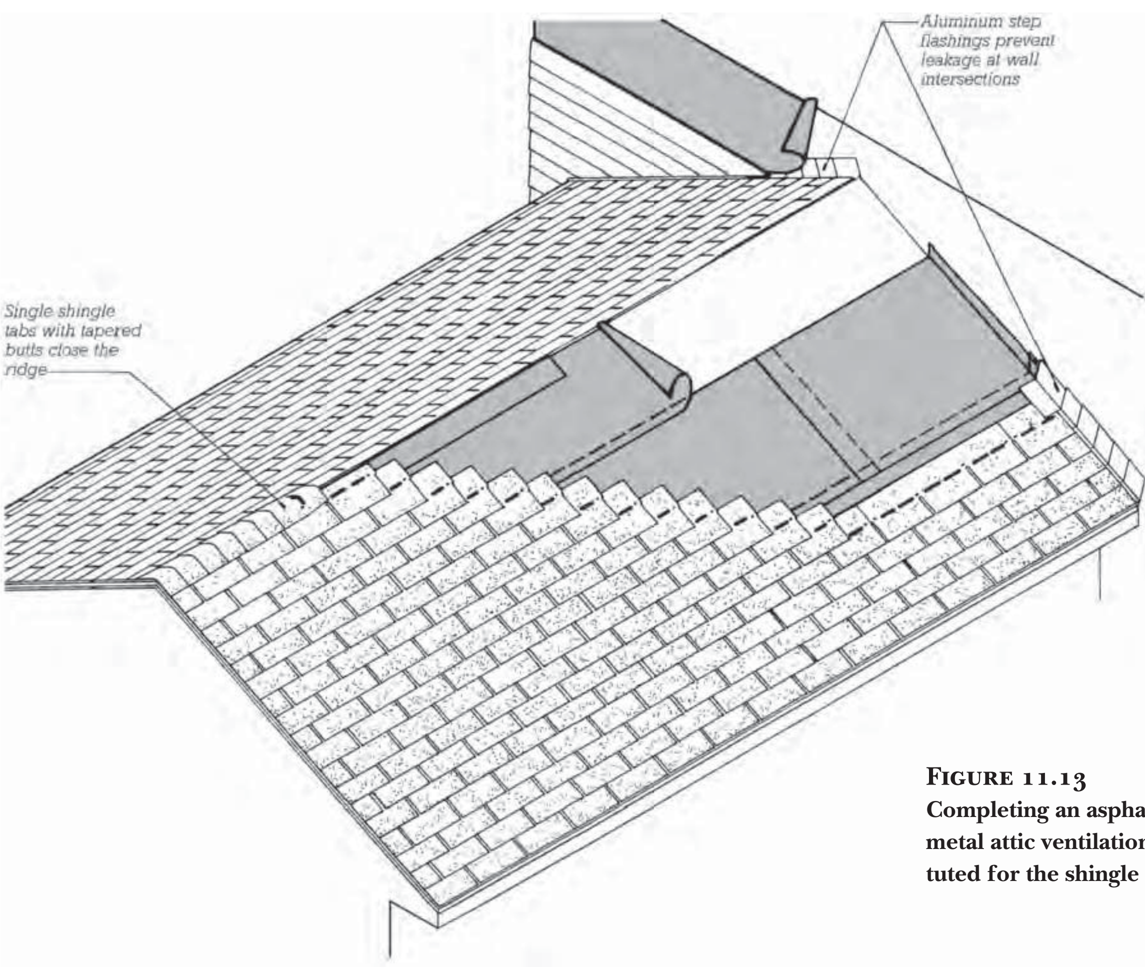


FIGURE 11.13
Completing an asphalt shingle roof. A metal attic ventilation strip is often substituted for the shingle tabs on the ridge.

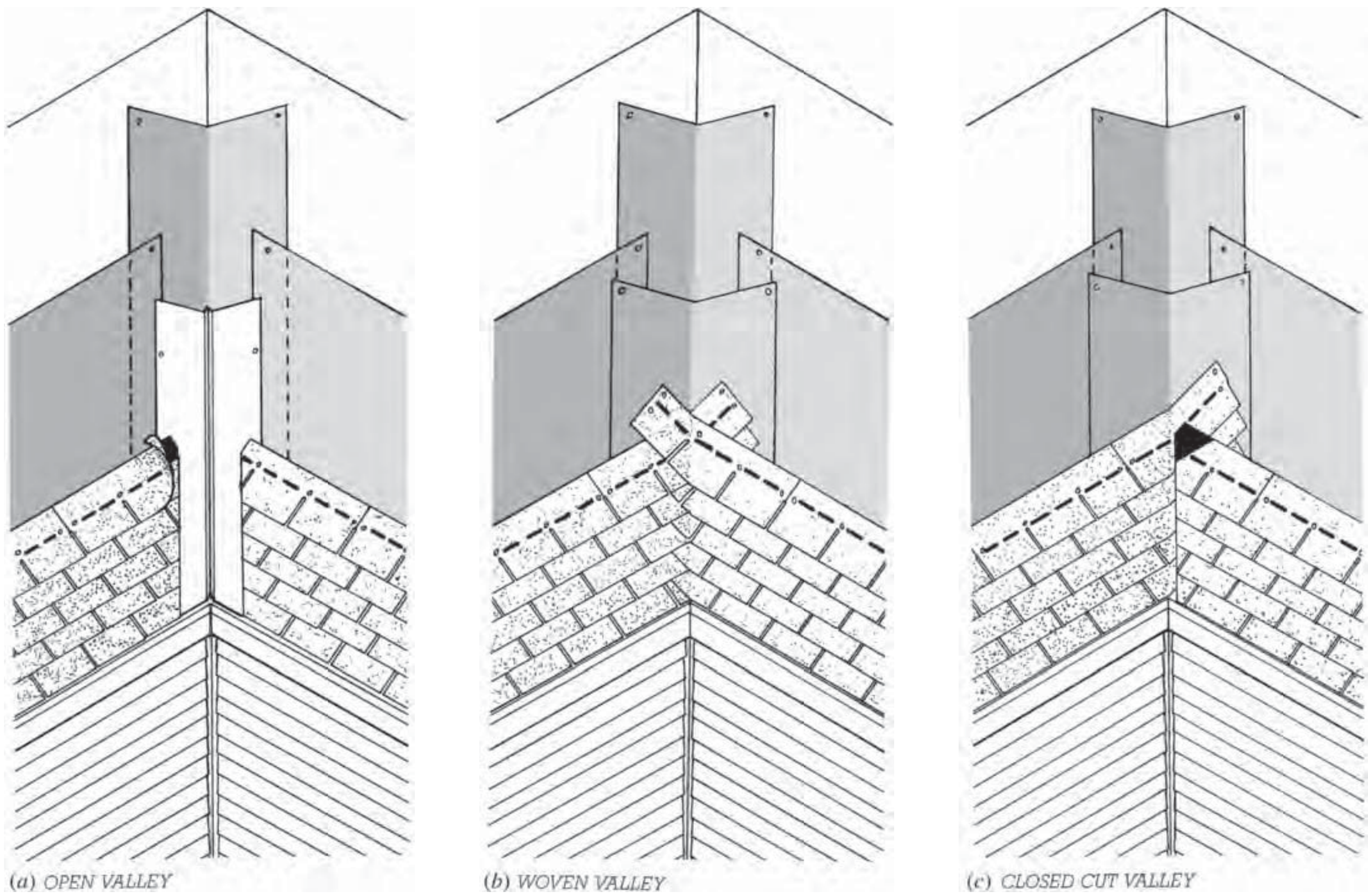


FIGURE 11.14
Three alternative methods of making a valley in an asphalt shingle roof. (*a*) The open valley uses a sheet metal flashing; the ridge in the middle of the flashing helps prevent water that is coming off one slope from washing up under the shingles on the opposite slope. The woven valley (*b*) and closed cut valley (*c*) are favorites of roofing contractors because they require no sheet metal. The solid black areas on shingles in the open and closed cut valleys indicate areas to which asphaltic roofing cement is applied to adhere shingles to each other.

Figure 11.15
Shingles and shakes, although made from the same material, are very different in appearance and durability. Shingles, seen here on the walls, are sawn on both sides so that both faces are relatively smooth, and all shingles taper uniformly from bottom to top. Shakes, seen here on the roof, are split from a short section of log called a "bolt" and are typically sawn diagonally after splitting to create the taper. The sawn face of a shake is its underside. The split upper side of a shake appears rough and irregular compared to the sawn face of a shingle. *(Photo by Edward Allen)*

Wood Shingles and Shakes

Wood shingles are thin, tapered slabs of wood sawn from short pieces of tree trunk, with the grain of the wood running approximately parallel to the length of the shingle. *Shakes* are split from the wood, rather than sawn, and are thicker, with a much more irregular face texture than wood shingles (Figure 11.15). Most wood shingles and shakes in North America are made from red cedar, white cedar, or redwood, because of the natural decay resistance of these woods (Figure 11.16). Wood shingles and shakes are moderately expensive to purchase and install. They are not resistant to fire unless they have been pressure treated with fire-retardant chemicals.

Both wood shingle and shake roofs can be applied over spaced sheathing (Figure 11.17). Wood shakes naturally breathe better than shingles because their uneven texture tends to allow

Figure 11.16
A house is both roofed and sided with red cedar shingles to emphasize its sculptural qualities. Note that the shadow lines created by the shingles are horizontal. *(Architect: William Isley. Photo by Paul Harper. Courtesy of Red Cedar Shingle and Handsplit Share Bureau)*

Figure 11.17
Installing red cedar shakes on spaced sheathing. Small corrosion-resistant nails are driven near each edge at the midheight of the shingle. Each succeeding course covers the joints and nails in the course below. The spaces between the sheathing boards allow the undersides of the shingles to dry out between storms. *(Photo by Rob Thallon)*

Figure 11.18
Shake application over a new roof deck using air-driven, heavy-duty staplers for greater speed. The strips of asphalt-saturated felt have all been placed in advance with their lower edges unfastened. Each course of shakes is laid out from one end of the house to the other, slipped up under its felt strip, then quickly fastened by roofers walking across the roof and inserting staples as fast as they can pull the trigger. *(Courtesy of Senco Products, Inc.)*

more air circulation between layers. However, the looseness of fit also increases the opportunity for wind-driven rain and snow to penetrate the roofing. To counteract this shortcoming, most codes require that shakes be applied with an 18-inch-wide strip of 30-pound asphalt-impregnated *interlayment* woven between each pair of courses (Figure 11.18).

Tile Roofs

Tile roofs in general are heavy, durable, highly resistant to fire, and have a relatively high first cost. Their weight (up to 10 psf, which is five times the weight of asphalt shingles) can require a stronger roof structure.

Clay tiles have been used on roofs for thousands of years. It has been said that the tapered barrel tiles traditional to the Mediterranean region (similar to the mission tiles in Figure 11.19) were originally formed on the thighs of the tilemakers. Many other patterns of clay tiles are now available, both glazed and unglazed. Clay tiles are most commonly used in the southwestern United States, where they are

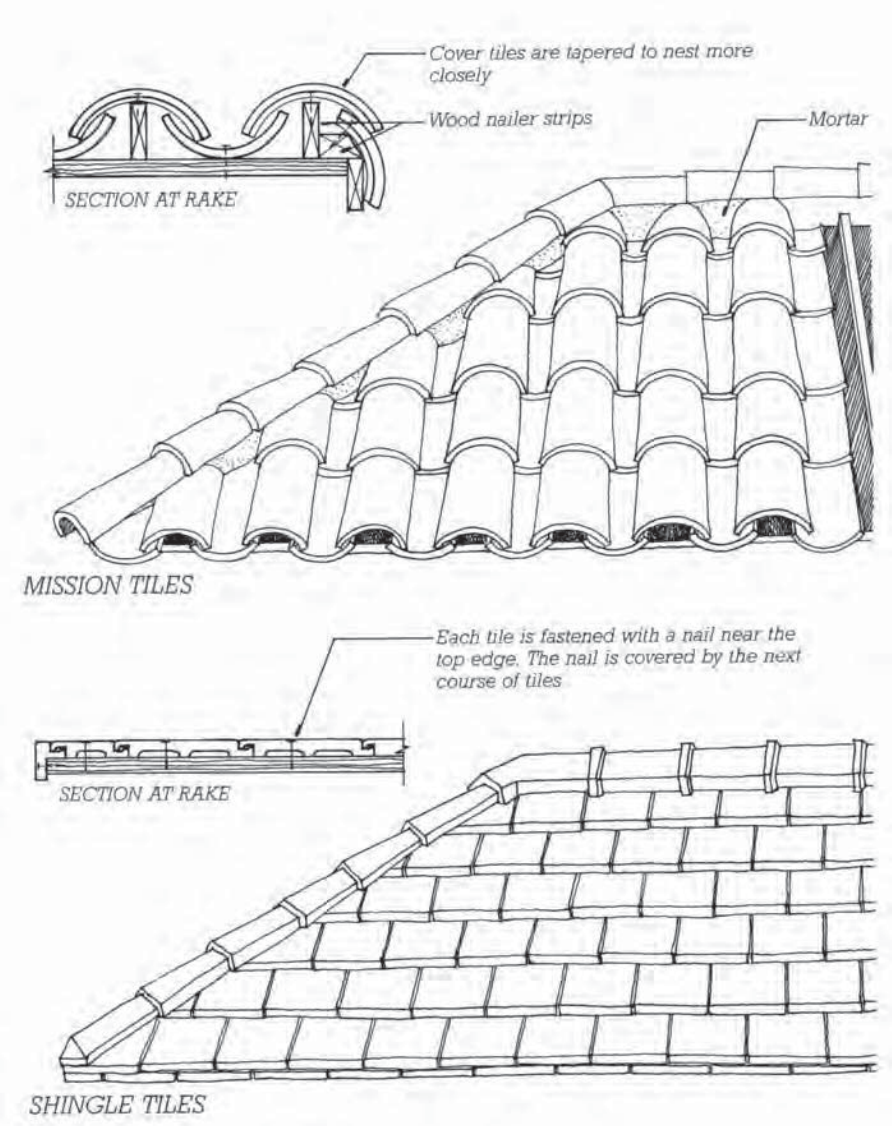
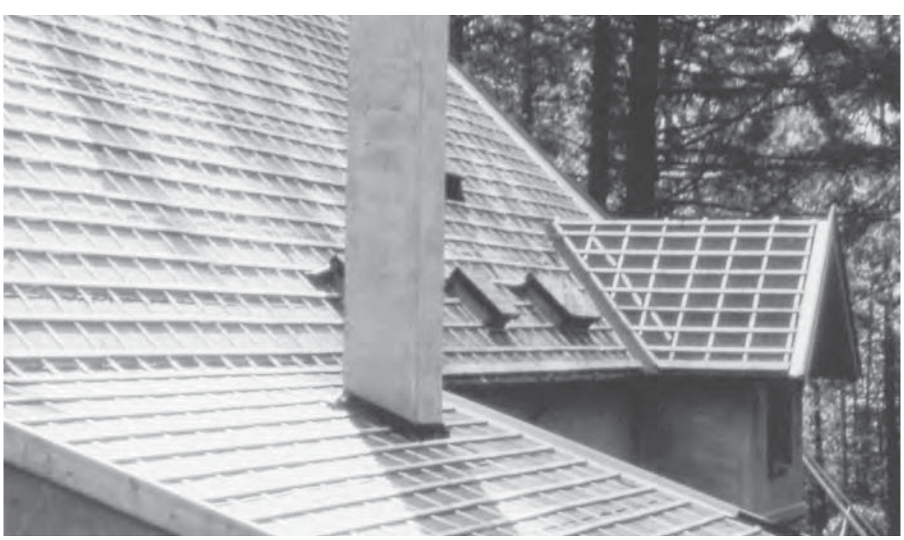


FIGURE 11.19
Two styles of clay tile roofs. The mission tile has very ancient origins.



related historically and climatically to a Spanish heritage.

Concrete tiles are generally less expensive than clay tiles and are available in many similar patterns. Made of high-density concrete, these tiles are also more consistent in shape and dimension than clay tiles because they are not subject to the distortions that are often caused by high-temperature firing. The relative precision of their manufacture allows concrete tiles to lie flatter on the roof with less need for packing of gaps between tiles with mortar (Figure 11.19). Concrete tiles are coated with a resin to make them waterproof and are typically installed over 30-pound underlayment and preservative-treated horizontal nailing battens (Figure 11.20).

Slate tiles form a fire-resistant, long-lasting roof that is suitable for buildings of the finest materials. It is relatively costly but is among the most durable of all roofing materials. Slate for roofing is delivered to the site split, trimmed to size, and punched or drilled for nailing (Figure 11.21). Both in their shape and by the method by which they are laid on the roof, slate tiles resemble wood shingles or shakes (Figure 11.22), although the natural stone material is similar to clay or concrete tile.

FIGURE 11.20
A roof set up for the installation of concrete tiles. Plywood sheathing has been covered with underlayment, and furring strips running up and down the slope of the roof have been nailed on top of the underlayment. The uppermost layer is composed of preservative-treated nailing battens attached to the furring strips. The furring strips hold the battens above the level of the underlayment so that moisture that finds its way through the roofing can flow unrestricted down the slope of the roof. The battens are spaced at intervals that correspond with the length of the roofing tiles. The tiles will be held in place by means of a lip at their top edge, which will hook over the battens. Some tiles will also be mechanically fastened to the battens with screws or nails that pass through predrilled holes in the tiles. *(Photo by Rob Thallon)*

Figure 11.21
Splitting slate for roofing. The thin slates in the background will next be trimmed square and to dimension, after which nail holes will be punched in them. *(Photo by Flournoy. Courtesy of Buckingham-Virginia Slate Corporation)*

Figure 11.22
A slate roof during installation. *(Courtesy of Buckingham-Virginia Slate Corporation)*

Sheet Metal Roofing

Sheets of lead and copper have been used for roofing since ancient times. Both metals form self-protecting oxide layers that are very beautiful and last for many decades. Today's metal roofing materials include enamel-coated galvanized steel, copper, lead-coated copper, stainless steel, terne, and terne-coated stainless steel. All are relatively high in first cost, but they can be expected to last for many decades. They are installed in small sheets using ingenious systems of joining and fastening to maintain watertightness at the seams. The modern *standing-seam* roof is made with long sheets of metal crimped together on the roof (Figures 11.23 and 11.24). The seams create a strong visual pattern that can be manipulated by the designer to emphasize the qualities of the roof shape.

FIGURE 11.23
An automatic roll seamer, moving under its own power, locks standing seams in a copper roof. A cleat is just visible at the lower right. *(Courtesy of Copper Development Association, Inc.)*

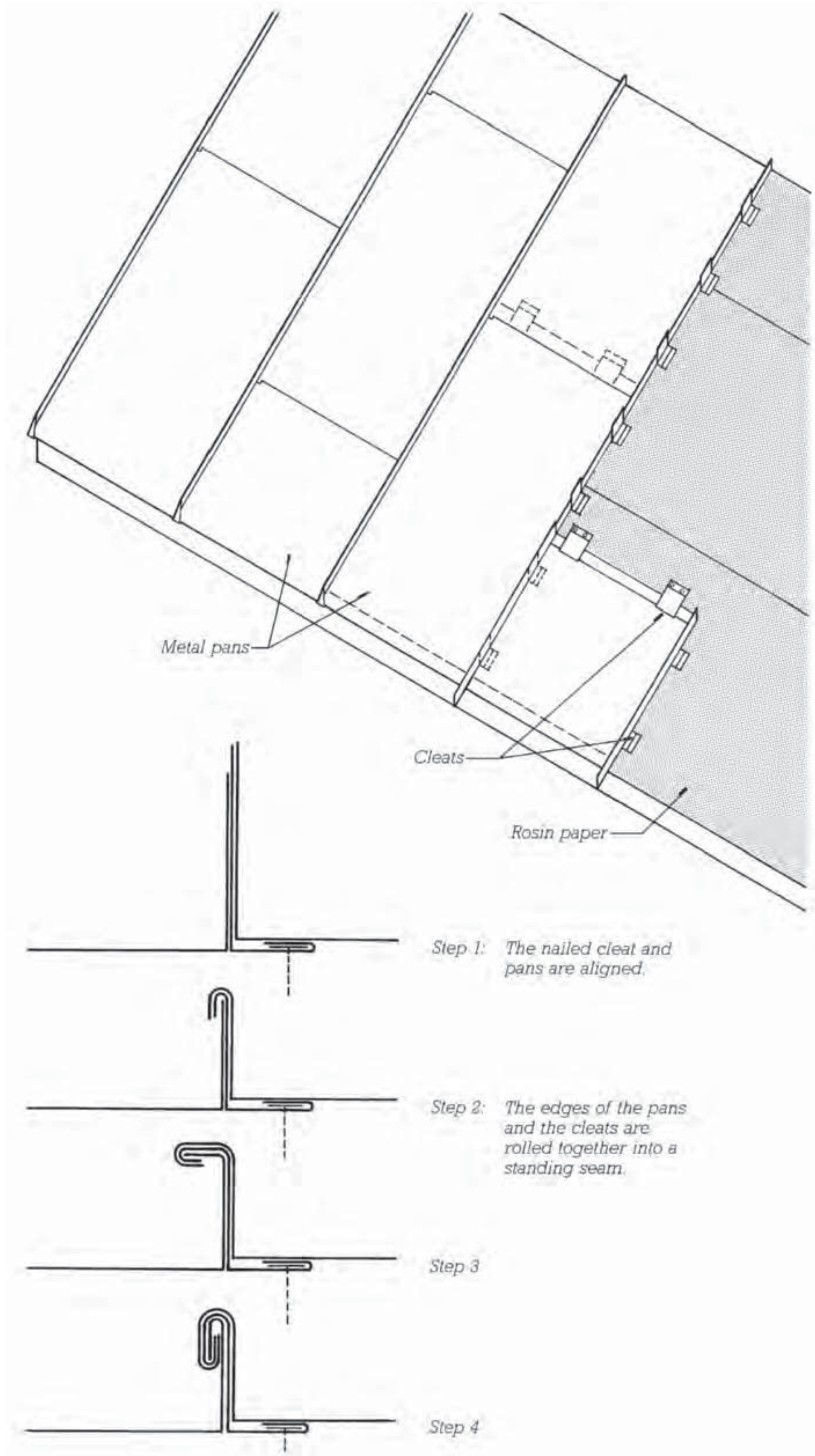


FIGURE 11.24
Installing an architectural standing-seam metal roof.

Figure 11.25
A metal panel roof such as the one on this residence is long-lasting and can be recycled when it is replaced. Many people expect a metal roof to be noisy in a rainstorm, but thermal insulation generally provides acoustical insulation as well so that the sound of rain on the roof does not reach the interior of the house. *(Photo by Rob Thallon)*

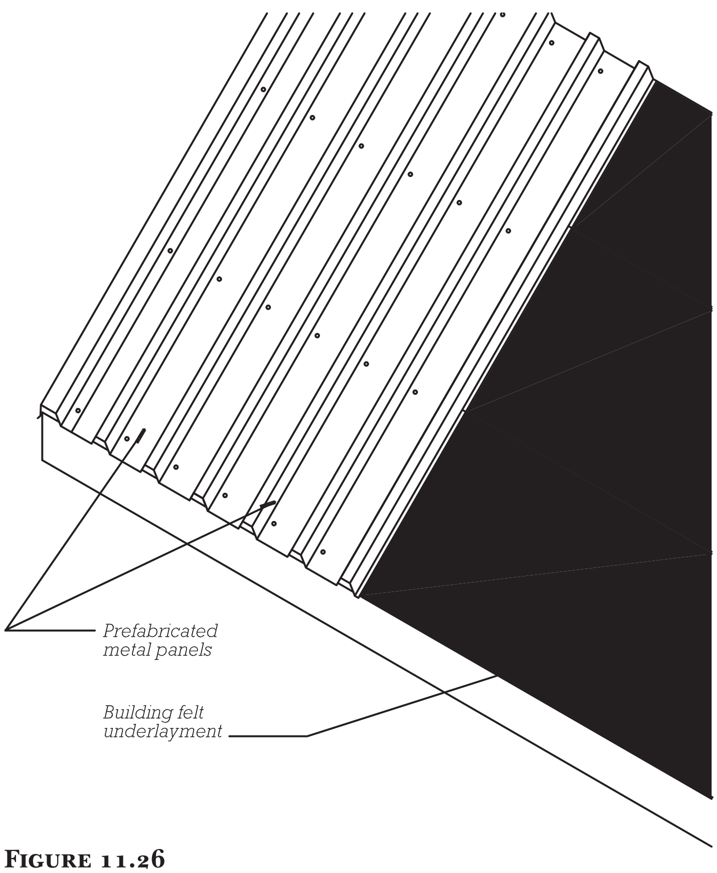


Figure 11.26
Installing a prefabricated metal panel roof.

A new generation of metal roofing, *panel roofing,* has gained popularity in recent years (Figure 11.25). Like the low-cost corrugated metal roofing used on agricultural buildings, panel roofing is preformed and requires no specialized equipment for installation at the site. The panels are made of long sheets of galvanized or aluminized steel, usually coated with long-lasting polymeric coatings in various colors. The most common panels are 2 feet (610 mm) wide and come in a variety of profiles with ridges running lengthwise. Panels are precut to length (from eave to ridge) at the factory and are fastened to the roof with exposed screws sealed with neoprene washers (Figure 11.26). Narrower panels approximately 12 inches (305 mm) wide are also available. These panels are produced with raised edge seams that include a means of concealed attachment to the roof deck

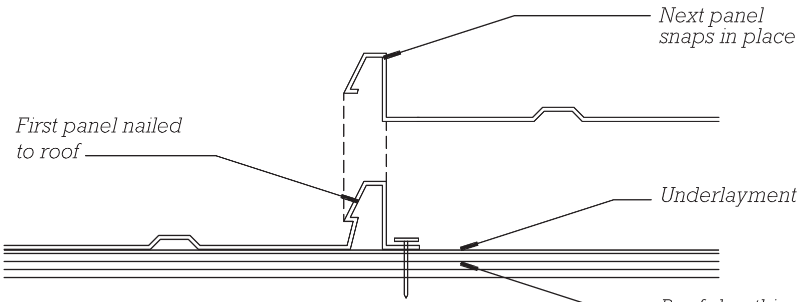


FIGURE 11.27
A concealed-fastener snap-lock metal panel roofing system. During installation, the leading edge of the metal panel is nailed to the roof sheathing. The trailing edge of the next panel snaps onto the leading edge of the previously installed panel, covering the fastener.

and a snap-together interlocking mechanism (Figure 11.27). Architectural panel roofs are considerably less costly than traditional forms of sheet metal roofing. Most types (as well as standing-seam types) can be used on slopes below 4 : 12 (Figure 11.6).

The same metal should be used for every component of a sheet metal roof, including the fasteners and flashings. If this is impossible, metals of similar galvanic activity should be used. This is because when strongly dissimilar metals touch in the presence of rainwater, which is generally acidic, the galvanic action will cause rapid corrosion (Figure 11.28).

FIGURE 11.28
A galvanic series for metals used in buildings. Each metal is corroded by all those that follow it in the list. The wider the separation between two metals on the list, the more severe the corrosion is likely to be. Some families of alloys, such as stainless steels, are difficult to place with certainty because some alloys within the family behave differently from others. To be certain, the designer should consult with the manufacturer of any metal product before installing it in contact with dissimilar metals in an outdoor environment.

Aluminum
Zinc and galvanized steel
Chromium
Steel
Stainless steel
Cadmium
Nickel
Tin
Lead
Brass
Bronze
Copper

Roll Roofing

The same sheet material from which asphalt shingles are cut is also manufactured in rolls 3 feet (900 mm) wide as asphalt roll roofing. Roll roofing is very inexpensive and is used primarily on storage sheds and very low cost residential buildings. It can be manipulated by skilled designers, however, to make an attractive roof (Figure 11.29). Its chief drawbacks are that thermal expansion of the roofing or drying shrinkage of the wood deck can cause unsightly ridges to form in the roofing and that thermal contraction can tear it.

FIGURE 11.29
Roll roofing is generally reserved for agricultural and utility buildings, but it can be used on residences as well. This house has two colors of roll roofing: one at the edge, the other in the field of the roof. *(Photo by Rob Thallon)*

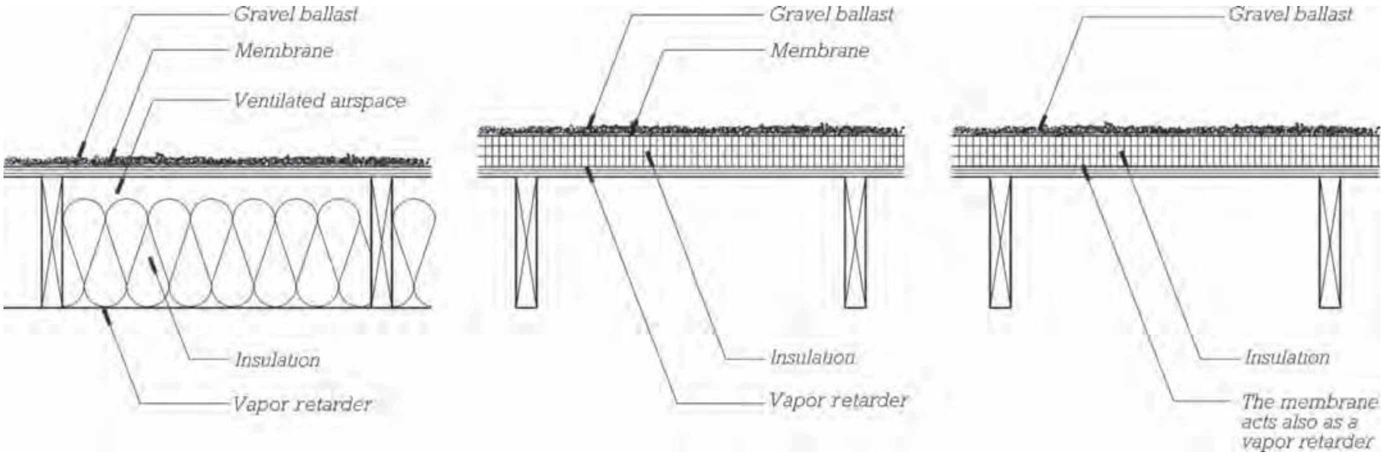


Figure 11.30
Low-slope roofs with thermal insulation in three different positions, shown here with a wood joisted roof deck. At left, insulation below the deck, with a vapor retarder on the warm side of the insulation. In the center, insulation between the deck and the membrane, with a vapor retarder on the warm side of the insulation. At right, a protected membrane roof, in which the insulation is above the membrane.

Low-Slope Roofs

A roof with a pitch lower than 4 : 12 is referred to as a low-slope roof. The distinction is made at this pitch because most of the roofing materials suitable for steep roofs do not perform well below the 4 : 12 pitch. At the steeper end of this range (4 : 12 down to 2 : 12), several of the roofing materials used for steep roofs, such as asphalt shingles or sheet metal panels, can be employed, provided that extra precautions are taken to compensate for the low pitch (Figure 11.6). Roll roofing can be used on slopes as low as 1 : 12. Below this, none of the materials used on steep roofs will perform adequately, and an entirely different approach must be taken.

To prevent the penetration of water at such low slopes, roofing materials need to be entirely continuous and are referred to as *membranes*. A membrane is an impervious sheet of material that keeps water out of the building. A membrane roof is a complex, highly interactive assembly made up of several components. The *deck* is the structural surface that supports the roof. *Thermal insulation* is installed to slow the passage of heat into and out of the building. A *vapor retarder* is essential in colder climates to prevent moisture from accumulating within the insulation. *Drainage* components remove the water that runs off the membrane. Around the membrane's edges and wherever it is penetrated by pipes, vents, expansion joints, electrical conduits, or roof hatches, special flashings and details must be designed and installed to prevent water penetration.

The Roof Deck

Roof sheathing for a low-slope roof is referred to as the *roof deck*. To provide drainage, the roof must slope toward drainage points at an angle sufficient to drain reliably and overcome any structural deflections. A slope of at least ¼ inch per foot of run (1 : 50) is recommended. To create this slope in a low-slope roof (often inaccurately referred to as a flat roof), two basic methods may be employed. In one, the joists or beams that support the deck may be sloped. This approach creates a sloped ceiling surface below if the joists are not tapered. Alternatively, the slope may be created over a dead-level deck with a system of tapered rigid insulation boards or a tapered fill of lightweight insulating concrete.

If a roof is insufficiently sloped, puddles of water will stand for extended periods of time in the low spots that are inevitably present, leading to premature deterioration of the roofing materials in those areas. The roof membrane must be laid over a smooth surface. A wood deck that is to receive a roof membrane should have gaps or knotholes filled with a nonshrinking paste filler.

Thermal Insulation

Thermal insulation for a low-slope roof may be installed in any of three positions: below the structural deck, between the deck and the membrane, or above the membrane (Figure 11.30).

Insulation below the Deck

Below the deck, fibrous batt insulation is installed between framing members above a vapor retarder made of polyethylene sheeting. A ventilated airspace should be provided between the insulation and the deck

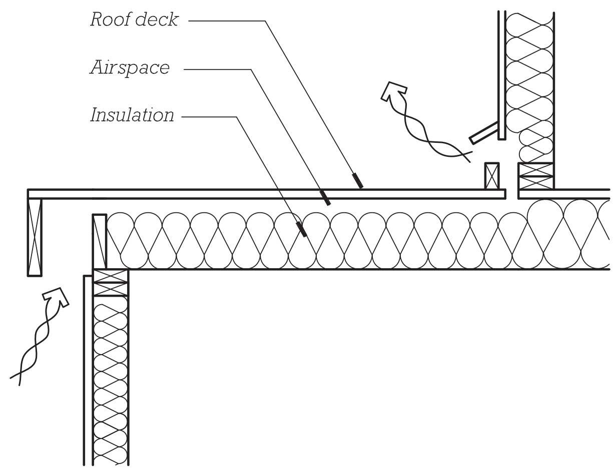


Figure 11.31
Low-slope roofs with insulation below the deck must be vented. Venting the joist cavities from the eave is usually adequate, but venting from two opposite sides provides better airflow. The drawing illustrates ventilation air entering through an eave or outside edge and exiting through a parapet or wall at the opposite side of the roof.

to dissipate stray water vapor. Vents should be located at opposite sides of the roof, at eaves, parapets, or walls (Figure 11.31). This organization of roofing, insulation, vapor retarder, and ventilation space is the same basic arrangement found in most steep roofs. Insulation in this position in low-slope roofs is relatively economical and trouble-free, but it leaves the membrane exposed to the full range of outdoor temperature fluctuations.

Insulation between the Deck and the Membrane

The traditional position for low-slope roof insulation is between the deck and the membrane. Insulation in this position must be in the form of low-density rigid panels in order to support the membrane. The insulation protects the deck from temperature extremes and is itself protected from weather by the membrane. The roof membrane in this type of installation is subjected to extreme temperature variations, and any water or water vapor that may accumulate in the insulation will become trapped beneath the membrane, which can cause the insulation and roof deck to decay. In addition, vapor pressure from the trapped moisture can cause the membrane to blister and eventually to rupture. (See Chapter 17 for an explanation of insulation and vapor problems.)

Two precautions are advisable in cold climates for insulation that is located between the deck and the membrane. A vapor retarder should be installed below the insulation, and the insulation should be ventilated to allow the escape of any moisture that may accumulate there. Ventilation is accomplished by installing *topside vents*, one per thousand square feet (100 m^2) or so, that allow water vapor to escape upward through the membrane. Topside vents are most effective with a loose-laid membrane, which allows trapped moisture to work its way toward the vents from any part of the insulating layer.

Insulation above the Membrane: The Protected Membrane Roof

Insulation above the roof membrane, known as a *protected membrane roof (PMR)*, is a relatively new concept (Figure 11.32). It offers two major advantages. First, the membrane is protected from extremes of heat and cold. Second, the membrane is on the warm side of the insulation, where it is immune to vapor blistering problems. Because the insulation itself is exposed to water when placed above the membrane, the insulating material must be one that retains its insulating value when wet and does not decay or disintegrate. Extruded polystyrene foam board is the one material that has all these qualities.

The insulating board is either laid loose or embedded in a coat of hot asphalt to adhere it to the membrane below. It is held down and protected from sunlight (which disintegrates polystyrene) by a layer of ballast. The ballast may consist of crushed stone, a thin layer of concrete that has been factory laminated to the upper surface of the insulating board, or interlocking concrete blocks (Figure 11.33). Critics of the protected membrane roof system originally predicted that the membrane would disintegrate quickly because of its continual exposure to dampness trapped under and around the insulating boards. However, experience of more than 30 years has shown that the membrane ages little when protected from sunlight and temperature extremes by the insulation boards, despite the presence of moisture.

Vapor Retarders for Low-Slope Roofs

When the insulation is above the membrane, the membrane itself also serves as the vapor retarder. In all other low-slope roof constructions, a separate vapor retarder is advisable except in warm, humid climates, where wintertime condensation is not a problem and summertime air conditioning can cause water vapor to migrate inward through the roof. In every case, the potential migration of moisture through the insulation should be considered in relation to the membrane, which always acts as a vapor retarder (no matter what its position relative to the insulation).

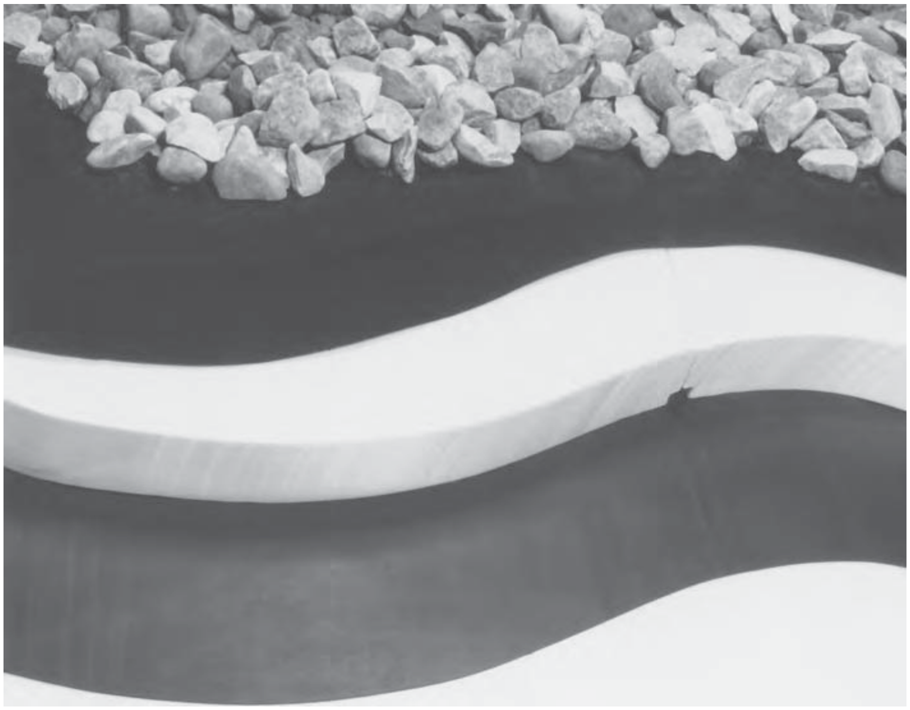


FIGURE 11.32
A cutaway detail of a proprietary type of PMR shows, from bottom to top, the roof deck, the membrane, polystyrene foam insulation, a polymeric fabric that separates the ballast from the insulation, and the ballast. *(Courtesy of Dow Chemical Company)*

FIGURE 11.33
Roofers embed stone ballast in hot asphalt to hold down and protect the panels of rigid insulation in a PMR. The area of the membrane behind the wheelbarrow has not yet received its insulation. *(Courtesy of Celotex Corporation)*

The Low-Slope Roof Membrane

The membranes used for low-slope roofing fall into three general categories: the built-up roof membrane, the single-ply roof membrane, and the fluid-applied roof membrane.

The Built-Up Roof Membrane

A *built-up roof (BUR) membrane* is assembled in place from multiple layers of asphalt-impregnated felt bedded in bitumen (Figures 11.34 and 11.35). The felt fibers may be cellulose, glass, or synthetic. The felt is saturated with asphalt at the factory and delivered to the site in rolls. The bitumen is usually asphalt derived from the distillation of petroleum, but for PMR or very low-slope roofs, coal-tar pitch is used instead, because of its greater resistance to standing water. Both asphalt and coal-tar pitch are applied hot in order to merge

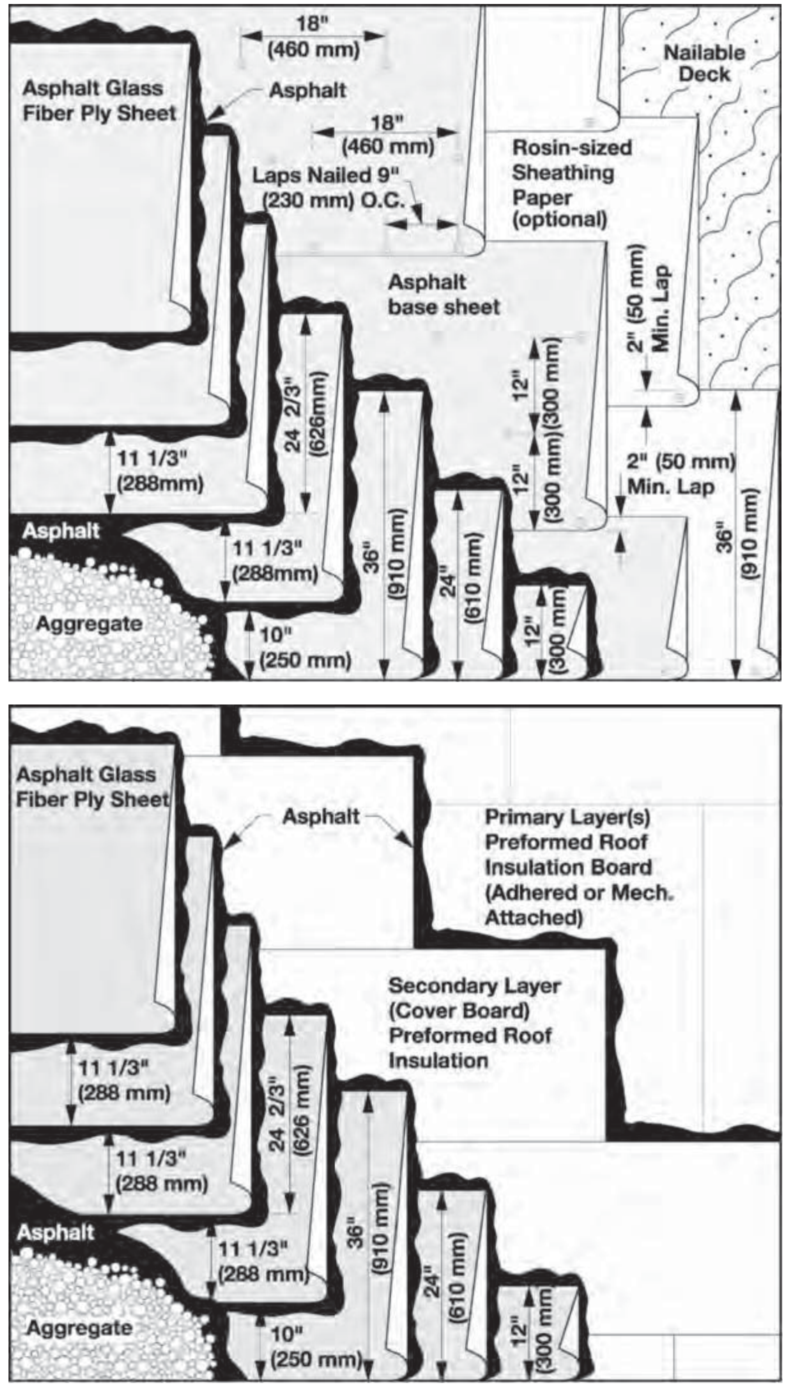


Figure 11.34
Two typical BUR constructions, as seen from above. The top diagram is a cutaway view of a BUR over a plywood roof deck. The membrane is made from plies of felt overlapped in such a way that it is never less than four plies thick. A nonpermeable base sheet isolates the membrane from the deck, which will move slightly due to changes in loading and moisture content. The insulation for this roof is below the deck between the structural joists. The bottom diagram shows how rigid insulation boards are attached to a plywood roof deck to provide a firm, smooth base for application of the membrane. The insulation acts in the same manner as the base sheet in the top diagram to isolate the membrane from movement in the roof deck. A three-ply membrane is shown. In cold climates, a vapor retarder should be installed between the layers of insulation. *(Courtesy of National Roofing Contractors Association)*

with the saturant bitumens in the felt and form a single-piece membrane. The felt is laminated in overlapping layers (plies) to form a membrane that is two to four plies thick. The more plies used, the more durable the roof. To protect the membrane from sunlight and physical wear, a layer of aggregate (crushed stone or other mineral granules) is embedded in the surface (Figure 11.33).

Cold-applied mastics may be used in lieu of hot bitumen in BUR membranes. A roofing mastic is compounded of asphalt and other substances to bond to felts or to synthetic fabric reinforcing mats at ordinary ambient temperatures. The mastic may be sprayed or brushed on and hardens by the evaporation of solvents.

Single-Ply Roof Membranes

Single-ply membranes are a diverse and rapidly growing group of sheet materials that are applied to the roof in a single layer. Compared to built-up membranes, they require less on-site labor, and they are usually more elastic and therefore less prone to cracking and tearing. They are affixed to the roof by any of several means: with adhesives, by the weight of ballast, by fasteners concealed in the seams between sheets, or, if they are sufficiently flexible, with ingenious mechanical fasteners that do not penetrate the membrane.

The materials currently used for single-ply membranes fall into two general groups, thermoplastic and thermosetting. *Thermoplastic materials* may be softened by applying heat. Sheets of thermoplastic membrane may be joined at seams by heat welding or solvent welding. *Thermosetting materials* cannot be softened by heat. They must be joined at seams by adhesives or pressure-sensitive tapes.

The most common thermoplastic membrane is made of polyvinyl chloride (PVC), a relatively low cost compound commonly known as "vinyl." PVC sheet for roofing is 0.045 to 0.060 inch (1.14 to 1.5 mm) thick. It may be laid loose, mechanically attached, adhered, or used as a protected membrane. Other thermoplastic membranes with increased flexibility, cohesion, toughness, resistance to ultraviolet deterioration, and fire resistance are also available.

The most widely used thermosetting material for single-ply roof membranes is ethylene propylene diene monomer (EPDM). Relatively low in cost, it is a synthetic rubber manufactured in sheets 0.030 to 0.060 inch (0.75 to 1.5 mm) thick. It may be laid loose, adhered, mechanically fastened, or used in a protected membrane roof. Other thermosetting materials are also available.

Fluid-Applied Membranes

Fluid-applied membranes are used primarily for domes, shells, and other complex shapes that are difficult to roof by conventional means. Such shapes are often too flat on top for shingles, but too steep on the sides for built-up roof membranes, and, if doubly curved, are difficult to fit with single-ply membranes. Fluid-applied membranes are applied in liquid form with a roller or spray gun, usually in several coats, and cure to form a rubbery membrane. Materials applied by this method include neoprene (with a weathering coat of chlorosulfonated polyethylene), silicone, polyurethane, butyl rubber, and asphalt emulsion.

Traffic Decks

Often, a terrace is desired on the upper floor of a house over a low-slope roof covering a portion of the floor below. In this case, the membrane is generally applied directly to the sheathing, and the insulation is in the structure below (Figure 11.36). Because people and furniture can be expected to be moving about on the

Figure 11.35
Overlapping layers of roofing felt are hot-mopped with asphalt to create a four-ply membrane. *(Courtesy of Manville Corporation)*

Figure 11.36
A heat-sealed, single-ply roof at the low corner of a small roof terrace. The single-ply roofing has been applied directly to plywood sheathing and heat-sealed at the joints. A copper drain in the floor leads to a scupper and downspout. The hole in the wall is an overflow drain that will allow water to escape in case the main drain gets clogged. Siding will lap over the edges of the roofing, and concrete pavers set on building felt will protect the roofing against abrasion. *(Photo by Rob Thallon)*

terrace, it is necessary to protect the membrane from abrasion. One common approach for small terraces is to use concrete pavers that are set on a thin bed of sand or on a 30-pound felt slip sheet that acts as a cushion between pavers and membrane. The pavers must be retained at all edges, so this approach works best when the terrace is bounded by a solid railing with a scupper for drainage (Figure 11.37). Another common detail for this situation employs a thin lightweight concrete slab over the membrane. The structure below must be very stiff to prevent cracking in the slab, especially if the terrace is large. Wood duckboards, essentially a thin wooden deck on sleepers, may also be used to protect terrace membranes.

Roof Edge Details

The outer edge of a steep roof, where it meets the wall at the eave and rake, requires special attention by the building's designer. Several objectives must be kept in mind. The eaves and rakes should be designed so that the siding can be easily attached. The edges of the roofing material should be positioned and supported in such a way that water flowing over them will drip free of the trim and siding below. The eaves must be ventilated to allow for the free circulation of air beneath the roof sheathing (Figure 11.38). Finally, provision must be made to attach gutters or to provide another means to drain rainwater and snowmelt from the roof without damaging the structure below.

Details at the edges of low-slope roofs have similar requirements. Where overhangs occur, details should be similar to eaves for steep roofs. Parapets require details that ensure that the roof membrane is turned up onto the wall a sufficient distance to contain rainwater and snowmelt and

Figure 11.37
A completed roof terrace similar to the one under construction in Figure 11.36.
(Photo by Rob Thallon)

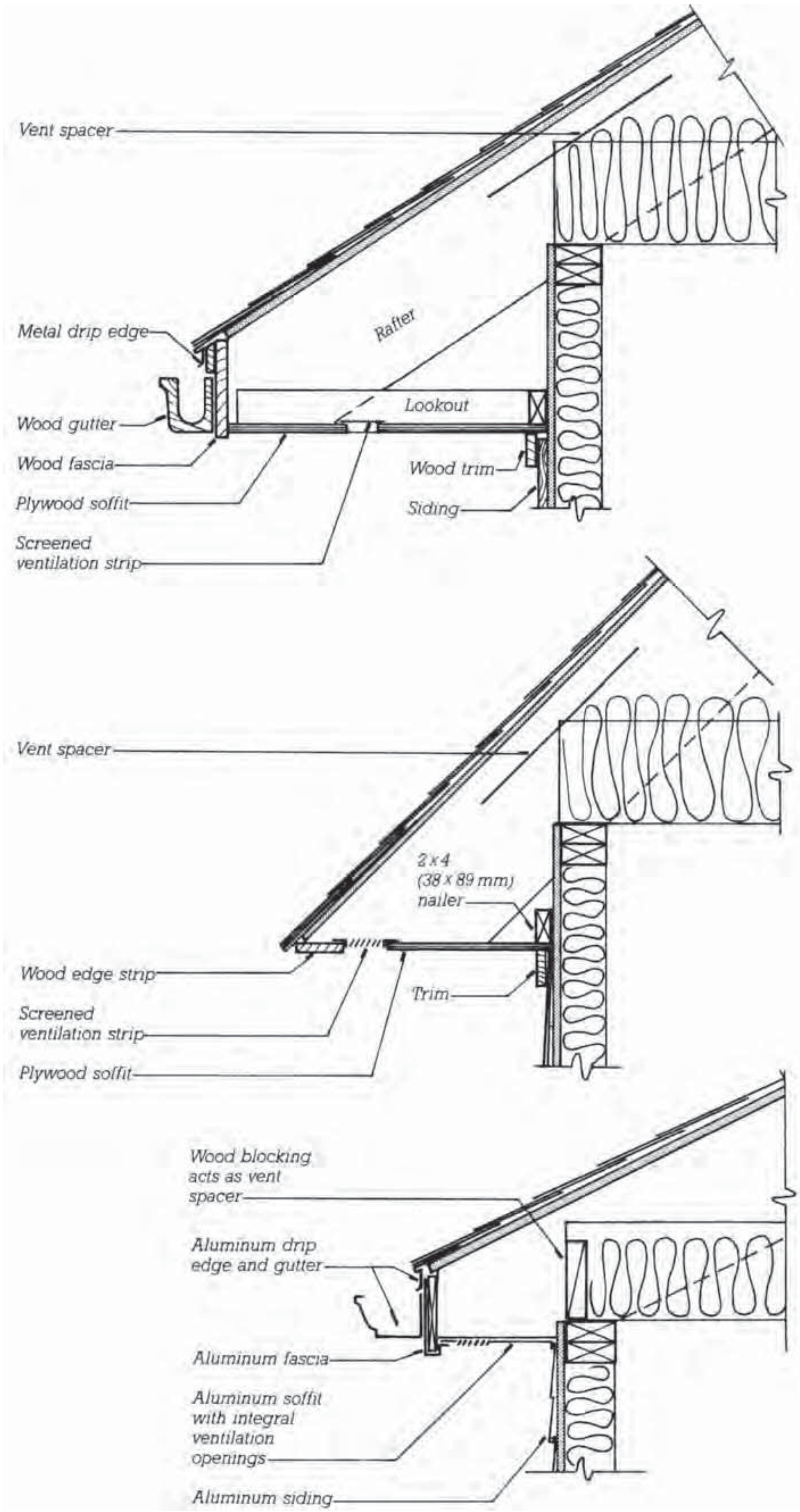
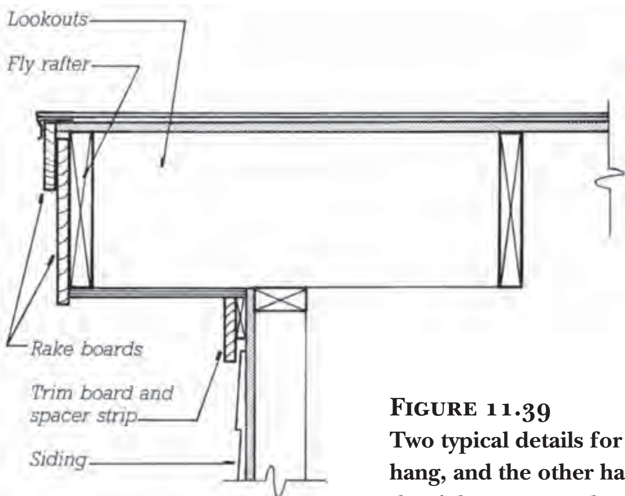


Figure 11.38
Three ways, from among many, of finishing the eaves of a wood light frame building. The top detail has a wood fascia and a wood gutter. The gutter is spaced away from the fascia on wood blocks to help prevent decay of the gutter and fascia. The width of the overhang may be varied by the designer, and a metal or plastic gutter may be substituted for the wood one. The sloping line at the edge of the ceiling insulation indicates a vent spacer as shown in Figure 17.26. The middle detail has no fascia or gutter; it works best for a steep roof with a sufficient overhang to drain water well away from the walls below. The bottom detail is finished entirely in aluminum. It shows wood blocking as an alternative to vent spacers for maintaining free ventilation through the attic. Sometimes, designers entirely eliminate eave overhangs and gutters from their buildings for the sake of a "clean" appearance, but this is ill-advised because the water from the roof washes over the walls, which leads to staining, leaking, decay, and premature deterioration of the windows, doors, and siding.

that siding has sufficient clearance from wet surfaces. Where neither eave nor parapet is present at the edge of a low-slope roof, venting is usually provided through the wall or fascia. Some typical details of low-slope roofs are presented in Figures 11.40 to 11.42. All are shown with built-up roof membranes, but details for single-ply membranes are similar in principle.

The construction of eaves, rakes, and parapets is done by the framing contractor and is generally completed before the roofing is installed, though the trim is usually left off until the time when the siding is installed. If weather permits, the eaves and rakes are often painted before the roofing is installed.



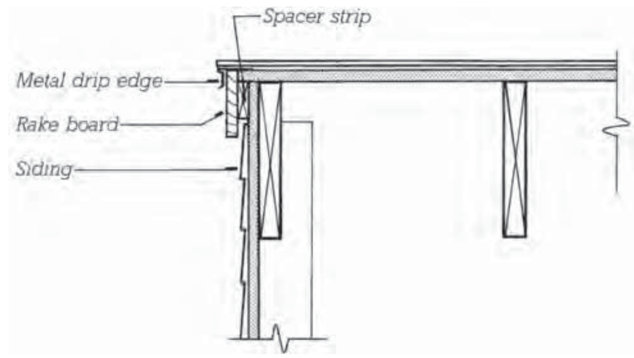


Figure 11.39
Two typical details for the rakes (sloping edges) of sloping roofs. One detail has no rake overhang, and the other has an overhang supported on lookouts. The spacer strip in the detail at the right supports the rake board slightly away from the siding—forming a drip edge that also trims the top of the siding.

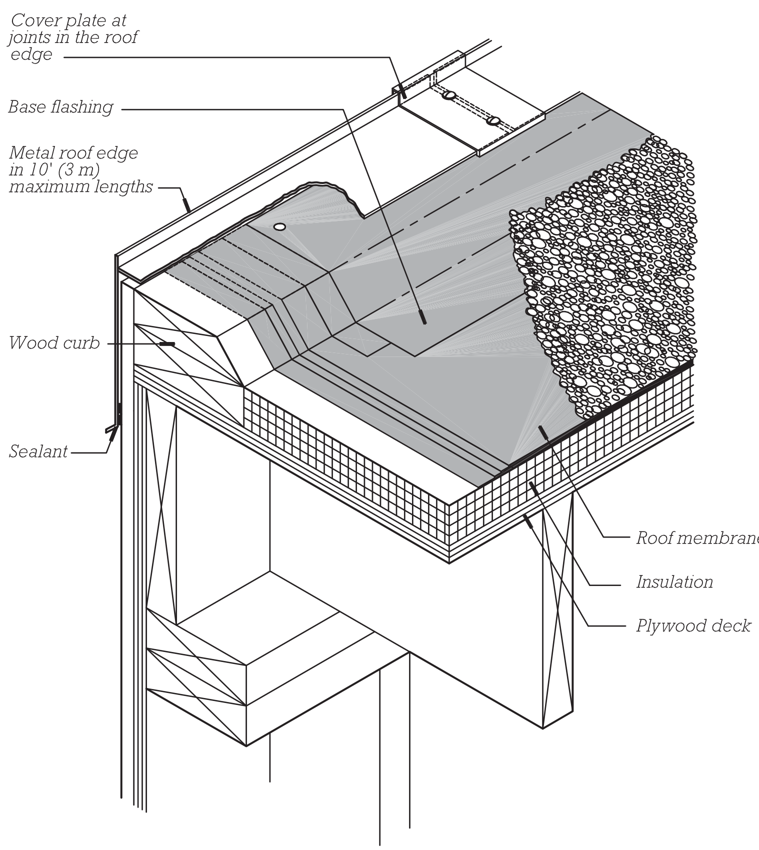


Figure 11.40
A roof edge for a conventional built-up roof. The membrane consists of four plies of felt bedded in asphalt with a gravel ballast. The base flashing is composed of two additional plies of felt that seal the edge of the membrane and reinforce it where it bends over the curb. The curb directs water toward interior drains or scuppers rather than allowing it to spill over the edge.

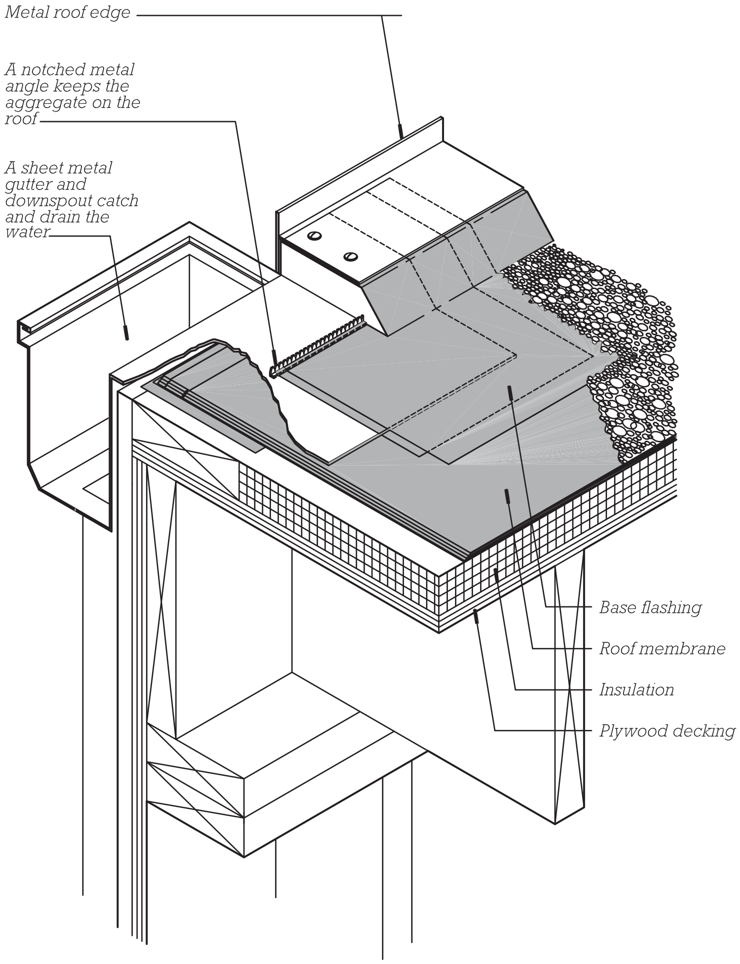


FIGURE 11.41
Detail of a scupper. The curb is discontinued to allow water to spill off the roof into a gutter and downspout. Additional layers of felt, called "stripping," seal around the sheet metal components. Large roofs use interior drains rather than scuppers as their primary means of drainage.

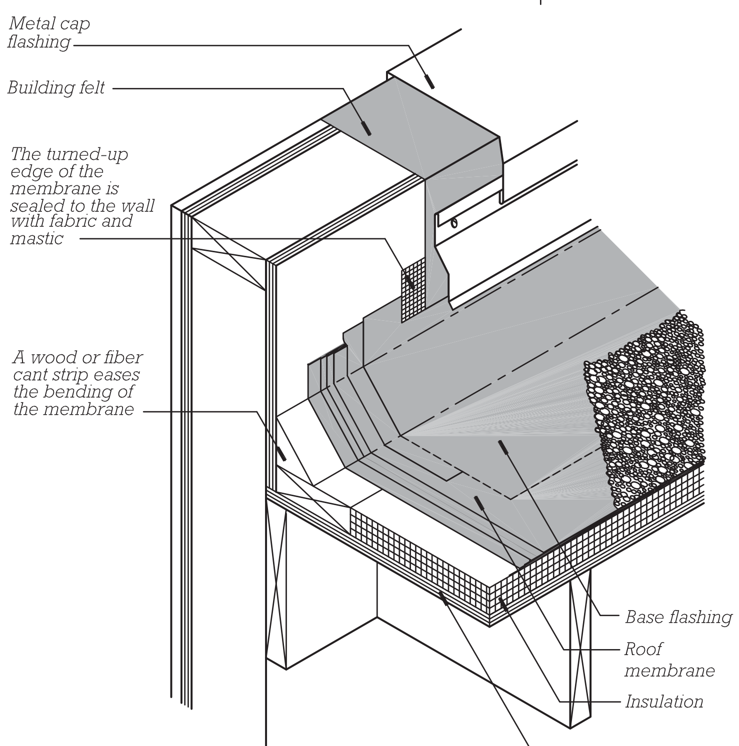


FIGURE 11.42
A conventional parapet design.

ROOF DRAINAGE

Gutters with *downspouts* (downspouts are also called "leaders") are usually installed along the eaves of a sloping roof to remove rainwater and snowmelt without allowing them to wet the walls or cause splashing or erosion on the ground below (Figure 11.43). By far the most common gutter system in use today is the *continuous metal gutter,* which is formed at the site in uninterrupted lengths of up to 40 feet or more (Figure 11.44). Usually made of steel or aluminum with a baked-enamel finish, continuous gutters come in a variety of shapes and virtually eliminate joints, which are the most common source of gutter failure.

Gutters are usually spiked to the eave of the building (Figure 11.45) and are gently sloped toward the points at which vertical downspouts drain away the collected water. The spacing and flow capacities of downspouts are determined by formulas based on local rainfall history. At the bottom of each downspout, a means must be provided for getting the water away from the building, in order to prevent soil erosion and basement flooding. A system of underground storm drain pipes can collect the water from all the downspouts and conduct it to a storm sewer, a dry well, or a drainage ditch (Figure 7.23). In locations where storm drainage is not required, *splash blocks* at the base of each downspout minimize erosion and direct runoff away from the building.

FIGURE 11.43
Gutters collect rainwater runoff at the level eave of a roof, and downspouts conduct this runoff to the ground, where it is discharged. In this case, the downspout discharges onto a lower roof over which the water will run until it reaches another gutter at the eave. Gutters and downspouts are usually made with a wide range of standard parts that allows them to control the runoff from virtually any roof. *(Photo by Rob Thallon)*

Gutters made of plastic are generally more durable than metal gutters because they will return to their original shape after being deformed. Plastic gutters are more expensive than metal gutters, however, and require many more fittings because they are not as strong or as stiff, so they require more time to install. Nevertheless, they remain popular in some geographical areas and with owner/builders. Wooden gutters, although antiquated, expensive, and impermanent, are still used in some regions for aesthetic reasons. Custom-made gutters that are recessed into the surface of the roof are popular with architects because they are virtually invisible (Figure 11.46), but they are expensive and difficult to construct sufficiently well to prevent water from entering the building if the gutters should become clogged with debris.

Some codes allow rainwater gutters to be omitted entirely if the overhang of the roof is sufficient, thus avoiding the problems of clogging and ice buildup commonly associated with gutters. Typical minimum overhangs for gutterless buildings are 1 foot (300 mm) for single-story buildings, and 2 feet (600 mm) for two-story buildings. To prevent soil erosion and mud spatter from dripping water, the drip line at ground level below the gutterless eave must be protected with a bed of stone (Figure 11.47).

FIGURE 11.44
Continuous seamless gutters are made with a trailer-mounted gutter machine. A roll of sheet metal is fed into one end of the machine, which forms it into continuous lengths of gutter. Workers need only install end caps and downspout fittings to the gutter before it is mounted on the house. Most such machines are owned and operated by sheet metal shops. *(Photo by Rob Thallon)*

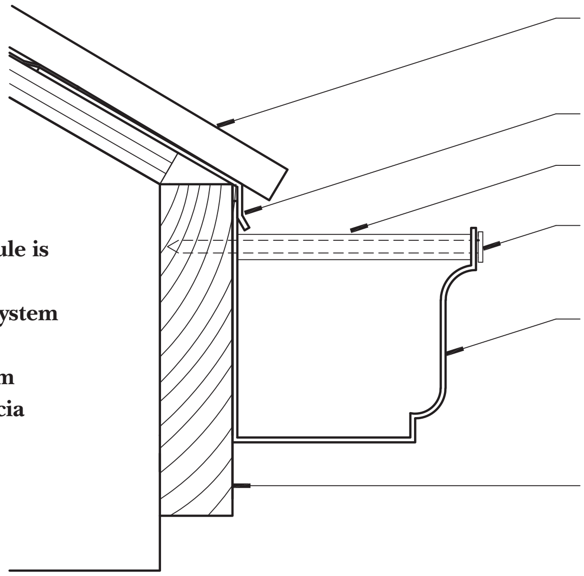


Figure 11.45
The spike and ferrule is the most common gutter attachment system because it is the simplest. The system requires a solid fascia with a vertical face.

Figure 11.47
There are ways other than downspouts to control storm water runoff from a roof. Runoff from the left side of this roof will be conducted to the ground over the surface of a chain. Runoff from the right side will drip directly from the roof into a stone splash bed. *(Photo by Rob Thallon)*

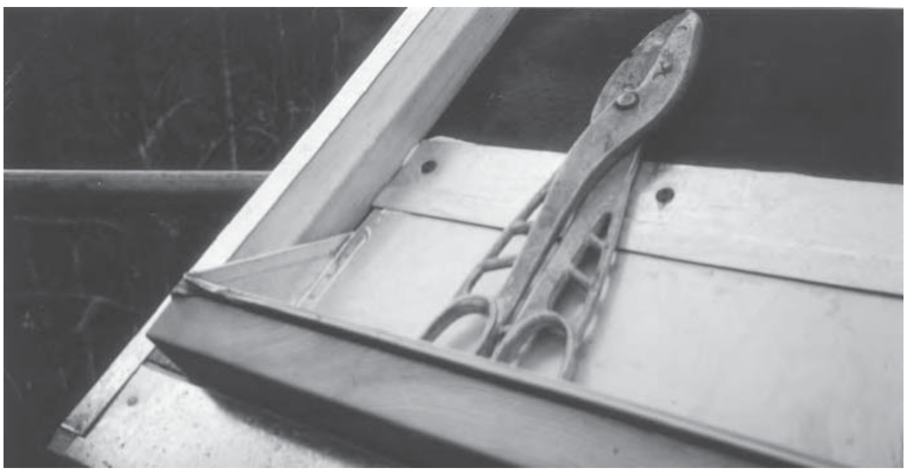


Figure 11.46
This custom gutter system will be hidden behind a flashing at the base of a standing-seam roof. *(Photo by Rob Thallon)*

Roofing and the Building Codes

Manufacturing standards and installation procedures for roofing materials are specified by all the model building codes. Building codes also regulate the type of roofing that may be used on a building, based on a required level of resistance to flame spread and fire penetration as measured by ASTM International (formerly the American Society for Testing and Materials; ASTM) procedure E108. Roofing materials are grouped into the following four classes:

- *Class A* roof coverings are effective against severe fire exposure. They include slate, concrete tiles, clay tiles, most asphalt shingles, most built-up and single-ply roofs, and other materials certified as Class A by approved testing agencies. They may be used on any building in any type of construction.
- *Class B* roof coverings are effective against moderate fire exposure and include many built-up and single-ply roofs, sheet metal roofing, and some composition shingles.
- *Class C* roof coverings are effective against light fire exposure. They include fire-retardant-treated wood shingles and shakes.
- Nonclassified roof coverings such as untreated wood shingles may be used on most residential construction and on some agricultural, accessory, and storage buildings.

ASTM E108 applies to whole roof assemblies, including deck, insulation, membrane or shingles, and ballast, if any. Therefore, the classifications given in the preceding list should be taken only as a general guide. It is difficult to summarize with precision the classification of any particular type of shingle or membrane without knowing the other components of the assembly. The required class of roofing for a particular building may also be affected by an urban fire zone in which the building is located and by the proximity of the building to its neighbors.

Building Green with Roofing

The roof of a building has the potential to play many roles that can make buildings more sustainable:

- A roof can capture rainwater and snowmelt and conduct them to a cistern, tank, or pond for use as domestic water or irrigation.
- A roof can reduce solar overheating of the occupied space of a building in several ways, as listed below:
- A properly proportioned overhang can shade south-facing windows from the high summer sun but admit warming light from the low winter sun.
- A light-colored or metallic roof covering, if kept clean, can reflect most solar heat away from its surface so as to keep it from reaching the occupied space below. Darker-colored roof surfaces are much more absorbent of solar heat. However, selectively absorbing pigments that reduce the heat absorption of darker-colored shingles and roof membranes by about 25 percent are available from many roofing manufacturers.
- In a hot climate, a shading layer above a roof, with a freely ventilated space between, can eliminate most solar heat gain through the roof surfaces. The shading layer might consist of latticework, fabric, or corrugated metal. The exact material is less important than providing both shading and ventilation.
- If appropriately oriented and inclined, a roof surface can support flat-plate solar heat collectors and/or arrays of photovoltaic cells.

Low-Slope Membranes

Low-slope roof membranes have varying impacts on the environment:

- Built-up roofing is largely based on asphaltic compounds derived from coal and petroleum.
- Roofing operations with hot asphalt and pitch give off plentiful quantities of fumes that are decidedly unpleasant and potentially unhealthy, but once the roof has cooled, these emissions subside.

A low-slope roof can be made green quite literally by adding a layer of organic soil and then planting a meadow on the soil. The plants and soil add thermal insulating value to the roof and store some of the rainwater and snowmelt that the roof gathers. They create a passive cooling effect through the vaporization of soil moisture into the air. The plants consume carbon dioxide and produce oxygen, as well as presenting a more attractive surface than conventional roof assemblies, but they do require constant attention to keep them growing and extra structure to support the weight of the soil.

C.S.I./C.S.C.
MasterFormat Section Numbers for Finishing the Roof

07 30 00	Steep Slope Roofing
07 31 00	Shingles and Shakes
07 32 00	Roof Tiles
07 33 00	Natural Roof Coverings
07 41 00	Roof Panels
07 50 00	MEMBRANE ROOFING
07 51 00	Built-up Bituminous Roofing
07 52 00	Modified Bituminous Membrane Roofing
07 53 00	Elastomeric Membrane Roofing
07 54 00	Thermoplastic Membrane Roofing
07 56 00	Fluid-Applied Roofing
07 58 00	Roll Roofing
07 60 00	FLASHING AND SHEET METAL
07 61 00	Sheet Metal Roofing
07 62 00	Sheet Metal Flashing and Trim
07 65 00	Flexible Flashing
07 70 00	ROOF AND WALL SPECIALTIES AND ACCESSORIES
08 60 00	ROOF WINDOWS AND SKYLIGHTS

Selected References

1. National Roofing Contractors Association. *Roofing and Waterproofing Manual.* Rosemont, IL: National Roofing Contractors Association. Updated frequently.

Covers all types of roofs, both low and high slope. It's the roofing industry bible.

2. Patterson, Stephen, and Madan, Mehta. *Roofing Design and Practice.* Upper Saddle River, NJ: Prentice Hall, 2001.

This is a general text, well illustrated and readable, that covers all kinds of roofing.

Key Terms and Concepts

roofing square
underlayment
ice-and-water shield
roof flashing
roof slope
steep roof
low-slope roof
roof jack
solid sheathing
sheathing clip
spaced sheathing (open or skip sheathing)
thermal insulation
vapor retarder
shingle
roof tile
sheet metal roofing
roll roofing
asphalt shingle
wood shingle
shake
interlayment
tile roof
clay tile
concrete tile
slate tile
standing seam
panel roofing
membrane
drainage
roof deck
topside vent
protected membrane roof (PMR)
built-up roof (BUR) membrane
single-ply membrane
thermoplastic material
thermosetting material
fluid-applied membrane
traffic deck
gutter
downspout
continuous metal gutter
splash block
Class A, B, C roofing

Review Questions

1. What are the major differences between a low-slope roof and a steep roof? What are the advantages and disadvantages of each type?

2. Discuss the three positions in which thermal insulation may be installed in a low-slope roof and the advantages and disadvantages of each.

3. Explain in precise terms the function of a vapor retarder in a low-slope roof.

4. Compare a BUR membrane to a single-ply roof membrane.

5. What is the difference between cedar shingles and cedar shakes?

6. What are some reasons for and against adding gutters to the roof of a house? What precautions should be considered when gutters are not used?

7. What are the advantages and disadvantages of the various types of gutter systems?

8. At what point in exterior finishing operations can interior finishing operations begin?

Exercises

1. Sketch the eave detail of a steep roof system of your choice. Now sketch the rake detail of the same system and figure out how the eave and rake connect at the corner. You may have to make a scale model to understand this completely.

2. Find a low-slope roof system being installed and take notes on the process until the roof has been completed. Ask questions of the roofers, the architect, or your instructor about anything you don't understand.

3. Examine a number of existing roofs around your neighborhood, looking for evidence of problems such as cracking, blistering, and leaking. Photograph the problem area and explain to your class the reasons for each problem that you discover.