CHAPTER 4 - Rain and Water Vapor

4.1 General

The most common and disastrous durability problems are frequently related to bulk moisture or rain penetrating a building's exterior envelope without any opportunity to drain or dry out rapidly. If rain penetration occurs repetitively and continues undetected or uncorrected, it can cause wood framing to rot, mold to grow, and steel to corrode. In fact, particularly bad cases of this type of problem have resulted in severely rotted wood frame homes within the period of a couple of years. However, most rain penetration problems can be isolated to inadequate detailing around windows and door openings and similar penetrations through the building envelope.

The objective of designing a weather barrier system is pure and simple–keep rain water away from vulnerable structural materials and interior finishes. Keeping these components dry will maintain a building's structural integrity and help prevent moisture-related problems like mold. Within this guide, "weather barrier" is a general term for a combination of materials used as a system that protects the building from external sources of moisture.

Important related issues are water vapor diffusion and drying potential. These issues are considered in tandem since they are practically inseparable design issues, creating the need to have an integrated design approach (i.e., one that adequately considers all factors and their potential impact on durability).

Some of the information presented in this chapter is generic in nature and will apply to most house designs (e.g., overhangs), while other recommendations are geared more towards specific configurations like vinyl or wood siding installed over wood sheathing. The Rules of Thumb listed in the sidebar to the right and the recommendations in this chapter should help to address the durability and performance issues related to liquid moisture (rain), perhaps the most significant durability factor.

4.2 Recommended Practices

Building walls are subject to water penetration and repeated wetting depending on their exposure, the climate, and the integrity of the siding system. While you can't change the climate in which you build, it *is* possible to improve the shielding of walls and to design walls that are appropriate for "imperfect" (i.e., leaky) siding systems.

4.2.1 Recommendation #1: Roof Overhangs

Figure 4.1 illustrates the frequency of building walls having moisture penetration problems in a particularly moist, cool climate (British Columbia) as a function of roof overhang length. The shielding effect of roof overhangs is illustrated in Figure 4.2. Note that a roof overhang's impact will depend on the climate (Figure 4.3) and type of construction protected. The potential for wind-driven rain should also be considered. The climate index map of Figure 4.3 does not directly account for wind-driven rain—

RULES OF THUMB

- Liquid *water or rain obeys the following rules with respect to movement:*
  - Gravity - *water runs downhill*
  - Capillary - *water is attracted into small cracks due to capillary action or surface tension*
  - Wind - *wind can drive rain into places it would not otherwise go and create building interior and exterior pressure differentials that move it uphill, breaking the first rule (gravity)*
- *NO wall or roof covering is perfectly waterproof, especially considering that there will be wall openings, roof penetrations, and other materials that compromise even the "waterproof" materials—particularly in view of the effects of time.*
- *Avoid depending on caulk as a primary barrier to moisture penetration (i.e., use flashing).*

a condition that varies with local climate or site exposure. Some important considerations regarding roof overhangs include:

- Roof overhangs protect exterior walls and foundations from excessive wetting by rain water—the culprit in many moisture problems in residential buildings.
- Just as the safety factor is important to providing for a reasonable structural design that accounts for foreseen events and unexpected extremes, so is the roof overhang to those interested in durable wood-frame building construction.
- The width of roof overhang to use depends on a variety of factors, including construction cost, wall type below, amount of windows and doors exposed, and the height of the wall. Recommended overhang widths are provided in Table 4.1 for typical conditions.
- Greater flexibility in architectural design with respect to the use (or non-use) of overhangs for rain water protection is afforded in more arid climate conditions; in other areas there are significant durability trade-offs (see Figure 4.1).
- In moist climates with significant rainfall, liberal use of overhangs is recommended.
- Roof overhangs also provide durability and energy benefits in terms of solar radiation (see Section 5.2).

In Table 4.1, the recommended overhang widths are given with the assumptions that: all walls have a properly constructed weather barrier, roofs are adequately guttered, and normal maintenance of exterior will occur. For overhangs protecting more than two-story walls with exposed windows and doors, larger overhangs should be considered. Rake (gable end) overhangs also deserve special consideration because more costly “outrigger” framing methods will be required for overhangs exceeding about 12 inches in width and the appearance may not be acceptable to some home buyers. Also, for sites subject to frequent wind-driven rain, larger overhangs and drainage plane techniques that include an air space behind the siding should be considered (see Section 4.2.3). For non decay-resistant wood sidings and trim (as for windows and door casings), greater overhangs and porch roofs are recommended.

4.2.2 Recommendation #2: Roof Gutters and Down-spouts

Properly designed roof gutters reduce the amount and frequency of roof run-off water that wets above-grade walls or the foundation. A list of recommendations and a rule-of-thumb design approach are presented below to help in the proper use of gutters. Figure 4.4 illustrates a typical gutter installation and components.

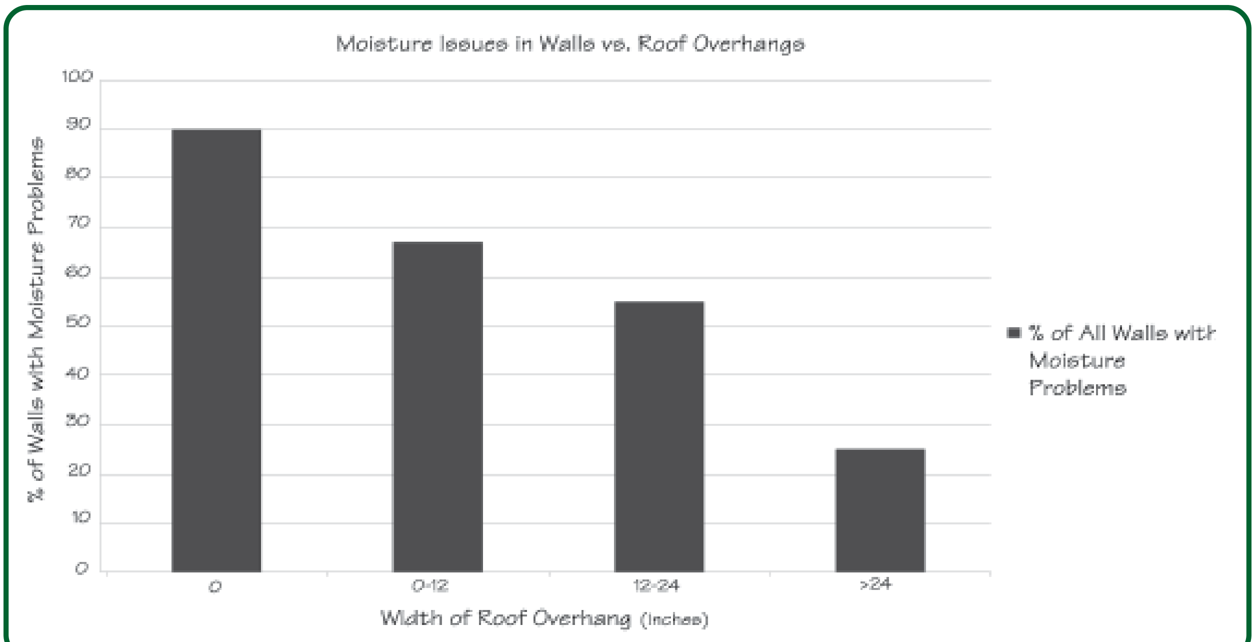


Figure 4.1 - Frequency of Moisture Problems in Walls of Selected Buildings in a Moist, Cool Climate
(Climate Index of approximately 70 based on Figure 4.3)

Source: Morrison Hershfield Limited, *Survey of Building Envelope Failures in the Coastal Climate of British Columbia,* Canada Mortgage and Housing Corporation, Burnaby, BC, Canada, 1996. Figure is based on a selection of 46 buildings of up to eight years old, three to four stories, wood-frame, with various wall claddings. Fifty percent of walls with problems used direct-applied stucco cladding over building paper and oriented strand board (OSB) wood panels.

TABLE 4.1 - RECOMMENDED MINIMUM ROOF OVERHANG WIDTHS FOR ONE- AND TWO-STORY WOOD FRAME BUILDINGS[1]

Climate Index (Figure 4.3)	Eave Overhang (Inches)	Rake Overhang (Inches)
Less than 20	N/A	N/A
21 to 40	12	12
41 to 70	18	12
More than 70	24 or more	12 or more

Source: Modification of *Prevention and Control of Decay in Homes* by Arthur F. Verrall and Terry L. Amburgey, prepared for the U.S. Department of Agriculture and U.S. Department of Housing and Urban Development, Washington, DC, 1978.
[1]Table based on typical 2-story home with vinyl or similar lap siding. Larger overhangs should be considered for taller buildings or wall systems susceptible to water penetration and rot.

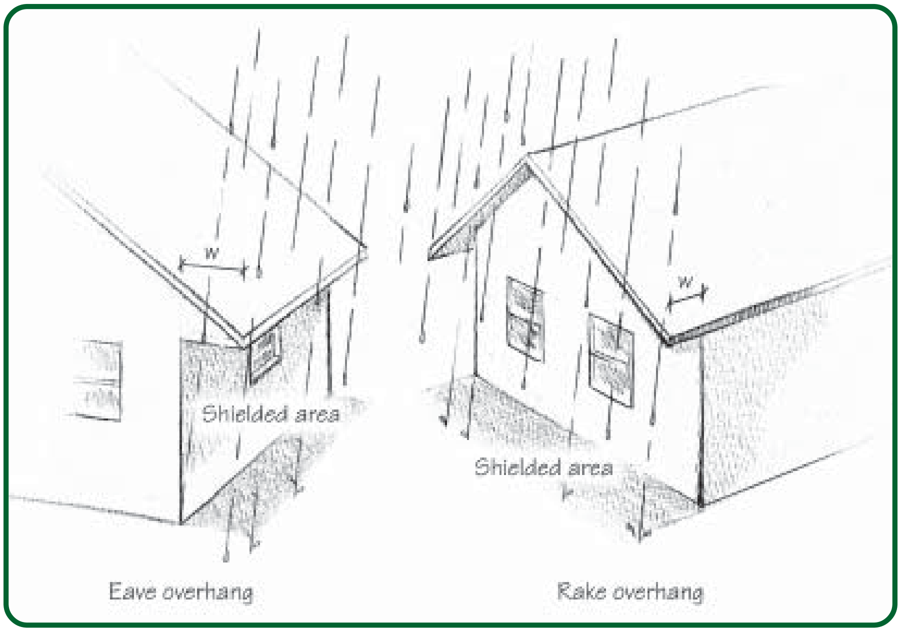


Figure 4.2 - Roof Overhangs

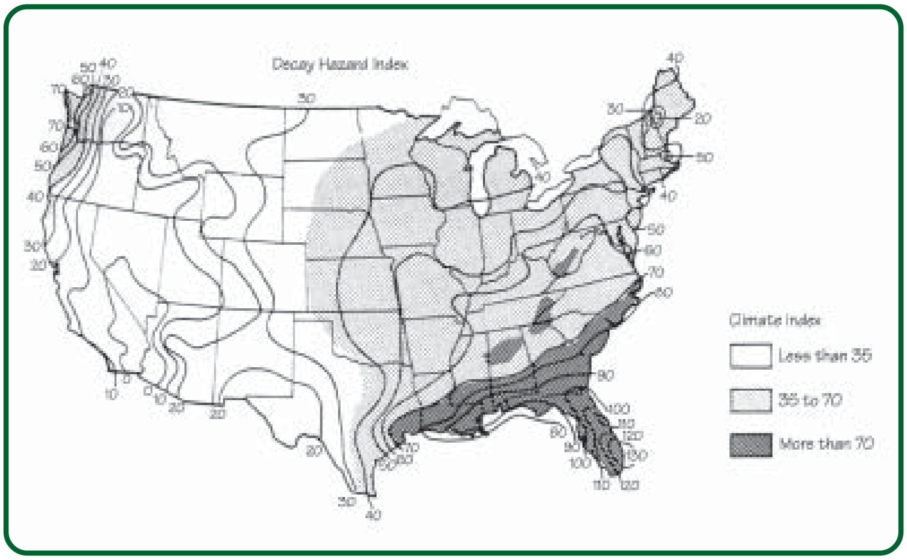


Figure 4.3 - Climate Index Map Based on Wood Decay Potential
Prepared by the U.S. Weather Bureau.

Source: Theodore C. Scheffer, "A climate index for estimating potential for decay in wood structures above ground," *Forest Products Journal,* Vol. 21, No. 13, October 1971.

Site specific indices may be determined using the following formula, where T is the monthly mean temperature (ºF), D is the mean number of days in the month with 0.01 inch or more of precipitation, and Σ *is the summation of products (T-35)(D-3) for respective months of the year.*

$$\text{Climate Index} = \frac{\sum_{Jan}^{Dec}\left[(T-35)(D-3)\right]}{30}$$

NOTE: Roof overhangs also provide protection from sunlight; refer to Chapter 5 for advice on using overhangs to minimize the impact of UV radiation. Roof overhangs in hurricane-prone locales may require additional anchorage of the roof.

- Downspouts that discharge to the surface should do so at least two feet outward from the building. Splash blocks or plastic corrugated pipe are recommended to prevent erosion and to give further extension of discharge water away from the foundation, particularly for downspouts located at inside corners of buildings.
- Downspouts that discharge water below grade should do so into non-perforated corrugated or smooth plastic pipe. The pipe should be run underground to a suitable outfall. Do not connect the gutter drain pipe to the perforated foundation drain pipe, this practice will soak the foundation.
- Gutters and downspouts should be resistant to corrosion and abrasion from flowing water; material choices include aluminum (most popular), vinyl or plastic, copper, and coated metal (baked enamel or galvanized).
- Use a gutter splash shield at inside corners (i.e., valleys) where fast moving water in a roof valley may "overshoot" the gutter.
- Gutters, downspouts, and splash blocks must be cleaned and properly maintained by the homeowner.

Sizing of Gutters and Downspouts

Generally, a standard 5-inch deep gutter and 2-inch by 3-inch downspouts are adequate for most homes in most climate conditions in the United States. However, the following simplified sizing method may help to avoid problems when unique situations are encountered. An example is provided on page 20.

Step 1: Determine the horizontal projected roof area to be served by the gutter and multiply by the roof pitch factor from Table 4.2.

Step 2: Estimate the design rainfall intensity (see map in Figure 4.5).

Step 3: Divide selected gutter capacity (Table 4.3) by the rainfall intensity estimated in Step 2 to determine the maximum roof area served.

Step 4: Size downspouts and space along gutter in accordance with factored roof area calculated in Step 1 for the selected gutter size and type. As a rule of thumb, one square inch of down-spout cross section can serve 100 square feet of roof area (i.e., 2"x3"downspout for 600 ft^2; 3"x4" downspout for 1,200 ft^2).

(Source: "All About Gutters" by Andy Engel, *Fine Homebuilding*, August/September 1999).

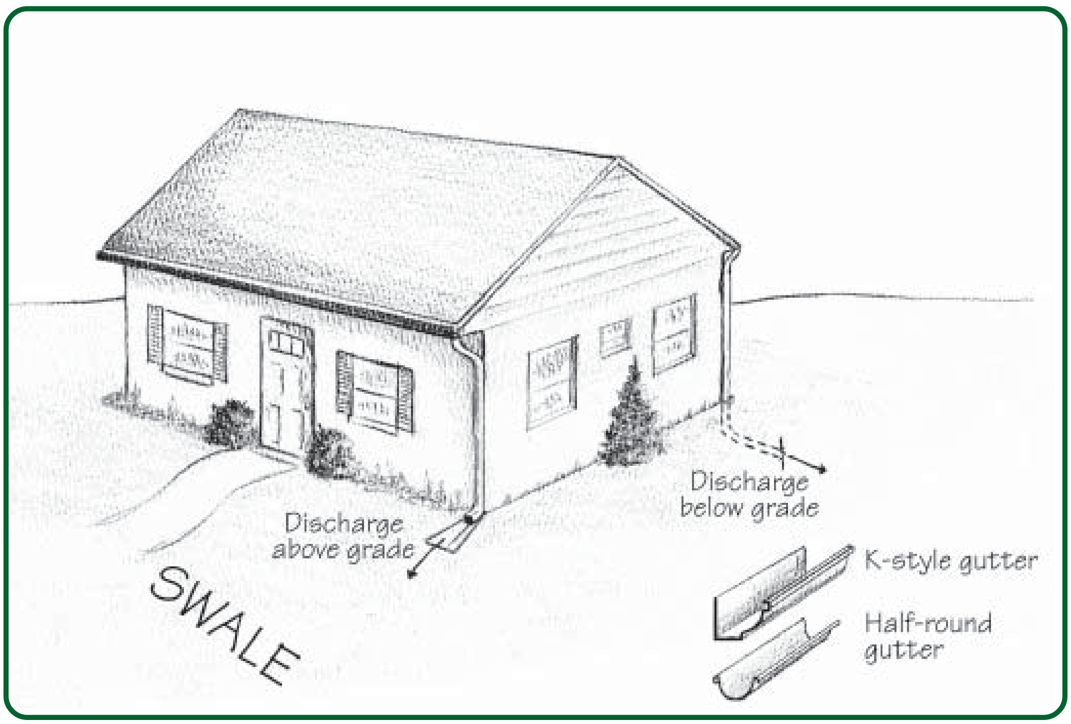


Figure 4.4 - Roof Gutters and Discharge Methods

TABLE 4.2 - ROOF PITCH FACTORS	
Roof Pitch	Factor
Flat to 3:12	1
4:12 to 5:12	1.05
6:12 to 8:12	1.1
9:12 to 11:12	1.2
12:12	1.3

TABLE 4.3 - GUTTER CAPACITY (ROOF AREA SERVED IN SQUARE FEET) BASED ON 1 IN/HR RAINFALL INTENSITY[1]

Gutter Shape	Gutter Size	
	5-inch depth	6-inch depth
K-style	5,520 ft^2	7,960 ft^2
Half-round	2,500 ft^2	3,840 ft^2

Note:
1. Values based on a nearly level gutter. Increasing gutter to a slope of 1/16 inch per foot, multiply values by 1.1 or by 1.3 for 1/8 inch per foot slope.

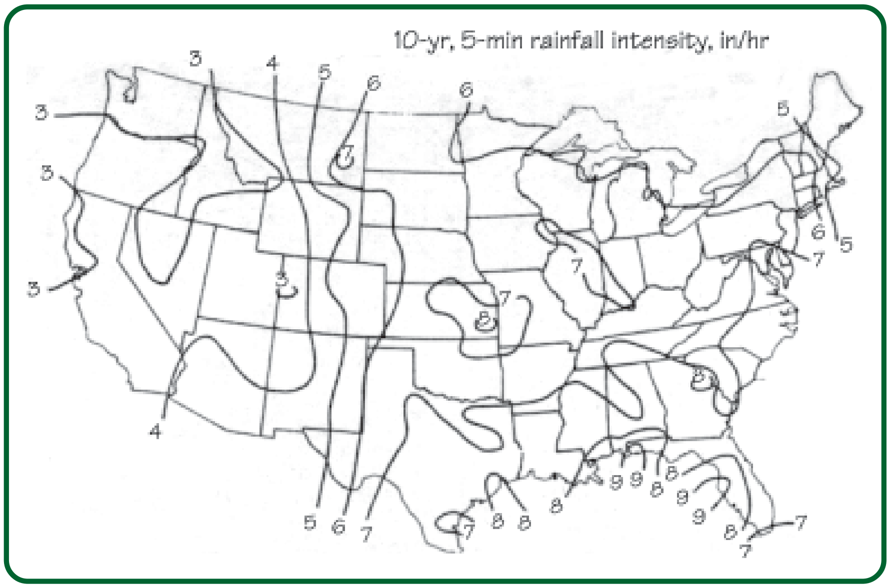


Figure 4.5 - Rainfall Intensity Map of the United States

4.2.3 Recommendation #3: Weather Barrier Construction

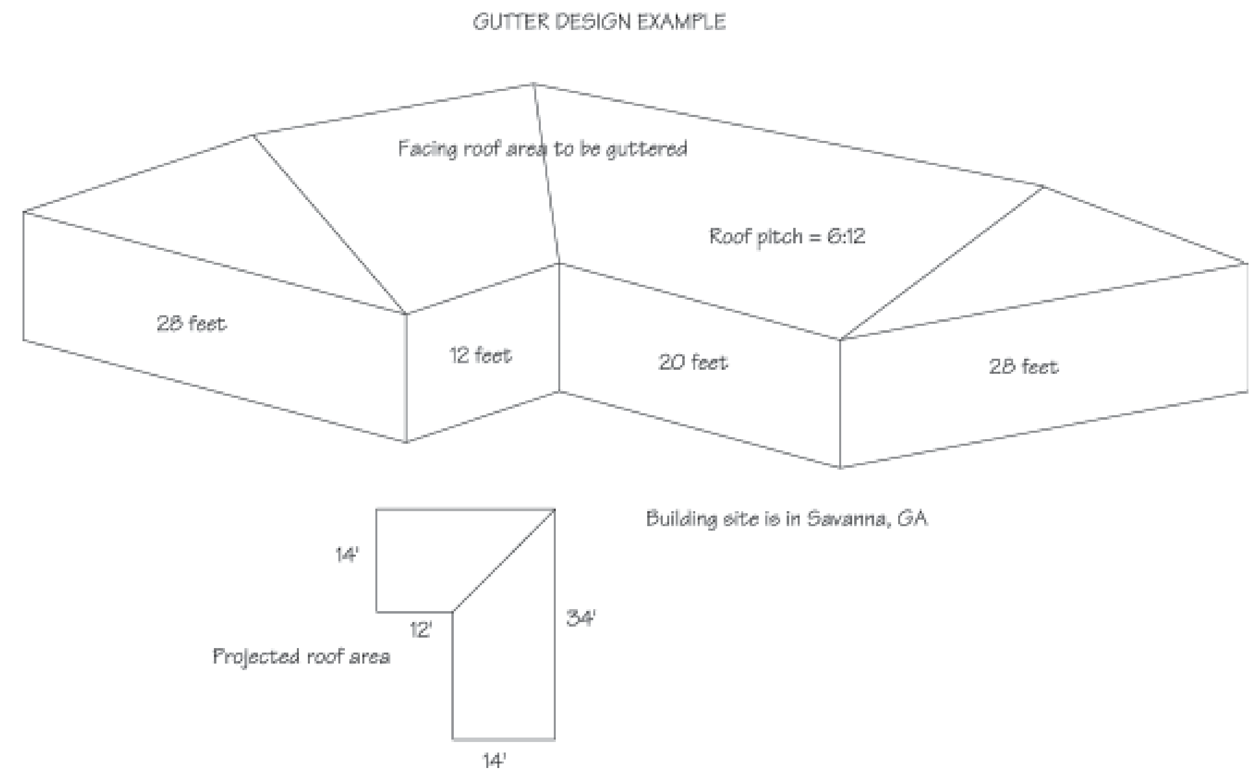
Weather barrier is a broad term for a combination of materials including siding, roofing, flashing, sheathing, finishes, drainage plane, and vapor retarders that, as a system, exhibit water retarding and vapor retarding characteristics and may also possess thermal insulation and air infiltration barrier characteristics.

Drainage Planes

The primary goal in protecting a building wall is to shield the wall from bulk moisture through the use of overhangs, gutters, siding, and opening protection (i.e., flashing or overhangs). As a second line of defense, a drainage plane provides a way out to drain any moisture that penetrates the wall's primary line of defenses (i.e., rain water that gets behind cladding). In less severe climates (low climate index - see Figure 4.3) or when a wall is otherwise protected from rain, the use of a specially detailed

DRAINAGE, VAPOR, AND AIR

Drainage planes do just what their name implies—they drain away liquid water that gets past siding or exterior cladding. ***But*** *that's not all they do. Drainage planes made from building paper or housewrap can affect how water vapor passes (or tries to pass) through a wall. Table 4.4 gives recommendations on this. Drainage planes like housewrap may also serve as air barriers, a boundary around the house that reduces air infiltration. Even if housewrap is only used as an air barrier to cut down air infiltration, it's crucial to understand that it will also collect and channel liquid water that gets past the wall's cladding—like it or not. Housewrap Recommendations (page 25) gives guidance on this issue.*



Step 1
Horizontal projected roof area = (14' x 12') + (14' x 34') = 644 ft^2
Factored area = (1.1)(644 ft^2) = 708 ft^2

Step 2
From rainfall intensity map, Figure 4.5, the estimated rainfall intensity is 7 in/hr.

Step 3
Select a K-style gutter with a 5-inch-depth and a 5,520 ft^2 - in/hr rating from Table 4.3.

*Divide by rainfall intensity as follows: (5,520 ft^2 * in/hr)/(7 in/hr) = 788 ft^2 > 708 ft^2 OK*
Therefore, the gutter is capable of serving this area.

Step 4
A single 2" x 3" downspout is not large enough (i.e., 600 ft^2 < 708 ft^2). Therefore, use one 3"x 4" downspout (at one of the outside corners) or two 2" x 3" downspouts (one at each outside corner). Be sure the gutter is sloped evenly from near its midpoint toward each downspout so that a nearly equal roof area is served by each.

barrier may have little durability benefit. However, for wall systems that are not extremely well-protected from bulk moisture, that are in wind-driven rain climates, or that are sensitive to wetting, the use of a secondary drainage plane should be employed.

Figure 4.6 shows a typical wall system with siding. It's safe to assume that all types of wall coverings (siding, brick, masonry) are imperfect and will leak at some point—some more than others. Therefore, it is important to consider the use of a drainage plane behind the siding material. In some climates, like arid regions with infrequent rain events, a drainage plane may be unnecessary or of very little use. Rain water that does penetrate wood-framed wall systems in these regions can take advantage of wood's capacity to temporarily store moisture, and the wall can dry out via air movement and vapor diffusion once arid outdoor conditions resume (see below for more about Drying Potential).

It may be advisable to use an air space between siding and a drainage plane if:

- A house is in a particularly severe climate (frequent rainfall or wind-driven rain) such as coastal regions subject to hurricanes; and
- Moisture-sensitive siding materials (e.g., wood) are used.

This air space (e.g., use of furring in Figure 4.6), in conjunction with vents (and general air leaks) that allow air to move behind the exterior siding or cladding, provides pressure equalization and creates a capillary break between the back of the siding and the drainage plane. These features will help to reduce the amount of rain water that penetrates behind the exterior cladding and promote better drying potential for the siding and the inner wall. However, creating this space using furring strips applied on top of the drainage plane material must account for the effect on details for flashing and finishing around wall openings such as windows and doors.

Depending on the wall design approach and the climate, a drainage plane needs to exhibit certain characteristics for allowing or retarding the transmission of water vapor, while still rejecting the passage of liquid water like rain. Table 4.4 provides guidance in selecting appropriate wall drainage plane characteristics for various climates. The table considers both how well certain materials reject *liquid* water and how readily they allow water *vapor* to pass through them. This is an important issue that affects the drying potential of walls.

The properties of materials that can be used for drainage planes are found in Table 4.5. In all applications, any material used as a drainage plane should have high resistance to liquid water penetration.

Vapor Retarders

While it's obvious that the drainage plane of a wall must be located on the outer face of a wall or just behind the siding, it is just as important to remember one rule of thumb related to moisture vapor transport in walls. Namely, any vapor retarder must be located on the warm-in-winter side of the wall (i.e., inside) in all climates except hot/humid climate where it should be placed on the warm-in-summer side of the wall (i.e., outside) if one is used at all.

Water vapor in the air is transported by vapor diffusion and bulk air movement. Vapor retarders are intended to restrict the transmission of water vapor via diffusion. A common application of a vapor

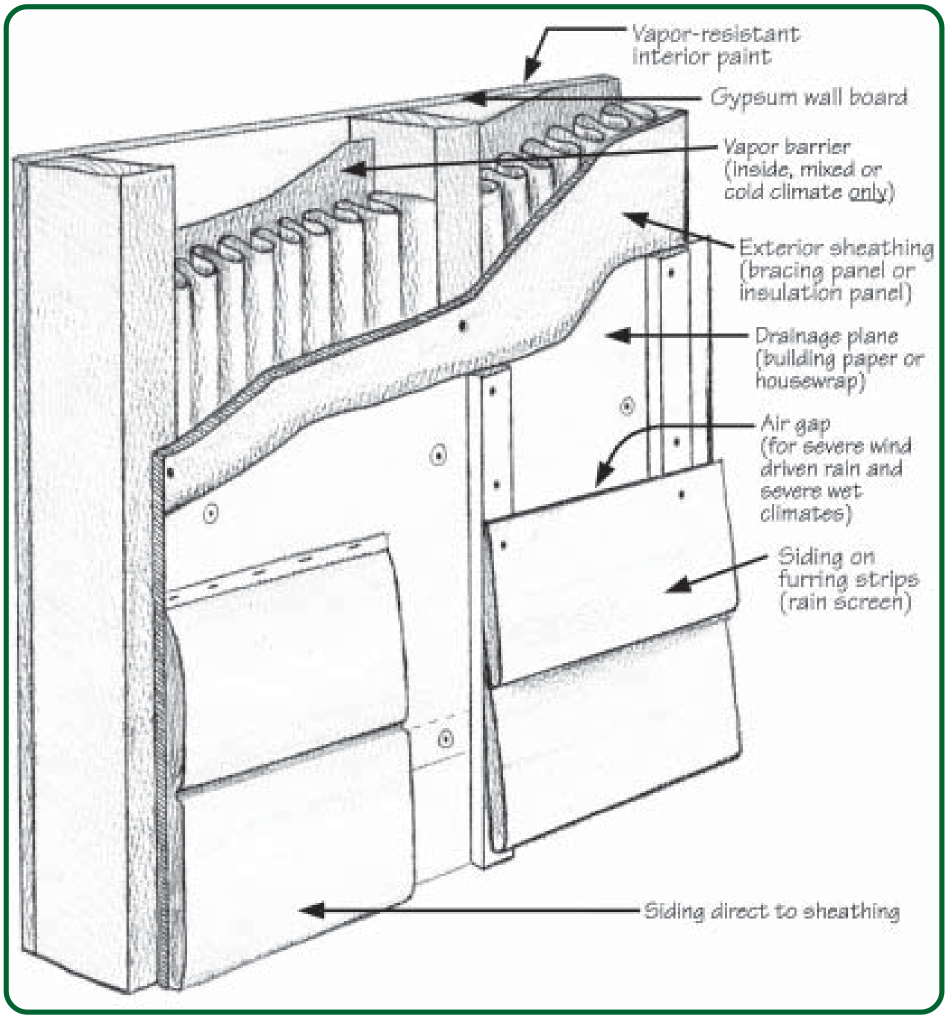


Figure 4.6 - Weather Barrier Construction

retarder would be the use of a polyethylene sheet or kraft paper between drywall and framing of exterior walls in cold climates. However, bulk air movement (i.e., air leakage containing water vapor) is far more significant in terms of the amount of water vapor that can be transmitted, moving roughly 10 to 100 times more moisture than diffusion. This being said, the vapor retarder can still play an important role in controlling the movement of water vapor in walls, particularly in very cold climates.

Table 4.6 provides guidance on appropriate locations and characteristics of vapor retarders for various climates. When using a vapor retarder, it must be installed on the correct side of the wall or ceiling. Otherwise, condensation will form and cause sudden or eventual damage. Also, some older codes established minimum perm ratios for the inner and outer faces of a wall (e.g., a minimum outer face to inner face perm ratio of 5:1 in cold climates to facilitate drying to the outside). Design rules like this one point out that many materials can and will affect vapor diffusion even if they are not classified as vapor retarders. This point, and the fact that air movement can also move large amounts of water vapor, are equally important to designing a wall to handle water vapor.

Building Paper vs. Housewrap

The question "should I use building paper or housewrap" is often asked. And for certain climates in Table 4.4, the question remains. This leads to a discussion of the two product categories and their relative performance characteristics.

Any discussion of this sort should be prefaced by recognizing that *neither* product will work effectively if not installed correctly – and could even do serious harm to a building's durability if used incorrectly.

TABLE 4.4 - RECOMMENDED DRAINAGE PLANE CHARACTERISTICS FOR EXTERIOR WALLS IN VARIOUS CLIMATE CONDITIONS

Climate Condition[1]	Drainage Plane Characteristic		Recommended Product Type
	Liquid Water Resistance	Water Vapor Permeability (low = little vapor passes; high = vapor passes easily)	
Hot & Humid Climate Index >70 HDD < 2,500	High	Moderate to Low[2]	15# tarred felt
Mixed Climate Index >20 2,500 < HDD < 6,000	High	High to Moderate	15# tarred felt or housewrap
Cold HDD > 6,000	High	High[3]	15# tarred felt or housewrap
Dry Climate Index < 20	N/A	N/A[4]	optional

Notes:

[1]HDD refers to Heating Degree Days relative to 65ºF (see Figure 4.7). See Figure 4.3 for Climate Index.

[2]HOT/HUMID CLIMATE CONCERNS: The drying potential of hot/humid climates is through the interior wall, and the layer of lowest vapor permeability (i.e., vapor retarder) must be located to the outside of the wall. If a drainage plane material is used with a low permeability (i.e., polyethylene sheet or foam panel insulation) then it is imperative that a high permeability is achieved on the inside face of the wall (which may affect interior finish selection such as paint type and limit use of materials such as wall paper – see Table 4.5 below). In addition, it becomes more important in hot/humid climates to carefully size HVAC systems so that they operate without "short cycling." Again, moisture entry to the building and condensation potential can be significantly reduced by use of a foundation/ground vapor barrier (Chapter 3).

[3]COLD CLIMATE ALTERNATIVES AND CONCERNS: In this case, energy efficiency can be a conflicting objective to the table's recommendation. For instance, interest in energy efficiency (or code mandated minimum R-values) often leads builders in cold climates to place an impervious layer of insulation (i.e., polystyrene or foil-faced poly-isocyanurate) on the outer surface of the wall. These materials generally have a low permeability to water vapor (see Table 4.5). Since vapor barriers are often required on interior (warm-in-winter side) of walls in cold climates, this can create a situation where a wall has low drying potential. Therefore, this approach should be used with caution in areas that are cold but are also subject to substantial rainfall which may penetrate an improperly installed weather barrier or one that fails to maintain its resistance to liquid water penetration over time. In addition, it becomes critical to seal key leakage areas judiciously to prevent leakage of moist, warm indoor air into the wall cavity where it may condense. Condensation in the wall cavity can also be prevented by controlling indoor air humidity. At a minimum, interior moisture sources should be addressed by using bathroom and kitchen exhaust fans to remove the significant moisture that is produced in these areas of the building. Finally, moisture entering the building/walls from the ground should be minimized by the use of foundation and ground vapor barriers (see Chapter 3).

[4]No drainage plane is required for durability purposes in a dry climate, although care should be taken to seal major air-leakage points for sake of keeping infiltration air out of wall assemblies.

Housewrap products are sometimes viewed solely as air barriers – a product that will reduce air infiltration and do nothing else. Wrong. As discussed in Table 4.4, housewrap products also block liquid water that gets past siding, making this type of product useful for a drainage plane.

And in fact, housewraps will act to collect and channel liquid water whether the installer intends for them to do so or not. This can lead to trouble if housewrap is installed in a manner (e.g., not lapped correctly, drains water behind windows) that doesn't allow for channeling water out of a wall system. So the lesson is: housewraps are not just air barrier products, they can – and should be – used as drainage planes as well. Their vapor diffusion characteristics aren't sufficient to allow quick drying should misinstallation result in bulk water penetration.

PLUG UP THE LEAKS

In all cases, major air leakage points through the building envelope should be sealed to limit the flow of air, heat, and moisture. Places to air seal include areas around door and window frames, attic hatches, kneewalls, HVAC chases, and electrical and plumbing penetrations into attics.

TABLE 4.5 - DRAINAGE PLANE AND VAPOR RETARDER MATERIAL PROPERTIES[1,2]

Material	Weight or Thickness	Permeance, Perms[3] (vapor retarder = 1 perm or less)			Liquid Water Loss[5]
		Dry-cup Method	Wet-cup Method	Other	
15# asphalt felt	14 lb/100 sf	1.0	5.6	—	30%
15# tar felt	14 lb/100 sf	4.0	18.2[4]	—	—
Building wraps (6 brands)	—	5.0 - 200.0	5.0 - 200.0	—	0 to 80%[6]
Blanket Insul., asphalt coated paper	6.2lb/100 sf	0.4	0.6 - 4.2	—	—
6mil polyethylene	0.006 in	0.06	—	—	—
Aluminum foil	0.001 in	0.0	—	—	—
Gypsum board	3/8 in	—	50.0	—	—
Plywood (interior glue)	1/4 in	—	1.9	—	—
Block	8 in	—	2.4	—	—
Brick	4 in	—	0.8	—	—
Concrete	4 in	—	0.8	—	—
Polystyrene, expanded board	1 in	2.0 - 5.8		—	—
Polystyrene, extruded board	1 in	1.2		—	—
Vapor retarder paint	0.0031 in	—	0.5	—	—
Primer sealer paint	0.0012 in	—	6.3	—	—
Exterior acrylic house and trim paint	0.0017 in	—	5.5	—	—

Notes:

[1]These values only relate to performance in standardized and constant test conditions and do not necessarily represent actual behavior under actual conditions of use. Leakage as a result of discontinuities and other conditions experienced in construction of buildings may easily alter, by a factor of 2 or more, the overall or localized performance of a vapor retarder in comparison of these standardized values. Therefore, these values can be used for indexing purposes only.

[2]Differences in perm ratings between dry-cup, wet-cup, and other test methods are substantial and any cross comparison should be made on the bases of similar test methods and conditions. Manufacturer data should be consulted when available.

[3]Usually tested according to ASTM E 96.

[4]Value can vary to more than 60 perm in 95% relative humidity test conditions.

[5]Tested using AATCC 127 test method modified to a 3.5 inch head for 2-hour duration (University of Massachusetts, Building Materials and Wood Technology, Paul Fisette, as reported on www.umass.edu/bmatwt/weather_barriers.html, October 1999).

[6]Of six brands tested, R-Wrap and Tyvek received the best possible rating of 0 water loss (liquid water transmission). However, when these products were subjected to soapy water and a cedar extractives water solution, the loss rates increased slightly.

In addition to air barrier and drainage plane functions, housewraps are designed to allow water vapor to diffuse through them. Housewraps should not be considered as vapor retarders. Research conducted by the University of Massachusetts (www.umass.edu/bmatwt/weather_barriers.html) examined 6 brands of housewrap and found permeability levels ranging from 5 to 200 perms.

This research also stated that the housewraps appeared to have their ability to reject liquid water degraded somewhat by the use of soapy water (from power washing) and, to a lesser degree, water laden with a cedar extractive.

On the other hand, 15# felt paper has a lower perm rating (~ 4 perms at low relative humidity) than housewrap products, enhancing its ability to limit

TABLE 4.6 - RECOMMENDED VAPOR RETARDER CHARACTERISTICS FOR BUILDING EXTERIORS OR INTERIORS IN VARIOUS CLIMATE CONDITIONS

Climate Condition[1]	Location of Vapor Retarders	Water Vapor Permeability[2] (low = little vapor passes high = vapor passes easily)	Recommended Product Type[2]
Hot and Humid HDD < 2,500	Outer side of wall	Low to moderate (see Table 4.4, Drainage Plane)[3]	15# tarred felt
	Foundation (slab, crawl, or basement)	Low	6 mil polyethylene plastic sheet on ground
	Attic & Cathedral Roof	High	None
Mixed 2,500 < HDD < 6,000	Inner side of wall	Moderate (2,500 HDD) to Low (6,000 HDD)	Kraft paper on batts or vapor retarder paint on interior
	Foundation (slab, crawl, or basement)	Low	6 mil polyethylene plastic sheet on ground
	Attic & Cathedral Roof (ceiling side)[4]	High (2,500 HDD) to Moderate (6,000 HDD)	None to Kraft paper on batts (6,000 HDD)
Cold HDD > 6,000	Inner side of wall	Low	3 mil polyethylene or vapor retarder paint on interior
	Foundation (slab, crawl, or basement)	Low	6 mil polyethylene on ground
	Attic & Cathedral Roof (ceiling side)[4]	Moderate (6,000 HDD) to Low (9,000 HDD)	Kraft paper on batts to 3 mil polyethylene or vapor retarder paint on interior

Notes:
[1]HDD refers to Heating Degree Days relative to 65ºF (see Figure 4.7).
[2]These recommendations are based on both the material properties (perms) and how they are used. A product that is not applied continuously over a surface (e.g., kraft faced batts in a ceiling) will allow more vapor to pass than a continuous layer.
[3]Because it is equally important to ensure that the interior surface of a wall has a high permeability finish, select paint with high permeability and avoid finishes such as vinyl wall paper that will act as a vapor barrier. *Prevention and Control of Decay in Homes*, USDA/HUD, 1978, recommends that “In warm climates, walls and ceilings without vapor barriers are safer.”
[4]Attic vapor barriers for hip and gable roofs, if used in mixed and cold climates, should be placed on the warm-in-winter side of the attic insulation. The same applies to cathedral ceilings.

vapor transmission through the wall (in either direction). This characteristic is a benefit in hot and humid regions and in designs where some resistance to vapor movement from outside to inside is desired (e.g. behind brick veneer or unsealed wood siding). While building paper is not usually viewed as an air barrier product, it can still be used in conjunction with other measures (e.g. caulk and foam sealants) to produce a wall system with reduced air infiltration.

So both products can shed liquid water. Housewrap tends to be more vapor permeable than building paper (check the perm rating for specific brands though), allowing water vapor to diffuse more easily; but neither product would be considered a vapor retarder even though both slow the movement of vapor to some degree. Housewrap can be used as an air barrier, whereas building paper would likely be used in tandem with other air sealing measures. These differences, as well as price, should be the basis for a choice when a decision needs to be made. But once more, keep in mind that *neither* type of product will perform the way it's supposed to if it's not properly installed and integrated with flashing of windows and doors (see Section 4.2.4 on flashing and housewrap installation).

Housewrap Recommendations

Housewraps are relatively new materials that serve a dual role as a secondary "weather resistant" barrier and an air barrier. However, this dual role of building materials has been known for some time for materials such as building paper or "tar paper" (USDHEW, 1931). Even lath and plaster has been classified as an effective air barrier–a finding that also stands for its modern day counterpart, gypsum wallboard. Of course, an air barrier is not a substitute for proper sealing of penetrations in the building envelope around windows, doors, utilities, and other leakage points.

Therefore, as with the application of building paper, housewraps should be viewed and installed with the main goal of serving as a secondary weather-resistant barrier (i.e. drainage plane). Like tar paper, the edges of housewrap should be lapped to provide a drainage pathway for water out of the wall. It is only necessary to tape lapped edges if some improvement in air-barrier performance is desired. However, building wraps are not all created equal in terms of their "breathability" and this additional sealing can affect the drying time of the wall system should it become inadvertently wetted by condensation or, more importantly, rain water (See Table 4.5). At wall penetrations, the housewrap should be properly detailed or flashed (See Section 4.2.4). In some cases, housewraps are installed *after* window and door installation (Figure 4.13), and manufacturer-recommended tapes must be used to seal the joints. While this practice is not uncommon, a preferred method is to install the building wrap prior to window and door installation and to additionally flash window and door heads as shown in Figure 4.12.

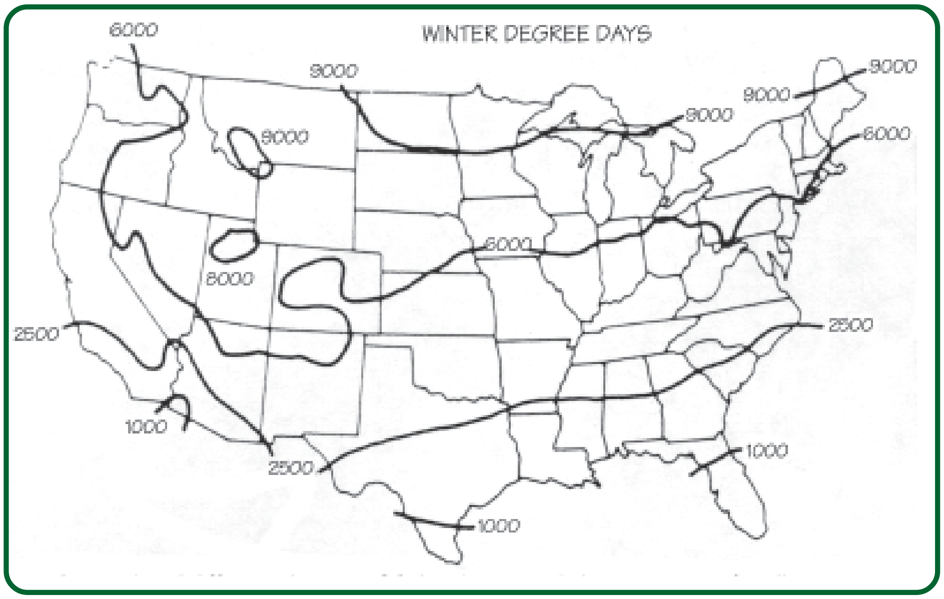


Figure 4.7 - Heating Degree Day (HDD) Map of the United States (65°F basis)

Drying Potential

Drying potential, the ability of a wall system to dry out after it is wetted, is important because it can compensate for conditions when water gets where it's not supposed to be. High drying potential will allow walls that are moist to dry out in a reasonable amount of time and limit the consequences. An ideal wall would be one that doesn't let any moisture in from interior vapor, exterior vapor, rain, snow, or ice. This would require a hermetically-sealed wall, which is not practical in residential construction. If this design approach of a "perfect" sealed wall is pursued and water does get into the wall, it will be trapped there and the results can be disastrous.

Therefore, it is imperative to make less than ideal materials work satisfactorily through careful design, careful construction, and an expectation that water will get into walls. Appropriate solutions will depend on climate conditions, the building use conditions, and common sense.

An ideal wall material acts as a storage medium, safely absorbing excess moisture and expelling it when the relative humidity decreases during periods of drying. Heavy masonry walls do this. To some degree, natural wood materials also exhibit this characteristic and create a beneficial "buffering effect" to counter periods where moisture would otherwise accumulate to unacceptable levels. This effect is part and parcel of the "breathing building" design approach and it serves as a safety factor against moisture problems, just like a roof overhang.

Materials such as concrete, masonry, and brick also exhibit a moisture storage or buffering capacity as do many contents of a home. This creates a lag effect that should be considered in building design and operation. For example, moisture levels in building materials tend to increase during warm summer months. As the weather cools in the fall, a moisture surplus exists because the expulsion of excess moisture lags in comparison to the rate of change in season temperatures.

Bear in mind that most building moisture problems are related to exterior moisture or rain. Moisture vapor and condensation is usually only a problem in extremely cold climates (upper Midwest and Alaska) or in extremely hot and humid climates, particularly when significant moisture sources exist within a home. For instance, a small house in a cold climate with high internal moisture loads (people, bathing, cooking), little natural or mechanical ventilation, and the lack of a suitable interior vapor retarder (i.e., between drywall and external wall framing) will likely experience moisture problems.

4.2.4 Recommendation #4: Proper Flashing

Flashing is perhaps one of the disappearing crafts in the world of modern construction and modern materials that seem to suggest simple installation, "no-worry" performance, and low maintenance. An emphasis on quick installations often comes at the expense of flashing.

Good flashing installations take time. But it's time well invested. So, if flashing is to be installed, it is best to invest the effort to make sure it's done right. In Figures 4.8 - 4.16 some typical but important flashing details are provided as models for correct installation techniques.

RULES OF THUMB AND TIPS

- *Flashing is necessary for proper drainage plane performance in walls and for roofing systems.*
- *Most leakage problems are related to improper or insufficient flashing details or the absence of flashing.*
- *All openings in exterior walls and roof penetrations must be flashed.*
- *Caulks and sealants are generally not a suitable substitute for flashing.*
- *Water runs downhill, so make sure flashing is appropriately layered with other flashings or the drainage plane material (i.e., tar, felt, or housewrap).*
- *Water can be forced uphill by wind, so make sure that flashings have recommended width overlap.*
- *Sometimes capillary action will draw water into joints between stepped flashing that is not sufficiently lapped or that is placed on a low-pitch roof – take extra precaution in these situations.*
- *Avoid joint details that trap moisture and are hard to flash.*
- *Treat end joints of exterior wood trim, railings, posts, etc. prior to painting; paint end joint prior to assembly of joints; if pre-treating, be sure the preservative treatment is approved for use with the type of paint or stain being used.*
- *Minimize roof penetrations by use of ventless plumbing techniques, such as air admittance valves, side wall vents, and direct vented appliances (check with local code authority for approval).*
- *Use large roof overhangs and porches, particularly above walls with numerous penetrations or complex window details.*

BASIC FLASHING MATERIALS AND TOOLS

- *Flashing stock (coated aluminum, copper, lead, rubber, etc.)*
- *15# felt paper*
- *Bituminous adhesive tape*
- *Utility knife*
- *Aviator snips or shears*
- *Metal brake (for accurate bending of custom metal flashing)*

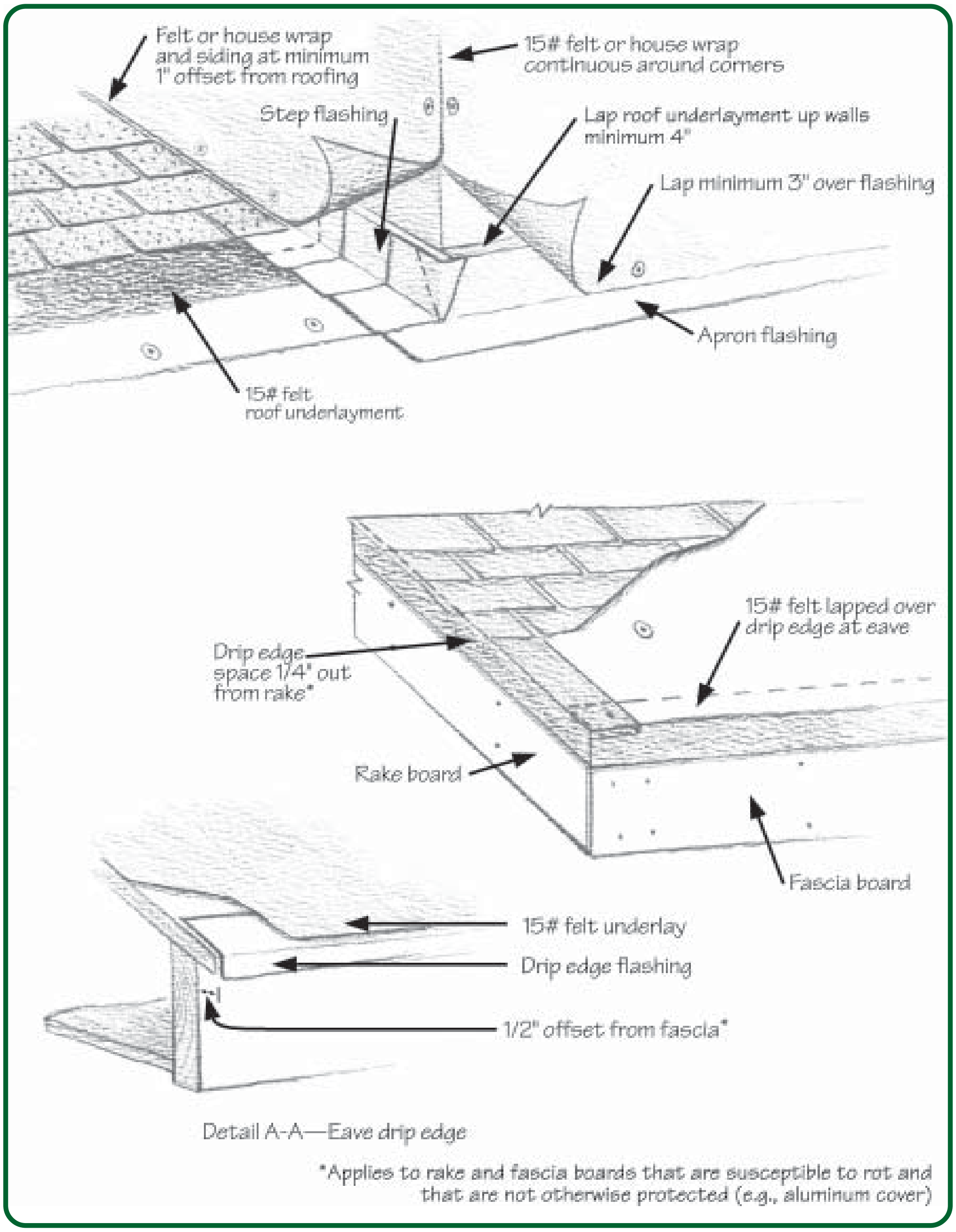


Figure 4.8a - Basic Roof Flashing Illustrations

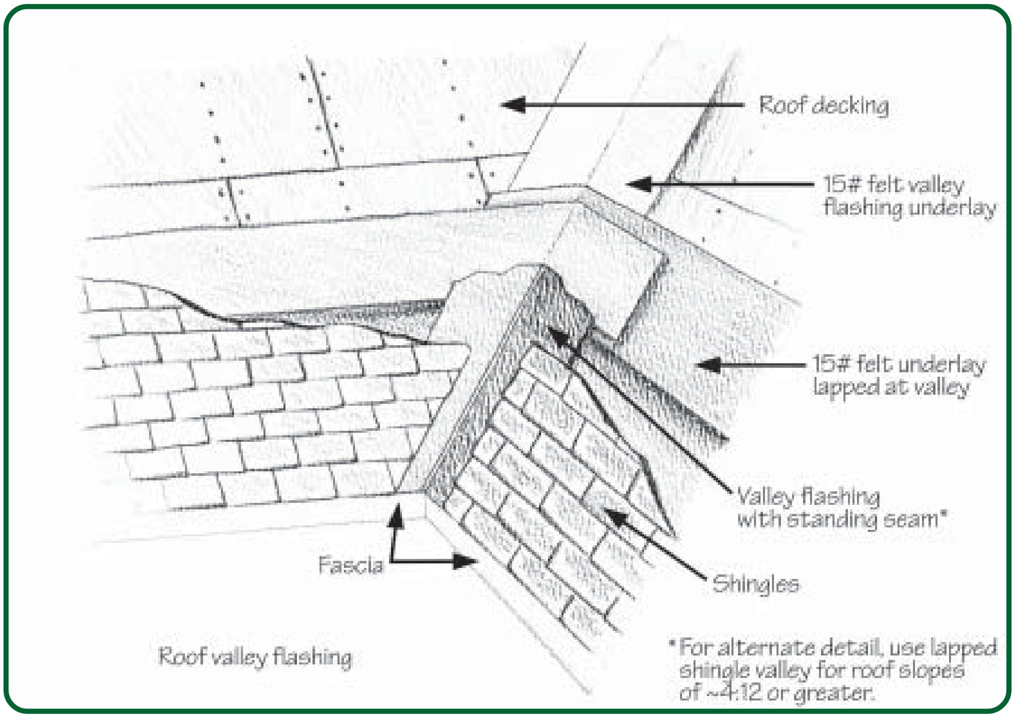


Figure 4.8b - Basic Roof Flashing Illustrations (continued)

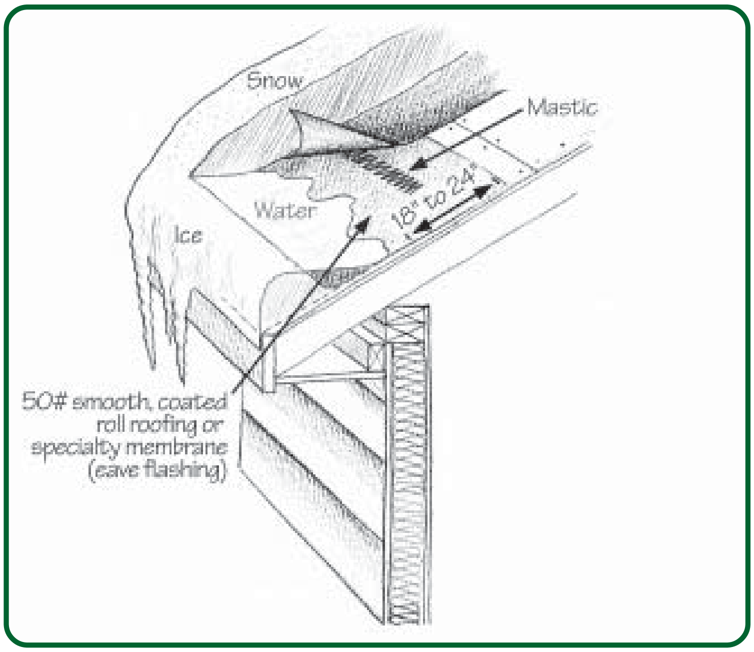


Figure 4.9 - Eave Flashing for Preventing Ice Dams

NOTES for Figure 4.9:
[1]Extend eave flashing 18 to 24 inches inside the plane of the exterior wall.
[2]Overhang eave flashing 1/4 - inch beyond drip edge flashing.
[3]Apply mastic continuously to joints in eave flashing.
[4]If joints in the eave flashing are not avoidable, locate them over the soffit rather than the interior area of the building.

[5]While eave flashing is generally recommended for areas with an average January temperature less than 25ºF, ice dams can be prevented by (1) adequate sealing of ceilings and tops of interior and exterior walls to prevent warm indoor air from leaking into the attic space, (2) adequate attic/roof insulation (usually local code requirements are sufficient) all the way out to the plane of the exterior walls and (3) proper ventilation through the eave and attic space.

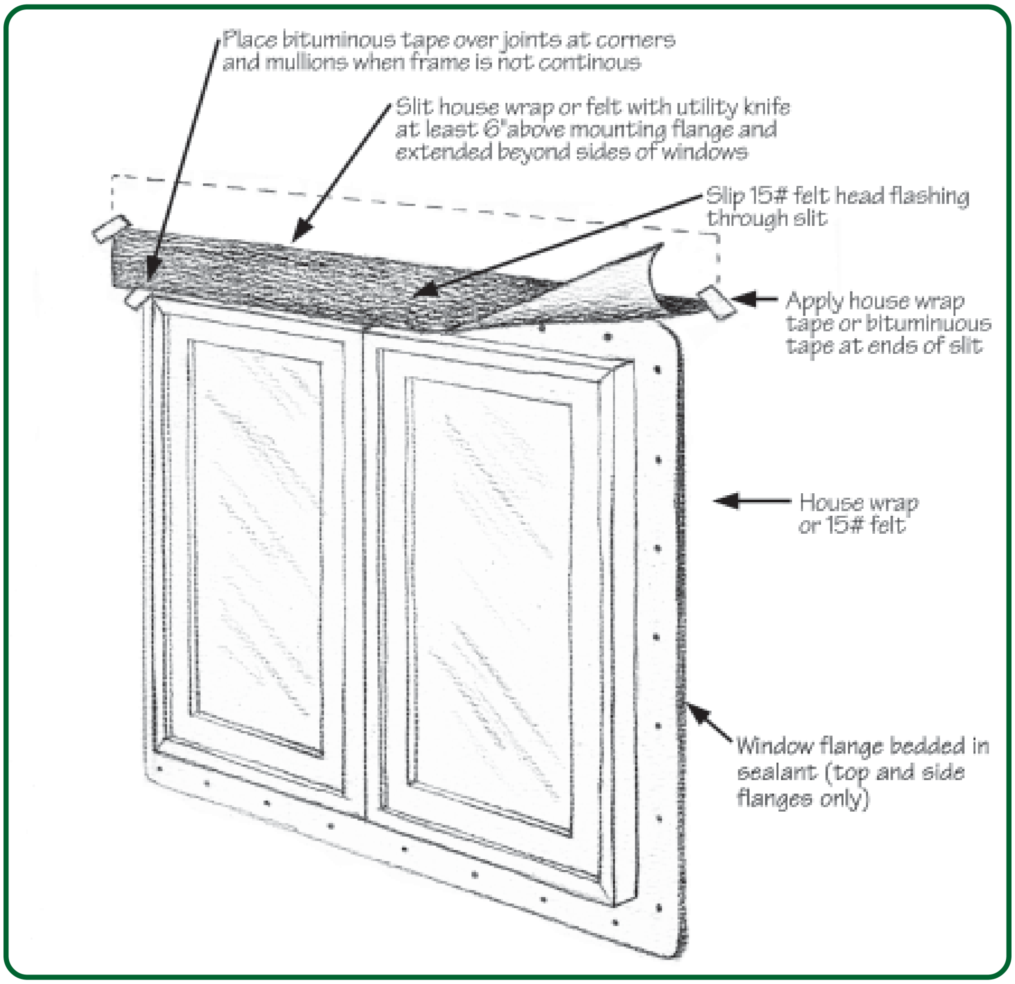


Figure 4.10 - Window Flashing Illustration
(building wrap installed prior to window; typical nail flange installation)

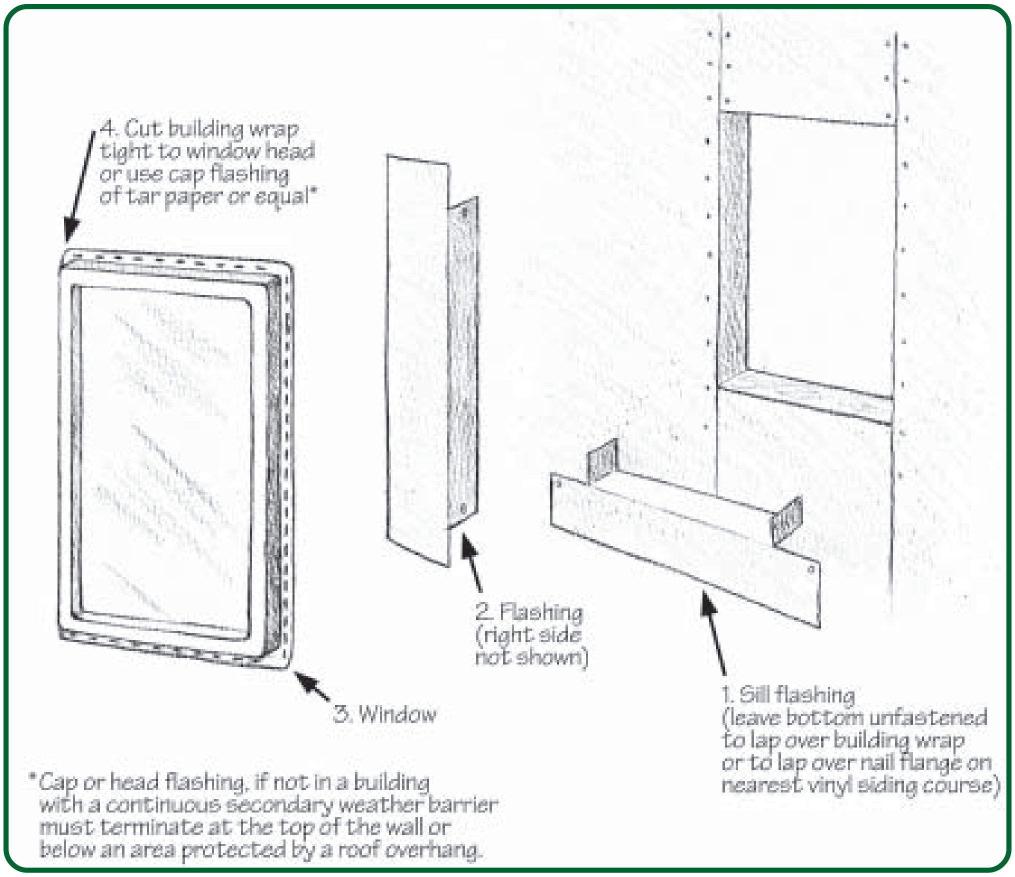


Figure 4.11 - Window Sill and Jamb Flashing Detail

(building wrap installed after window)

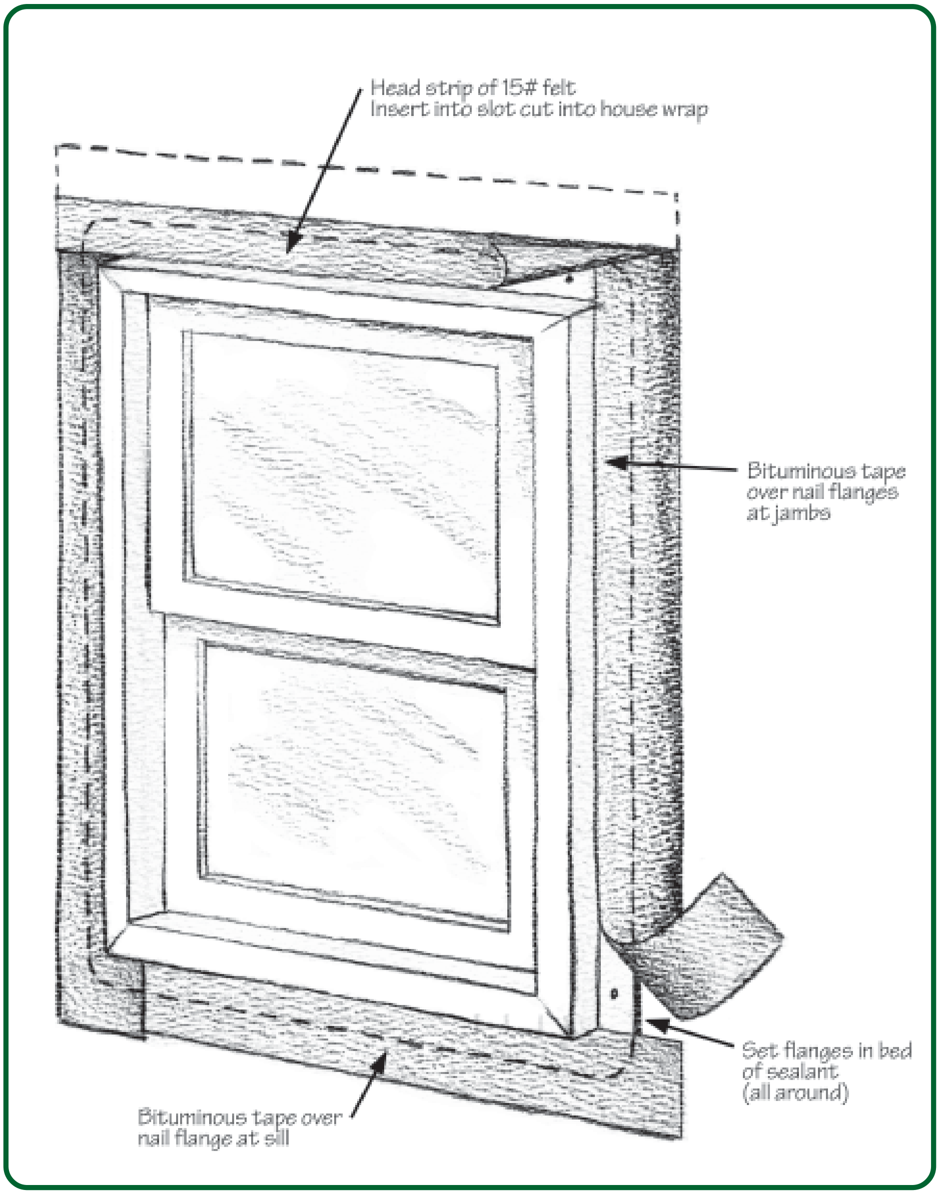


Figure 4.12 - Window Flashing for Severe Weather
(areas subject to frequent wind-driven rain)

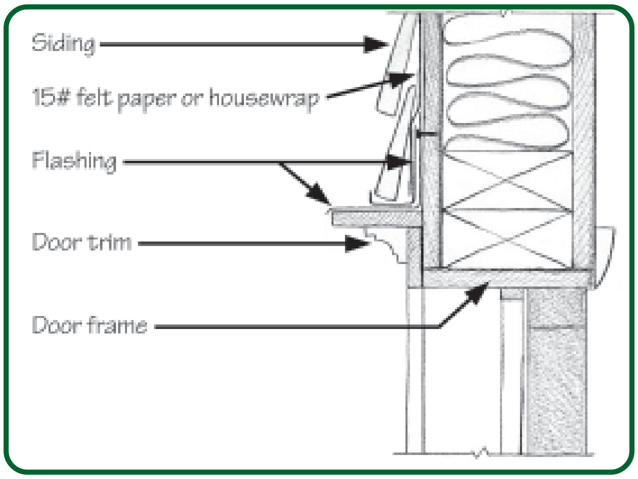


Figure 4.13 - Door and Head Trim Flashing Detail

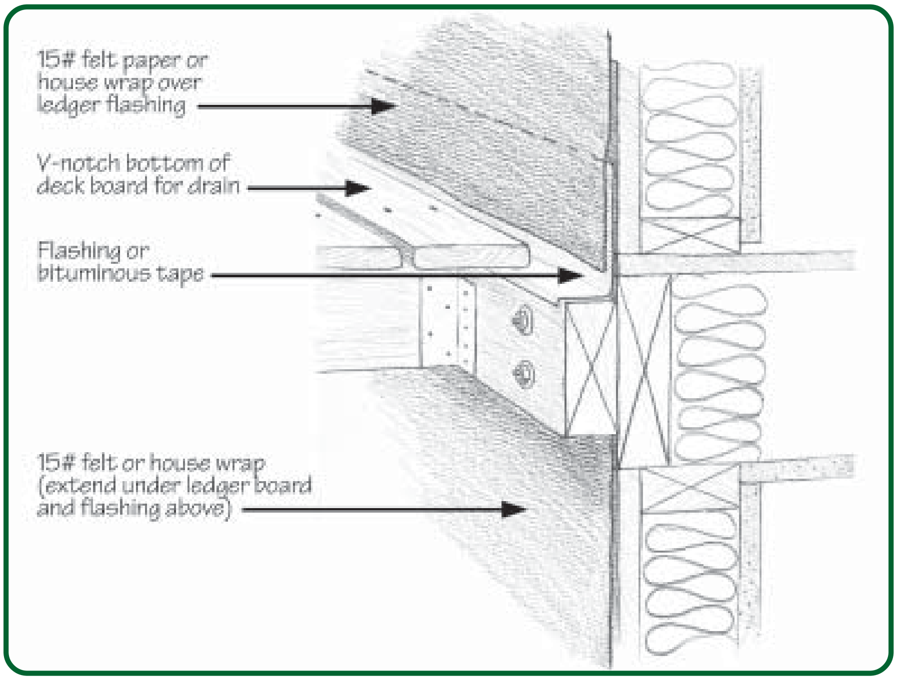


Figure 4.14 - Deck Ledger Flashing Detail

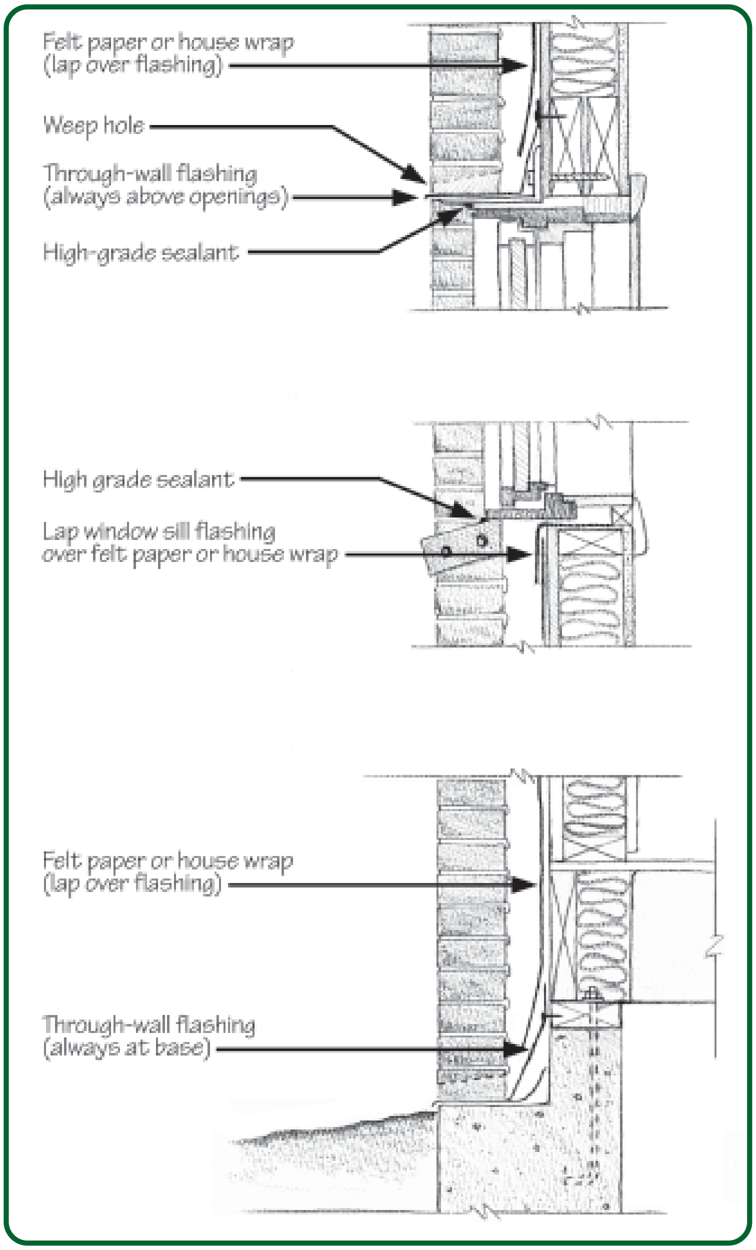


Figure 4.15 - Typical Brick Veneer Flashing Details

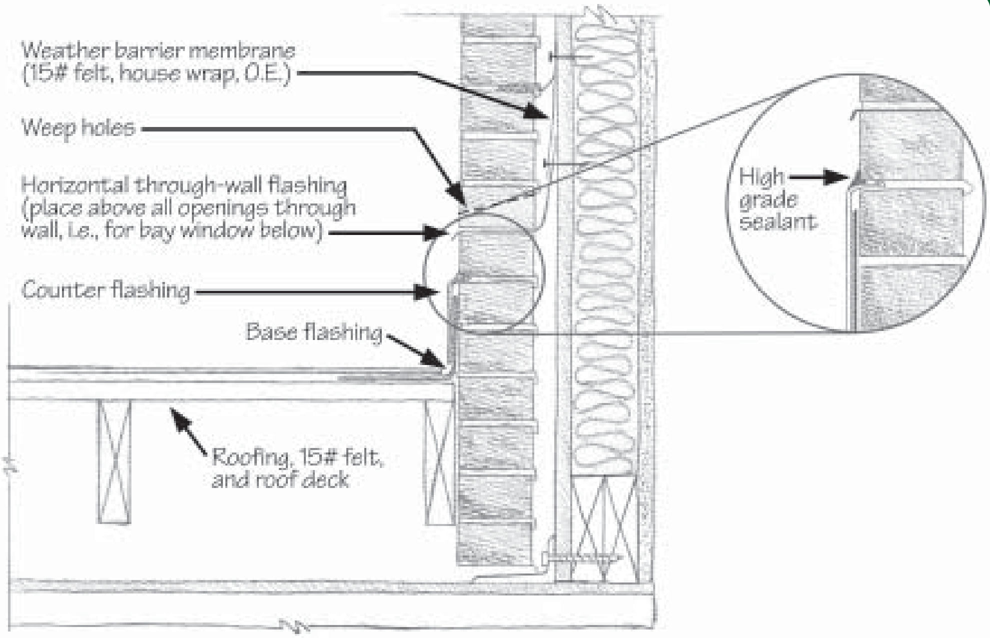


Figure 4.16 - Brick Veneer Flashing at Roof Intersections

4.2.5 Recommendation #5: Sealants and Caulking

In general, do not depend on sealants and caulking for long-term service. Using normal quality caulks and sealants with typical surface preparation, combined with shrinkage and swelling of building components, usually results in failure of a water tight seal within 2 to 3 years or less, particularly on southern exterior exposures. Nonetheless, there will be joints and seams that will benefit from appropriate use and maintenance of caulks and sealants. Optimally, joints in exterior wood trim or framing should be simple enough not to trap water and allow quick drying.

With reasonable adherence to manufacturer instructions (particularly with respect to surface preparation and conditions during installation), high quality caulks and sealants can be made to endure for a reasonable time (i.e., up to 5 years or considerably more when not severely exposed). Some recommendations regarding selection of quality caulks and sealants are provided in Table 4.7. In addition, caulks and sealants should be stored in a warm environment and should not be stored for more than a couple of years before use. Finally, the need for homeowner maintenance and replacement of caulking must be strongly emphasized.

4.2.6 Recommendation #6: Roof and Crawl Spaces - To Ventilate or Not to Ventilate

The use of ventilation has been a topic of confusion for some time. Until recently there has been little convincing research to confirm traditional practices or to suggest better ones. To aid in decisions regarding roof and crawlspace ventilation, recommendations are provided in Table 4.8 based on the best information available on the topic. Prior to use, the reader should consult local building code requirements and roofing manufacturer warranties to identify potential conflicts.

Roofs vents (when required) must be installed in accordance with the local building code or accepted practice. Plastic vent louvers commonly used on gable ends must contain UV inhibitors. Vents must be adequately screened to prevent vermin or insect entry. In addition, ridge vents (if used) should be installed and attached to the roof in accordance with manufacturer recommendations – numerous incidents of improper installation have resulted in damage during wind events or rain/snow entry to the roof. Vent area ratios, such as 1 square foot of vent opening for every 300 square feet of attic area refer to the *net* vent area, not gross area; so the sizing of vents must account for obstructions to vents from louvers and screens.

The roof ventilation recommendations in Table 4.8 are based primarily on durability concerns. These recommendations are further based on the assumption that the following good practices have been employed:

- All bath and kitchen exhaust fans exhaust moist indoor air directly to outdoors.
- Indoor relative humidity is kept within reasonable limits (i.e., 40-60%) and significant point sources of moisture (e.g. hot tubs) are controlled with ventilation.
- Ceiling vapor barriers are used in accordance with Table 4.6.
- Proper attic insulation levels are installed for the given climate and location.

While non-vented roof assemblies are a viable alternative (especially in hot/humid climates), performance data on such designs over time is still lacking. Further, the required detailing that goes along with such a design (e.g., insulation detailing, controlling surface temperatures in the assembly to prevent condensation) may be less forgiving than a traditional ventilation approach in terms of durability. If a non-vented design *is* employed, some critical items to consider include:

- Local building department approval;
- Implications for roofing material warranty;
- All major air leakage points between the living space and the attic (wire penetrations, recessed light cans, plumbing lines, HVAC boots and chases, attic hatches) have been sealed to limit air leakage; and
- Perimeter wall insulation detailing to satisfy local fire and insect design requirements.

TABLE 4.7- CAULK CHARACTERISTICS AND APPLICATION RECOMMENDATIONS[1]

Caulk	Life (yrs)	Best Uses	Adhesion	Shrink-free	Primer Use [2]	Joint Type	Tack-free (hrs)	Cure (days)	Clean up with[3]	Paint	Available Colors
Oil-base	1-7	not desirable	fair-good	poor	porous surfaces	non-moving to 1/4”w, 3/4”d	2-24	to 365	paint thinner	must	white, natural, gray
Acrylic-latex	2-10	indoors, protected, or painted	excellent, except metal	fair	porous surfaces for best results	non-moving to 1/4” w	1/4-1/2	3	water	best	white, black, gray, bronze
Butyl rubber	7-10	narrow openings in wood, metal, glass, masonry	very good	fair	none needed	non-moving up to 1/4”x1/4”	1/2-1 1/2	7	paint thinner, naphtha	best	white, clear, gray, black, brown, redwood, beige, bronze, sandstone
Polysulfide rubber	20+	anywhere	excellent	excellent	special primer on all but metal	all up to 1/2”x1/2”	24-72	7	TCE, toluene, MEK	if desired	white, black, gray limestone, bronze, brown
Silicone rubber	20+	outdoor metal, heat ducts, shallow joints	good, excellent with primer	excellent	porous surfaces	all from 1/4” d	2-5	2-5	paint thinner, naphtha, toluol, xylol	read label	white, black, clear, gray
Urethane	20+	anywhere	excellent	excellent	none needed	all to 1/4”x1/2”	4-14	4-14	MEK, acetone, lacquer thinner	if desired	white, gray, black, limestone, bronze; special colors
Weatherstrip/ caulking cord	to 20	temporary draft sealing and hole plugging	none	excellent	none needed	non-moving	--	none	not sticky	no	clear, gray

Source: *Structures and Environment Handbook*, Eleventh Edition (Midwest Plan Service, 1983)

NOTES:

[1]Based on advancement in caulk formulation and materials, this table may be in need of revision and may not include newer materials.

[2]“Porous” includes wood, wood products, concrete, and brick.

[3]MEK = methyl-ethyl-ketone, TCE = trichloroethylene.

For crawlspaces, a non-ventilated crawlspace design can be employed in all of the climate regions shown in Table 4.8. A non-ventilated crawlspace offers benefits in terms of both moisture control and energy performance. Ventilated crawlspaces, especially in humid and mixed regions, often introduce moist outdoor air into a cooler crawlspace environment. The result is condensation and the resulting problems like mold and degradation of building materials. In terms of energy, an unventilated crawlspace also provides an area for HVAC equipment and ducts that doesn't present the temperature swings (and energy penalties) found in ventilated crawlspaces.

There's more to it than just taking out the vents however. The following steps must also be followed when building a unventilated crawlspace:

- Careful attention to exterior grading (4% slope *minimum*);
- Air sealing between outdoors and the crawlspace area to prevent humid air from getting into the crawlspace;
- Insulating at the crawlspace perimeter walls–not the floor;
- 6 mil polyethylene groundcover in crawlspace with joints lapped; and
- Damp-proof foundation wall.

TABLE 4.8 - ROOF AND CRAWL SPACE VENTILATION RECOMMENDATIONS

Climate[3]	Attic[1,5]	Cathedral Roof[4]	Crawl Space[2]
Hot/Humid	Yes	Yes	No
Mixed	Yes	Yes	Not Preferred
Cold	Yes	Yes	Optional
Arid (dry)	Yes	Yes	Optional

NOTES:
[1]All roof ventilation recommendations are based on the ceiling being sealed at all major air leakage points (i.e., chases, electric and mechanical penetrations, etc.) and bath and kitchen vent ducts adequately routed to expel air out-of-doors. In some climates (see Table 4.6), a ceiling vapor retarder (i.e., vapor retarder paint, polyethylene sheet, or asphalt coated paper) is required in addition to adequate attic/roof insulation.
[2]All recommendations are based on properly graded sites and the use of a continuous ground vapor retarder applied to the foundation area.
[3]Climates are defined as in Table 4.4.
[4]Cathedral roof ventilation must be continuous along soffit/eave and ridge.
[5]Net attic vent area should be 1/300 of attic area and vents shall be continuous along soffit/eave and also located at the ridge and/or gable ends.

CHAPTER 5 - Sunlight

5.1 General

Sunlight is made up of visible light and non-visible radiation such as ultraviolet (UV) and infrared (IR). Depending on the color and surface characteristics of an object, various wavelengths of solar radiation may be absorbed, reflected, and emitted (i.e., "released"). The more light absorbed and the less heat capacity (i.e., thermal mass), the greater the object's ability to be heated by sunlight. For example, a dark driveway becomes much hotter on a sunny day than a light colored concrete sidewalk. Thus, the sun produces two significant effects that attack materials and shorten their life-expectancy:

(1) chemical reaction (i.e., breakdown) from ultraviolet radiation and heat

(2) physical reaction (i.e., expansion and contraction) from daily temperature cycles caused by objects absorbing and emitting heat gained from sunlight.

The chemical and physical reactions caused by sunlight can cause colors to fade and materials to become brittle, warp, or crack. Deterioration can happen relatively quickly (a year or less) or over longer periods of time depending on the characteristics of a material and its chemical composition. In some cases, materials like plastics that are vulnerable to UV degradation can be made resistant by adding UV inhibitors to the chemical formulation.

A prime example is vinyl siding. As an alternative approach, materials can be protected from sunlight by matter of design (e.g., providing shading or using reflective coatings).

UV light from the sun is not all bad. For example, it is UV light that causes a chemical reaction on special paper that forms the blue lines on blue prints. However, most everyone has witnessed or experienced the painful effects of UV radiation on skin, which causes sunburn. Consider that the exterior of a house is like its skin. Therefore, the proper selection of materials determines to what degree the building exterior will be able to withstand the damaging effects of UV radiation. The amount of solar radiation also varies by geography (see Figure 5.1); the number of cloudless days affects the dose of UV radiation over the lifetime of a product.

The following section presents a few measures that can help to counter the effects of solar radiation on building materials and systems. For homes, some of the primary problems associated with solar radiation are color fading, premature asphalt roof shingle failure, and vinyl siding warping. Excessive exposure to sunlight will also cause caulk joints to fail quickly. In addition, when shining through windows, sunlight can cause interior colors to fade.

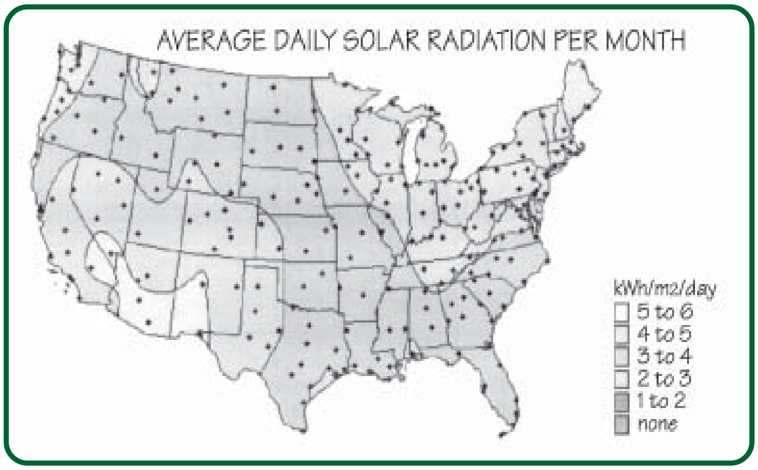


Figure 5.1 - Solar Radiation Map of the United States

Source: National Renewable Energy Laboratory

5.2 Recommended Practices

5.2.1 Recommendation #1: Overhangs

As with rain on the building envelope, properly sized roof overhangs can minimize the exposure to solar radiation and, hence, minimize radiation-related problems. The width of a roof overhang that will protect walls from excessive solar exposure in the summer while allowing heat gain through windows from winter sunshine depends on where the building is located with respect to the equator. The sun is higher overhead in the summer than in the winter. In addition, for any day of the year, at higher latitudes the sun is lower in the sky than at lower latitudes. Therefore, buildings situated farther south receive greater protection from the summer sun by roof overhangs, as shown in Figure 5.2.

The solar angle factors of Table 5.1 can be used to help determine overhang width to achieve the desired shading effect on south-facing surfaces. An example calculation shows how the solar angle factor is used.

TABLE 5.1 - SOLAR ANGLE FACTORS[1]

Date	Latitude (degrees North)			
	24	32	40	48
To prevent winter shading:				
Dec 21	1.5	2.0	3.0	5.4
Jan 21 and Nov 21	1.2	1.7	2.4	3.8
Feb 21 and Oct 21	0.8	1.0	1.4	1.9
Mar 21 and Sept 21	0.4	0.6	0.8	1.1
To produce summer shading:				
April 21 and Aug 21	0.2	0.4	0.5	0.7
May 21 and July 21	0.1	0.2	0.4	0.5
June 21	0.0	0.1	0.3	0.5

Source: *Structures and Environment Handbook*, Eleventh Edition, Midwest Plan Service, Iowa State University, Ames, Iowa, 1983.

[1]Factors apply for times between 9:00am and 3:00pm for winter shading and at noon for summer shading. Direct south facing orientation is assumed.

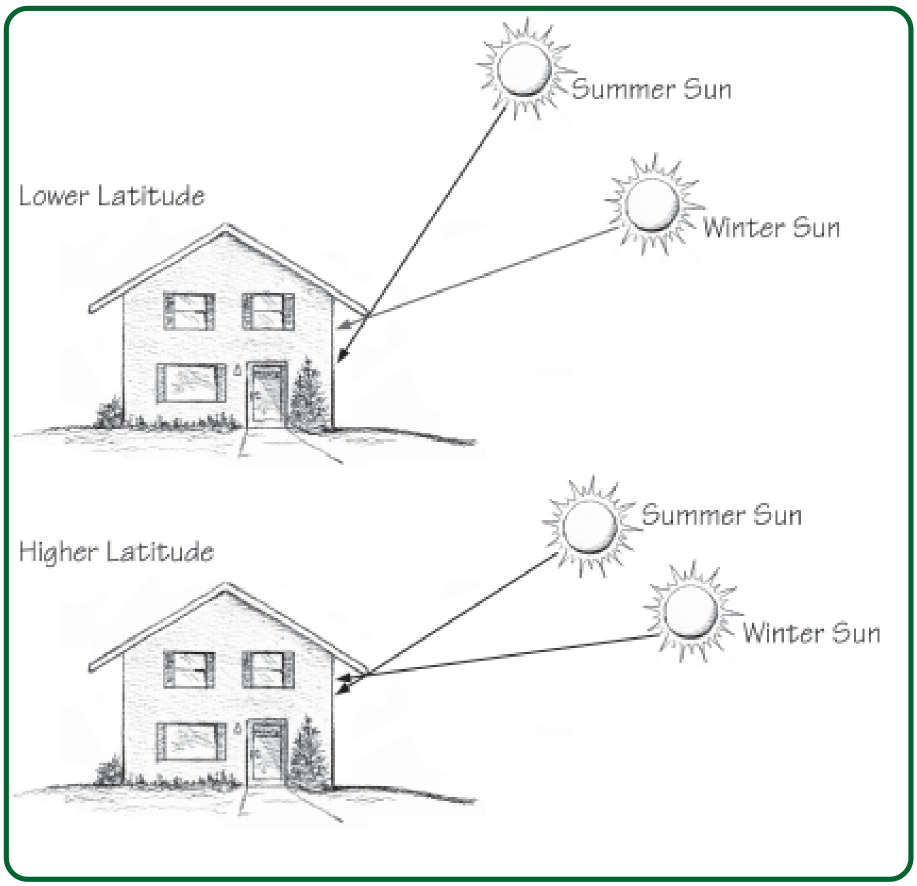


Figure 5.2 - Effect of Building Latitude on Effectiveness of Overhangs

EXAMPLE: DETERMINE ROOF OVERHANG WIDTH TO PROTECT WALL AGAINST SUMMER SUN

Find the overhang length (OL) to shade 6 feet of wall below the roof overhang for June through July. Building is located at latitude of 32 degrees North (consult Atlas for latitude). It is desired to provide shade for 6 feet of wall below the overhang at mid-day (i.e., to bottom edge of windows).

Solar Angle Factor (SAF) = 0.2 (for July 21) from Table 5.1
Wall distance below overhang to shade (WD) = 6 feet
OL = SAF x WD = (0.2)(6 feet) = 1.2 feet

Use a 16-inch (1.33 feet) overhang which will provide roughly 6 feet 8 inches of shading below the overhang.

Determine degree of shading in the winter (using Feb 21) as follows:

WD = OL/SAF = 1.33 feet / 1.0 = 1.33 feet or 16 inches.

The selected overhang width will provide no more than about 16 inches of shading to the wall during the main winter months of November through February. However, some shading to the top few inches of windows will occur in the early and late winter months when maximum solar heat gain may be desirable. But, in this case, the overhang width should not be decreased in the interest of maintaining weather protection of the wall.

5.2.2 Recommendation #2: Light Colored Exterior Finishes

As a second line of defense against damage from solar radiation, light colored materials and finishes can be selected. White is excellent and aluminum, reflective-type coatings are even better. Light colors can also reduce summertime cooling load and should reduce energy bills especially in cooling dominated climates by lowering the solar heat gain into a building. If properly accounted for in cooling load calculations, lighter colored roofing may allow for the use of smaller capacity air conditioning units. In addition, light colored roof shingles reduce shingle temperature and, therefore, increase shingle life. The effect of building exterior color on solar heat gain is illustrated in Figure 5.3. It is very important, however, to keep light colored finishes like roofs relatively clean to take full advantage of their reflectivity.

5.2.3 Recommendation #3: UV Protective Glazing

Windows that receive direct sunlight and that are not treated to block UV radiation will allow sunlight to enter and fade susceptible materials such as furniture coverings, carpeting, and drapes. One solution is to specify interior materials that have UV inhibitors or that are not susceptible to UV radiation. Another solution is to specify colors that will not show fading. However, if these options are not desired or considered sufficient, there are glazing options for windows and doors that block UV radiation. These relatively expensive treatments need only be specified for south-facing windows.

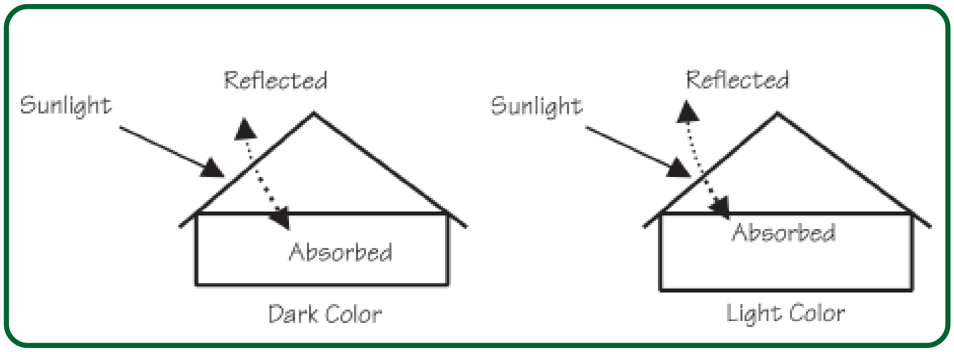


Figure 5.3 - Effect of Surface Coloration on Solar Heat Gain

5.2.4 Recommendation #4: UV Resistant Materials

Some materials are naturally UV-resistant, while others require the addition of UV inhibitors in the make-up of the material. For example, concrete or clay tile roofing and Portland Cement stucco or brick siding are naturally resistant to UV radiation and are also resistant to temperature effects compared to other exterior building materials. On the other hand, plastics are prone to “dry rot” (embrittlement from excessive UV exposure) unless UV inhibitors are provided. Plastics are also prone to significant expansion and contraction from temperature swings.

Be sure that UV inhibitors are used in materials that require protection. Many low budget components, such as some plastic gable end vents, may also lack UV resistance. All other factors being equal, choose the material with the best UV resistance if exposure to the sun is a concern.

5.2.4 Recommendation #5: Landscaping for Shading

Trees planted near a home along the southern exposure provide shading when most needed during the day (see Figure 5.4). Also, deciduous trees, such as maple or oak, should be used so that winter sun can reach the building. With appropriate planning, trees can also serve as a wind break to minimize the effects of wind-driven rain. Trees should be planted far enough away from a house to prevent possible damage from limbs or roots, as well as clogging gutters. Bear in mind that the greatest amount of solar radiation is generally received between 9 am and 3 pm. However, shading of only the late day sun (i.e., after 3 pm) is often a preferred and more practical solution for many sites.

Figure 5.4 - Illustration of Solarscaping

EXAMPLE: DETERMINE LOCATION OF SHADE TREE TO PROTECT AGAINST SUMMER SUN

Use the following equation and the solar angle factors (SAF) of Table 5.1 to determine the appropriate location of a maple tree (mature height of ~60') southward of a building wall (8' height) that is to be shaded during summer months. The building latitude is 40º North (refer to atlas for site latitude).

$$d = SAF \times h_o \left(h_o - h_s \right)$$

where:

d	=	*distance between object obstructing the sun at highest point and item to be shaded*
h_o	=	*height of the object obstructing the sun*
h_s	=	*height of object to be shaded*
SAF	=	*solar angle factor (from Table 5.1)*

The following values are given:

SAF	=	*0.4 from Table 5.1 at 40ºN latitude for May 21 or July 21*
h_o	=	*60 feet*
h_s	=	*8 feet*

Substituting in the equation above,

$$d = (0.4)(60\ ft - 8\ ft) = 20.8\ ft$$

Therefore, the center of the maple tree should be located about 21 feet southward from the wall or windows to be shaded. Note that the shading at the first day of summer (June 21) will be slightly less due to the higher solar angle than assumed above. In addition, the tree should not overhang the building at its mature age. Thus, a distance smaller than about 20 feet is not recommended and the distance should be increased for trees that are larger at maturity.