

Five Ds of Moisture Management: Deflection, Drainage, Drying, Distance, and Durable Materials

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Abstract

Throughout the world, properly constructed wood buildings have lasted for centuries. Wood has been the building material of choice for residential and light commercial builders because of its strength and durability. However, a shortage of well-trained construction trade professionals points to the need for extensive outreach to educate builders and design professionals on how to properly install and detail wood materials used in construction to provide maximum service life.

Most importantly, wood buildings provide outstanding structural performance. However, like all building materials, their performance can be compromised by the intrusion of moisture. APA's Build a Better Home program and AWC's *Design of Wood Frame Structures for Permanence* publication are examples of resources on proper moisture control techniques in construction applications including foundations, floors, walls, and roofs.

To limit the amount of water intrusion and obtain a balance of moisture content, general principles of water management including deflection, distance (separation), drainage, and drying should be followed. Following the general principles of water management requires that wetting and drying mechanisms be established and maintained to balance moisture content levels at or below the tolerance of building materials being used. Where the tolerance of building materials to moisture is likely to be exceeded, durable materials such as preservative-treated wood should be utilized.

Design of durable structures is the result of careful planning and understanding of loads, environmental exposure and forces that will likely act upon a building during its lifetime.

If these key elements are not taken into consideration, the designer may compromise the ability of the structure to remain fully functional over extended periods of time. This paper provides structural engineers with moisture management best practices for key elements of a wood structure.

Introduction

Throughout the world there are countless examples of wood buildings that have existed for centuries because of good construction practices that keep wood dry.



Figure 1: Borgund Stave Church, Norway 1180-1200 A.D.

This fully functional wood stave church in Urnes, Norway, built around 1200 A.D., clearly demonstrates that a wood frame structure can have a very long service life. The builders of this church used good design practices, such as a steeply sloped roof, to allow for good drainage. This allows for natural drying and avoids moisture collection points.

Management of moisture in buildings is key to mitigating issues that may occur with water and is just as important to the life of a building as protection from fire or structural collapse.

Building codes establish minimum requirements for fire protection and prevention of structural collapse, however, the codes do not address all of the issues that promote long-term durability of buildings and structures. The *California Building Code* does provide some language related to the exterior wall envelope as follows:

[A] 107.2.4 Exterior wall envelope. *Construction documents* for all buildings shall describe the *exterior wall envelope* in sufficient detail to determine compliance with this code. The *construction documents* shall provide details of the *exterior wall envelope* as required, including flashing, intersections with dissimilar materials, corners, end details, control joints, intersections at roof, eaves or parapets, means of drainage, water-resistive membrane and details around openings. The *construction documents* shall include manufacturer's installation instructions that provide supporting documentation that the proposed penetration and opening details described in the *construction documents* maintain the weather resistance of the *exterior wall envelope*. The supporting documentation shall fully describe the *exterior wall* system that was tested, where applicable, as well as the test procedure used.

Additionally, Chapter 14 on Exterior Walls has minimum requirements for exterior walls, exterior wall coverings, exterior wall openings, exterior windows and doors, architectural trim, balconies and similar projections, and bay and oriel windows, but these are minimum requirements and may not necessarily provide long-term durability.

Design of durable structures begins with an understanding of moisture loading and how it interacts with building materials. In order to prevent moisture intrusion, it is important to understand how it moves, its source, and physical state. The building site's climate and the construction materials selected also need to be considered. Water movement and the rate of transfer varies depending on its state (**Figure 2**). Water in vapor form will move via diffusion or air movement. In vapor form, water moves from hot to cold temperatures and from high to low vapor pressures. Vapor retarders are key in climates with extreme temperature differentials from the exterior to the interior of the building. Air leaks in the building envelope offer another opportunity for water to travel from high pressure to low. Buildings should be detailed and constructed to provide a sufficient air barrier system: often including a building wrap on the exterior with joints

caulked and sealed. Water in a liquid state will move from pressure, capillary action, or gravity. Wind driven rain, wood in contact with the ground, and improperly sloped roofs are three examples of how liquid moisture infiltrates structures.

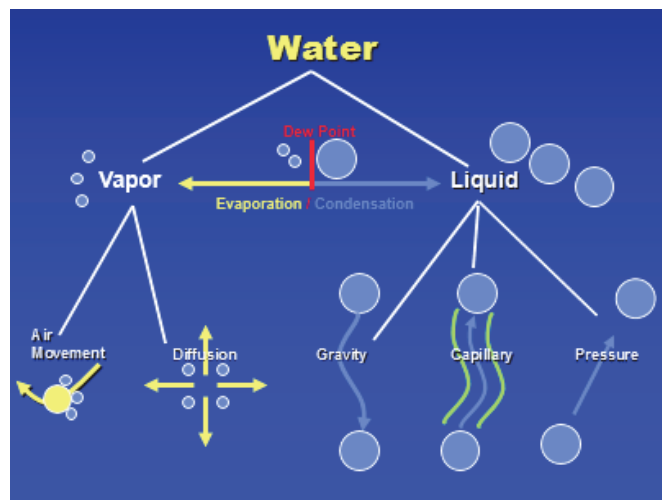


Figure 2: Water movement principles.

Another important item to consider is the rate of transfer from each of these states. To compare water intrusion, moisture would likely be measured from diffusion in teaspoons per year, air leakage in cups per week, and liquid water in gallons per hour. Therefore, while it's important to protect the building envelope from all forms of water movement, it's equally important to prioritize mitigating bulk water intrusion based on its rate of infiltration. As shown in **Figure 2**, the dew point is critical for moisture in the vapor state. As water in the vapor state travels from warm to cold in temperature, the goal is to prevent the dew point from occurring within the wall cavity where water would become liquid, and the challenge of eliminating it from the building envelope becomes more challenging.

The 5 D's

The primary objective when addressing moisture loads is to keep the building envelope dry by reducing the amount of water transported inside the building envelope and to achieve a balance of the moisture content within the building. To limit the amount of water intrusion and obtain a balance of moisture content, general principles of water management include deflection, distance (separation), drainage, durable and drying (e.g. ventilation). Where the tolerance of building materials to moisture is likely to be exceeded, durable materials such as preservative treated wood should be utilized.

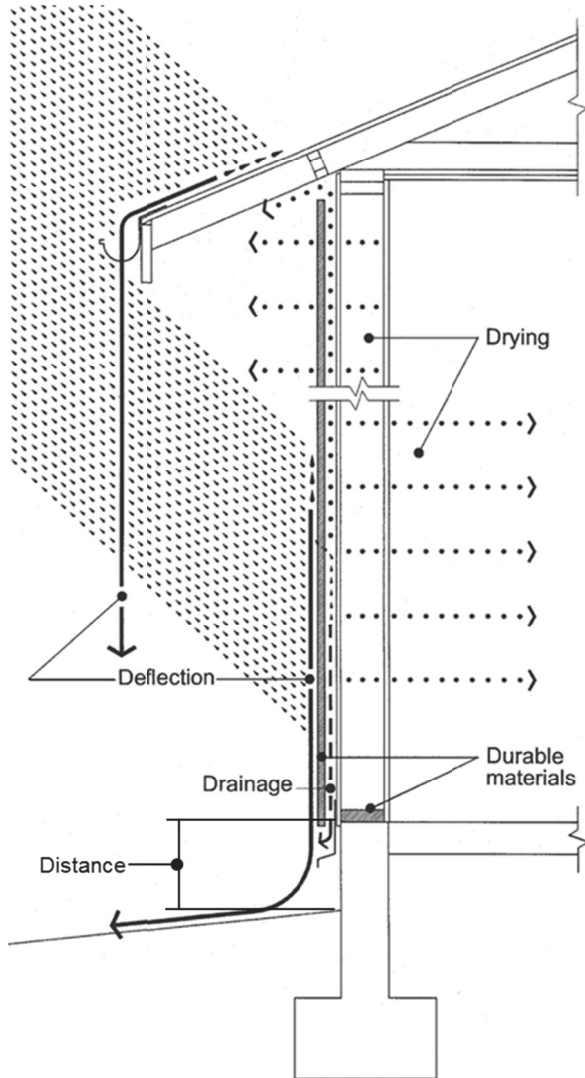


Figure 3: Principles of Water Management - 5 D's
Graphic source: Canadian Wood Council

Design principles should also reflect a building science approach to address moisture, pest, and durability issues in new and existing wood construction. The designer should always check with the authority having jurisdiction as they have the final authority in determining any local requirements.

Deflection

Gravity is key when considering deflection in a moisture management system. The goal is to have gravity work for and not against directing water away from key building components. Beginning with the roof, slope it towards the drainage system. The architect will often specify a roof slope to a drainage system. However, an improperly sloped roof can cause ponding which potentially has the following

adverse effects: excessive loading, moisture infiltration into the roof assembly and, if left undetected, deterioration of the assembly. Aside from deflecting water from the roof itself, a goal is to minimize contact with walls. Depending on the angle of the rain, larger overhangs deflect water away from the wall plane as well. A study from Vancouver, BC, (Survey of Building Envelope Failures in the Coastal Climate of British Columbia, Canada Mortgage and Housing Corporation, 1996) revealed a correlation between the size of roof overhangs and walls with moisture problems. At the time, they were taxing homeowners by how large the roof was; hence, eliminating overhangs lowered taxes. The consequences, however, may have cost many homeowners more in water damage repairs. As seen in **Figure 4**, deflection goes a long way toward protecting the building envelope.

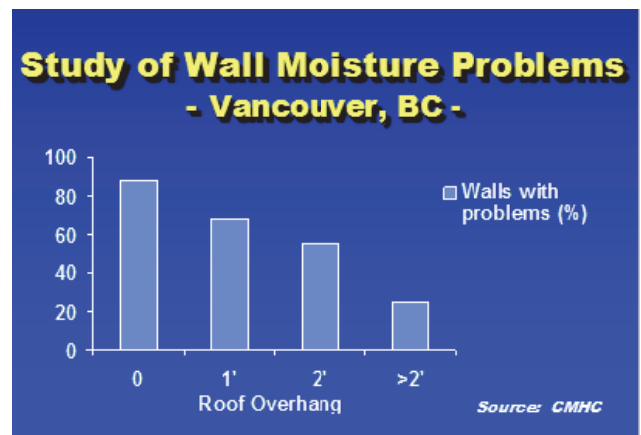


Figure 4: Roof overhang study

At the foundation level, the ground should be sloped away from the building and clearances provided from the ground to wood framing and siding. Wood, concrete, and masonry all have the ability to wick moisture through the material and create a moisture path into the building envelope. Therefore, it's important to mitigate capillary action via deflection, distance, and drainage as discussed in greater detail next.

Distance

To mitigate moisture issues and termite infestation, separation of untreated wood from the ground and other sources of moisture is very important. To maintain wood elements in permanent structures at a safe moisture content for decay prevention, this section provides minimum separations recommended for all buildings. It is also important to provide a moisture barrier between wood and concrete or masonry to prevent moisture wicking. Naturally durable or pressure treated wood is recommended when it is not possible or practical to provide the separation distances specified.

Table 1: Separation distance between wood elements and ground, concrete, or masonry.

Location	Description	Min. Distance	Detail
Crawl spaces & other similar unexcavated areas	Distance between bottom of wood joist, or a wood structural floor without joists and ground	18"	Figure 5
	Distance between post or column supporting a permanent structure intended for human occupancy and ground	8"	Figure 6a
	Distance between bottom of wood girders and ground	12"	Figure 6b
Basements, cellars or when exposed to the weather	Wood columns which support permanent structures should be supported by a metal or concrete pedestal and separated by an impervious moisture barrier. Distance between top of pedestal and concrete slabs or decks.	1"	Figure 7a
	Wood columns which support permanent structures should be supported by a metal or concrete pedestal and separated by an impervious moisture barrier. Distance between top of pedestal and exposed earth or weather.	6"	Figure 7b
Exterior walls	Air space between top, end, and sides of wood joists, beams or girders and exterior masonry or concrete walls	½"	Figure 8
Exterior of the building	Distance between wood sills resting on concrete or masonry exterior walls and exposed earth.	8"	Figure 5
Foundation wall	Distance between the bottom of wood joists, girders, and subfloors suspended from foundation and the horizontal projection of the outside grade level and should terminate at the interior face of any foundation wall studs.	8"	
Exterior of structure	Distance between wood siding and wood trim and exposed earth.	6"	Figure 5
Exterior structures	Distance between fences and similar items and the main structure.	2"	
Exterior wood steps	Distance between structural wood stairs (stringers, posts, etc.) and finished grade.	6"	Figure 9
Exterior porches, breezeways, and patios	Distance between beams and headers supporting floor framing and ground.	12"	Figure 6
	Distance between floor joists or the bottom of a wood structural floor without joists and ground.	18"	Figure 11
	Wood posts which rest on wood, concrete, or masonry floors should be supported on metal or concrete pedestal and separated by an impervious moisture barrier. Distance between top of pedestal and floor.	1"	Figure 7a
	Wood posts which rest on wood, concrete, or masonry floors should be supported on metal or concrete pedestal and separated by an impervious moisture barrier. Distance between top of pedestal and exposed earth.	6"	Figure 7b
Exterior concrete	Distance between the top of steps, porch slabs, patio slabs or planters resting on ground and the top of the foundation and from wood in the main structure otherwise protected from moisture or concealed termite penetration.	2"	Figure 10 & Figure 11

Architectural features applied on the exterior of the building such as shutters, window boxes, and other decorative attachments should be separated from exterior siding to avoid trapping rainwater. Moisture-permeable floors or roofs which are exposed to the weather, such as concrete or masonry slabs, should be separated from any wood structural members supporting them by an impervious moisture barrier.

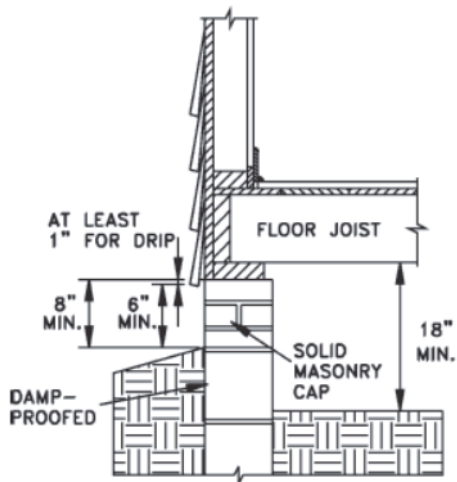


Figure 5: Clearance Between Wood Siding and Earth

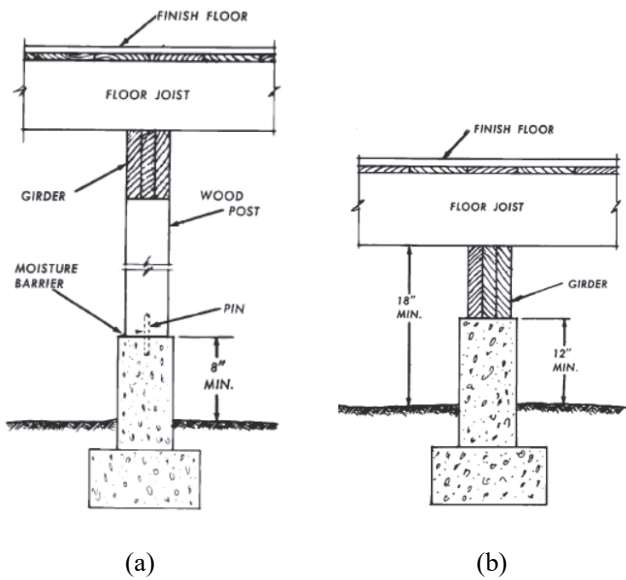


Figure 6: Clearance Between Wood and Exposed Earth in Crawl Space or Other Unexcavated Concealed Areas

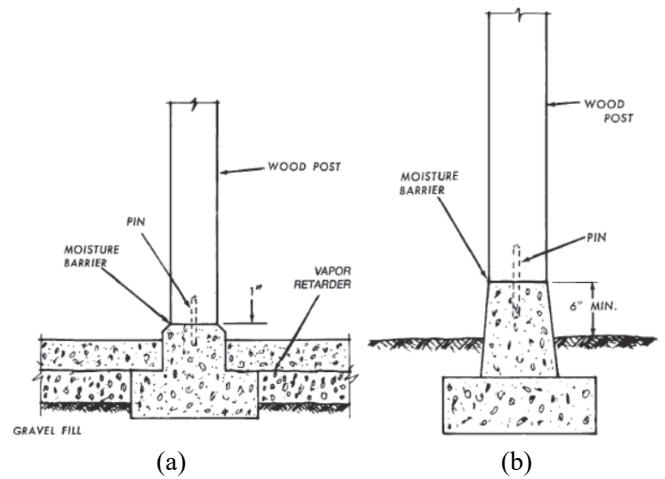


Figure 7: Clearance Between Wood Columns and Floor or Exposed Earth when in Basements or when Exposed to Weather

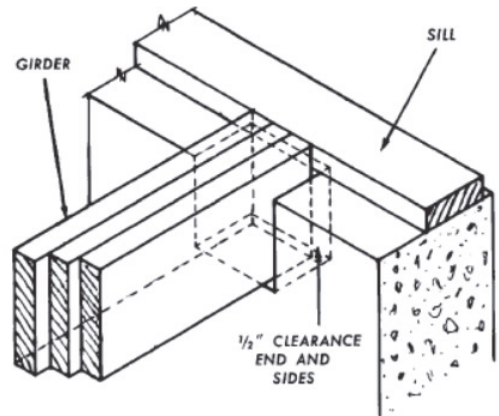


Figure 8: Wood Beams or Girder Framing into Masonry or Concrete Wall

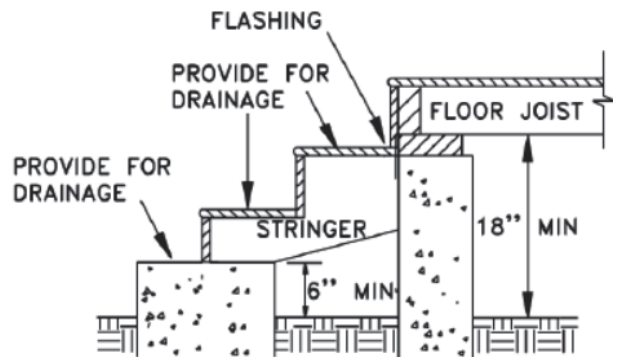


Figure 9: Exterior Wood Steps

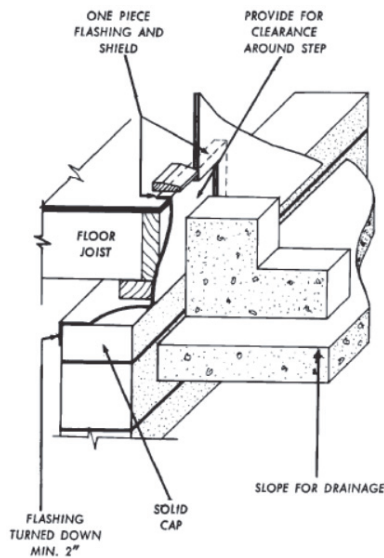


Figure 10: Exterior Concrete Steps

roofing material. The roof system also needs to tackle ventilation and insulation, as discussed later under “Drying.” As shown in **Figure 12**, shingling is utilized to lap layers of protection so there is not a path of travel for water into the roof assembly. Flashing is required around all roof penetrations (i.e. skylights, chimneys, HVAC) and at the intersection of a low roof to wall as shown in **Figure 13** Step flashing is provided at this intersection, again, to shingle the protective layers and prevent moisture intrusion into the adjacent wall assembly. Ultimately, the goal is to minimize water contact with walls below, so a complete system incorporates kick-out flashing to gutters and roof drains to the ground and away from the building at the exit.

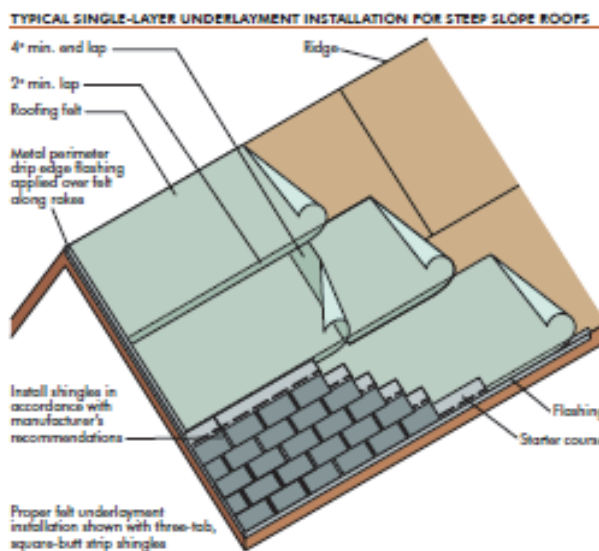


Figure 12: Roof Assembly Installation

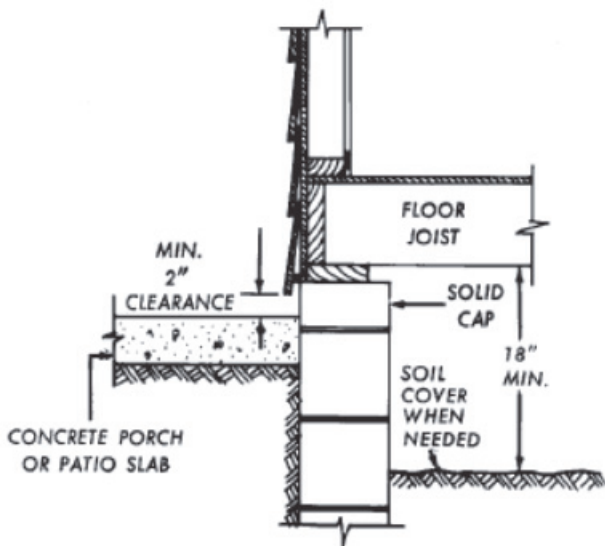


Figure 11: Concrete Porch or Patio Slab

Drainage

After deflection and distance, drainage is the third step in a moisture management system. The drainage system is based on layers of protection. These layers should be installed in a shingling fashion, so that each layer laps over the one underneath it, in order to create a continuous drainage plane for water to travel down and away.

The roof system components on a wood-framed structure include structural sheathing, roofing felt, flashing, and

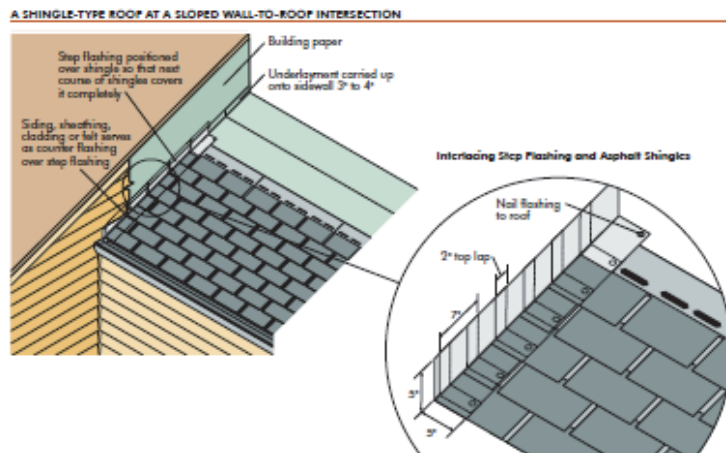


Figure 13: Roof to Wall Intersection

There are 16 unique climate zones in California in accordance with California’s Energy Code. A building envelope in Tahoe will have different challenges than one built in San Diego. Depending on the building site, water in the form ice and not just vapor and liquid should be considered as well. Ice damming can cause damage to the building envelope at the shingles and create an opportunity for water to penetrate the roof assembly as described in APA’s Build a Better Home: Roofs, Form A535, and depicted in **Figure 14**:

Ice dams are caused when natural heat losses through the roof cause the snow to melt. The melt water flows downward until it hits the roof overhang and then refreezes because this area of the roof is at ambient temperature. Given the right set of circumstances, this layer of ice in the roofing material can get thicker and thicker. Eventually, the melt water will pond up behind the ice dam and start backing up the roof slope. As the water backs up it moves up behind the shingles and, if improperly applied, even the underlayment. This can saturate the wood structural panel sheathing and cause leaks.

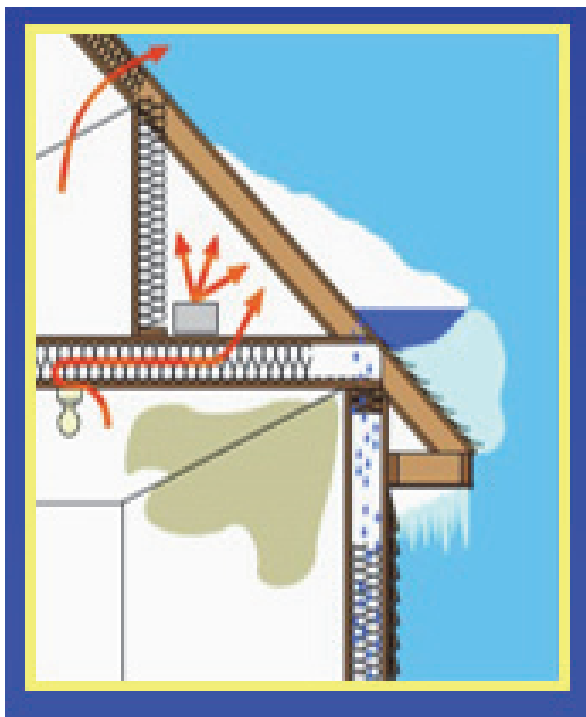


Figure 14: Ice Dam

Looking at a typical wall assembly, there is usually exterior cladding, an optional rain screen wall detail (additional drying potential), water-resistive barrier (WRB), and flashing of the penetrations (doors, windows, and vents). A water-resistive barrier is required per the California Building Code (CBC) as follows:

2510.6 Water-resistive barriers.

Water-resistive barriers shall be installed as required in Section 1404.2 and, where applied over wood-based sheathing, shall include a water-resistive vapor-permeable barrier with a performance at least equivalent to two layers of water-resistive barrier complying with ASTM E2556, Type I. The individual layers shall be installed independently such that each layer provides a separate continuous plane and any flashing (installed in accordance with Section 1405.4) intended to drain to the water-resistive barrier is directed between the layers.

Exception: *Where the water-resistive barrier that is applied over wood-based sheathing has a water resistance equal to or greater than that of a water-resistive barrier complying with ASTM E 2556, Type II and is separated from the stucco by an intervening, substantially nonwater-absorbing layer or drainage space.*

There are many different products used for water-resistive barriers, such as building paper, house wrap, and even liquid-based roll-on applications. The rain screen detail shown in **Figure 15** utilizes furring strips to create an air gap (drying space) behind the exterior cladding. Some WRBs have incorporated “air gaps” into their products by wrinkling the material or providing a grooved pattern to create more drying potential.

Oftentimes, the WRB acts as the air barrier as well. Per APA’s Build a Better Home: Walls, Form A530:

An air infiltration barrier such as house wrap can reduce the flow of moisture-laden air into the wall cavity if installed properly. The air barrier can be placed on the inside or outside surface of the wall. In a cold climate that requires a warm-side vapor retarder, the vapor retarder may act as the air barrier as well, if properly applied and sealed. Because the major model building codes allow air barriers to be used in lieu of building paper for most applications, the use of these products is on the rise. To get the full benefits of an air barrier, it must be sealed as described below to ensure that it is airtight. Air barriers are available in rolls up to 9 feet wide, allowing the builder to wrap the barrier all the way around the house during construction. This is the origin of the term “house wrap.” The large size speeds up installation and minimizes the number of seam seals. When the wrap is used as an air barrier, all of the splits, seams, penetrations and damaged areas must be repaired using a special adhesive-backed seam tape.

Like the roof, it is important to remember to shingle layers of protection and pay extra attention to detailing wall penetrations (windows, doors, venting). This is true at the bottom of the wall and connection to the foundation as well.

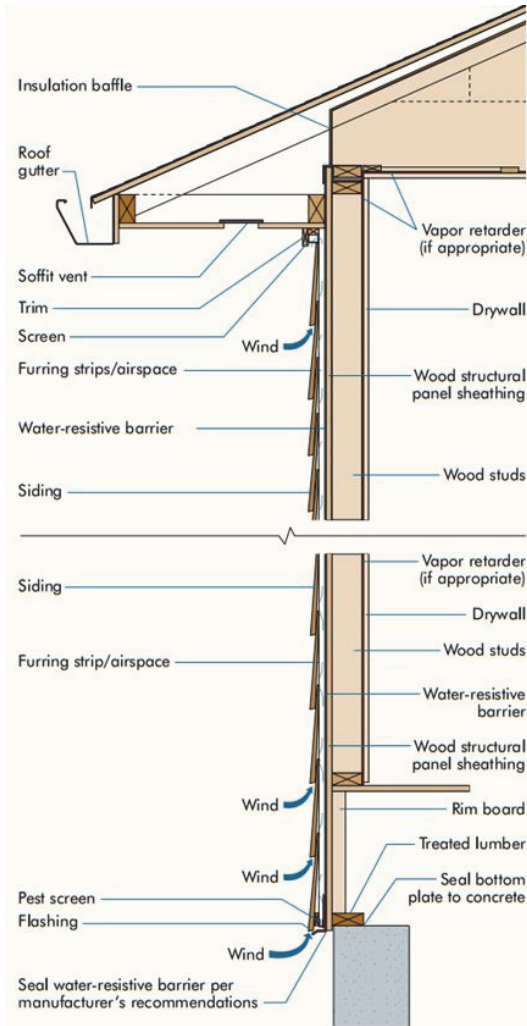


Figure 15: Rain-screen Wall Details (from APA Form A530)

At the wall to foundation intersection, provide “distance” (from ground contact) while maintaining layers of protection via the “drainage” system. APA provides assistance on detailing foundations in Build a Better Home: Foundations, Form A520, with details such as **Figure 16**. As noted previously, water infiltration needs to be prevented from the earth as well, as demonstrated in **Figure 16** by using perimeter drains and a capillary break in combination with a vapor retarder beneath the slab.

Drying

Moisture can originate from both inside and outside of the structure, and a mechanism to remove moisture is drying. Drying removes accumulated moisture by air movement or venting and vapor diffusion, which is direct movement

through wall and ceiling coverings. Mold and decay can occur if excessive moisture condenses on the underside of

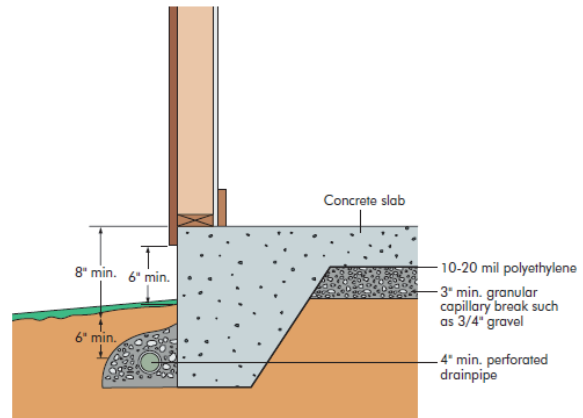


Figure 16: Slab-on-Grade Foundation

roof decking or inside walls for example. Providing adequate ventilation and strategically placing vapor diffusion retarders can mitigate this issue.

Both indoor air and outdoor air contains water vapor and wherever air goes, water vapor goes. Air will condense onto a cold surface when humid air contacts a surface that is cold enough.

As discussed previously, the air barrier is a means to prevent air leakage through the building envelope. An efficient and cost-effective way to achieve an effective air barrier on walls is to incorporate a continuous, solid layer on the exterior of a building. The continuous solid material should be stiff enough to minimize deflection when pressure is applied to tape or sealants at panel joints and around penetrations. Panel joints need to be properly sealed in order to complete an air barrier assembly. Continuous wood structural panel sheathing is one of the most common materials used in an air barrier system in exterior walls. The architect or energy rater typically details how all panel joints and other areas are to be sealed. This is most commonly done with a tape or sealant which is specifically recommended for use on plywood or OSB. Using continuous structural sheathing as part of the air barrier system provides a stiff support base for siding materials such as stucco, permits the option to incorporate box beam headers, and makes for more earthquake-resistant buildings.

There are a couple of cautions to note when using continuous wood structural panels as the air barrier. Some designers have been known to recommend adhesion of wood structural panels to framing in order to achieve a tight air barrier. The engineer should prohibit gluing wall sheathing to framing when restricted from use in high Seismic Design Categories

per *Special Design Provisions for Wind and Seismic (SDPWS)* Section 4.3.6.1. A second caution that builders in particular need to be aware of related to air barriers is to make sure that any sealant or tape used does not impede the ability of wood structural panels to expand due to unexpected increased moisture in the wall cavity or as a result of construction delayed wetting. Anything that prevents panel expansion into the recommended 1/8 inch spacing between panels could result in buckling of wall sheathing. And finally, a water-resistive barrier, such as house wrap, should always be installed over wood structural panel wall sheathing in order to direct any moisture that penetrates the cladding away from the sheathing and wall cavity.

The term “vapor barrier” may still be used, but “vapor diffusion retarder” is a more accurate descriptor. A vapor diffusion retarder is a material that reduces the rate at which water vapor can move through a material. The vapor diffusion retarders should always be located on or near the warm side of walls, floors, and ceilings. However, in ceiling assembly applications, vapor diffusion retarders are typically omitted if attics are well ventilated. For wall assemblies, the drying potential of both the cladding and the wall sheathing/framing must be considered as the permeability of the cladding, moisture barriers, vapor diffusion retarders, and interior finish materials will greatly affect the overall drying potential. Vapor diffusion retarders should be carefully installed to provide a complete envelope preventing moisture vapor produced inside the structure from entering enclosed spaces where condensation may occur.

Local climate conditions, types of occupancy, and design methods determine requirements for control of vapor movement and ventilation. Some energy-saving practices, such as reducing air leakage or adding insulation, may increase the potential for moisture condensation. Good construction practices (attention to detail) must be followed to prevent problems caused by condensation. General code provisions are largely based on houses where heating of the building is the primary concern. To build long-lasting, energy-efficient, healthy houses in areas where cooling of the building, not heating, is a primary concern, the climatic conditions of the area must be considered.

APA’s *Build a Better Home: Walls, Form A530*, addresses the selection and installation of a vapor retarder as follows: *When the warm side is determined to be the inside wall, the vapor retarder can be kraft paper or foil/kraft paper facing on the wall insulation. The effectiveness of this vapor retarder depends on how carefully the insulation is installed. The most effective installation technique is to cut the insulation batt length slightly oversize so it can be friction-fit to avoid gaps at the top and bottom wall plates. Also, the installation tabs of the insulation facing should be lapped and*

stapled onto the nailing surface of the studs instead of the sides of the studs to “seal” the insulation facing against air and moisture leakage and to minimize gaps between the insulation and studs. Alternatively, an effective continuous vapor retarder can be installed by using a separate layer of 4-mil polyethylene sheeting stapled over the interior side of the wall framing. In this case, unfaced insulation without an integral vapor retarder facing may be used and friction-fit to fill the stud cavities without gaps. While polyethylene sheeting makes a very good vapor retarder, it is relatively difficult to install. In most cases, the use of polyethylene is not necessary even in very cold regions. Ordinary interior latex paint applied over drywall can provide sufficient vapor retardant properties.

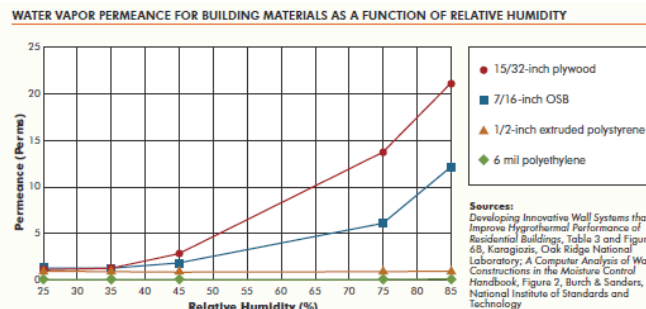


Figure 17: Water Vapor Permeance for Building Materials

Wood structural panels are considered “Smart Vapor Retarders” as discussed in APA’s Technical Note: *Water Vapor Permeance of Wood Structural Panels and Wood Wall Construction, Form J450*:

Figure 17 shows that some materials, such as polyethylene and vinyl sheeting tested by the NIST and ORNL, have very low vapor permeance. In many climates, it would be desirable to have a low permeance barrier on one side of a wall and then, in a different season, have a low permeance barrier on the other side of the wall. Fortunately, this complicated aspect of wall construction can be resolved through the use of smart vapor retarders, such as plywood and OSB. The permeance of smart vapor retarders is low when the relative humidity is low and increases as the relative humidity increases. The increased permeance when the wall humidity is elevated allows for greater vapor movement and faster drying of the wall. As shown in Figure 17, the water vapor permeance of 7/16-inch OSB is approximately 2 perms at 50 percent relative humidity, but that permeance may be increased by a factor of 6 (i.e., 12 perms) when the humidity is increased to 85 percent.

Ventilation, vapor diffusion retarders, and ground cover requirements may vary. Consult the local building department to confirm specific requirements.

Crawl Spaces

Ventilation. Crawl spaces under buildings, and other unexcavated concealed spaces under porches, breezeways, patios or other appendages should be naturally ventilated by openings in foundation walls or by suitable mechanical means. Such spaces should be provided with access panels so that they may be easily inspected. Crawl spaces must be designed to allow sufficient drying to prevent build-up of moisture to levels where water vapor will condense or where fungal growth can occur. In some hot and humid climates, local or state codes may restrict crawl space ventilation.

Minimum ventilation requirements for crawl spaces are specified in the codes. The requirements are usually based on the ratio of the free ventilation area to the area to be ventilated. Typically, the required ratio is 1 to 150. When a vapor diffusion retarder is placed over the ground within a crawl space, the ventilation ratio may be reduced to 1 to 1500.

Ventilation openings should be arranged to provide cross ventilation. They should be kept clear of shrubbery and should be covered with corrosion-resistant wire mesh, with mesh openings not less than 1/4 inch nor more than 1/2 inch in any dimension. Vents should be at least 3 inches above outside grade and below the bottom of floor joists, or wells with 6 inches of clearance around the vent should be provided. No unventilated, inaccessible spaces should be permitted.

It is very important that ventilation should not be cut off at any time during the year when it is the only means of moisture control in crawl spaces. Ventilation openings are not necessary when crawl space walls are insulated, an approved vapor diffusion retarder is provided over the ground, and conditioned air is provided to the crawl space. Ventilation requirements are based on the assumption that outside air has a lower absolute humidity than air in the crawl space. In hot and humid climates where exterior air has a high absolute humidity, use of natural ventilation may not be the best option for drying the crawl space.

Vapor Protection. Except in arid or semi-arid areas, soil should be covered with a fungi-resistant vapor diffusion retarder having a permeability of 1 perm or less, such as 6 mil polyethylene lapped approximately 4 inches at joints. The vapor diffusion retarder should conform to ASTM E1745 and be resistant to chemicals in the soil. Laps should be sealed. The vapor diffusion retarder should lap-up onto the foundation so that the concrete slab is isolated from the soil and the foundation. Seam tape should be used to seal the retarder to any pipes or other objects that penetrate the retarder and the slab. The ground surface should be leveled and the cover turned up at walls and piers.

Multi-Family and Nonresidential Buildings

For multi-family or nonresidential buildings where crawl space configuration or building location may reduce the efficiency of natural ventilation, the required net area of vent openings should be increased. A vapor diffusion retarder is also recommended for such installations.

Concrete Slab Foundations. Soil is a constant source of moisture, so deflection of soil moisture is important. The use of a sturdy vapor diffusion retarder beneath slabs prevents ground-based moisture from migrating up through the concrete by capillary action or diffusion. Lapping of joints in the vapor diffusion retarder and liberal use of tape and other sealants around pipe penetrations is critical. However, care should be taken in hot climates to slow the rate of concrete surface curing. Vapor diffusion retarders placed under the slab slow the rate of drying in the lower depth of the concrete. When the upper depth is exposed to high heat and dries too fast, it shrinks relative to the deeper concrete that cannot disperse its moisture as fast because of the vapor diffusion retarder. Surface cracking can result. After the surface initially hardens, some means of covering the slab to slow the rate of curing is advised.

Attics

Natural Ventilation. To eliminate the problem of moisture condensation on roof framing in cold weather and to permit escape of heat in hot weather, ventilation of all attic spaces is required by model building codes (**Figure 19**). In some hot and humid climates, local codes may limit attic space ventilation.

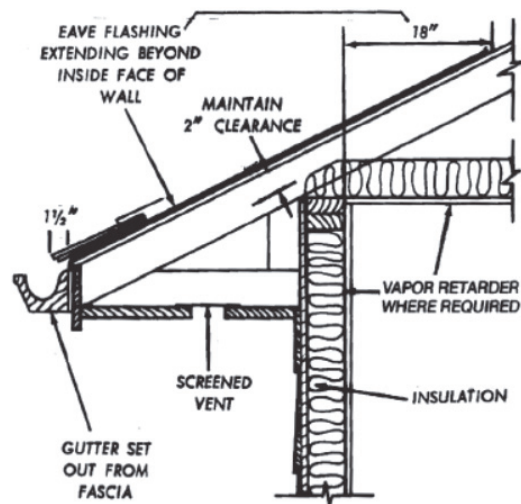


Figure 18: Shingles and Flashing at Eave

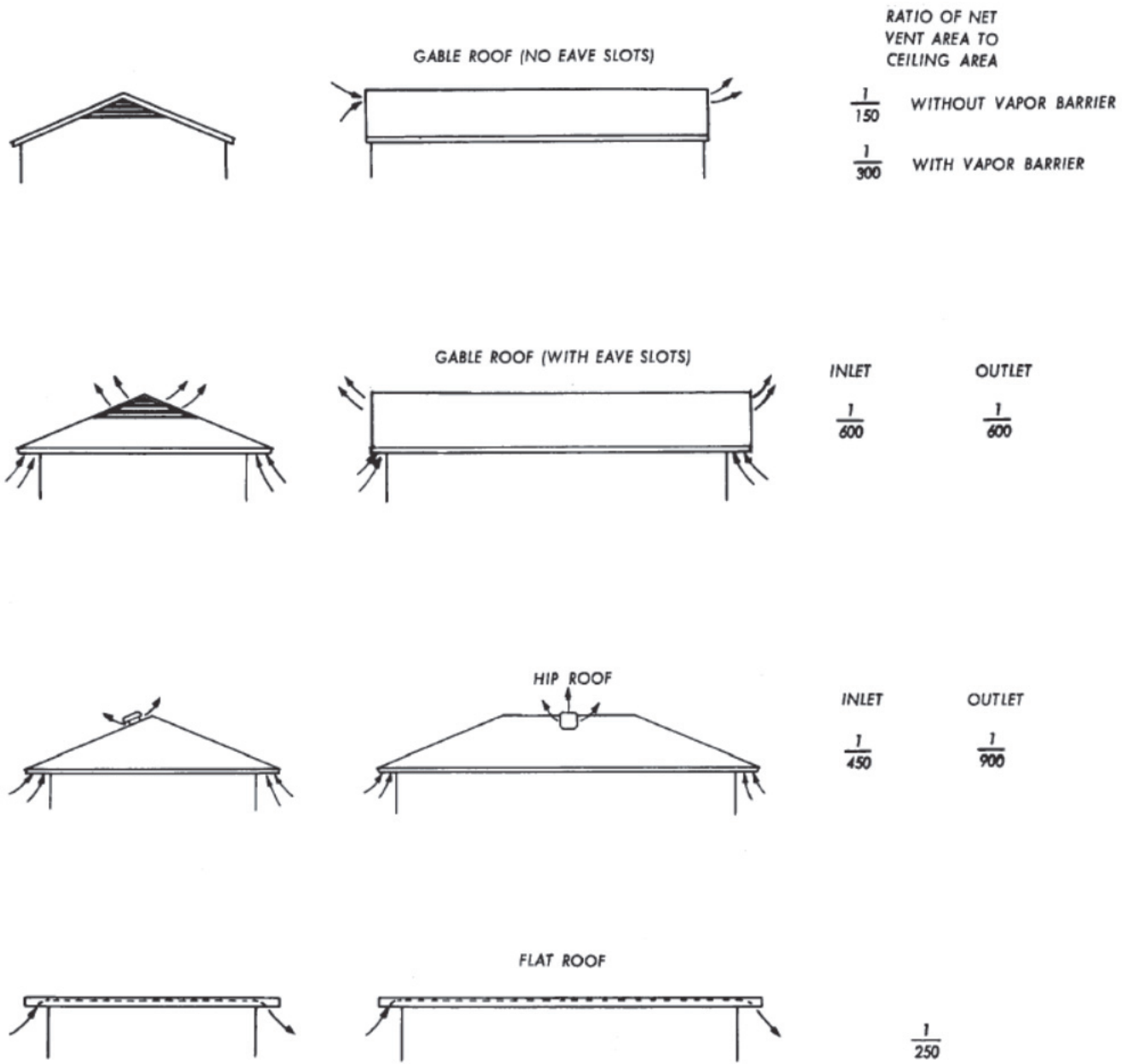


Figure 19 Methods of Ventilating Roof Spaces and Amount of Ventilation Required

For gable roofs that depend upon screened louvered openings for ventilation, a net open area of 1/150 of the area of the ceiling below should be provided. The free ventilating area may be reduced to 1/300 when a 3/4 inch slot is provided beneath the eaves in addition to the screened gable-end louvers (1/600 inlet and 1/600 outlet vent areas), or when a vapor diffusion retarder having a permeability of 1 perm or less is installed on the warm side of the ceiling (**Figure 18**). For hip roofs, it is customary to provide a 3/4 inch slot beneath the eaves and install ventilators near the peak to obtain net inlet and outlet open areas of 1/450 and 1/900, respectively, of the area of the ceiling below.

In hot and humid regions, attic spaces can heat up to 130°F or more on a hot summer day. Eventually, that heat transfers through the ceiling insulation into living spaces below, increasing the cooling load. To counter this problem, it is suggested that twice the recommended roof ventilation be used, and it is recommended that a radiant barrier be installed, such as labor-saving roof sheathing with foil laminated directly to it. The radiant barrier blocks transfer of heat from the roof to the attic. The radiant barrier should be applied to the underside of the roof, not on the attic floor, with adequate openings along the ridge and below the low-profile vents so that attic air can exhaust. Light-colored roofing may also be used to slow heat transfer into the attic space. A raised-heel truss is another technique to increase energy efficiency of the attic insulation at the ceiling level. A raised-heel truss is identical to a conventional truss except for one difference: it is raised higher, with a “heel” that extends up from the top of the wall and elevates the truss at the building’s edges. Raising the truss higher has two big advantages: it greatly simplifies attic ventilation, and it leaves ample room for insulation above exterior wall top plates. More information on this approach can be found on the APA website, www.apawood.org/raised-heel-trusses.

For flat roofs, blocking, bridging, and insulation should be arranged to permit unobstructed movement of air for ventilation. Such roofs may be ventilated along overhanging eaves on the basis of a net open area equal to 1/250 of the area of the ceiling below (**See Figure 19**). A vapor diffusion retarder having a maximum permeability of 1 perm should be applied to the warm side of the ceiling below flat roofs.

Mechanical Ventilation. In lieu of natural ventilation of attic spaces described previously, mechanical ventilation may be used. Such ventilation should provide minimum air changes of 0.7 cu. ft./min. (at 0.03” standard pressure) per sq. ft. of the ceiling below. Air intakes of 1 sq. ft. of free openings per 300 cu. ft./min. of fan capacity should be provided. Mechanical ventilation should provide adequate protection against harmful condensation throughout the year.

California Title 24 Energy Code Impacts

The State of California mandated Zero Net Energy (ZNE) goals for new construction with the following timeline for implementation:

1. All new residential construction will be ZNE by 2020.
2. All new commercial construction will be ZNE by 2030.

Basically, ZNE seeks to ensure that the amount of energy that a building consumes on an annual basis is approximately equal to the energy produced by on-site renewables. This goal is codified through California’s Energy Code, Title 24. There is one more code cycle to propose provisions to help reach this goal for residential construction and the California Energy Commission is focused on two portions of the building envelope where they feel construction can improve to bring down the energy demand: High Performance Attics and High Performance Walls. This is important to note, as the building envelope will continue to evolve with more rigorous U-factors being mandated. Many of the items already suggested (e.g. radiant barrier sheathing and raised heel trusses) help meet these goals.

Durable Materials

The final D to address is durable materials. In a perfect world, if all of the previously discussed water management principles were to be applied, this section would be unnecessary. But there is an expression often shared in the building science community, “It’s not if a leak happens, but rather when it does.” Therefore, the durability of wood framing and the consequences of too much exposure need to be understood.

What happens if water gets inside of the building envelope and cannot get out? Mold may grow or worse yet, over time there can be decay. Mold needs the following conditions to grow: nutrients (any organic substance such as wood or dirt on a plastic bathroom shower curtain), moderate temperatures (68 to 86 degrees Fahrenheit), oxygen, and moisture (prolonged relative humidity between 70 and 90 percent). Unfortunately, humans enjoy the same environment and the main factor that can be controlled is moisture.

What is the impact of mold on wood components? Per APA’s Build a Better Home: Mold and Mildew, Form A525:

As an organic material, mold and mildew readily grow on wood if moisture is present. Mold grows on wood if exposed to water or prolonged humidity in excess of 70%. Mold and mildew are of a different type of fungi than those that cause wood to rot. Unlike wood decay fungi, molds do not cause significant loss of the strength of wood products. Nonetheless, mold and mildew on wood may cause a health concern and indicate high moisture conditions are present. Prolonged

periods of high moisture may also support the growth of wood decay fungi, which is another reason why it is important to follow proper methods of design, handling, installation and maintenance that will control the growth of mold and mildew.

Finally, how should a structure that has mold be treated? First, the moisture source that caused the mold needs to be removed. Second, mold can be removed or cleaned with commercial mold removers or with a solution of one part household bleach mixed with three parts warm water taking care to allow drying and not introducing more moisture into the wood elements. For more resources on the topic, see APA's Build a Better Home: Mold and Mildew, Form A525. Finally, an evaluation of the structural integrity of the building materials needs to take place. As noted above, most instances of mold will not negatively affect the product structurally.

Typically, structural wood framing will be used in enclosed applications. If wood framing is exposed to the environment, there are two options for sawn or glued-laminated timber: preservative treatment or use of naturally durable species. The building code specifies decay resistant species: redwood, cedar, and black locust and termite resistant species: redwood and eastern cedar. Several wood species, such as Port Orford Cedar (POC) or Alaska Yellow Cedar (AYC), are readily available in California and may be exposed to weather without additional preservative treatment required.



Figure 20: Partially Exposed Glued-laminated Timber Truss

Specific to glued-laminated timber, naturally durable species have lower design values in comparison to Douglas-Fir (DF) or Southern-Pine (SP). For example, AYC glulam has a 20F-1.5E in comparison to a comparable DF 24F-1.8E. **Figure 20** shows an example where a truss was manufactured with AYC bottom chords and untreated DF top chords and web members. Since the roof is providing protection to much of

the truss, the engineer chose to use AYC for only the bottom chord members.

As an alternative to naturally durable species of wood, DF and SP beams may be preservatively treated. When specifying a treated wood member, consider the following: incising, fasteners, structural properties, field cutting, and the preservative use category. These topics are addressed in APA's Technical Note: Preservative Treatment of Glued Laminated Timber, Form S580, for glulam as highlighted here:

Incising is required for Douglas-fir, western hemlock, hem-fir, red maple and yellow poplar. Such incising is normally performed after gluing of the finished glulam. If laminating lumber is to be treated prior to gluing, the mating faces to be glued should not be incised. Incising is not considered to have a detrimental effect on the strength of glulam. The effects of incising on appearance, however, should be considered when ordering glulam where aesthetics are important. If incising is not specified, difficulties in meeting the specified treatment retention and penetration levels may result. This option should only be considered with caution. If the specifier waives the incising requirement, penetration and retention requirements may still apply.

On the topic of fasteners, S580 states:

AWPA recommends using fasteners that meet the requirements of the major model building codes, which specify that fasteners (including nuts and washers) in contact with preservative-treated wood shall be hot-dipped zinc-coated galvanized steel, stainless steel, silicon bronze or copper. Connectors that are used in exterior applications and in contact with preservative-treated wood shall have coating types and weights in accordance with the treated wood or connector manufacturer's recommendations. In the absence of manufacturer's recommendations, a minimum of ASTM A653 type G185 zinc-coated galvanized steel, or equivalent, shall be used.

Structural Properties

Regarding structural properties, S580 states:

The International Building Code (IBC) and International Residential Code (IRC) recognize glulam design values as specified in the latest edition of the National Design Specification for Wood Design (NDS). Although the NDS does not specify reductions in the dry design values for preservative-treated glulam according to AWPA Standards, it does specify that moisture content design capacity adjustment factors be used whenever the moisture content in service is 16 percent or more. It is important to note that the application of a moisture content adjustment factor is based on the judgment of the designer of record considering the end-use

environment to which the member is subjected and is not related to any preservative treatment that may be specified.

Lastly, S580 recommends that field cutting be minimized and, “*field treatments should be applied to saturation by dipping, brushing, spraying, soaking or coating in accordance with AWWA Standard M4.*”

Recently, there have been a number of cases where building envelopes have failed at elevated exterior elements. The Structural Engineers Association of California created an Elevated Exterior Elements committee to review these critical building elements and make recommendations to the California Building Standards Commission. A great summary of the events leading to the creation of this committee and the work to date is found in the April 2016 issue of STRUCTURE magazine. The authors propose the following enhancements:

1. *Confirm that the project actually has a building envelope and waterproofing designer.*
2. *Enhance coordination between the structural and architectural details, particularly at appendages and structural interfaces (stair stringers, guardrail anchorage, ledger attachments, cantilevered members, etc.)*
3. *Recognize the importance of drainage and slope for the performance of all waterproofing systems,*
4. *Use more durable materials such as pressure preservative treated lumber and steel but recognize that they have their own design challenges such as corrosion.*
5. *Know the 4 Ds.*

Termite Controls

Prevention of insect damage and decay caused by moisture penetration are key issues when building with wood. Proper construction detailing to ensure long-term durability of wood frame buildings has been previously covered.

Insects—mainly termites, carpenter ants, and powder post beetles—can cause significant property damage. The information in this section is intended to help prevent damage. Insect damage is not restricted just to wood-frame structures, as termites will chew cable shields, plastic laminates, and foam insulation. Carpenter ants and powder post beetles are found throughout the U.S. and parts of Canada but cause limited damage and are relatively easy to control, whereas subterranean termites can cause significant damage.

Termites attack above the ground by means of shelter tubes attached to foundation walls, piers, and other elements in contact with the ground. However, a colony is able to

penetrate and consume wood in-service *only* under conditions which permit the insect to establish and *maintain* contact with moisture. In contrast to termites, carpenter ants do not eat wood and other cellulose-based materials, but instead simply excavate living quarters and hatching chambers that are usually quite localized. Powder post beetles only do significant damage when multiple generations continually re-infest the same piece of wood. Also, powder post beetle damage is restricted to hardwoods, and since most structural framing is softwood lumber, it is rarely attacked by these insects.

There are more than 2,000 species of termites that include dampwood termites, drywood termites and subterranean termites. The subterranean termites consist of roughly 20 species and are the most damaging: they are called “subterranean” termites because of their nesting and foraging habits. Of the subterranean termites, Formosan are by far the most destructive in the U.S. Formosan termites, which were introduced to Hawaii and the southeastern United States from Southeast Asia at the end of World War II, can cause more damage than domestic termites and at a faster rate. Formosan colonies also tend to be larger than those of domestic subterranean termites. Native termites are found throughout the continental U.S., except Alaska, while Formosan termites are restricted mainly to states bordering the Gulf of Mexico and Hawaii.

The general information given below concerning protection against termites is applicable to Formosan as well as domestic termites. However, given the increased level of damage possible from Formosans, additional precautions should be taken where they exist. Those geographic areas near enough to current infestations to be reasonably threatened by existing Formosan termite colonies or by migration in the near future are considered to be areas of severe risk. Those areas elsewhere would be considered to be intermediate and low risk areas.

- **Suppression.** Suppression refers to measures intended to reduce and eventually eradicate termites from infested materials in designated area. Suppression methods include systematic location and destruction of colonies not associated with buildings (such as in street trees), systematic inspection of wood products, leaving an infested area to quarantine the infestation, burning of infested lumber and heat treatment of reclaimed lumber. Formosan termite colonies should be contained in their current geographic region of infestation. Precautions should be taken to assure that logs, soil, landscape timbers, mulch, and other transportable sources of infestation are free of termites.
- **Site Management.** Construction sites must be managed to assure that nothing exists that promotes establishment of colonies. All construction debris should be removed

from the site, along with dead trees, foliage, stumps and other sources of food for termites. During construction, it is important that: stumps be removed; all wood and other cellulose containing construction debris be removed from the site; survey pegs and concrete formwork be removed and disposed of properly, rather than buried or encased in concrete; excavation soil is not used to fill in under porches or steps; and site grading drains water away from the building. In addition, non-treated wood elements will be raised from the ground according to the previous section, "Distance." For landscape management of existing sites, there should be no wood-to-soil contact for untreated wood, including piles of wood, sheds or patios, and all posts should be mounted on metal brackets or concrete post supports.

- **Soil Barriers.** Soil barriers that kill or restrict movement of termites should be introduced based on the severity of infestation. Recently, a new generation of physical barriers promises longer effective life without negative environmental impacts. These barriers consist of either a 4" thick layer of precisely sized sand or crushed stone beneath slab foundations or inside the footer and along the outside of the stem wall of crawl-space foundations. The sand particles are too heavy for the termites to move, and the spacing between them too small for the termites to squeeze through. The most effective particle size has been found to be between 1/16" and 1/10" in diameter, but varies according to the termite species in question. In Hawaii, where they were first developed, sand barriers are referred to as basaltic termite barriers. In areas of severe risk, the use of barriers such as graded gravel or termite-resistant steel mesh is appropriate along with the use of chemical soil treatment or bait systems. In low-risk areas, soil barriers are not required.
- **Chemical Barriers.** Chemical soil treatment has been a standard practice for preventing termite infestation of structures for some time. A termiticide is placed into the soil under and around a structure to create a continuous chemical barrier that blocks potential routes of termite entry. Typically, a trench is dug around slabs, piers, or other supports touching the soil, which is then saturated with termiticides. Soil below the slab is also treated with the termiticide. Application of soil treatments should be carried out by a licensed professional in accordance with requirements of the authority having jurisdiction. The typical effective life of a soil treatment varies between products. Less toxic chemical barriers, such as pyrethroids, are now used, which have shorter effective lives of about 5 years compared with the highly toxic and persistent chemicals used in previous years that reduced termites for up to 50 years. These chemicals should not be used on sites with wells or other ground sources of water supply. Also, there may be difficulty in reapplying the treatment, particularly if the building has a slab on

grade. Application of chemicals and precautions involved in their use should be in accordance with manufacturer's recommendations (**Figure 21**). For permanent wood foundations (PWF 2015), soil treatment should be in accordance with the recommendations for poured concrete foundation walls, except that the treatment should extend below the wood footing.

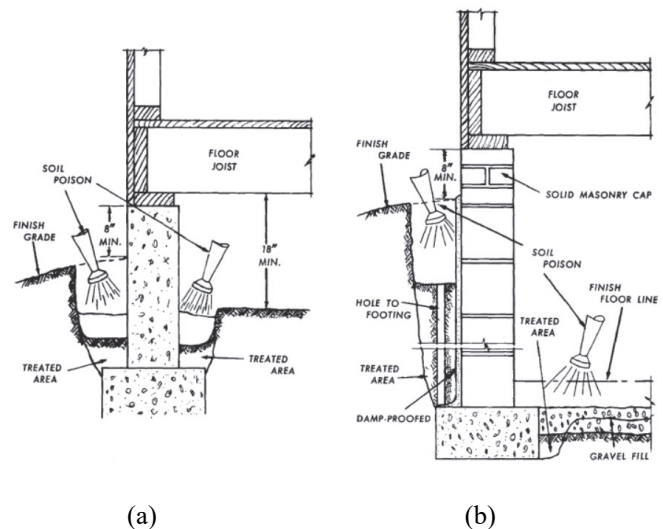


Figure 21: Application of Soil Treatment

- **Slab and Foundation Details.** Foundation walls and slabs should be designed to inhibit the entry of termites into the building and to facilitate inspection for shelter tubes. In all risk areas, the use of preservatively treated or naturally durable wood and termite barriers as discussed later is necessary. It is also important that foundation design be done with care. Depending on the type of foundation, use of graded gravel or termite-resistant steel mesh at points where piping penetrates slabs is reasonable. Where concrete masonry units are used as elements of the foundation, the bottom of the units should be protected with graded gravel or termite-resistant mesh, or the units should be filled with concrete. A critical element in controlling termite access to the structure is proper detailing during the building design process, particularly in those areas at ground level. For foundations:

 - Poured concrete foundation walls may allow access when cracks greater than 1/64" are present.
 - Poured reinforced concrete caps, which should be at least 4" thick on unit masonry foundations, may allow access when cracks greater than 1/64" occur.
 - Slab-on-ground construction requires special consideration in areas where a termite hazard exists. Concrete slabs vary in their susceptibility to penetration by termites and cannot be considered to

provide adequate protection unless the slab and supporting foundation are poured integrally (monolithic slab) to avoid cracks or holes through which termites may enter (**Figure 22**).

- Where other types of slab construction are used, termites may penetrate joints between the slab and wall. They may also enter through expansion joints or openings made for plumbing or conduit. Thus, it is necessary to provide a barrier at these points by use of termite shields or by chemical soil treatment (**Figure 23 & Figure 21**).

Stucco, masonry veneer, and other non-wood siding in contact with the ground may provide access for termites in infested areas. For this reason, the veneer or siding should be kept at least 8" above finished grade, unless termite shields are installed in an approved manner or the soil on the exterior has received a chemical treatment (**Figure 23**).

Rigid expanded polystyrene or polyurethane insulation used against foundations can provide concealed access and are easily penetrated by termites. Where such foundation wall insulation is used and a particular termite hazard is known to exist, it is important that soil treatment, shields, or pressure treated wood be used, as appropriate to the design.

- *Structural Protection.* In areas of severe risk, an increased level of protection of structural elements of the building is justified. The structural frame—including posts, poles, columns, joists, girders, rafters, structural sheathing, and bracing—should be either preservative-treated wood or naturally durable.

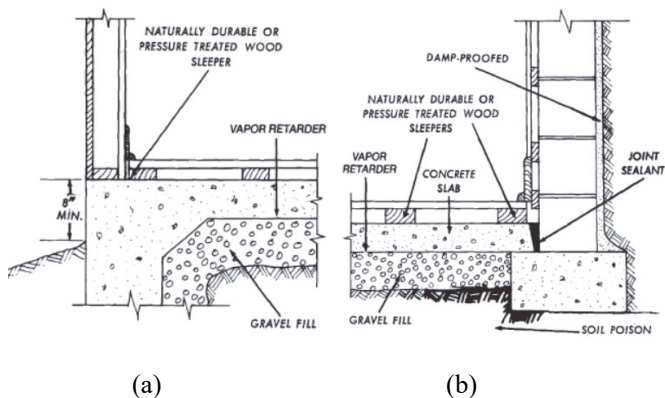


Figure 22: Termite Control for Slab-on-Ground Construction

The termite hazard will vary from one region to the next. In all areas, structures should still be designed to provide

adequate and accessible clearance between earth and wood in order to permit periodic inspection for termite shelter tubes and wood damage. Where clearances recommended under the "Distance" section are provided, no additional protection is required, unless a specific termite hazard is known to exist. However, all foundations and piers of hollow masonry units should have solid masonry caps in which all joints or voids are filled with mortar.

In addition, all roots, wood forms, stakes, and scraps of wood should be removed from the immediate vicinity of the house before back-filling and before placing a floor slab. Particular care should be taken to remove all scraps of wood from enclosed crawl spaces.

Where local experience indicates that additional protection against termites is required, one or more of the following systems should be specified depending on the degree of hazard:

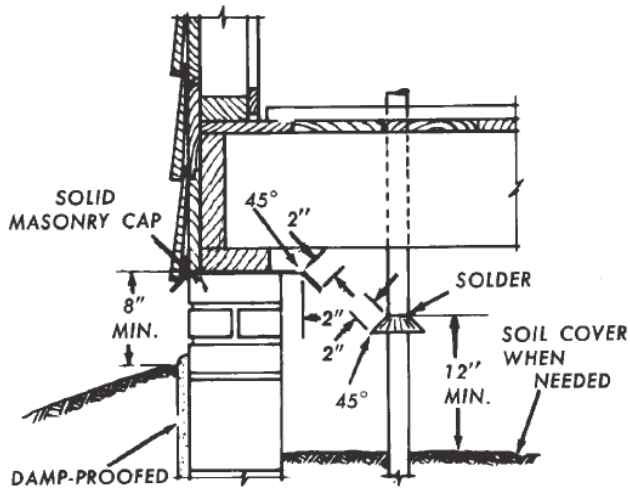
Termite Barrier

The most common method of control is a termite barrier, which is considered to be any building material or component which is impenetrable to termites and which drives the insect into the open where its activities can be detected. Properly installed termite shields should be of not less than 26 gauge galvanized steel, or other suitable metal of proper thickness, installed in an approved manner on top of all foundation walls and piers, and around all pipes leading from the ground (**Figure 23**). Longitudinal joints should be locked and soldered. Where masonry veneer is used, the shield should extend through the wall to the outside face of the veneer (**Figure 23**).

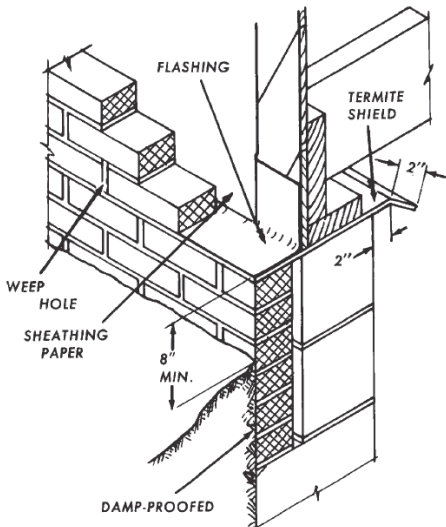
Any of the barriers mentioned can be installed without major changes in established construction methods. However, periodic inspection is essential to the successful function of any of the barrier types recommended.

In-Ground Bait Systems

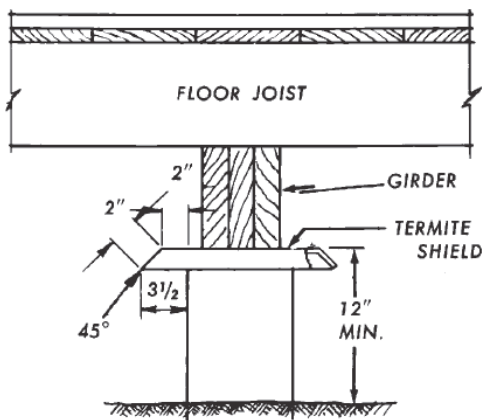
In-ground bait systems are a technology for treating subterranean termites. In-ground bait stations are placed around a house in the soil. Untreated cellulosic material is placed in several of the stations and monitored several times a year for signs of termite activity. Once termite activity is found in the station, the cellulosic material is replaced by termiticide-treated, cellulosic material that the termites will return to their colonies. In order for this system to be effective, it must be maintained and serviced.



(a)



(b)



(c)

Figure 23: Installation of Termite Shield

Fumigation

Structures subjected to a fumigation system are covered with a tent and a lethal gas is released into the structure. This treatment kills termites in the structure, but not termites in the soil. This system is effective in killing drywood termites as they infest and live self-contained in the wood of a structure. Fumigation is not recommended without other treatments for controlling subterranean termites because termites in the soil may re-enter the structure as soon as 24 hours after fumigation.

Construction Quality Control

As with fire and structural design of the building, the moisture management design of the structure is only successful if it is specified and constructed properly. It is important for the design intent to be clearly communicated in construction documents to the entire team. Various moisture control strategies should be communicated with specifications and critical details including both typical and non-typical details.

The builder may want to develop a rigorous set of procedures for quality control during construction to coordinate the work that is essential to ensure long-term performance, particularly with the building envelope where there may be different trades that interface. Pre-installation meetings are helpful to clarify, refine and verify the design as well as mock-ups of installations that are not typical. This allows the designer and builder to work with the various trades involved in building envelope construction and resolve issues related to constructability and sequencing. Once tested and approved, the mock-up can serve as a visible and tangible standard for future work on the project.

Control of Moisture During Construction

Control of moisture during construction is an important aspect of the success of moisture management in a building. During construction, some materials may get wet because they are exposed to rain or snow, there may be plumbing leaks, ground contact, etc. Effective control of moisture requires the following:

- Drain rain, irrigation water, and snowmelt away from the building
- Keep rain and irrigation water from leaking into the walls and roof
- Keep water from wicking into the building
- Prevent plumbing leaks
- Keep building materials dry while in storage onsite and avoid direct contact with the ground
- Avoid enclosing wet materials and allow ample time for wet material to dry out.

Wood materials that are exposed to moisture should be dried to a moisture content of < 20% prior to enclosure. On buildings that are exposed to significant wetting during construction, schedules should provide an allowance for properly drying framing and sheathing materials. Heaters, fans, and dehumidification machines can be utilized to speed the drying process.



Figure 24 Material Handling and Storage.

From *Designing for Durability – reThinkWood.com* Photo courtesy of KK Law

Conclusion

Moisture management is a critical component to the success and longevity of any building. Attention to detail is critical for the building envelope which encompasses the roof, walls, and foundations. Consideration of the building site’s climate and materials selected will affect the needed levels of protection.

Structural engineers, while not typically building scientists, should familiarize themselves with the 5Ds-Deflection, Distance, Drainage, Drying, and Durable materials-to add value to the project team. Coordination with the building envelope designer, as well as the contractor is critical to achieving long-lasting wood structures.

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