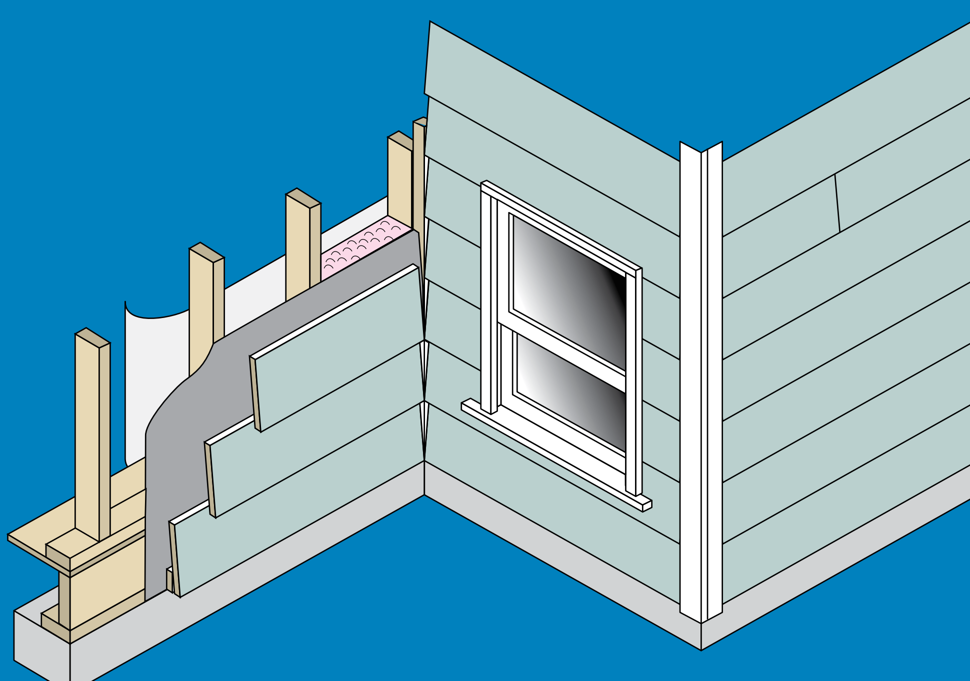
The VISUAL HANDBOOK of Building and Remodeling

4th EDITION

A Comprehensive Guide to Choosing the Right Materials and Systems for Every Part of Your Home



CHARLIE WING

Author of HOW YOUR HOUSE WORKS

The VISUAL HANDBOOK of Building and Remodeling

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A Comprehensive Guide to Choosing the Right Materials and Systems for Every Part of Your Home

CHARLIE WING

The Taunton Press

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Inspiration for hands-on living®

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Homebuilding is inherently dangerous. Using hand or power tools improperly or ignoring safety practices can lead to permanent injury or even death. Don't try to perform operations you learn about here (or elsewhere) unless you're certain they are safe for you. If something about an operation doesn't feel right, don't do it. Look for another way. We want you to enjoy working on your home, so please keep safety foremost in your mind whenever you're in the shop.

For Ray Wolf, agent, sailor and lifelong friend, without whom this book would never have been born.

Acknowledgments

As the dedication indicates, without the experience, insight, and doggedness of my agent, Ray Wolf, this book would have remained but a personal dream. Who would have thought, in 1990, *The Visual Handbook of Building and Remodeling* would become a building classic with new editions every eight years?

As soon as I had committed to leading a Bowdoin College seminar titled "The Art of The House," I started gathering information, not only on how houses were constructed, but how they worked. The seminar, in reality, should have been called, "The Physics of the House."

In addition to nearly 100 books, I soon had filing cabinets full of useful scraps of information gleaned from every element of the building industry: architect and builder friends, lumberyards, hardware stores, contractors, manufacturers and associations. When the usefulness of all of this seemingly disparate information became apparent, I began dreaming of gathering it all into a single book. Architects have their *Architectural Graphic Standards*; my book would be *Graphic Standards for the Rest of Us*.

For many years the dream remained just that. I could get no publisher to share my vision and enthusiasm. Simply put, they didn't get it. Then I met Ray Wolf. He had worked for many years at Rodale Press, publisher of *Organic Gardening* and *New Shelter Magazine.* He knew how publishers worked, how they thought. He knew how to present the project in terms they would understand. Better yet, he ran a set of numbers that promised profitability.

After signing the contract, the most trying task fell upon the shoulders of legendary editor Maggie Balitas, who patiently tempered my vision with the realities of publishing. To her then-young associate, David Schiff, Maggie assigned the duty of ensuring accuracy. I am sure that I am responsible for several years of his accelerated aging. These are the three individuals who helped me turn my dream into reality. I cannot thank them enough.

Of course, there would never have been a dream were it not for the legions of manufacturers and building trades associations, listed on pp. 668–672, who first produced the information in my files. I thank them for their efforts and their generosity in sharing their information.

Not least, thank you, Wid, for understanding that sitting in front of a computer eight hours a day, seven days a week, for a whole year is how I make a living.

Contents

Introduction

Twenty-eight years ago I proposed to Rodale Press through my agent, Ray Wolf, a "visual handbook for small builders and do-it-yourselfers." We told them, in our opinion, such a book could sell 50,000 copies and might, with periodic revision and addition, enjoy an indefinitely long life.

"Let's just see how the first edition sells," was the dubious but predictable reply. (They later confided they expected the book to sell only 5,000 to 10,000 copies.)

It turned out our gut instincts were right. In fact, we were so right we were almost wrong! The first edition sold not 50,000 but 200,000 copies and, at age seven, was showing little sign of slowing.

Eight years later Reader's Digest® purchased the book and issued a second edition with an additional 100 pages containing:

- span tables for U.S. and Canadian lumber
- checklists of building code requirements
- a catalog of metal framing aids
- design standards for access
- three times as many framing details

The Reader's Digest edition sold another 100,000 copies. In reading the Amazon.com℠ reviews, I discovered that, in addition to small builders and do-it-yourselfers, the people finding the book useful included home inspectors, energy auditors, codes officials, and vocational instructors.

Ten years later I was thrilled when Taunton Press—arguably the foremost publisher of building books—agreed to publish a third edition (and now a fourth), in large format and full color.

But let me go back and tell you why I felt compelled to create the handbook in the first place.

"Building a house requires thousands of decisions based on a million bits of information." This was the opening line of my lectures to thousands of potential owner/builders attending my three-week courses at Shelter Institute℠ and Cornerstone℠.

Teaching that course, and a precursor "physics of the house" seminar at Bowdoin College, taught me how to convey technical building information to people who are not professional builders. I put that training to work in five previous books, which covered every aspect of building, from retrofitting insulation to a drafty old house in *House Warming,* to siting, planning, and constructing a house from the ground up in *Breaking New Ground*.

But still, something was missing. I'd written all I had to say about designing and constructing a house, but I hadn't thoroughly covered the topic of what to construct a house of. What's more, it didn't seem to me that anyone else had, either. There was, and is, a plethora of technical literature for architects and structural engineers, but there was no thorough guide for people without formal technical training. The fact is, the majority of people who actually lay their hands on building materials—tradesmen, owner/builders, and do-it-yourselfers—are not trained architects or engineers. These people needed a book as thorough as the ones the architects use but that also offered explanations, formulas, and charts that would make the information accessible. *The Visual Handbook of Building and Remodeling*, I believed, would be that book.

Naturally, in my previous books, I discussed materials in the context of how to install them, as do most other how-to writers. But the *Visual Handbook* focuses on the materials themselves. Its purpose is to enable one to decide how much of which material of what size should be used for any given house on any given site. Some how-to-install information is included because the way materials are used is often relevant in deciding which material to use. However, the how-to is incidental to the what-to, instead of the other way around. For example, the chapter on siding discusses the pros and cons of each type of siding, from clapboards to vinyl, so you can make an informed decision about which is best for your particular site and climate.

But it also illustrates construction details, to help you decide which would work best on your particular house.

I could see right away that this had to be a highly visual book. Nowhere is the saying, "A picture (or drawing, in this case) is worth a thousand words," more true. Further, there is no way words could describe, for example, every standard molding profile. It is possible, however, to show each in scaled cross-section.

Three things have made it possible for me to create this visual handbook. The first is software for illustrating (*Adobe Illustrator*®) and desktop publishing (*Quark*® and *InDesign*®) that enabled me to create illustrations without training and camera-ready pages without being a printer. The second is that I am an information pack rat, a looter of lists, a burglar of booklets, a swiper of spec sheets. The third is the willingness of manufacturers and trade associations to allow me to adapt their diverse materials to a uniform format.

In the accretion of building information I am insatiable. No builder, no hardware clerk, no sawyer in the backwoods, not even architects are spared my quest. I raid their files, their bookshelves, and their minds. Over the years I have accumulated the best of what they found useful in the actual building of houses: tables, lists, government pamphlets, manufacturers' literature, building-trade association publications, even instructions from a package of asphalt shingles. And now there is the internet and Google™! Now I can sit at my computer and search for and download information that used to require road trips and photocopies.

The result is a book that should be useful to anyone who puts his or her hands on building materials or hires others who do so. If you hire a builder, you won't be limited to his or her preferences but will be able to take a more active role in deciding what materials to use. If you are an owner/builder, this book should complement the how-to books containing step-by-step instructions. And if you are a tradesman, I hope that you will keep a copy behind the seat of your truck for easy reference.

By the way, the opening line of my owner/builder course proved to be a bit off the mark. According to the computer, *The Visual Handbook of Building and Remodeling* now contains 317 million bytes of information.

Charlie Wing
South Portland, Maine

Design

Houses are designed for the comfort and safety of human beings. House dimensions must, therefore, be related to *human dimensions*.

Tied to human dimensions—but too often overlooked in our excitement over cathedral-ceilinged great rooms, spectacular kitchens, and commodious baths—are critical *window, closet, and passage dimensions*.

Central to the home, and tops in our list of priorities, are kitchens and baths. We are fortunate in having permission to present most of the recommendations of the National Kitchen & Bath Association's *Kitchen Design Guidelines* and *Bath Design Guidelines*.

With more fatal in-the-home accidents occurring on stairs than in any other area, building codes are becoming ever more specific and stringent about *stair design*. We are again fortunate in having permission from the Stairway Manufacturers' Association to adapt the illustrations from their excellent *Visual Interpretation of the IRC 2006 Stair Building Code*.

Although the 1990 Americans with Disabilities Act (ADA) was written to guarantee physically handicapped citizens access to public buildings and the workplace, many of its design requirements are equally applicable to the home. Because homeowners generally prefer to remain in their homes as long as physically practical, we have illustrated the applicable ADA specifications in the section titled *Access*.

Finally, we provide you with a checklist of requirements so that your foundation will *meet the IRC Code*.

Human Dimensions

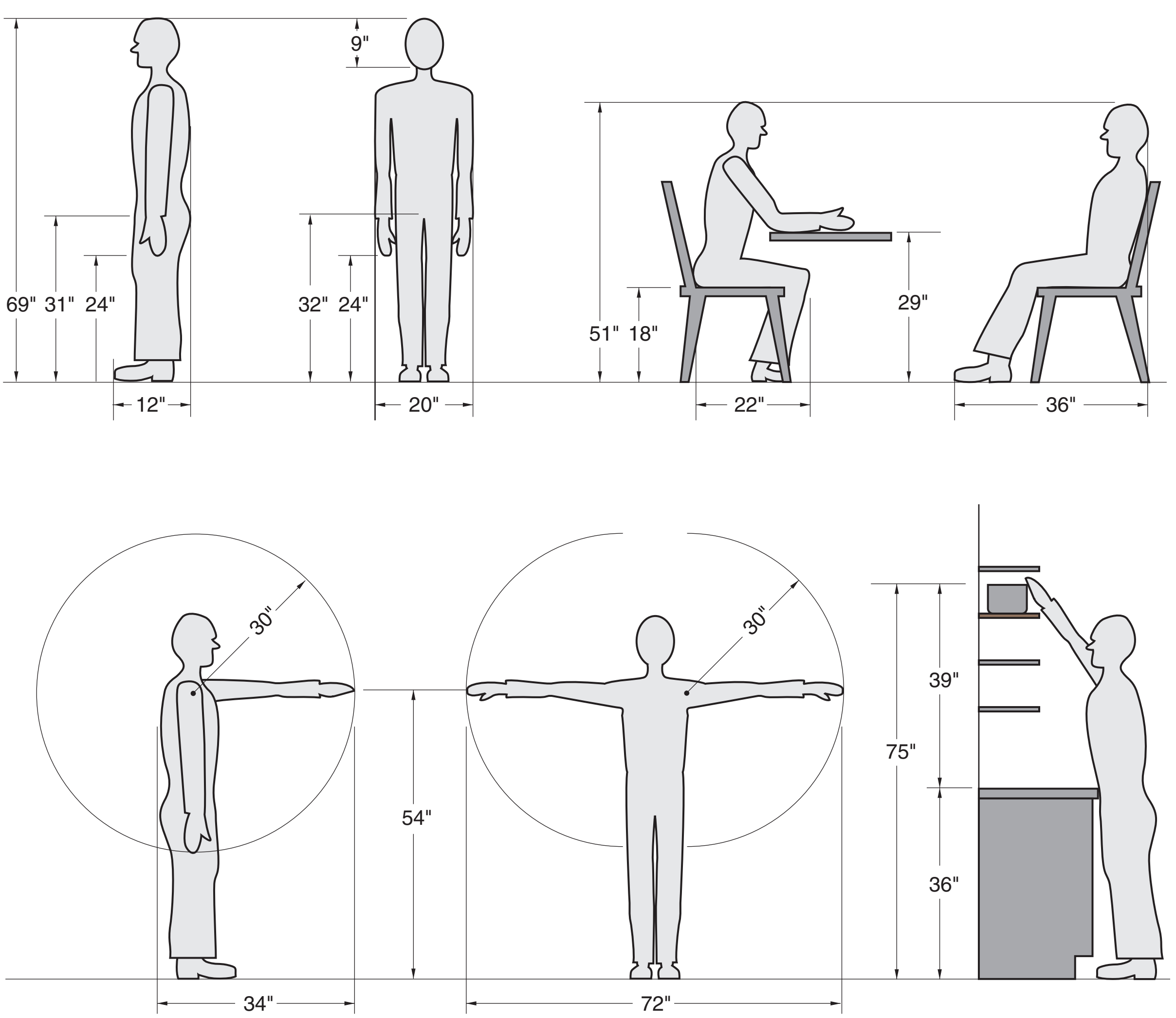
Why do we need typical human dimensions when designing buildings? Because buildings are for people. People need to reach shelves, move furniture from room to room, pass by each other, work side by side, and look outside through windows.

The typical human dimensions shown below are for an adult male of height 5 feet 9 inches. To determine typical dimensions for people who are taller or shorter than that, simply multiply the dimensions shown by the ratio of their heights.

Example: What is the standing eye level of a 5-foot (60-inch) person?

The standing height of the figure in the illustration is 69 inches and the height of the eye 65 inches. The standing eye level of the 60-inch person is therefore $65 \times 60 \div 69 = 56^1/_2$ (inches).

Typical Dimensions of a Human Male



Window, Closet, and Passage Dimensions

Too often overlooked by inexperienced builders are the critical heights of windows and the widths of closets and passageways within the house.

Window heights are important on both the inside and the outside of buildings. For exterior symmetry the tops of all windows should align with the tops of exterior doors. Sill heights of windows adjacent to counters or furniture should be at least 42 inches; view window sills should not exceed 38 inches; no window sill except that of a patio door should be less than 10 inches high.

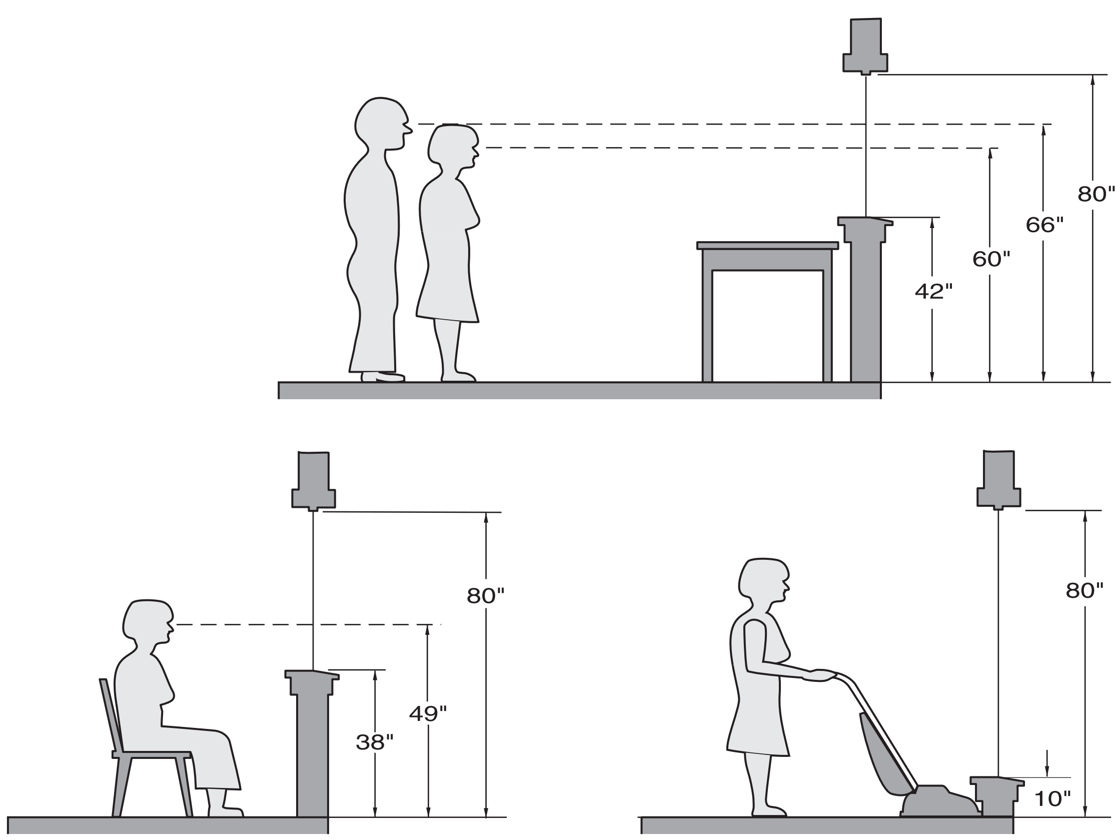
Closets are required for our ever-increasing wardrobes. Allow at least 36 inches of closet pole per occupant, with a hanger depth of 24 inches minimum. Provide at least one closet per bedroom, closets near front and rear entrances for coats, a linen closet, and at least one generous walk-in closet.

Passageway widths are dictated by the need to move large furnishings within the home and into or out of the home. The table below lists both minimum and recommended widths of passageways.

Widths of Passageways, inches

Passageway	Minimum	Recommended
Stairs	36	40
Landings	36	40
Main hall	36	40
Minor hall	36	40
Interior door	36	40
Exterior door	36	40
Basement door	36	48

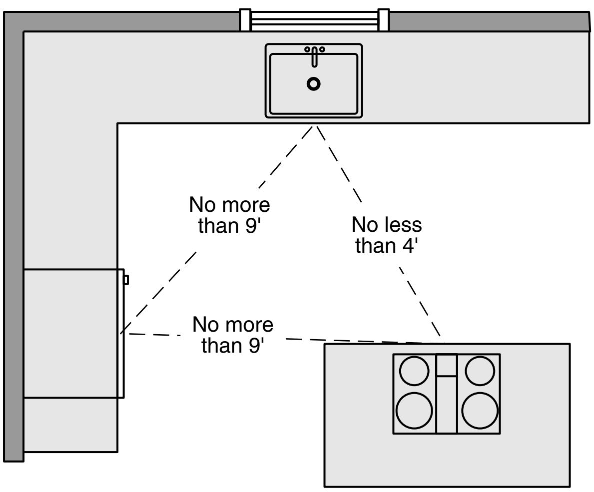
Critical Window Dimensions



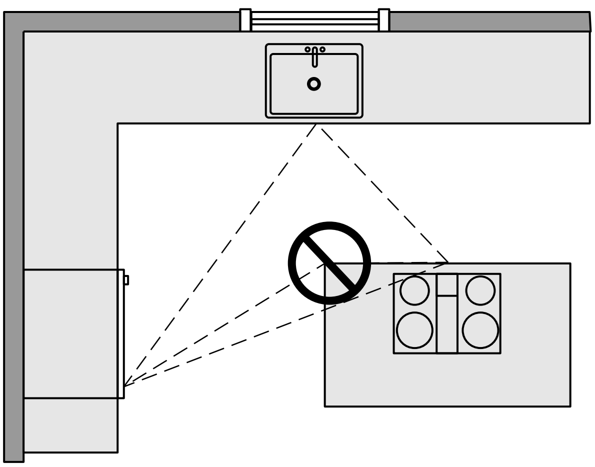
Kitchen Design Guidelines

More time is spent in the kitchen than in any other room of the home. The kitchen also accounts for the greatest cost per area. Thus its design merits careful consideration. As an aid, here are 21 of the 31 Kitchen Planning Guidelines of the National Kitchen & Bath Association (NKBA[SM]). The complete set may be viewed at the NKBA website *(www.nkba.org)*.

Distance between Work Centers

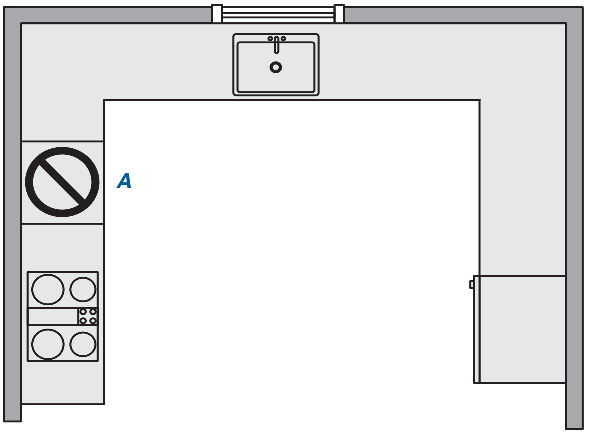


In a kitchen with three work centers, the sum of the three distances should total no more than 26', with no single leg of the triangle measuring less than 4' nor more than 9'.



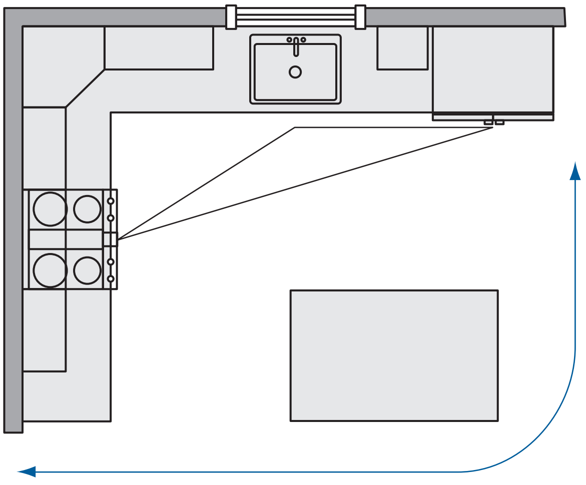
No work triangle leg should intersect an island/peninsula or other obstacle by more than 12".

Separating Work Centers



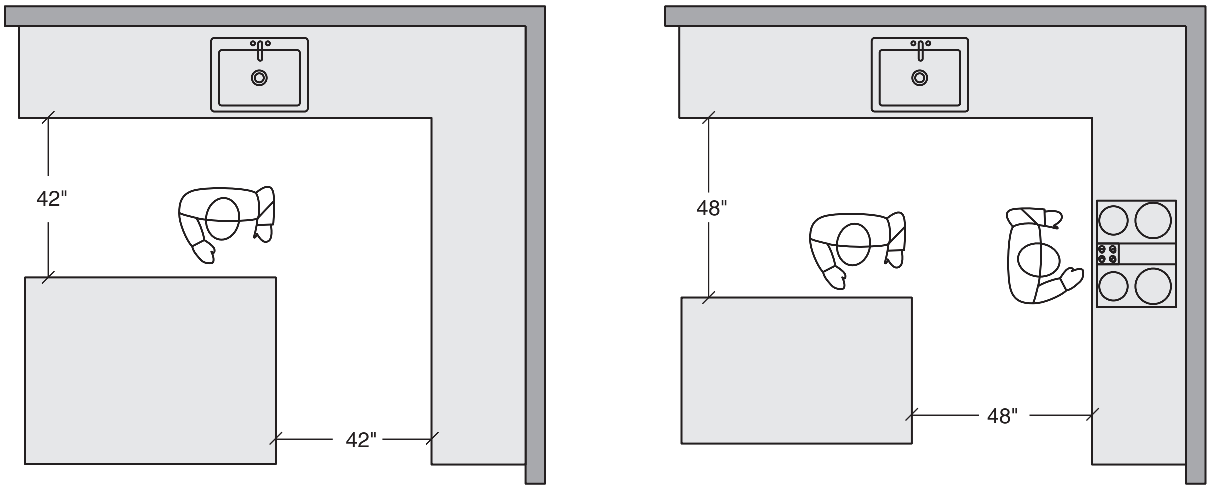
A full-height, full-depth, tall obstacle (A) should not separate two primary work centers. A properly recessed tall corner unit will not interrupt the workflow and is acceptable.

Work Triangle Traffic



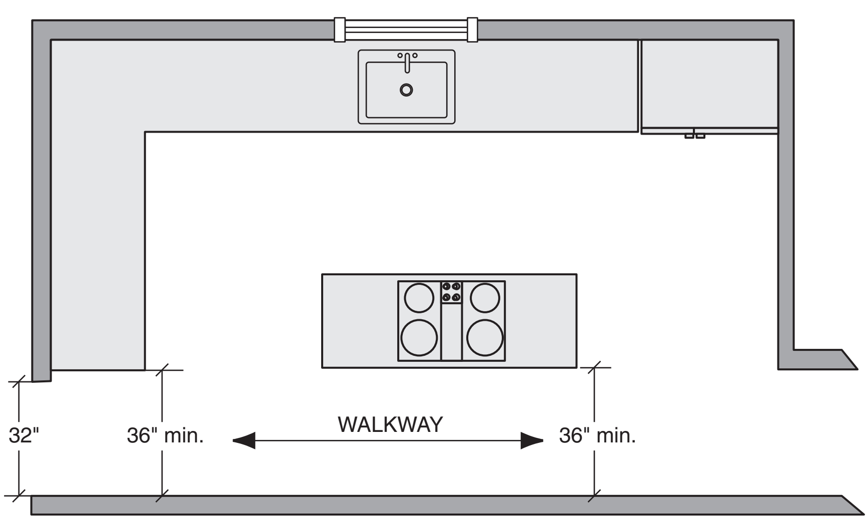
No major traffic patterns should cross through the basic work triangle.

Work Aisle



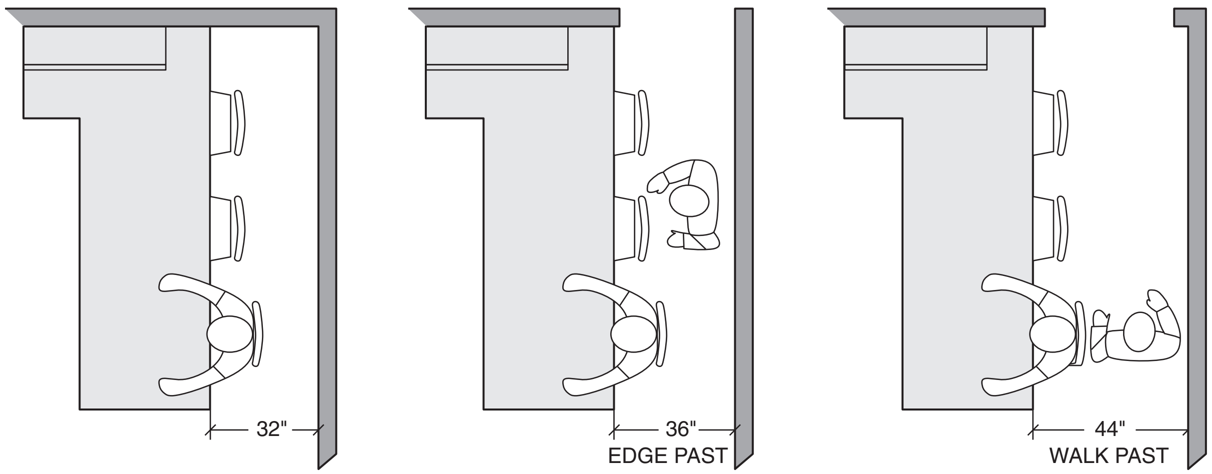
The width of a work aisle should be at least 42" for one cook and at least 48" for multiple cooks. Measure between the counter frontage, tall cabinets, and/or appliances.

Walkway



The width of a walkway should be at least 36".

Traffic Clearance at Seating



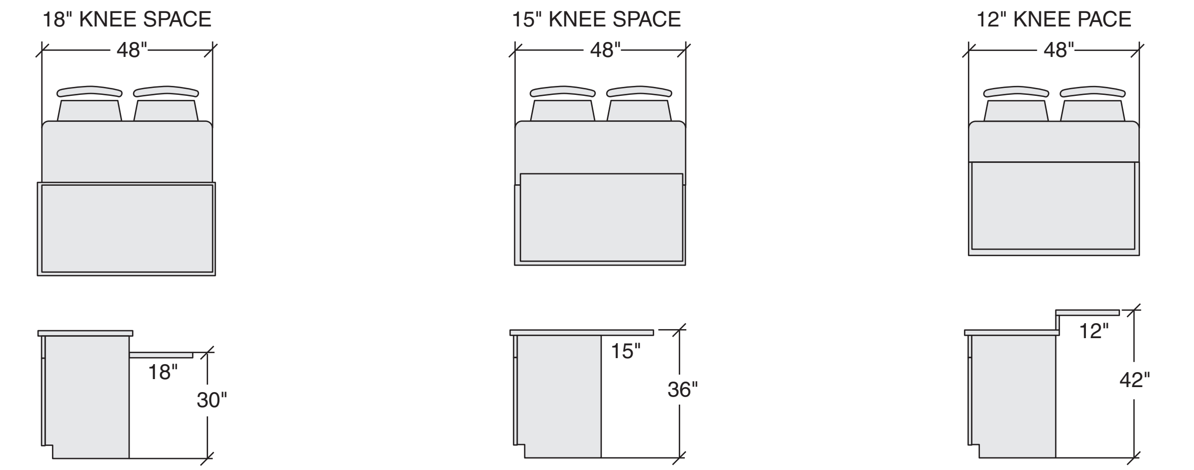
In a seating area where no traffic passes behind a seated diner, allow 32" of clearance from the counter/table edge to any wall or other obstruction behind the seating area.

a. If traffic passes behind the seated diner, allow at least 36" to edge past.

b. If traffic passes behind the seated diner, allow at least 44" to walk past.

Seating Clearance

Kitchen seating areas should incorporate at least the following clearances:

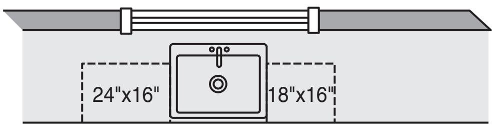


30"-high tables/counters: Allow a 24"-wide x 18"-deep counter/table space for each seated diner.

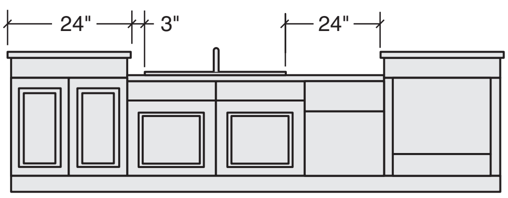
36"-high counters: Allow a 24"-wide by 15"-deep counter space for each seated diner and at least 15" of clear knee space.

42"-high counters: Allow a 24"-wide by 12"-deep counter space for each seated diner and 12" of clear knee space.

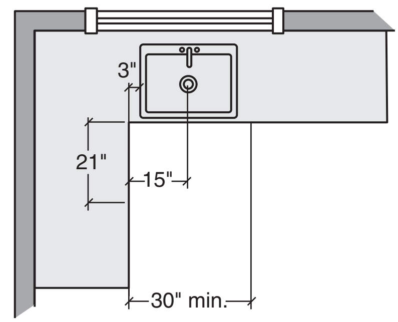
Cleanup/Prep Sink Placement



*Include at least a 24"-wide **landing area*** to one side of the sink and at least an 18"-wide landing area on the other side.*



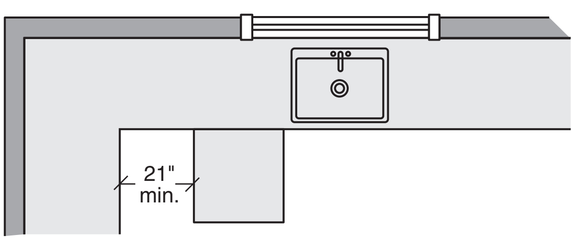
If all of the countertop at the sink is not at the same height, then plan a 24" landing area on one side of the sink and 3" of countertop frontage on the other side, both at the same height as the sink.



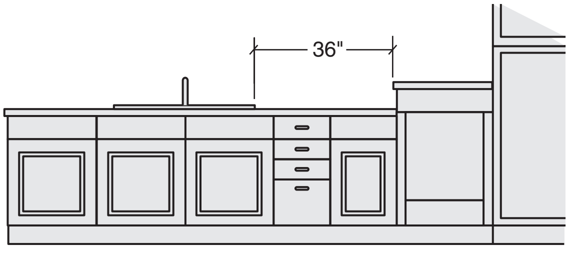
The 24" of recommended landing area can be met by 3" of countertop frontage from the edge of the sink to the inside corner of the countertop if more than 21" of countertop frontage is available on the return.

**__Landing area__ is measured as countertop frontage adjacent to a sink and/or an appliance. The countertop must be at least 16" deep and must be 28" to 45" above the finished floor in order to qualify.*

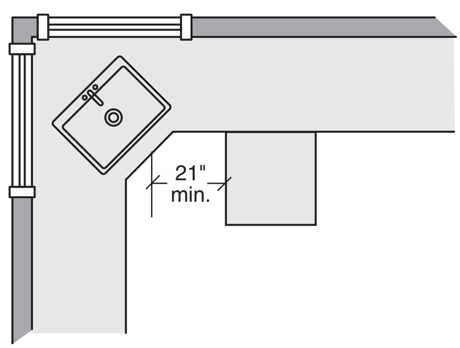
Dishwasher Placement



Provide at least 21" of standing space between the edge of the dishwasher and countertop frontage, appliances, and/or cabinets, which are placed at a right angle to the dishwasher.

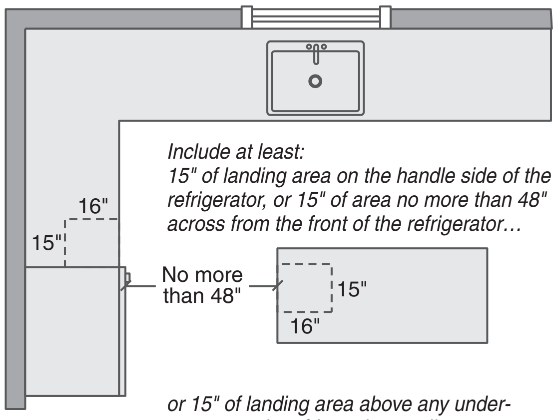


Locate nearest edge of the primary dishwasher within 36" of the nearest edge of a cleanup/prep sink.



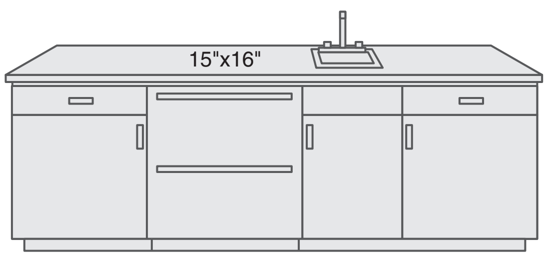
In a diagonal installation, the 21" is measured from the center of the sink to the edge of the dishwasher door in an open position.

Refrigerator Landing Area

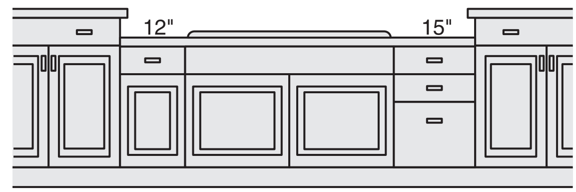


Include at least:
15" of landing area on the handle side of the refrigerator, or 15" of area no more than 48" across from the front of the refrigerator…

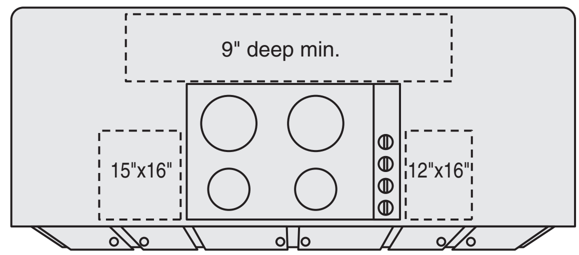
or 15" of landing area above any under-counter-style refrigeration appliance.



Cooking Surface Landing Area

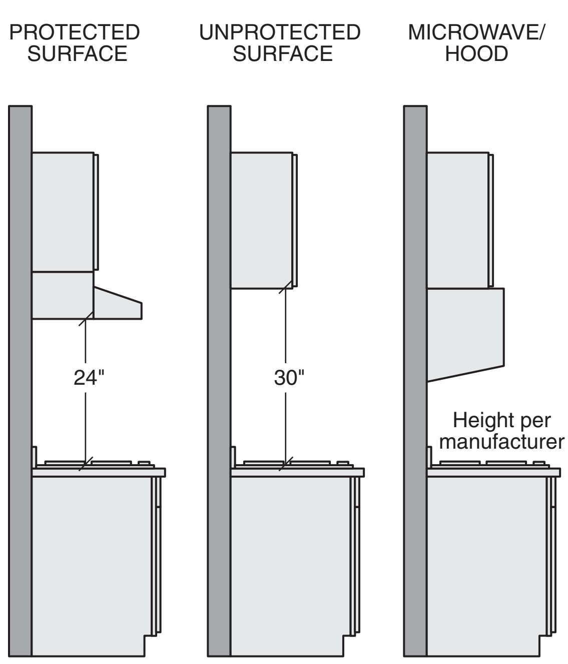


Include a minimum of 12" of landing area on one side of a cooking surface and 15" on the other side. If the cooking surface is at a different countertop height than the rest of the kitchen, then the 12" and 15" landing areas must be at the same height as the cooking surface.

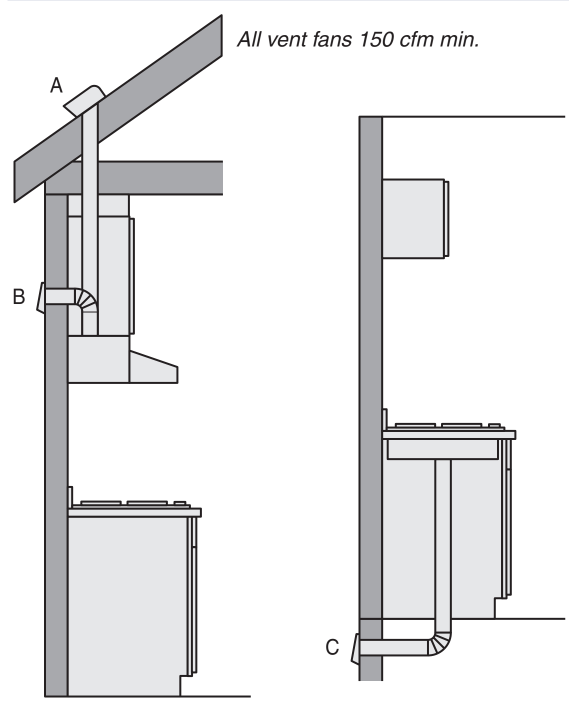


For safety reasons, in an island or peninsula situation, the countertop should also extend a minimum of 9" behind the cooking surface if the counter height is the same as the surface-cooking appliance.

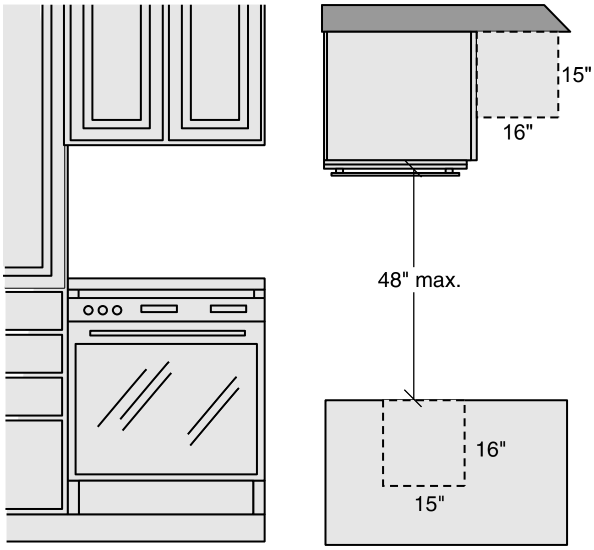
Cooking Surface Clearance



Cooking Surface Ventilation

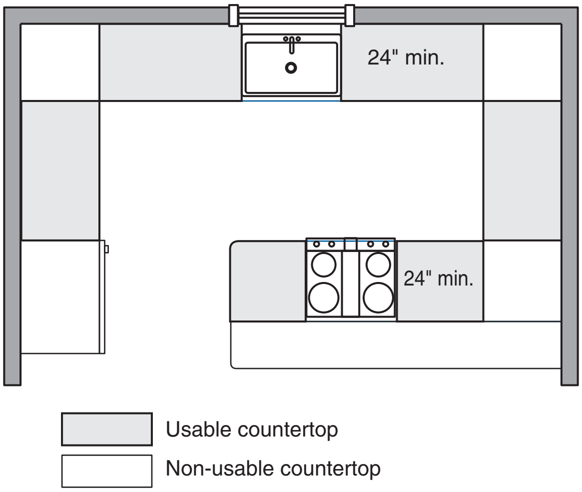


Oven Landing Area



Include at least a 15" landing area next to or above an oven. At least a 15" landing area not more than 48" across from the oven is acceptable if the appliance does not open into a walkway.

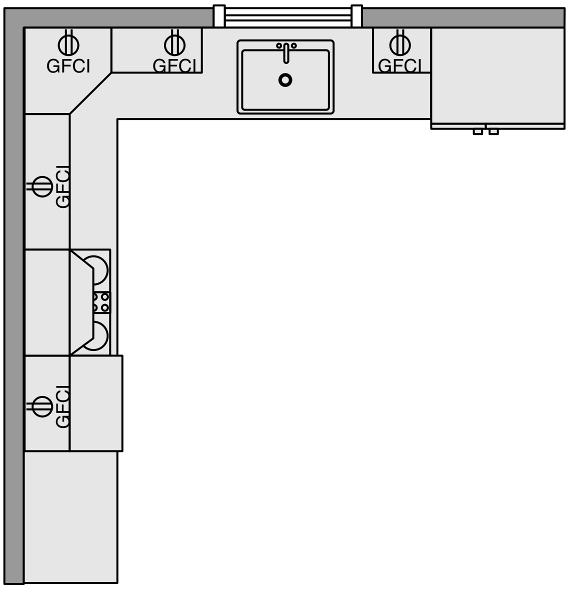
Countertop Space



A total of 158" of countertop frontage, 24" deep, with at least 15" of clearance above, is needed to accommodate all uses, including landing area, preparation/work area, and storage.

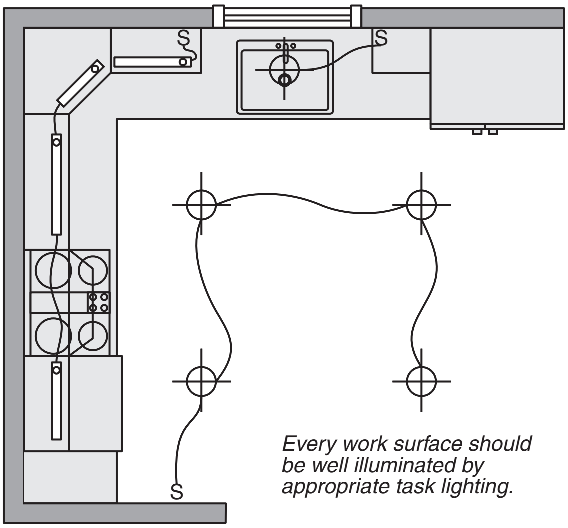
Built-in appliance garages extending to the countertop can be counted toward the total countertop frontage recommendation, but they may interfere with the landing areas.

Electrical Receptacles



GFCI protection is required on all receptacles serving countertop surfaces in the kitchen (IRC E 3902.6). Refer to IRC E 3901.3 through E 3901.4.5 for placement.

Lighting



Every work surface should be well illuminated by appropriate task lighting.

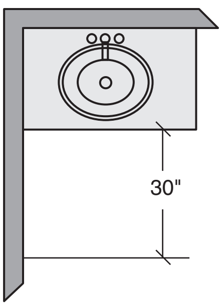
At least one wall switch–controlled light must be provided. Switch must be placed at the entrance (IRC E 3903.3).

Window/skylight area equal to at least 8% of the total square footage of the kitchen, or a total living space that includes a kitchen, is required (IRC R 303.1, IRC R 303.2).

Bath Design Guidelines

Bathrooms, along with kitchens, assume greater importance and account for a greater portion of construction cost with every year. As an aid to bathroom design, here are 20 of the 27 *Bathroom Planning Guidelines* of the National Kitchen & Bath Association. The Guidelines assure compliance with the IRC, as well as comfort and convenience. The complete set may be viewed at the NKBA website.

Clear Space



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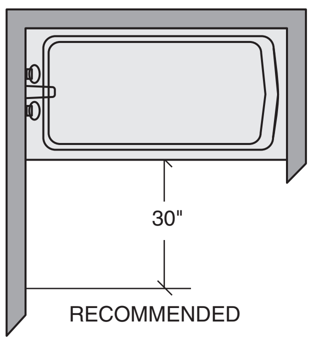

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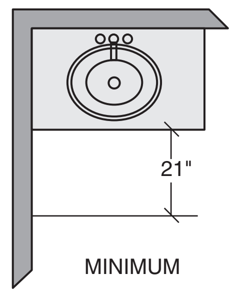
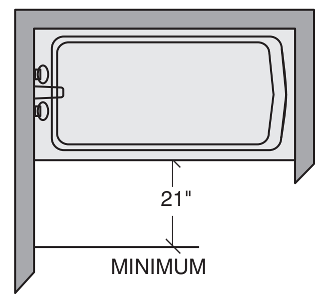


MINIMUM



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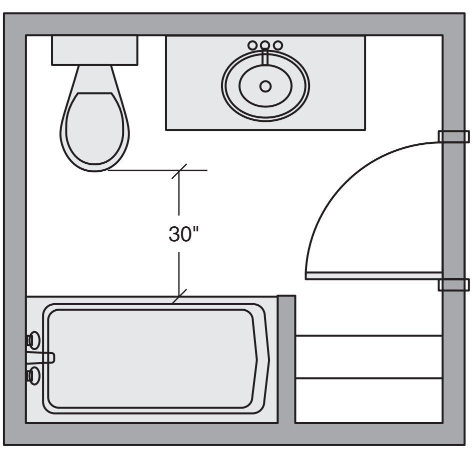

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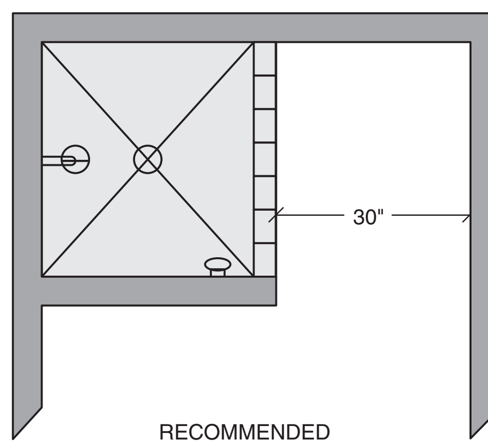
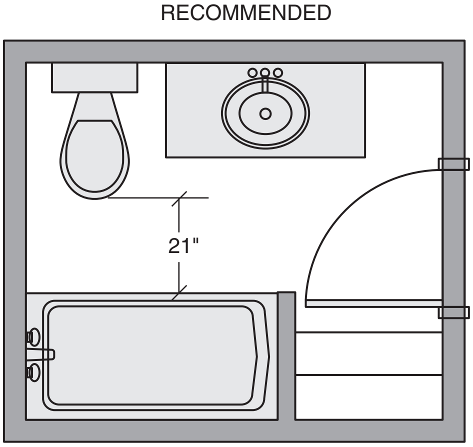
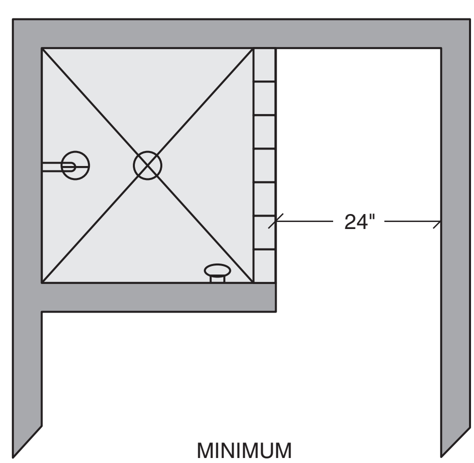


RECOMMENDED

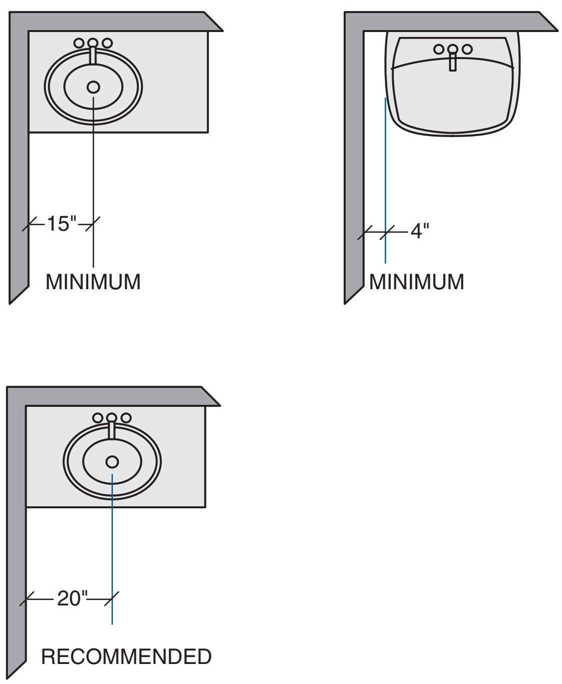


MINIMUM

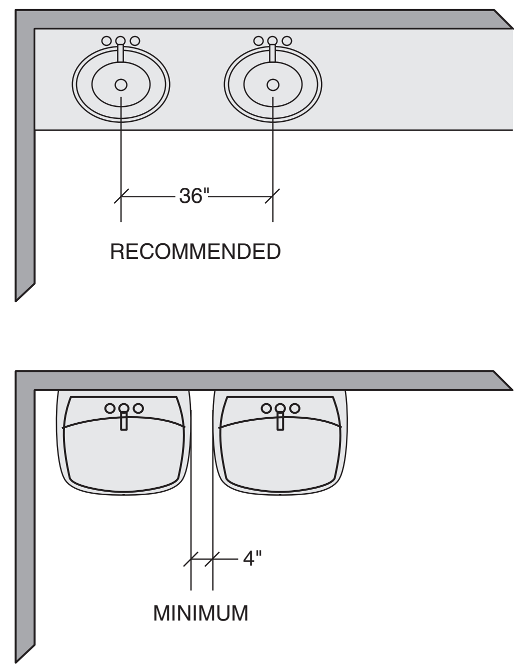


MINIMUM

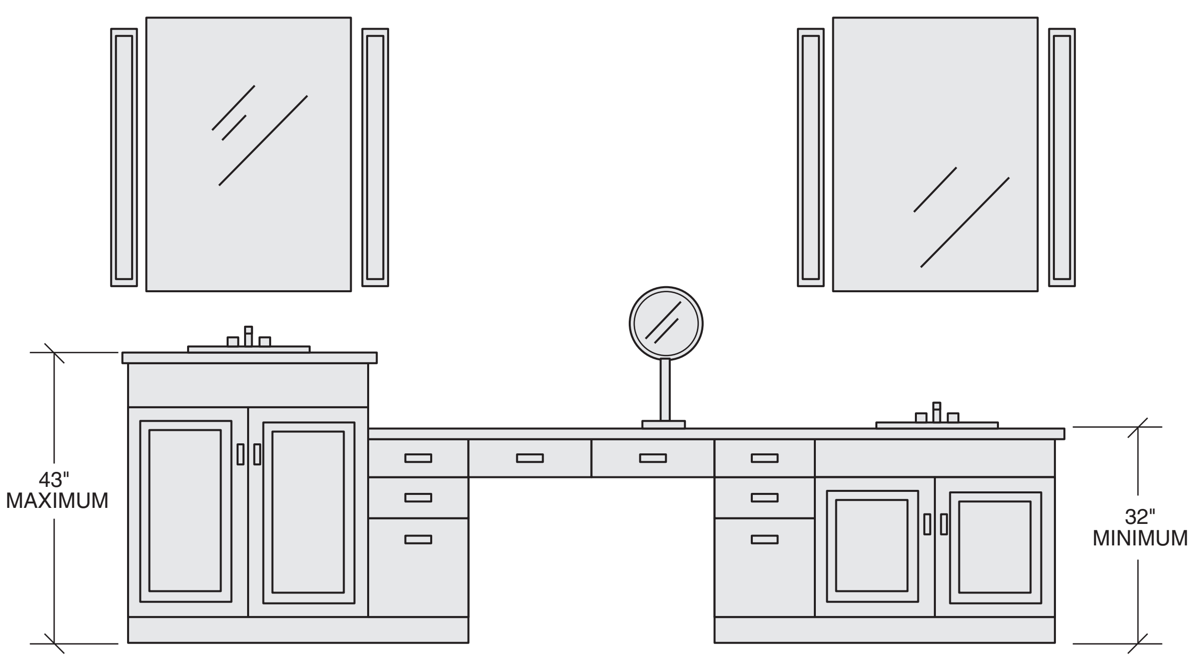
Single Lavatory Placement



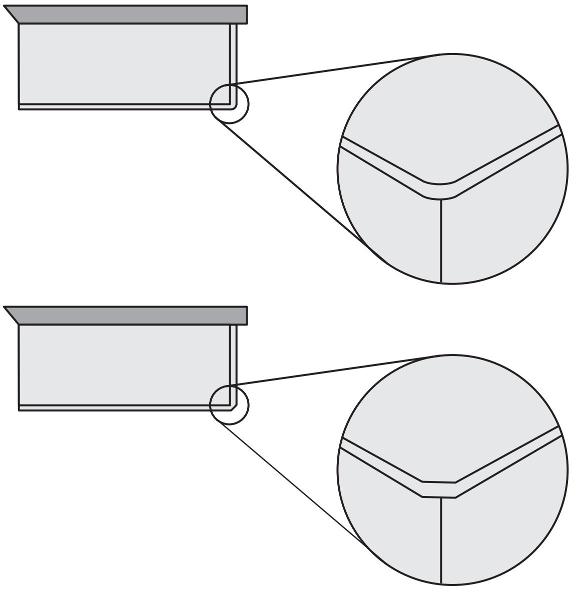
Double Lavatory Placement



Lavatory/Vanity Height

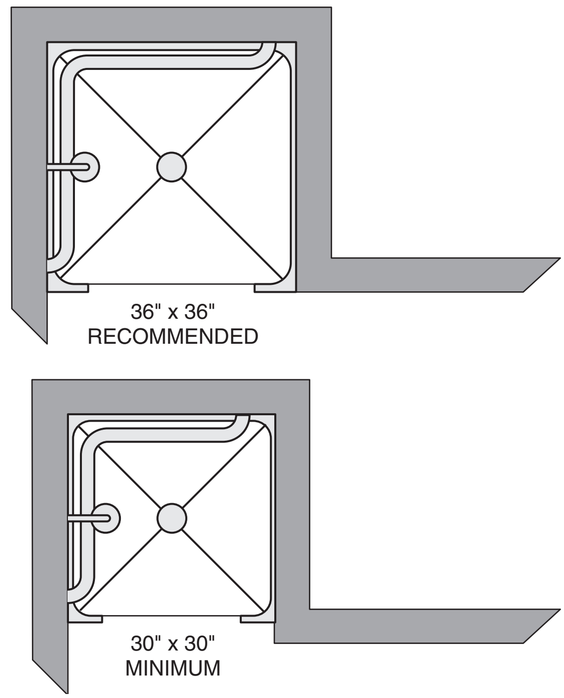


Countertop Edges

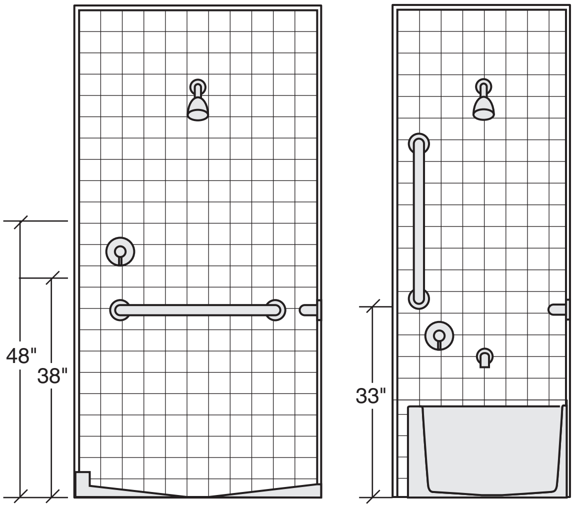


Specify clipped or round corners rather than sharp edges on all counters.

Shower Size



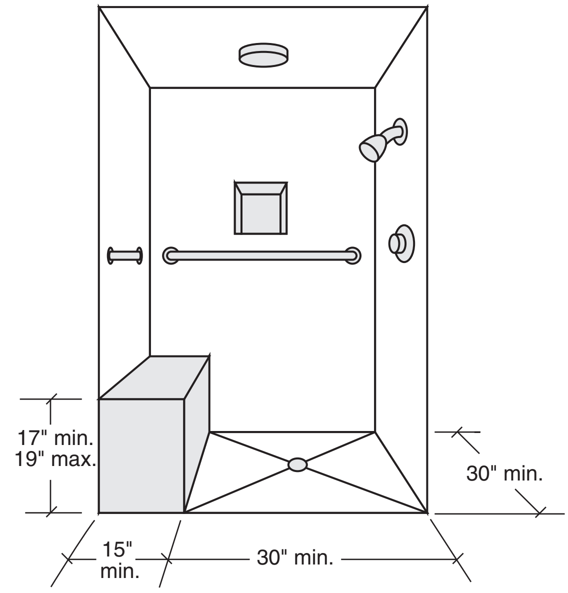
Tub/Shower Controls



The shower controls should be accessible from both inside and outside the shower spray and be located between 38" and 48" above the floor, depending on user's height.

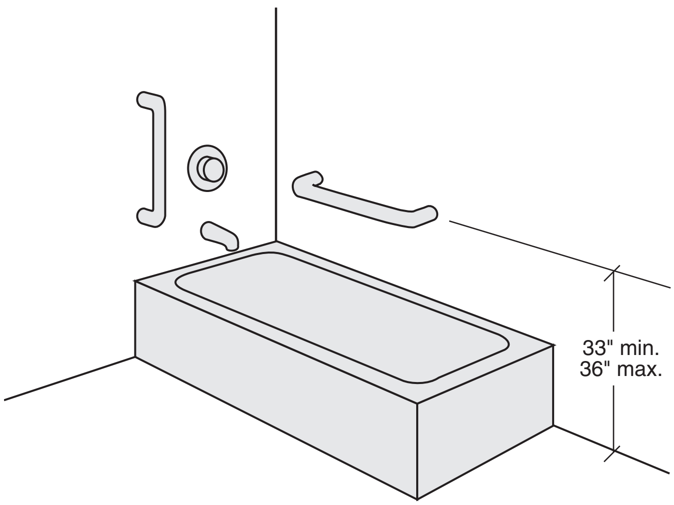
The tub controls should be accessible from both inside and outside the tub and be located between the rim of the bathtub and 33" above the floor.

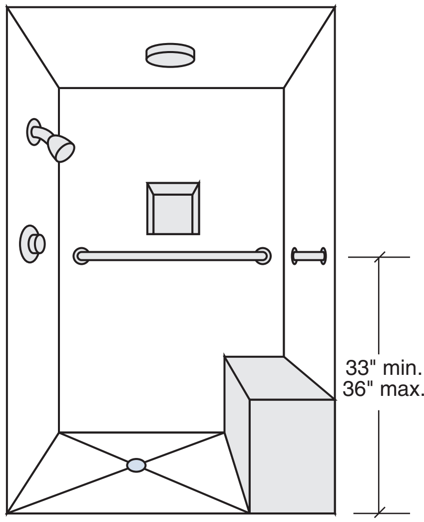
Shower Seat



Plan a seat within the shower that is 17"-19" above the shower floor and 15" deep.

Grab Bars

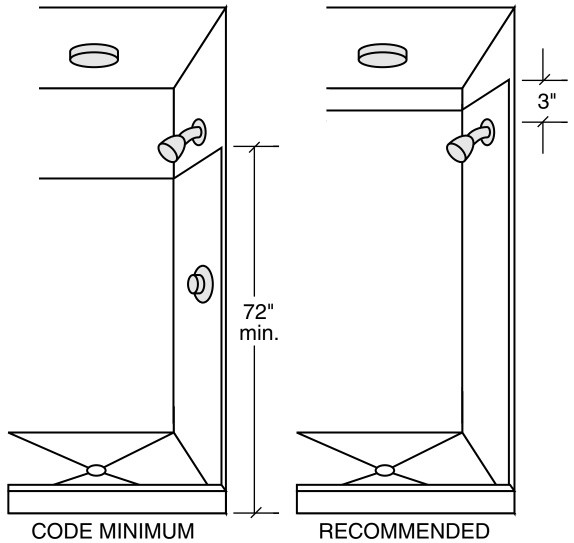




Plan grab bars to facilitate access to and maneuvering within the tub and shower areas. Tub and shower walls should be prepared (reinforced) at time of construction to allow for installation of grab bars to support a static load of 300 pounds.

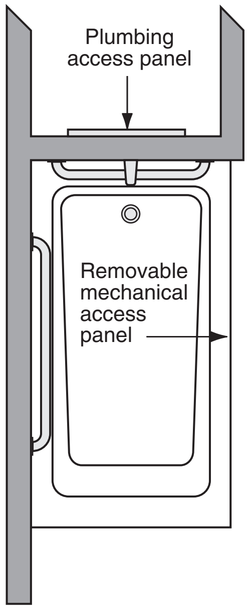
Grab bars should be placed at least 33" to 36" above the floor. Grab bars must be $1^1/_4$" to $1^1/_2$" in diameter and extend $1^1/_2$" from the wall.

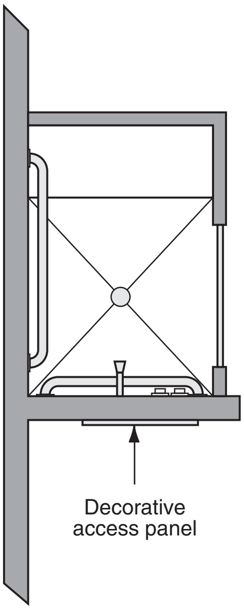
Tub/Shower Surround



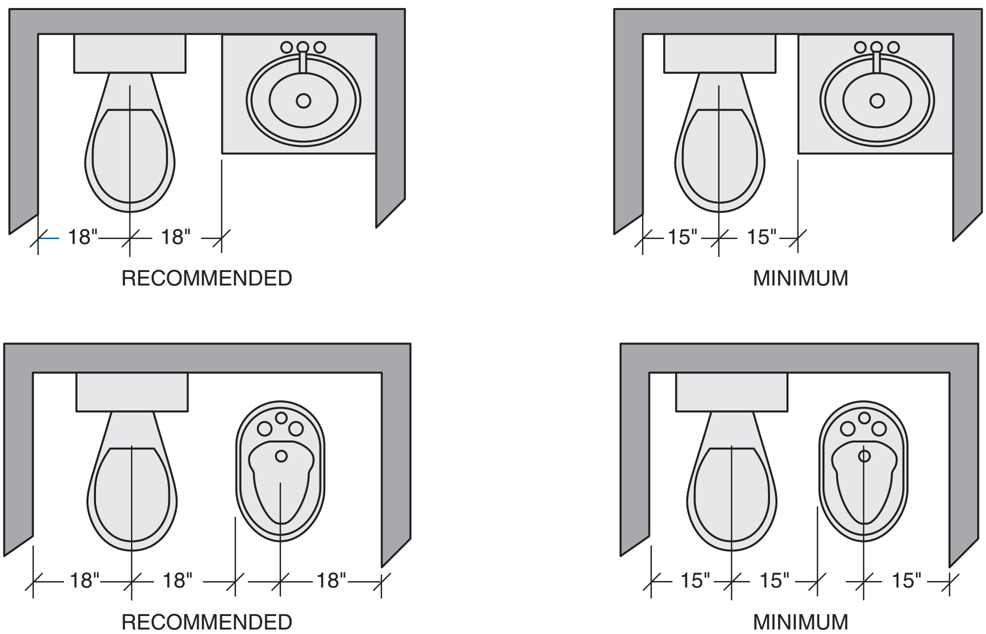
The wall area above a tub or shower pan should be covered in a waterproof material extending at least 3" above the showerhead rough-in.

Equipment Access



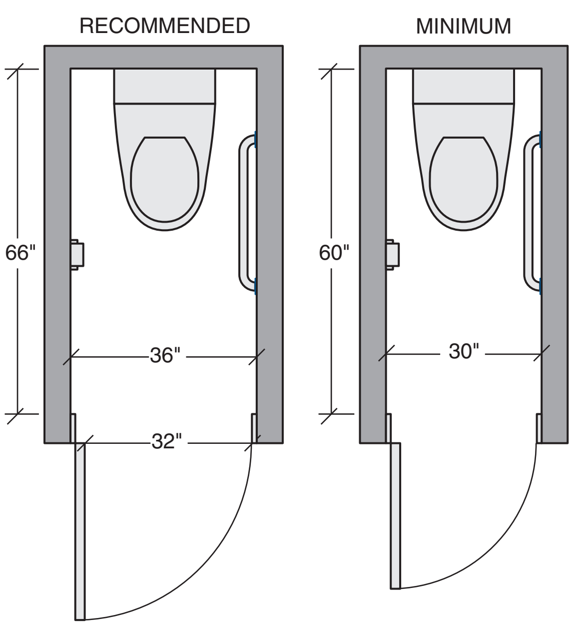


Toilet/Bidet Placement

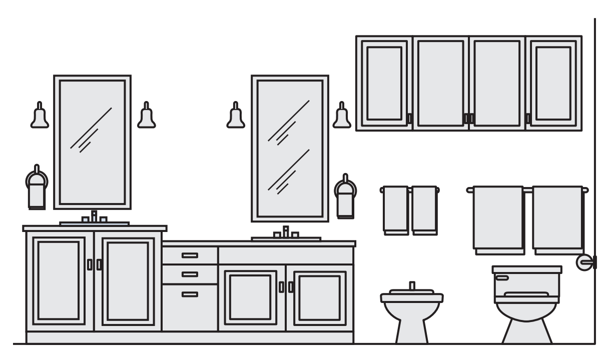


The distance from the centerline of toilet and/or bidet to any bath fixture, wall, or other obstacle must be at least 15".

Toilet Compartment



Accessories

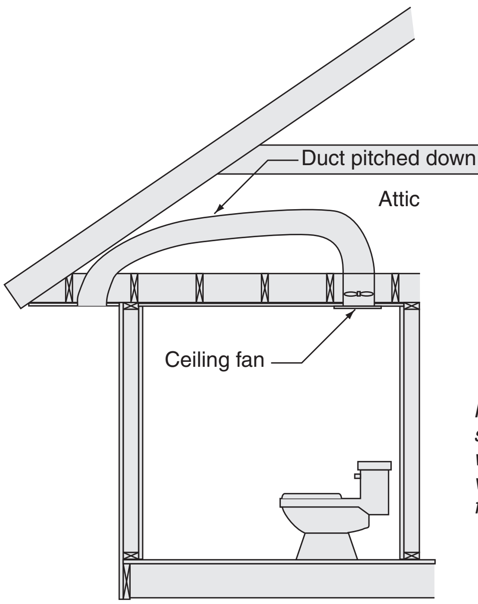


Place a mirror above or near the lavatory at a height that takes the user's eye height into consideration.

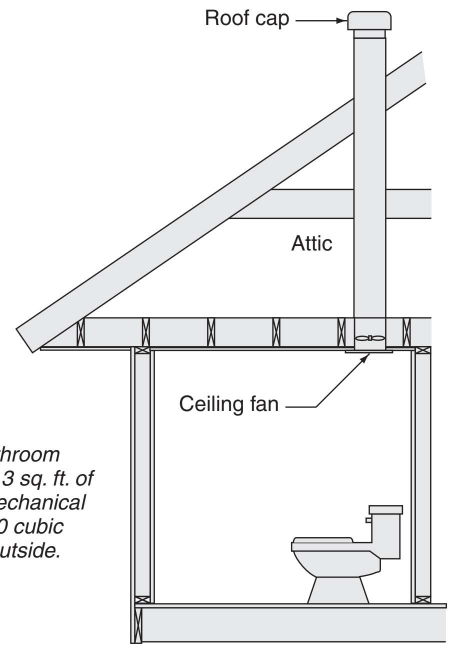
The toilet paper holder should be located 8" to 12" in front of the edge of the toilet bowl, centered at 26" above the floor.

Additional accessories, such as towel holders and soap dishes, should be conveniently located near all bath fixtures.

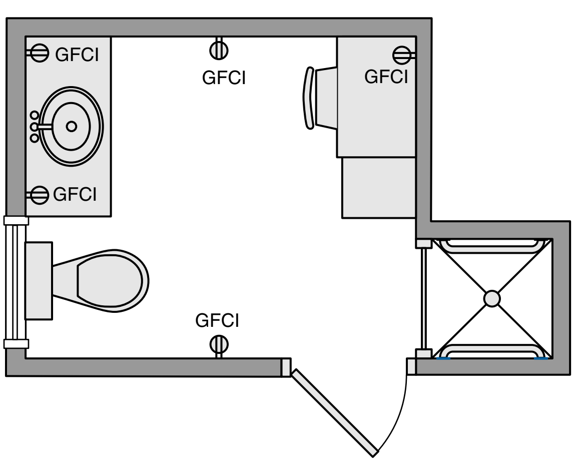
Ventilation



Minimum ventilation for the bathroom should be a window of at least 3 sq. ft. of which 50% is operable, or a mechanical ventilation system of at least 50 cubic feet per minute ducted to the outside.



Electrical Receptacles

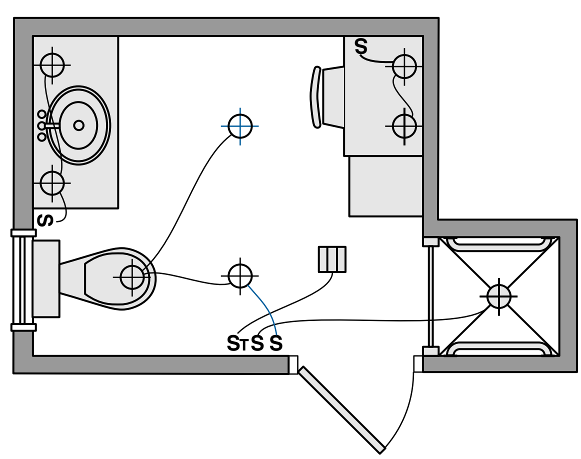


At least one GFCI-protected receptacle must be installed within 36" of the outside edge of the lavatory (IRC E 3901.6).

All receptacles must be protected by ground-fault-circuit-interrupters (GFCI) (IRC E 3902.1). A receptacle shall not be installed within a shower or bathtub space (IRC E 4002.11).

Switches shall not be installed within wet locations in tub or shower spaces unless installed as part of the listed tub or shower assembly (IRC E 4003.11).

Lighting



At least one wall switch–controlled light must be provided. Switch must be placed at the entrance (IRC E 3903.2, 4003.9).

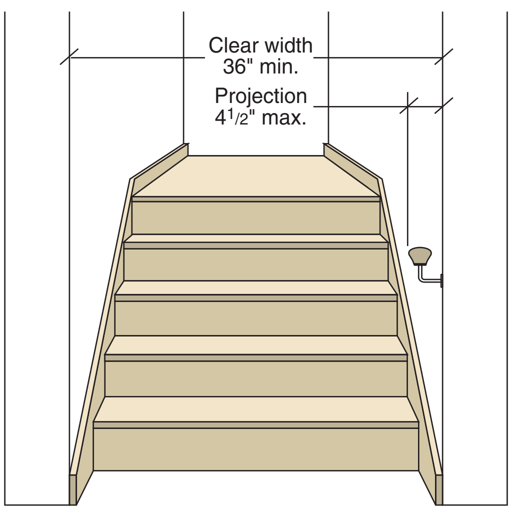
All light fixtures installed within tub and shower spaces should be marked "suitable for damp/wet locations" (IRC E 4003.10).

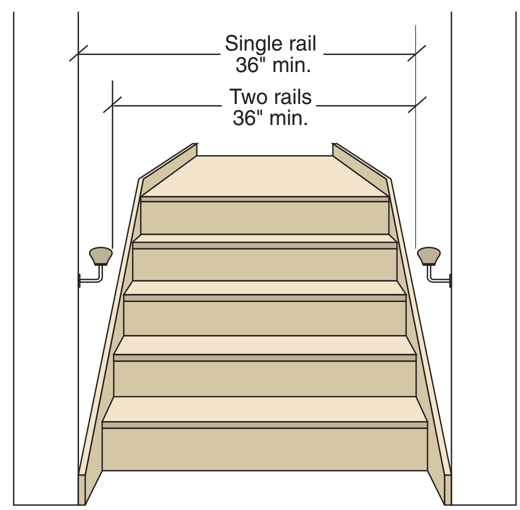
Hanging fixtures cannot be located within a zone of 3' horizontally and 8' vertically from the top of the bathtub rim (IRC E 4003.11).

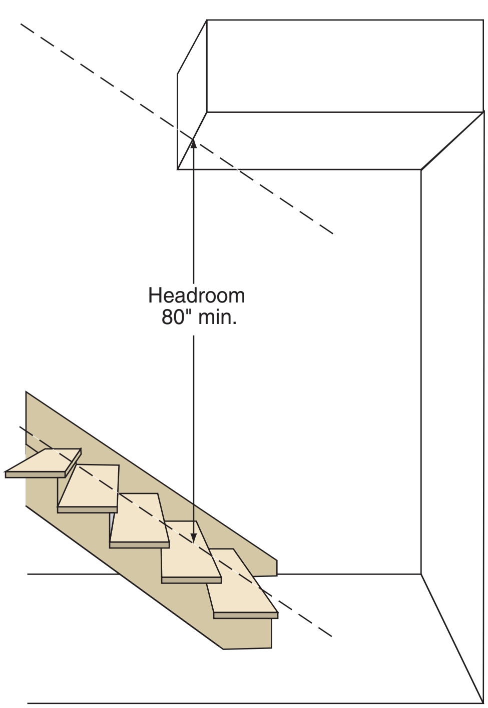
Stair Design

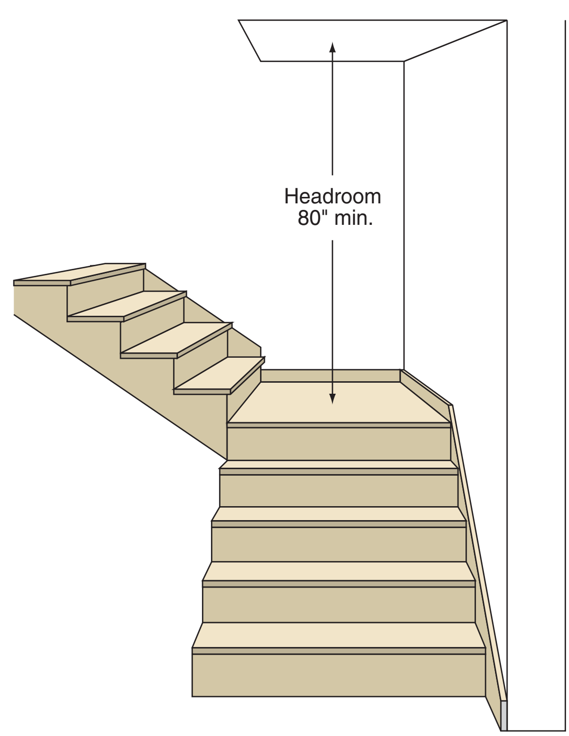
Stairs and stairways are all too often treated as afterthoughts. With stairway accidents accounting for a high percentage of all deaths and injuries in the home, the International Residential Code (IRC)® treats their proper design in great detail. A free 16-page *Visual Interpretation of the IRC 2006 Stair Building Code* is available in pdf format from the Stairway Manufacturers' Association (*www.stairways.org*).

Stairways

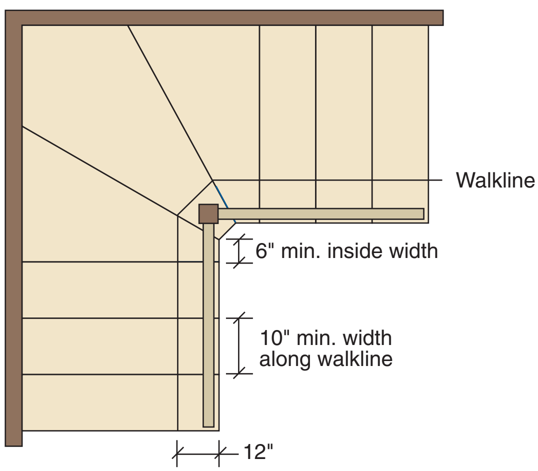


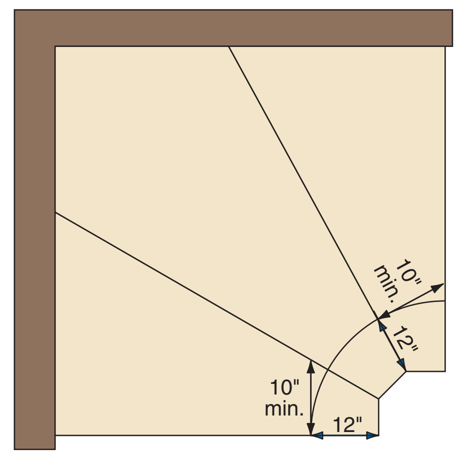


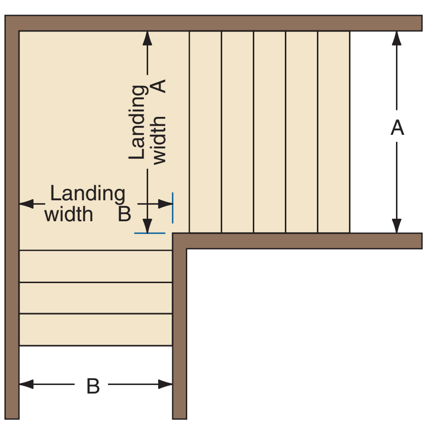


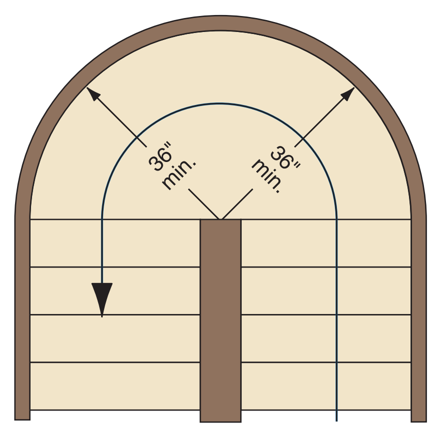


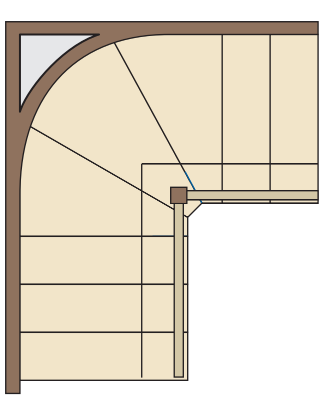
Stairways—*Continued*

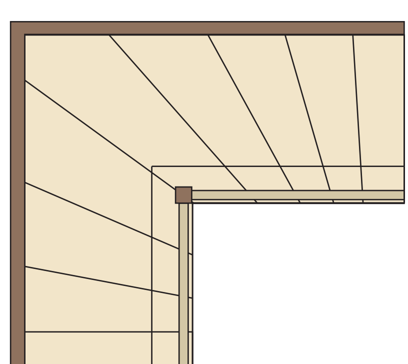


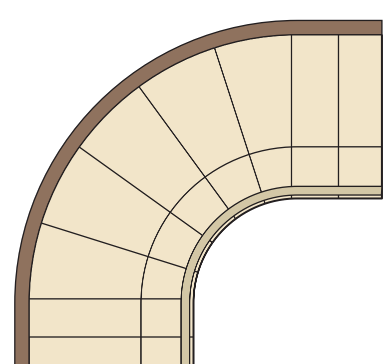




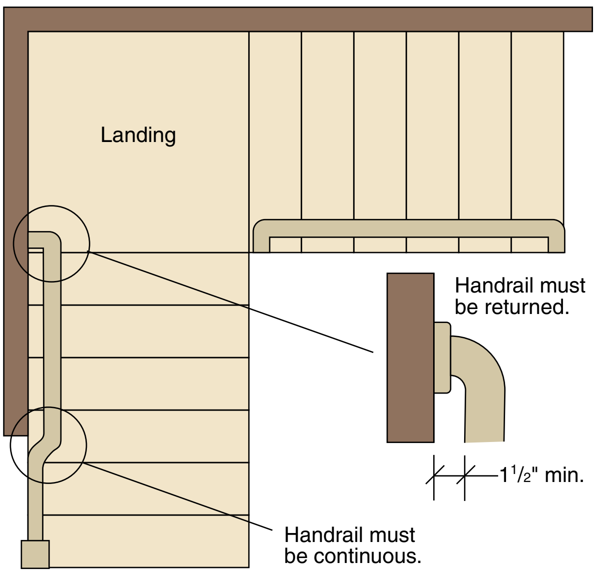


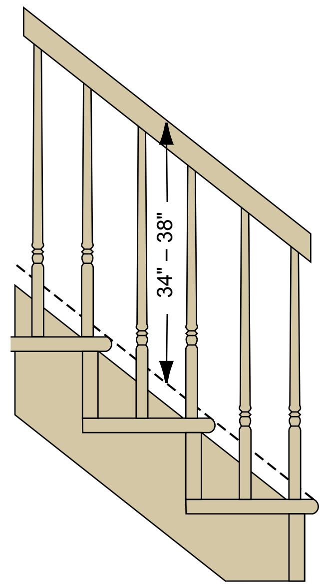


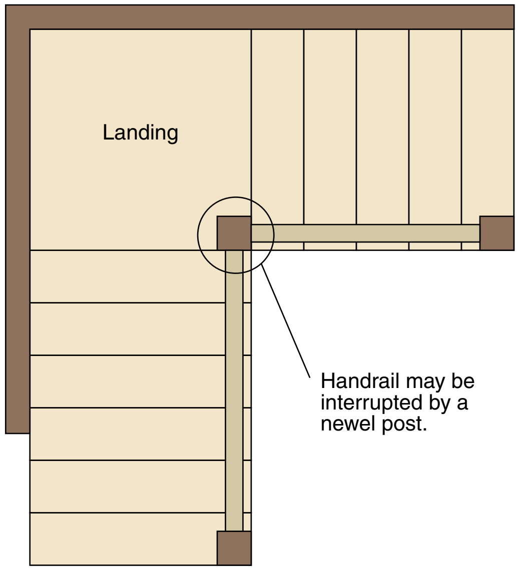


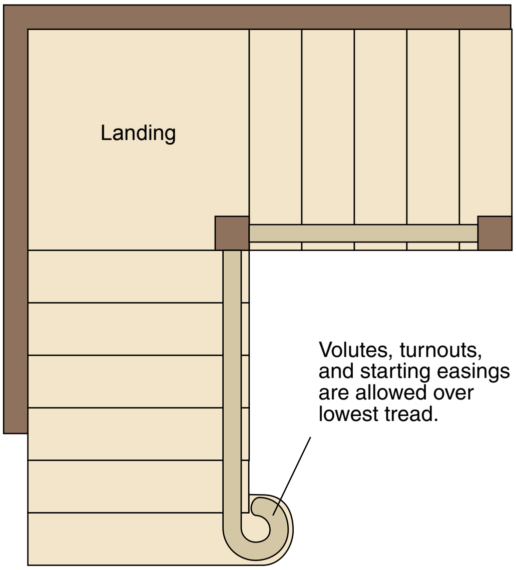


Handrails


Landing
Handrail must
be returned.
1 1/2" min.
Handrail must
be continuous.

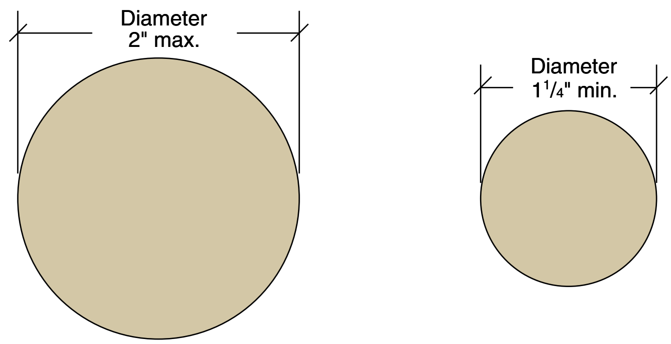

34" – 38"


Landing
Handrail may be
interrupted by a
newel post.

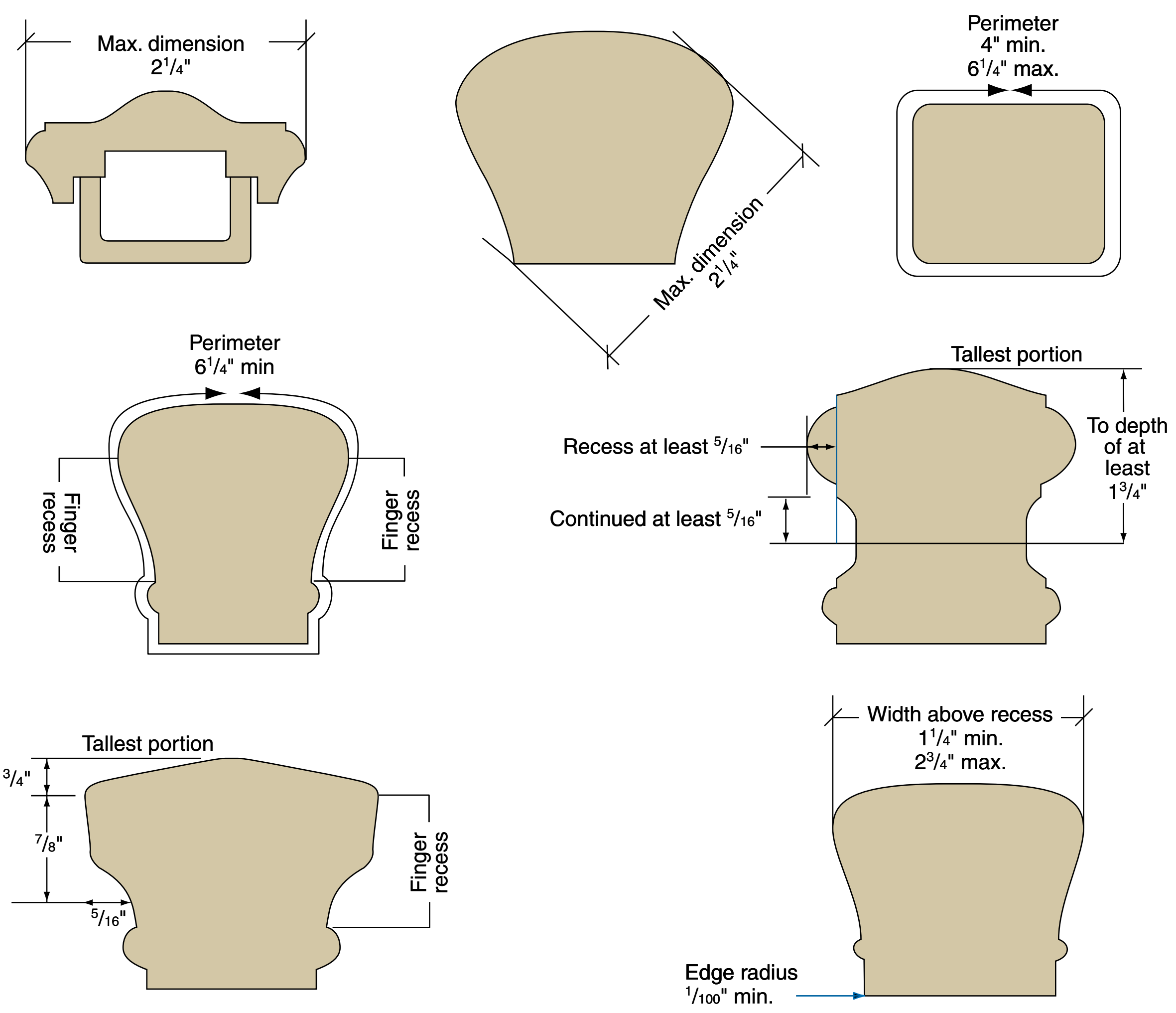

Landing
Volutes, turnouts,
and starting easings
are allowed over
lowest tread.

Handrails—*Continued*

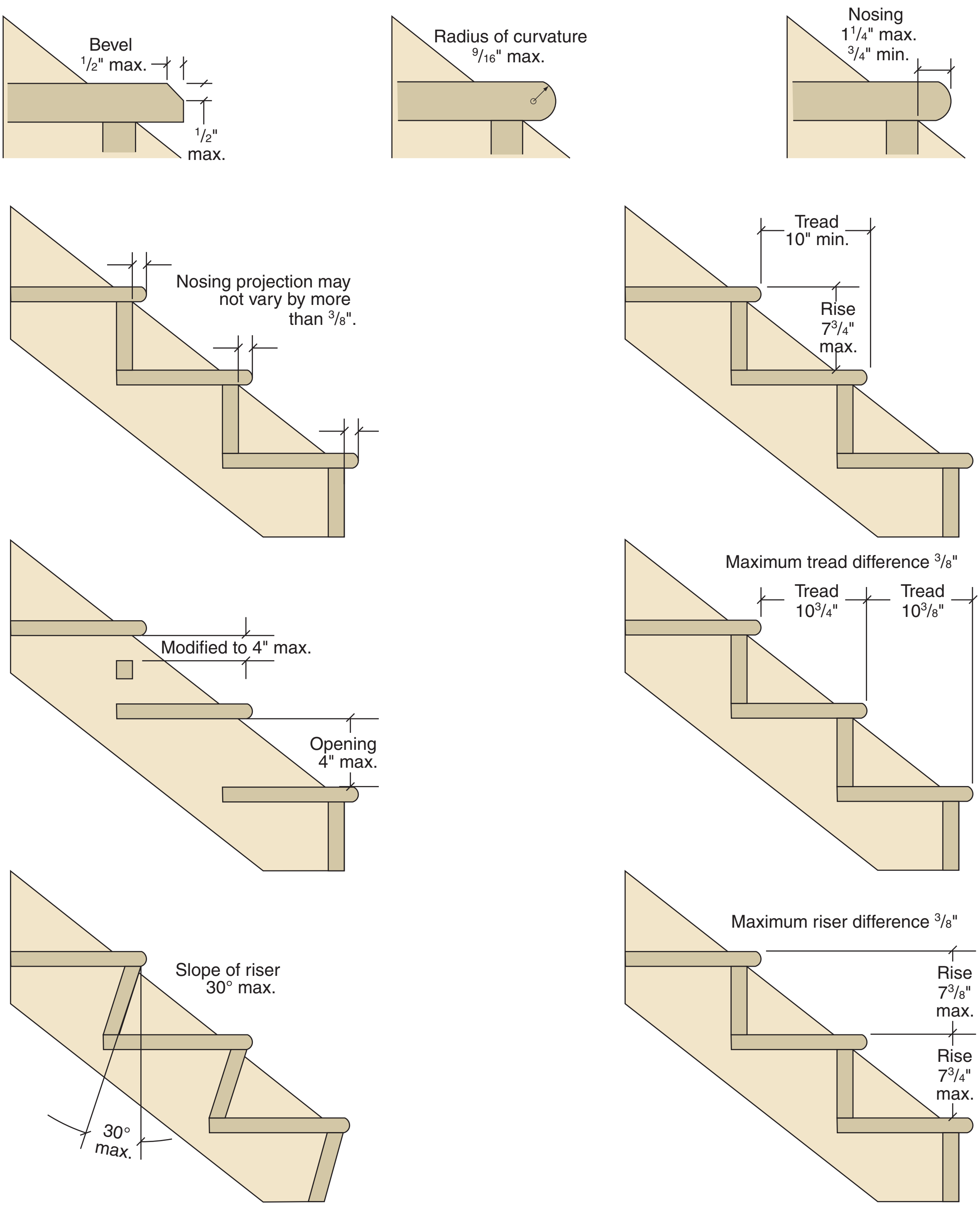
CIRCULAR CROSS SECTIONS



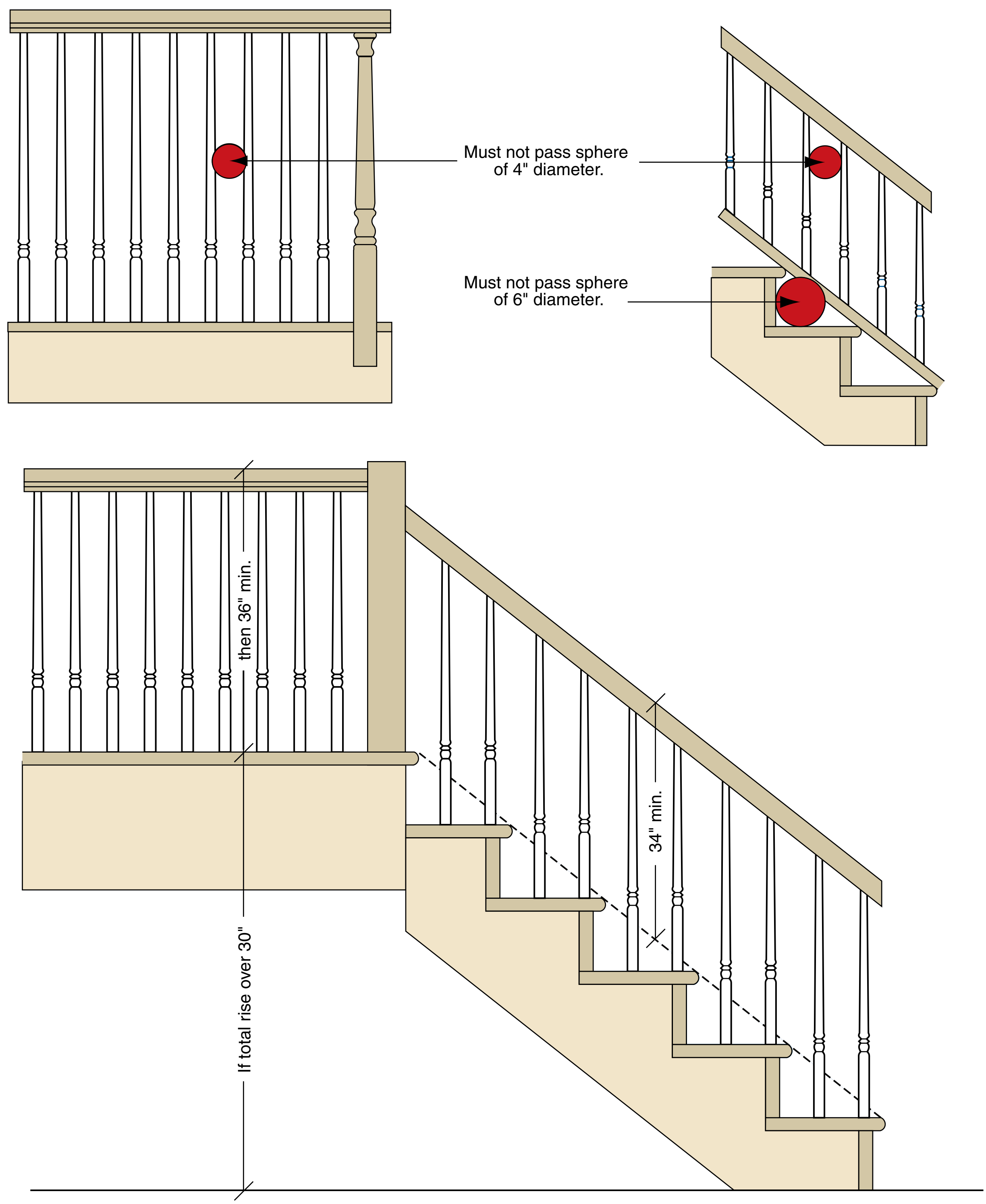
NON-CIRCULAR CROSS SECTIONS



Treads and Risers



Guards



Must not pass sphere of 4" diameter.
Must not pass sphere of 6" diameter.
then 36" min.
If total rise over 30"
34" min.

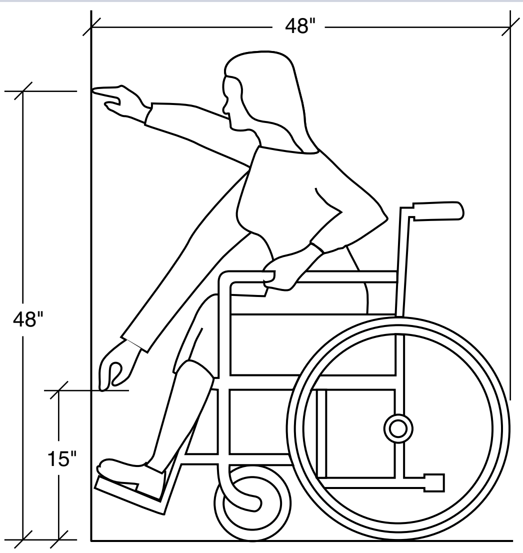
Access

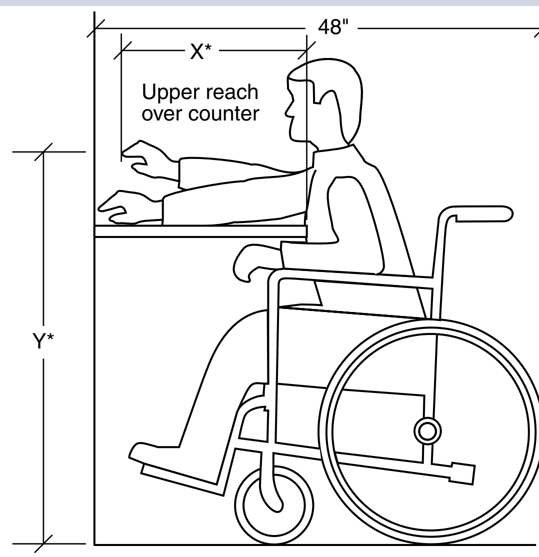
The Americans with Disabilities Act of 1990 prohibits employers from discriminating against individuals having physical disabilities who are otherwise qualified for employment. The regulations are contained in 28 C.F.R. § 36.

The regulations regarding building design are useful in designing not only public buildings but also homes that are "elder-friendly."

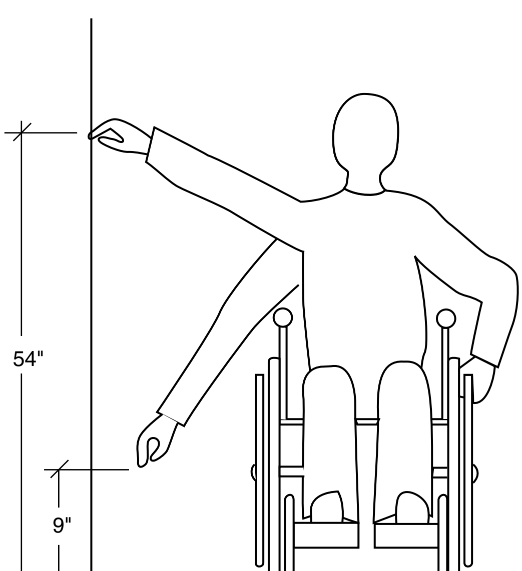
The illustrations on the following 10 pages are adaptations of those in Appendix A of Part 36. The complete *ADA Standards for Accessible Design* can be downloaded at *www.ada.gov/regs2010/2010ADAStandards/2010ADAStandards.pdf.*

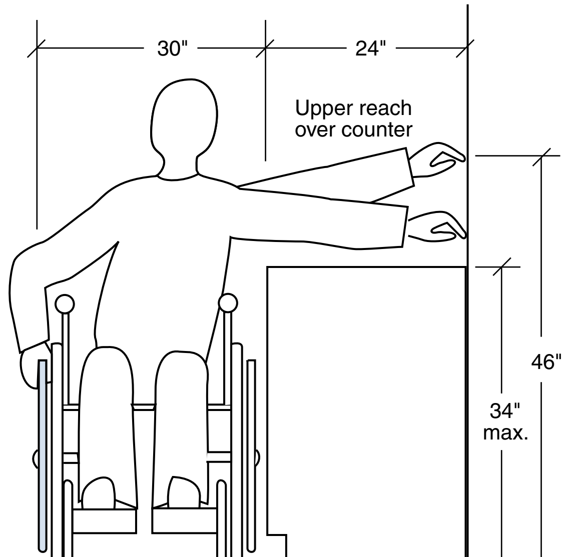
Reach Limits



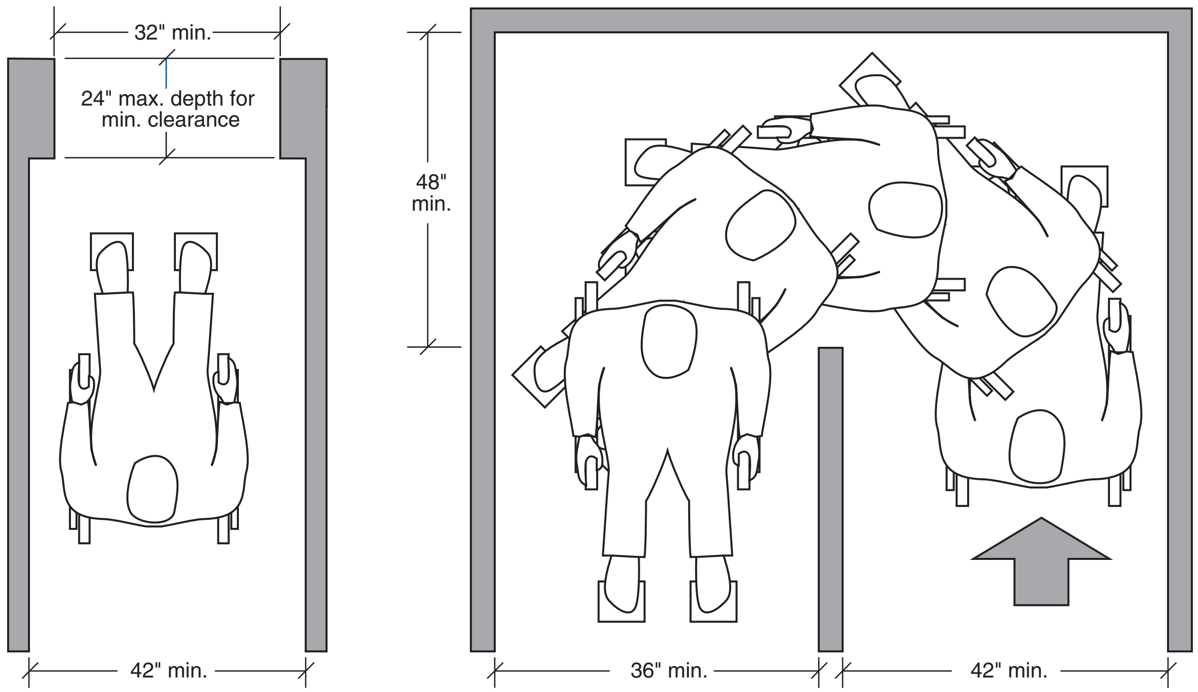


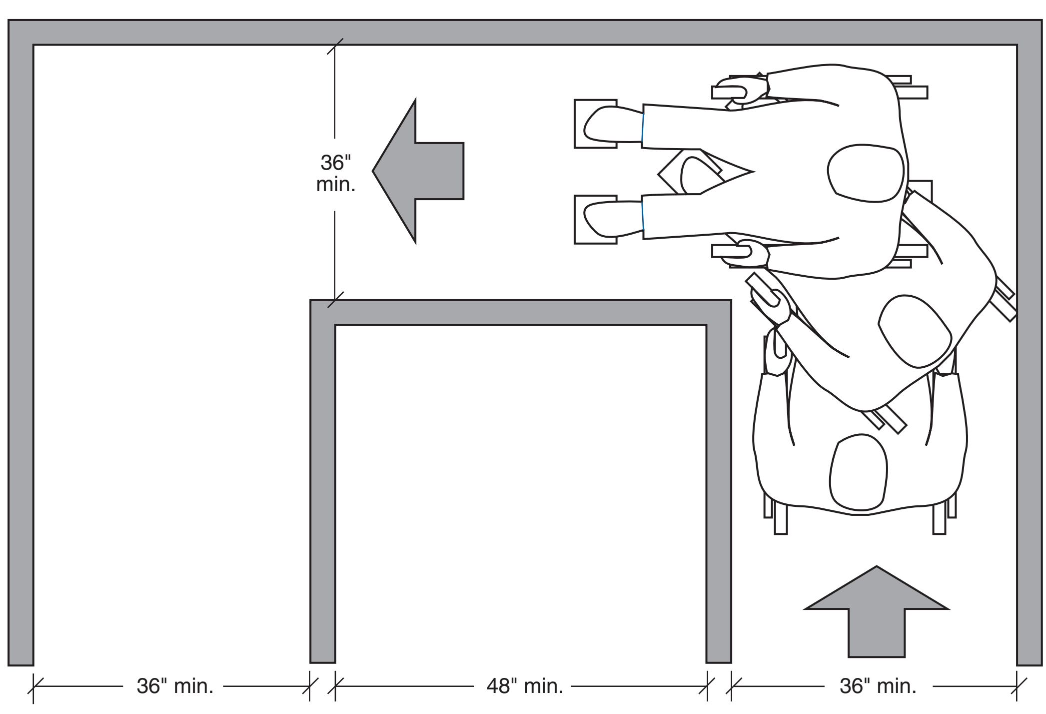
*Upper reach over counter:
If X < 20", Y = 48"
If X=20"–25", Y = 44"



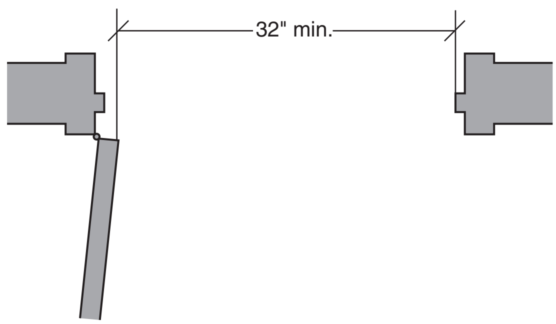


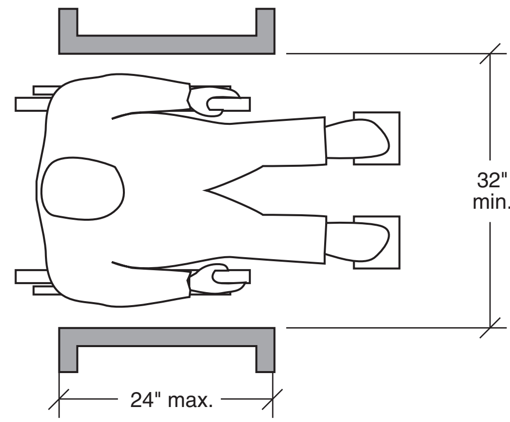
Clear Space and Turning



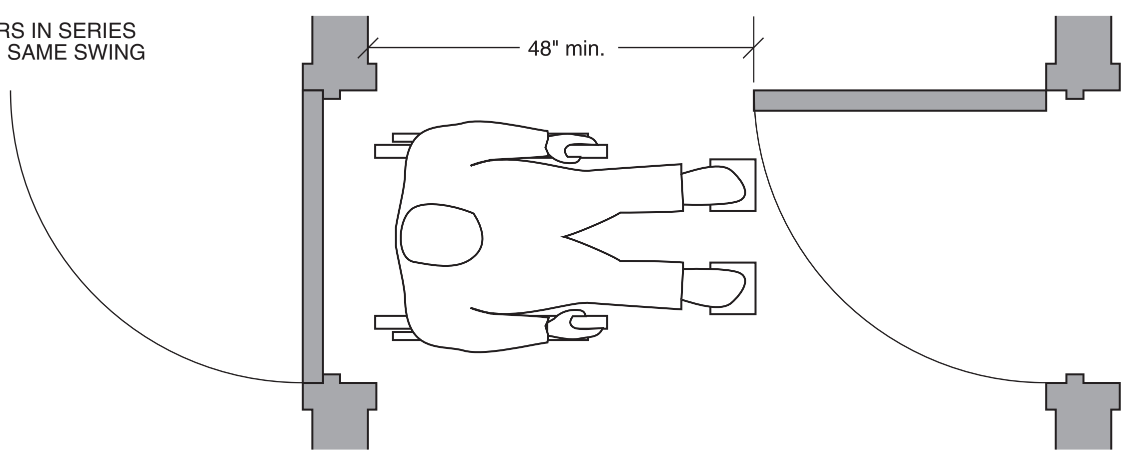


Doorways

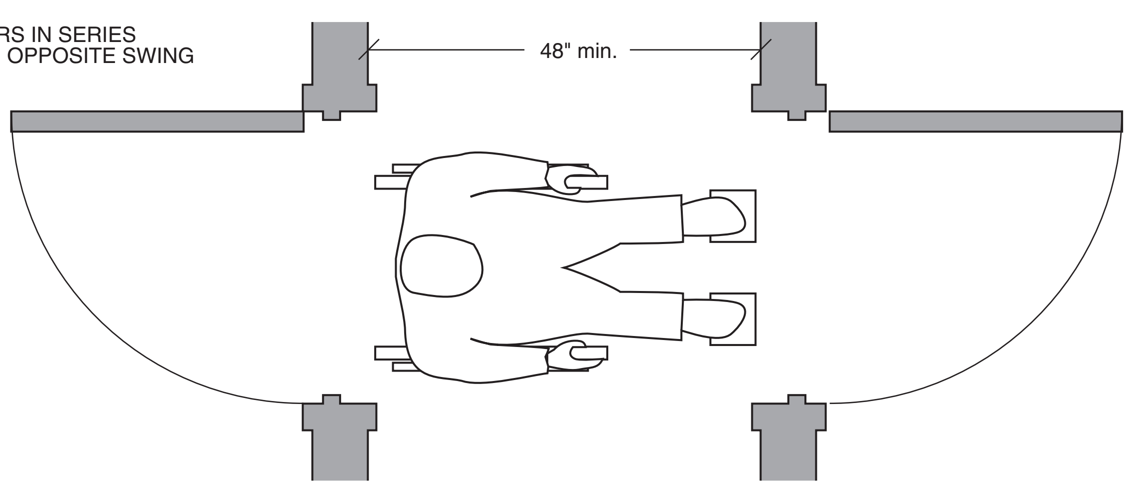




DOORS IN SERIES
WITH SAME SWING

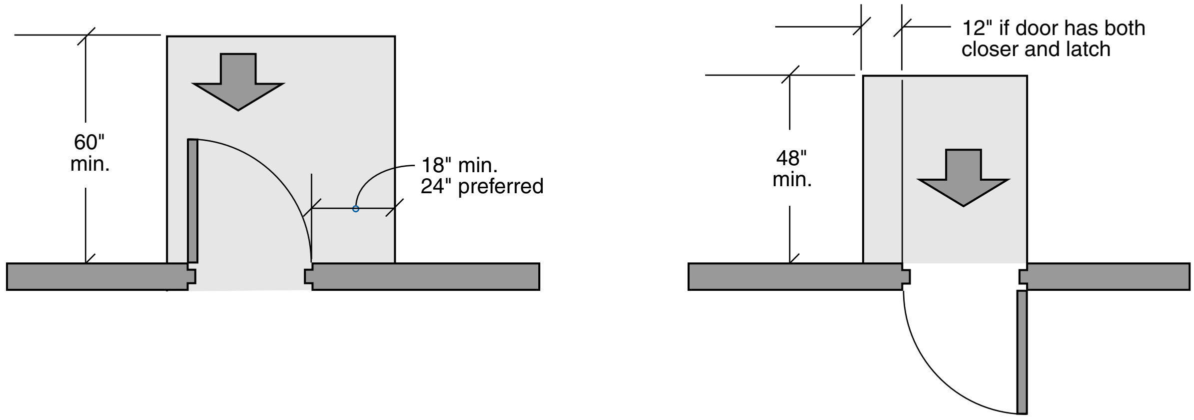


DOORS IN SERIES
WITH OPPOSITE SWING

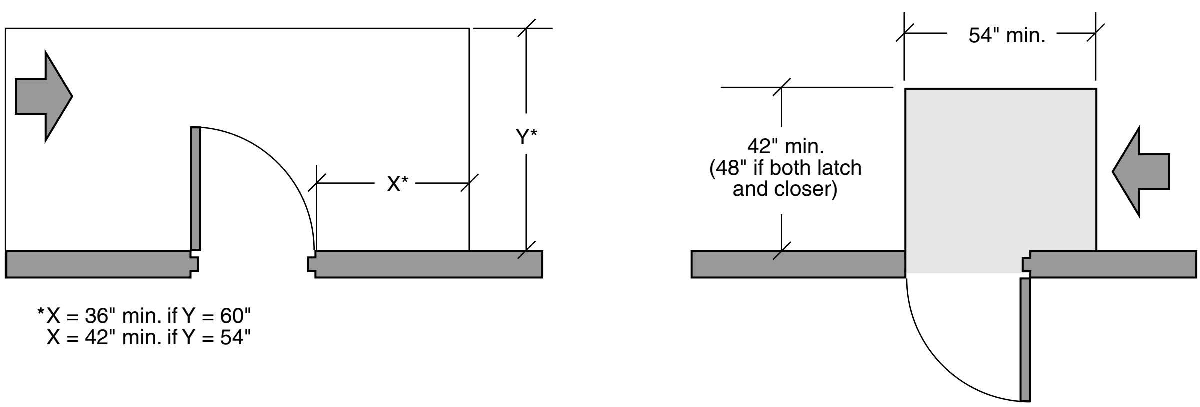


Doorways—*Continued*

FRONT APPROACHES

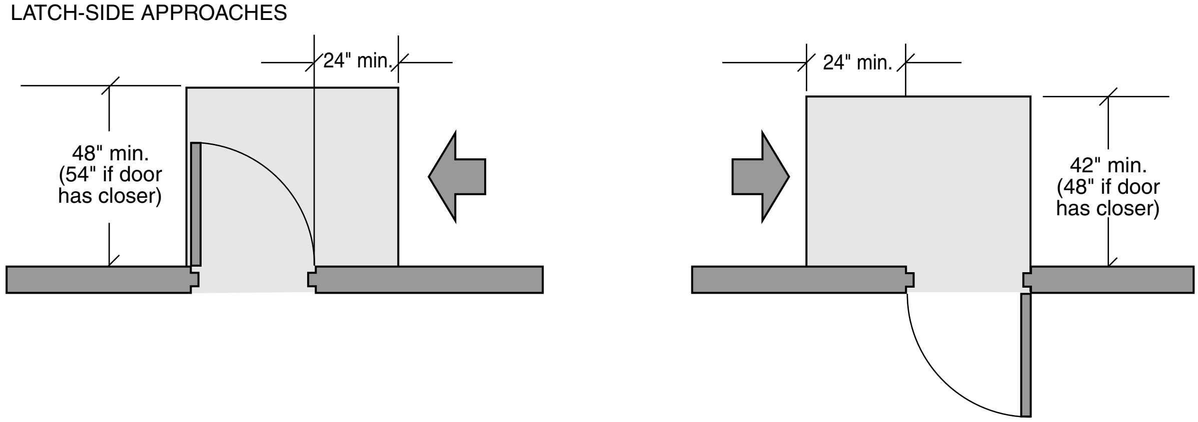


HINGE-SIDE APPROACHES

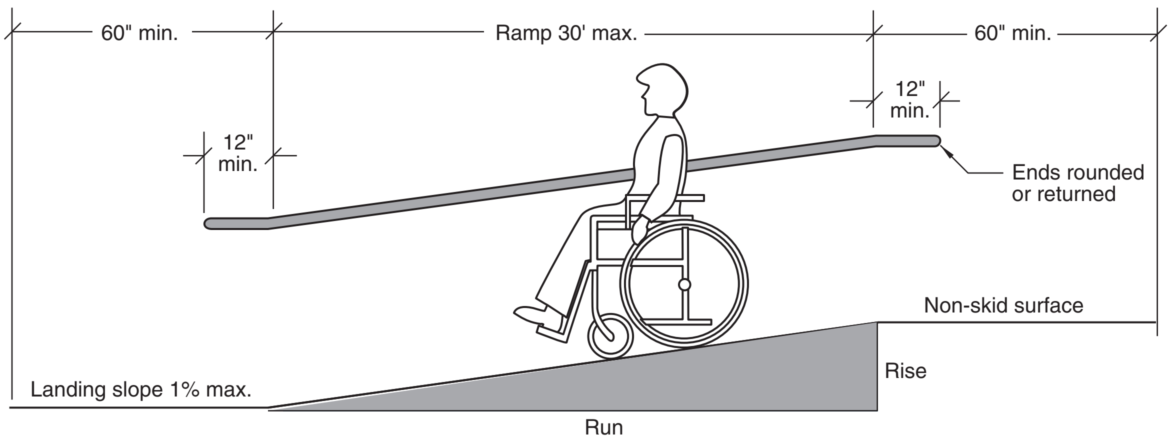


*X = 36" min. if Y = 60"
X = 42" min. if Y = 54"

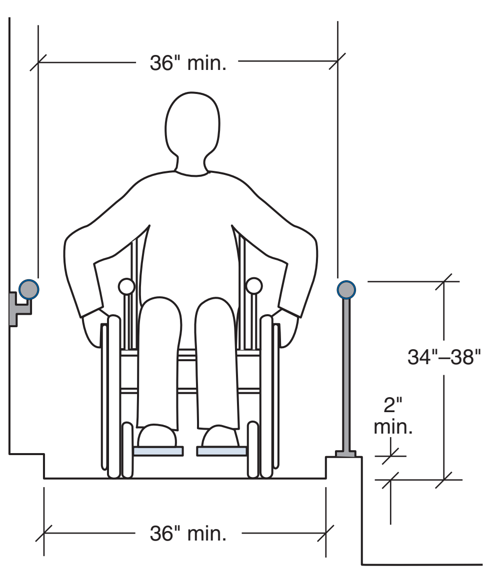
LATCH-SIDE APPROACHES

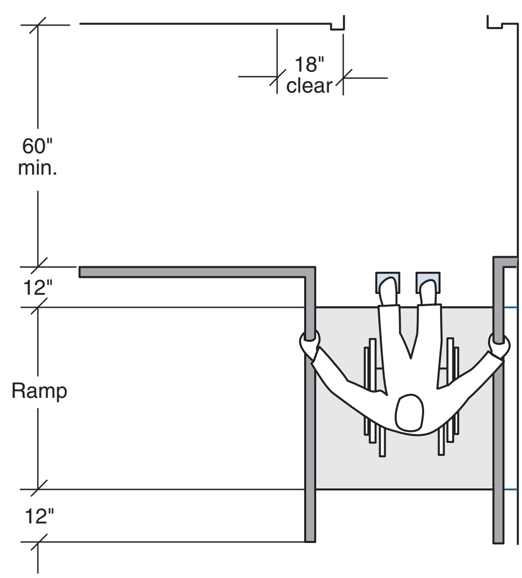


Walks, Ramps, and Level Changes

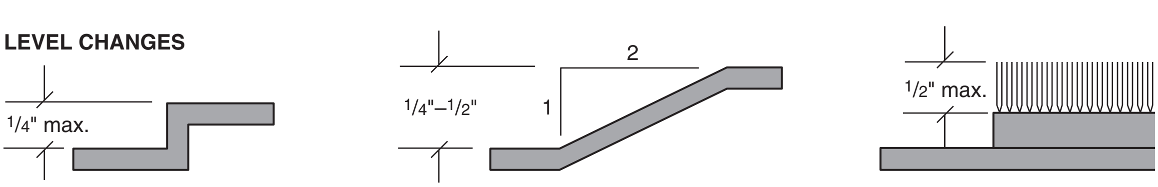


Slope (Rise/Run)	Max. rise, inches	Max. run, feet
1:12 to < 1:16	30	30
1:16 to < 1:20	30	40



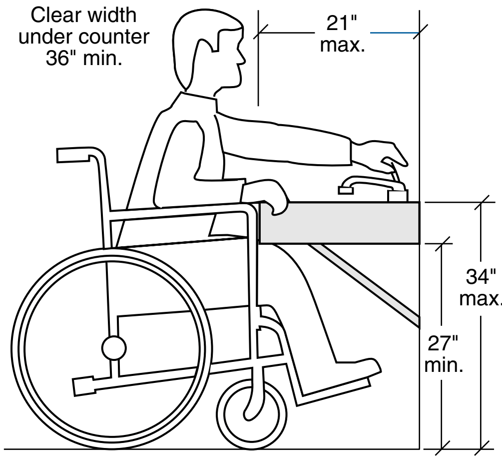


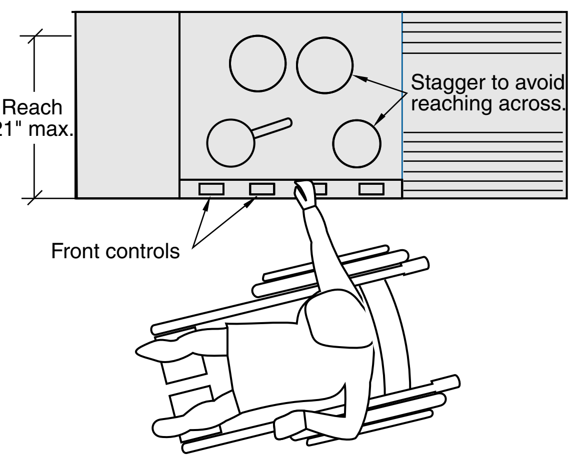
LEVEL CHANGES



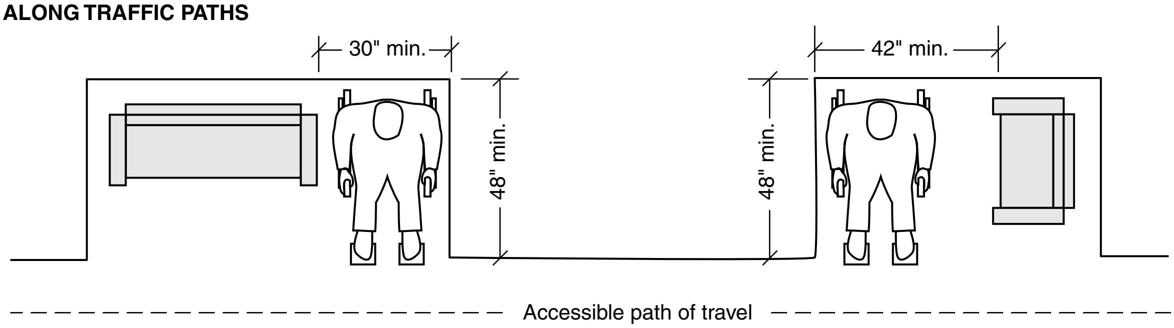
Kitchens and Seating

COUNTERS AND RANGES

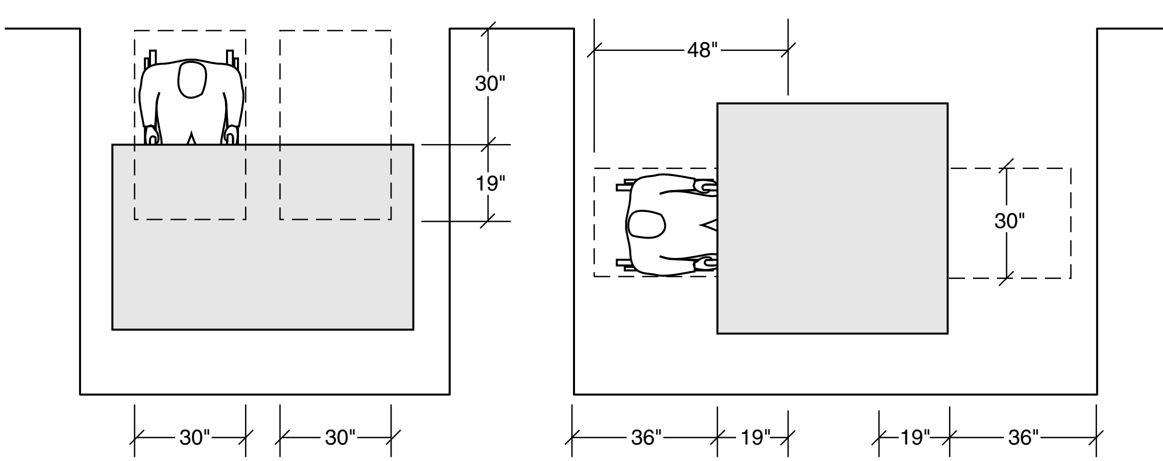




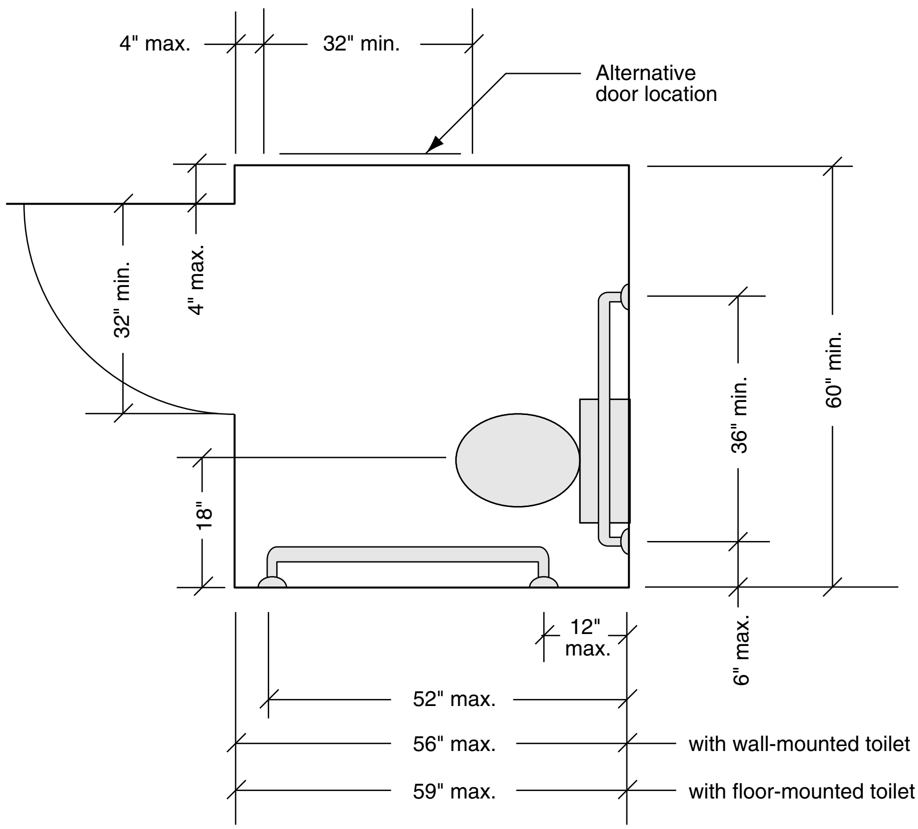
ALONG TRAFFIC PATHS



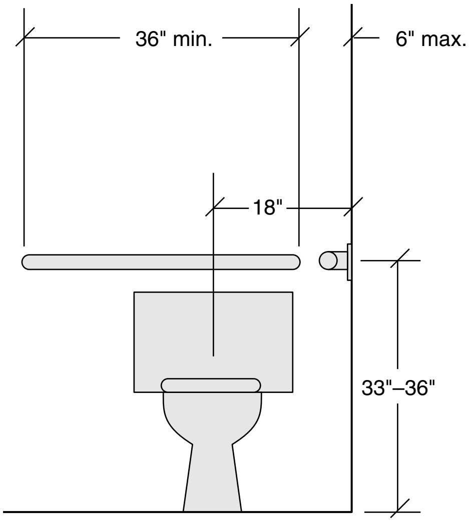
SEATING AT TABLES



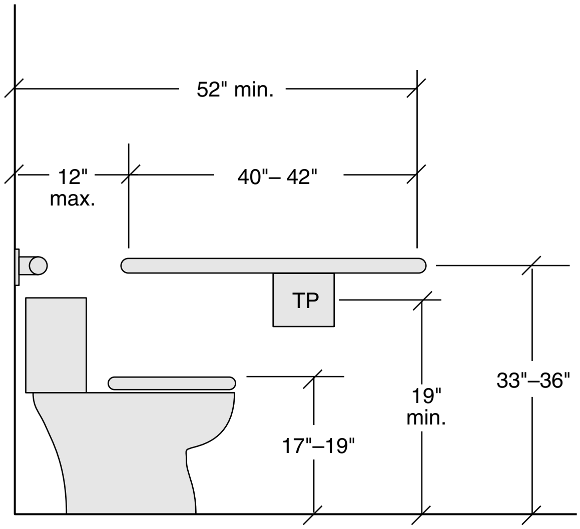
Toilets



4" max.
32" min.
Alternative door location
32" min.
4" max.
36" min.
60" min.
18"
12" max.
6" max.
52" max.
56" max.
with wall-mounted toilet
59" max.
with floor-mounted toilet

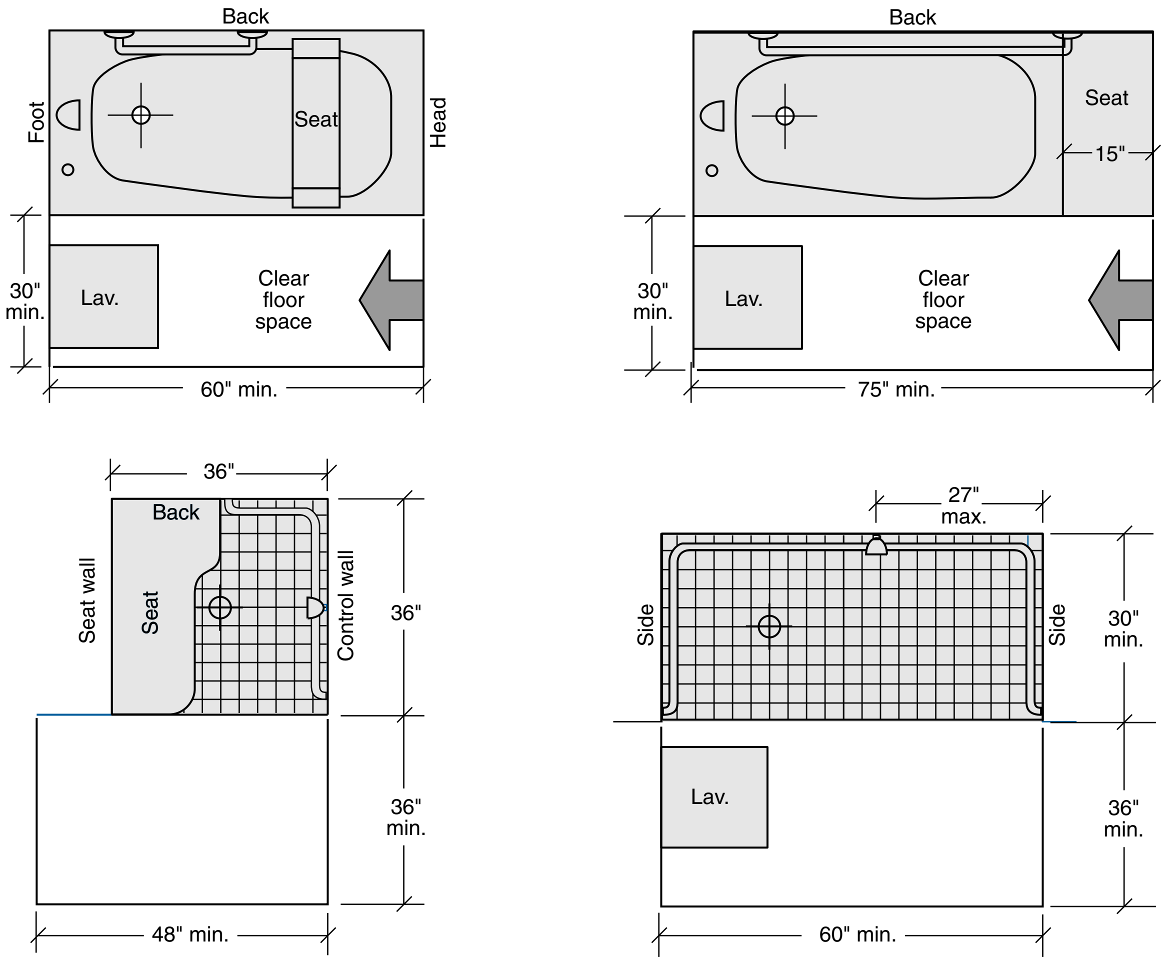


36" min.
6" max.
18"
33"–36"

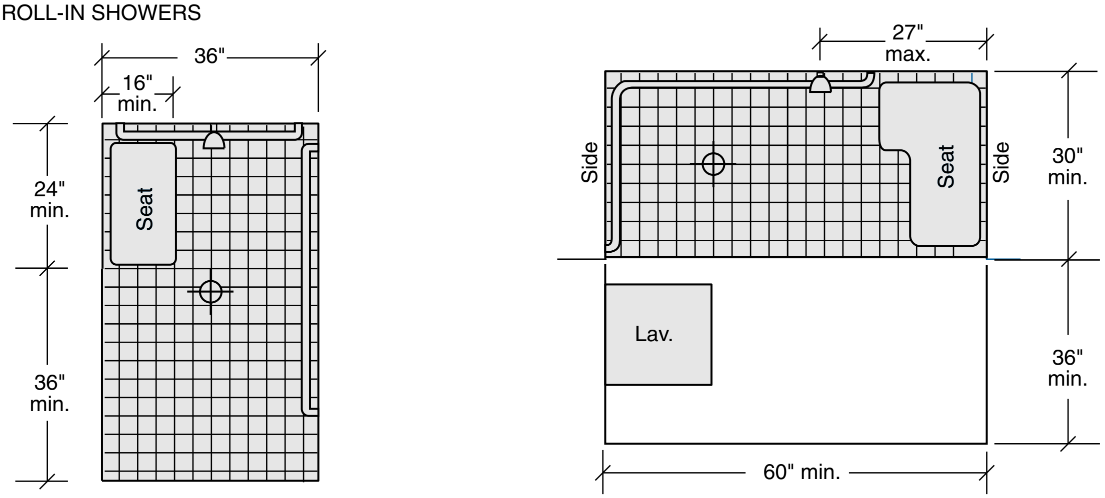


52" min.
12" max.
40"– 42"
TP
33"–36"
19" min.
17"–19"

Tub and Shower Floor Spaces

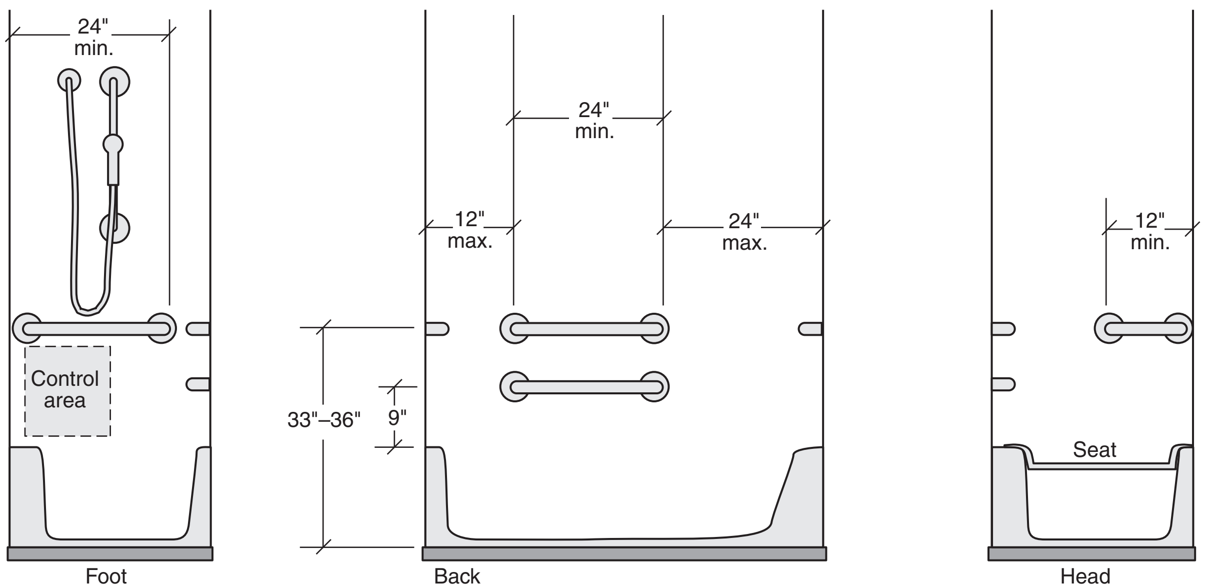


ROLL-IN SHOWERS

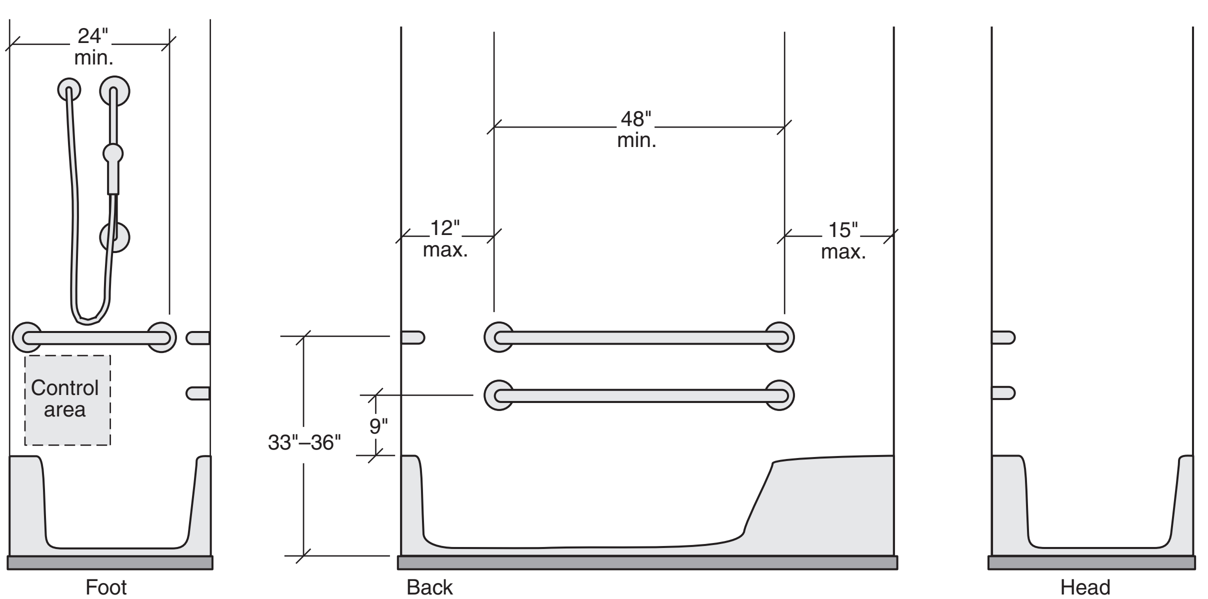


Tub Grab Bars

WITH SEAT IN TUB

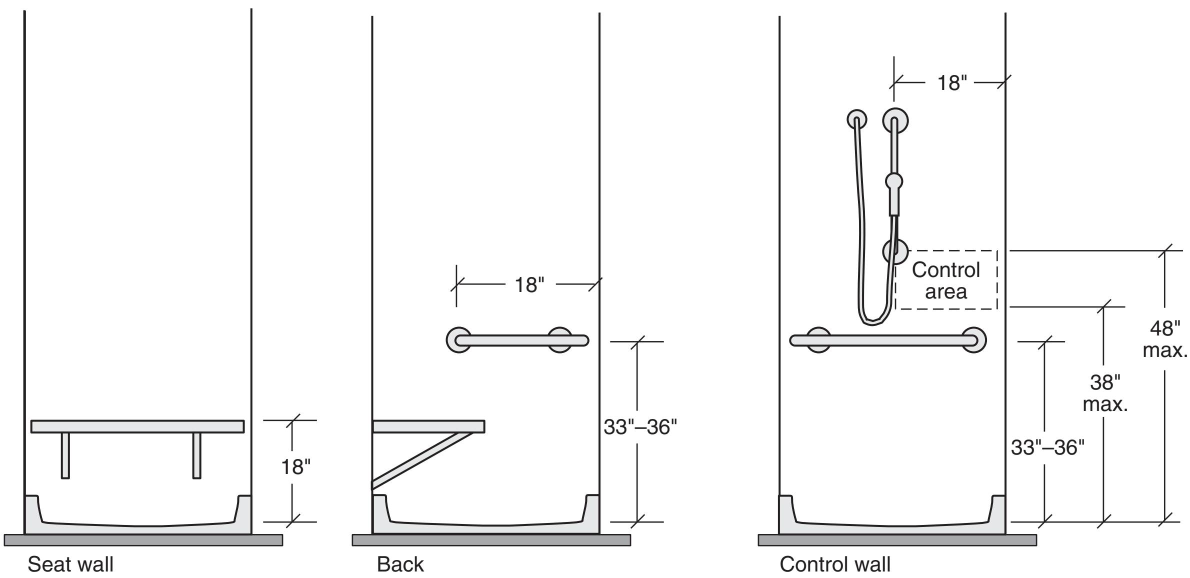


WITH SEAT AT HEAD OF TUB

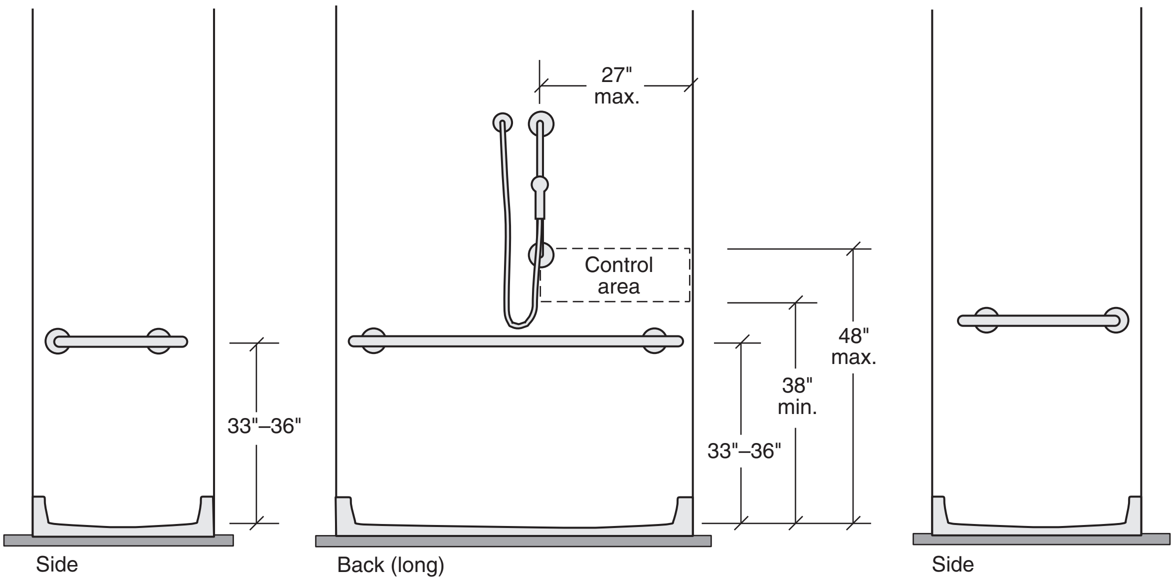


Shower Grab Bars

36" x 36" STALL



30" x 60" STALL



Meet the Code (IRC)

The following is a partial list of requirements from the *2015 International Residential Code (IRC) for One- and Two-Family Dwellings.* Consult the publication for the full text and additional provisions.

Garages (R302)

- doors to sleeping room prohibited
- doors to other rooms: solid 1 3/8" wood or 20-min. fire-rated
- dwelling walls: 1/2" gypsum board on garage side
- ceilings under habitable rooms: 5/8" Type X gypsum board on garage side
- dwelling walls within 3' of separate garage: 1/2" gypsum board on dwelling interior
- dwelling wall: 1/2" gypsum board on garage side
- floor: noncombustible, sloped toward exterior door

Light and Ventilation (R303)

Habitable Rooms:

- glazing area ≥8% of floor area unless lighting provides ≥6 foot-candles
- ≥50% of glazing must be openable unless not required for egress, and a (new construction) whole-house or (existing) mechanical ventilation system of ≥50 cfm is installed
- for purposes of light and ventilation, an adjoining room is considered part of a room when ≥50% of the common wall is open

Bathrooms:

- glazing area ≥3 sq. ft., half openable
- glazing not required with light and ventilation of ≥50 cfm intermittent or 20 cfm continuous

Stairway Illumination:

- interior stairs must be lighted to ≥1 foot-candle either at each landing or over each section of stairs
- exterior stairs must be lighted at top landing; basement bulkhead stairs at lower landing
- lighting for interior stairways of ≥6 stairs must be controllable from both levels
- unless continuous or automatic, lighting for exterior stairs must be controllable from inside

Minimum Room Areas (R304)

- all habitable rooms must be ≥70 sq. ft. (excepting kitchens)
- min. horizontal dimension (except kitchens): 7'
- areas having a sloping ceiling of height <5' or a furred ceiling of height <7' do not count as habitable space

Ceiling Height (R305)

- general ≥7'0"
- bathrooms: ≥6'8" over fixtures and in showers
- basement (unhabitable) ≥6'8"
- basement beams, girders, ducts, or other allowed to project to 6'4"

Toilet, Bath, and Shower Spaces (R307)

- toilet centerline from adjacent wall: 15" min.
- clear space in front of toilet, lavatory, or bathtub: 21" min.
- shower stall dimensions: 30" × 30" min.
- clear space at shower stall opening: 24" min.
- walls of tubs and shower enclosures having shower heads must be water resistant to ≥6'0"

Emergency Escape and Rescue Openings (R310)

Emergency Escape:

- basements and every sleeping room must have an operable emergency escape window or door opening into a public way, yard, or court (exception: equipment basements of ≤200 sq. ft.)
- egress sill height: ≤44"
- net area: ≥5.7 sq.ft. (grade-floor ≥5.0 sq.ft.)
- opening height: ≥24"
- opening width: ≥20"
- operational from inside without a key or tools

Means of Egress (R311)

Doors:

- at least one egress door directly to outside from habitable area of house (not through garage)

- side-hinged
- clear width when open: 32" min.
- height: 6'6" min.
- operational from inside without a key or tools

Landings:
- landing each side of egress door: width of door × 3'-deep min.
- landing: ≤1 1/2" lower than threshold, except ≤7 3/4" provided door doesn't swing over landing

Ramps:
- max. slope: 1/8 (12.5%)
- handrail required for slope >1/12 (8.3%)
- landing each end of ramp: 3' × 3' min.

Stairways:
- width above handrail: 36" min.
- width at and below one handrail: 31 1/2" min.
- width at and below two handrails: 27" min.
- headroom over nosing: 6'8" min.

Landings for Stairways:
- landing top and bottom of each stairway, except interior stairway if door does not swing over stairs
- width of landing: ≥width of stairs
- length of landing: 36" min.
- stairway rise: ≤12'3" between floors or landings

Stair Treads and Risers:
- riser: 7 3/4" max.
- riser and tread variations: 3/8" max.
- tread width (nose to nose): 10" min.
- nosing projection: 3/4" min. to 1 1/4" max.
- nosing not required if riser open
- riser sloped 0°–30° max. from vertical

Winders:
- tread width: ≥10" at 12" from narrower side
- tread width: ≥6" at all points
- tread variation at 12" walk line: 3/8" max.
- handrail required on narrow-tread side

Spiral Stairs:
- min. width: 26"
- tread: ≥7 1/2" at 12" from narrower side
- all treads identical
- riser: ≤9 1/2"
- headroom: 6'6" min.

Handrails:
- 34" to 38" above tread nosing
- at least one side when ≥4 risers
- on outside of spiral stairways
- continuous except if interrupted by newel post at a turn
- ends return or terminate at newel posts
- spaced from wall: ≥1 1/2"
- diameter if of circular section: 1 1/4" to 2"
- perimeter of non-circular section: 4" to 6 1/4" and max. diagonal dimension 2 1/4"

Guards (R312)

- required for floors and stair treads >30" above floor or grade below
- min. height of rail above floor: 36"
- min. height of rail above stair nosing: 34"
- not allow passage of 4" diameter sphere, except 6" for triangle formed by tread, riser, and bottom rail

Smoke Detectors (R314)

- all detectors interconnected in new construction
- in each sleeping room
- outside each sleeping area
- every floor, including basement, but not including crawl spaces or unfinished attics
- required as if new construction with renovation or addition requiring building permit
- must be powered in new construction by both unswitched house wiring and battery
- smoke and CO_2 detectors may be combined

2

Site and Climate

Architects often say, "You cannot build a good house on a bad site." They mean by this that the building site is, by far, the single most important element in a house design. Of course, the qualities of a site involve a number of variables, some quantifiable, some not. In this limited space we describe the most important of those variables and how to deal with them.

We begin with *plot plans*, the drawings that describe the dimensions of the site and the project, and that must be presented to the building codes official in order to obtain a building permit.

Your site's soil properties can have a great effect on the cost of developing the site, particularly the costs of foundation and driveway, so we include the Unified Soil Classification System table of physical *soil properties*.

To take advantage of solar energy, whether photovoltaic or passive heating, you must know the geographic *site orientation*. We show how to determine true, or solar, south using times of sunrise and sunset.

The topographic relief, or variations in elevation, of your site influence the costs of foundation, driveway, and grading, so we show a simple method of *determining elevations*.

Automobiles (and trucks of various sizes) play important roles in modern life. We show how to design *driveways* that safely access public highways and that provide adequate space in which to maneuver.

Throughout this book, whether predicting your heating bill or determining where to place windows for ventilation, you will have need for *climate data*, which we present in the form of simple maps.

In areas where too much winter wind results in high heating bills and drifting snow, *shelterbelts* consisting of strategically placed trees and bushes can provide significant relief.

Important in selecting *trees* are the typical height and width at maturity. We have included a table of tree dimensions and a chart of tree silhouettes showing mature trees to scale and next to a typical house.

Last but not least, we have provided a table and map of grass seeds to consider in establishing *lawns*.

Plot Plans

Plot plans showing the building footprints, lot lines, setbacks, driveway, and locations of utilities and utility easements are usually required before a building permit can be secured. Plans showing elevation contours, both existing and planned, are additionally useful in setting foundation heights, laying out leach fields, and estimating excavation costs. To create a plot plan with elevations:

1. Using a 100-foot tape measure, stake out a baseline of elevation points along one of the property lines.

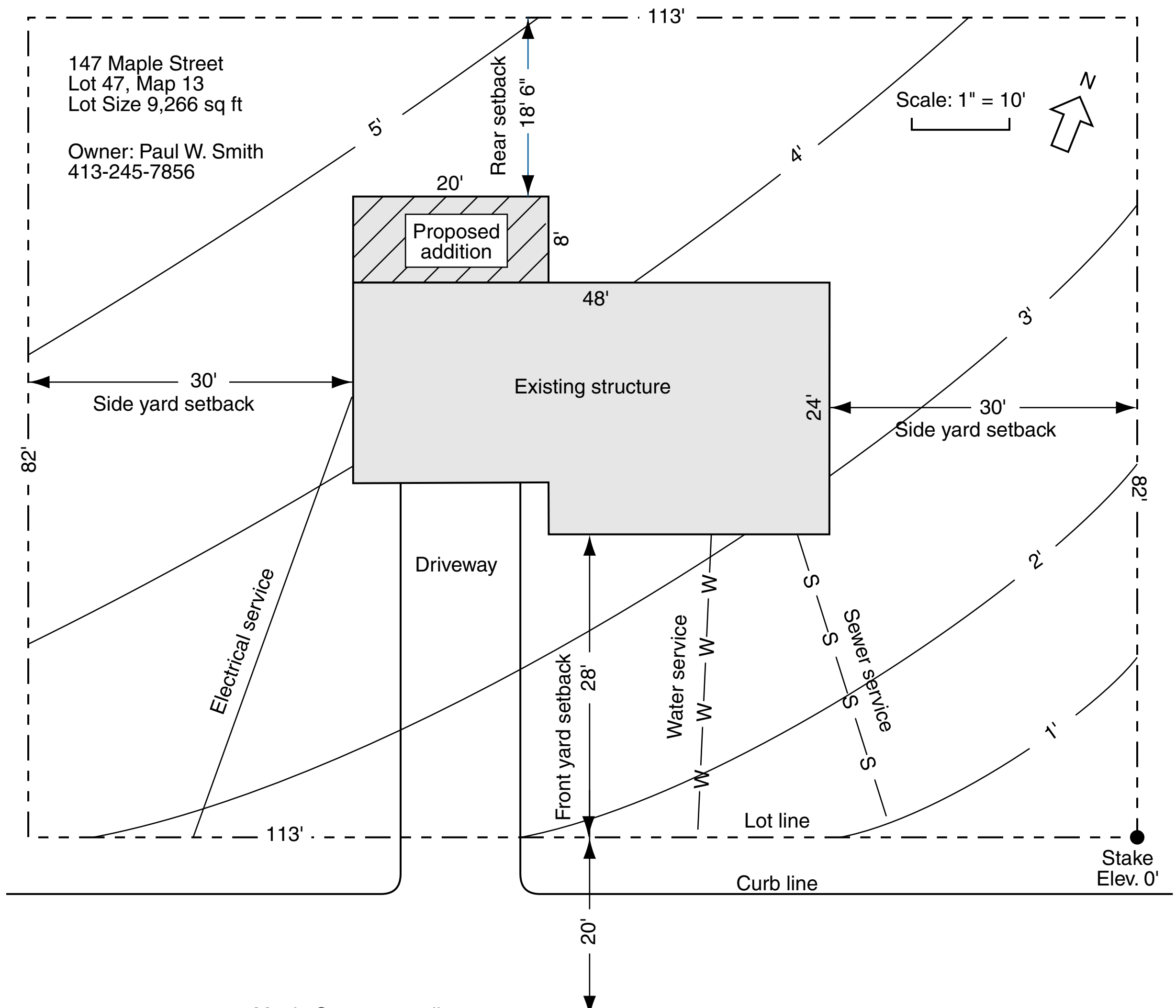
2. With a transit and tape, lay out a grid of secondary lines of points at right angles to the baseline.

3. Beginning at the lowest point, measure the relative elevation of each point in the grid (see p. 39).

4. Draw a plot plan to scale (check with your permitting official for an acceptable scale), interpolating lines of equal elevation (contour lines) between grid points. If grading is planned, draw the proposed final contours, as well.

Below is an example of a plot plan.

Sample Plot Plan



Soil Properties

Knowing the type(s) of soil on your property is useful at least in preliminary planning. It is particularly important to know if your soil has diminished weight-bearing capacity or if it is likely to heave in winter.

If you are lucky, your site has already been classified by the USDA Soil Conservation Service and described in one of the *Soil Surveys* available free through local soil and water conservation district offices in every state. Below are the characteristics of soils in the Unified Soil Classification System.

Unified Soil Classification System

Group	Soil Type	Description	Allowable Bearing[1] lb/sq ft	Drainage[2]	Frost Heave Potential	Expansion Potential[3]
NA	BR[4]	Bedrock	30,000	Poor	Low	Low
I	GW	Well-graded gravels or gravel-sand mixtures, little or no fines	8,000	Good	Low	Low
I	GP	Poorly graded gravels or gravel-sand mixtures, little or no fines	8,000	Good	Low	Low
I	SW	Well-graded sands, gravelly sands, little or no fines	6,000	Good	Low	Low
I	SP	Poorly graded sands or gravelly sands, little or no fines	5,000	Good	Low	Low
I	GM	Silty gravels, gravel-sand-silt mixtures	4,000	Good	Medium	Low
I	SM	Silty sand, sand-silt mixtures	4,000	Good	Medium	Low
II	GC	Clayey gravels, gravel-clay-sand mixtures	4,000	Medium	Medium	Low
II	SC	Clayey sands, sand-clay mixture	4,000	Medium	Medium	Low
II	ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands with slight plasticity	2,000	Medium	High	Low
II	CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays	2,000	Medium	Medium	Medium[5]
III	CH	Inorganic clays of high plasticity, fat clays	2,000	Poor	Medium	High[5]
III	MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts	2,000	Poor	High	High
IV	OL	Organic silts and organic silty clays	400	Poor	Medium	Medium
IV	OH	Organic clays of medium to high plasticity	0	Unsat	Medium	High
IV	PT	Peat and other highly organic soils	0	Unsat	Medium	High

[1] Allowable bearing value may be increased 25% for very compact, coarse-grained, gravelly, or sandy soils or very stiff, fine-grained, clayey, or silty soils. Allowable bearing value shall be decreased 25% for loose, coarse-grained, gravelly, or sandy soils or soft, fine-grained, clayey, or silty soils.

[2] Percolation rate for good drainage is over 4"/hr, medium drainage is 2–4"/hr, and poor is less than 2"/hr.

[3] For expansive soils, contact a local soil engineer for verification of design assumptions.

[4] Classification and properties added by author for comparison.

[5] Dangerous expansion might occur if these soil types are dry but subject to future wetting.

Site Orientation

The orientation of a building is important, not only for obtaining a building permit but also for the performance of any type of solar collector, including passive solar buildings. Solar gain is maximum for glazings facing *true south*, the direction to the sun when at its greatest altitude.

Due to the symmetry of the sun's path, peak altitude occurs not at noon as shown by clocks set to the time zones in the map below but at *solar noon*, exactly halfway between the times of sunrise and sunset. Thus, true south can be found by averaging the times of sunrise and sunset on a particular day and observing the sun's shadow at solar noon.

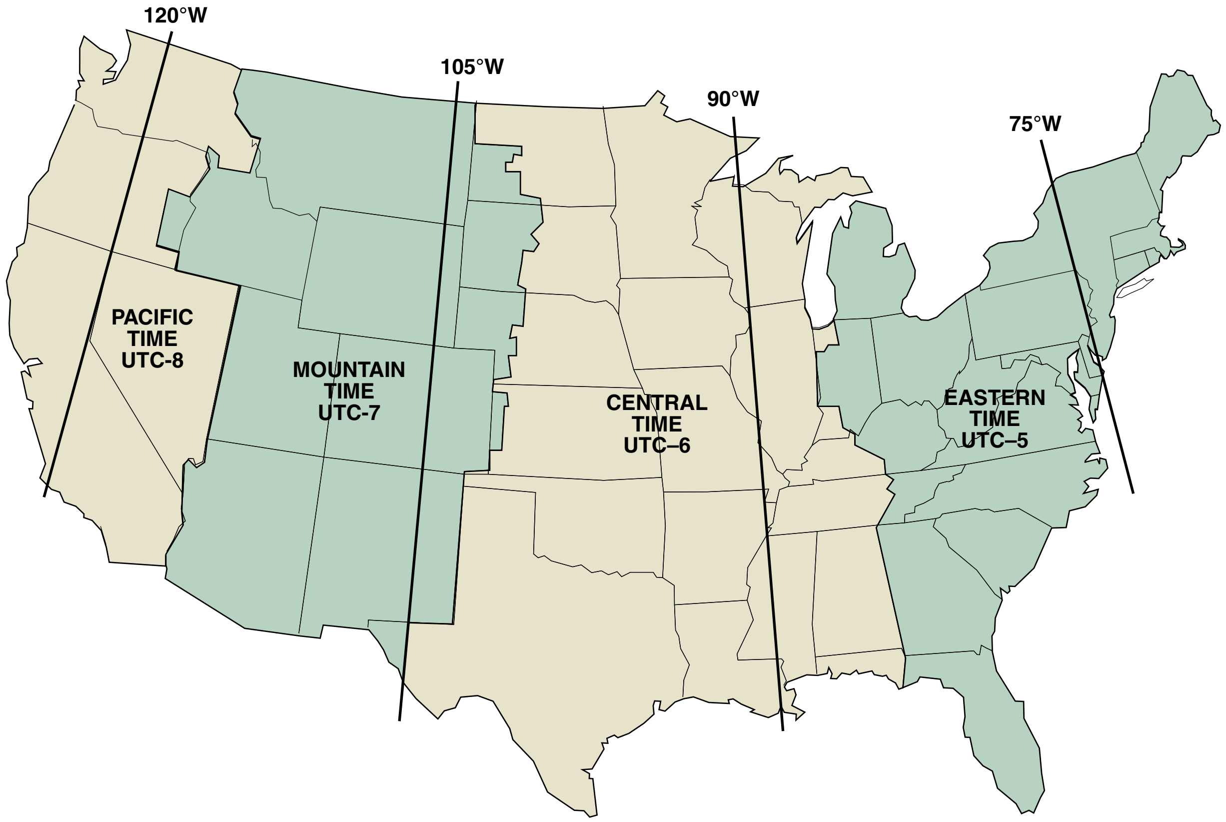
Local times of sunrise and sunset are often given in newspapers and televised weather forecasts. They can also be found from online calculators, such as: *www.calendar-updates.com/sun.asp*.

Example: Find the direction of true south at a site in Salina, Kansas, on August 18 (Daylight Savings in effect). Go to the website: *www.calendar-updates.com/sun.asp*. Enter the 5-digit zip code for Salina, KS, 67401, the date, August 18, and set DST (Daylight Saving Time) to "Y." The calculator returns the values: Sunrise (6:47AM) and Sunset (8:20PM).

Since a day actually consists of 24 hours, we convert both times to 24-hour notation: 06:47 and 20:20. Averaging the two times, the sun will be at its maximum altitude and in the direction true south at (06:47 + 20:20)/2 = 13:33 (1:33PM).

Drive or hold a tall vertical stake in the ground. The stake's shadow will fall on a true north-south line at exactly 1:33PM.

United States Time Zones

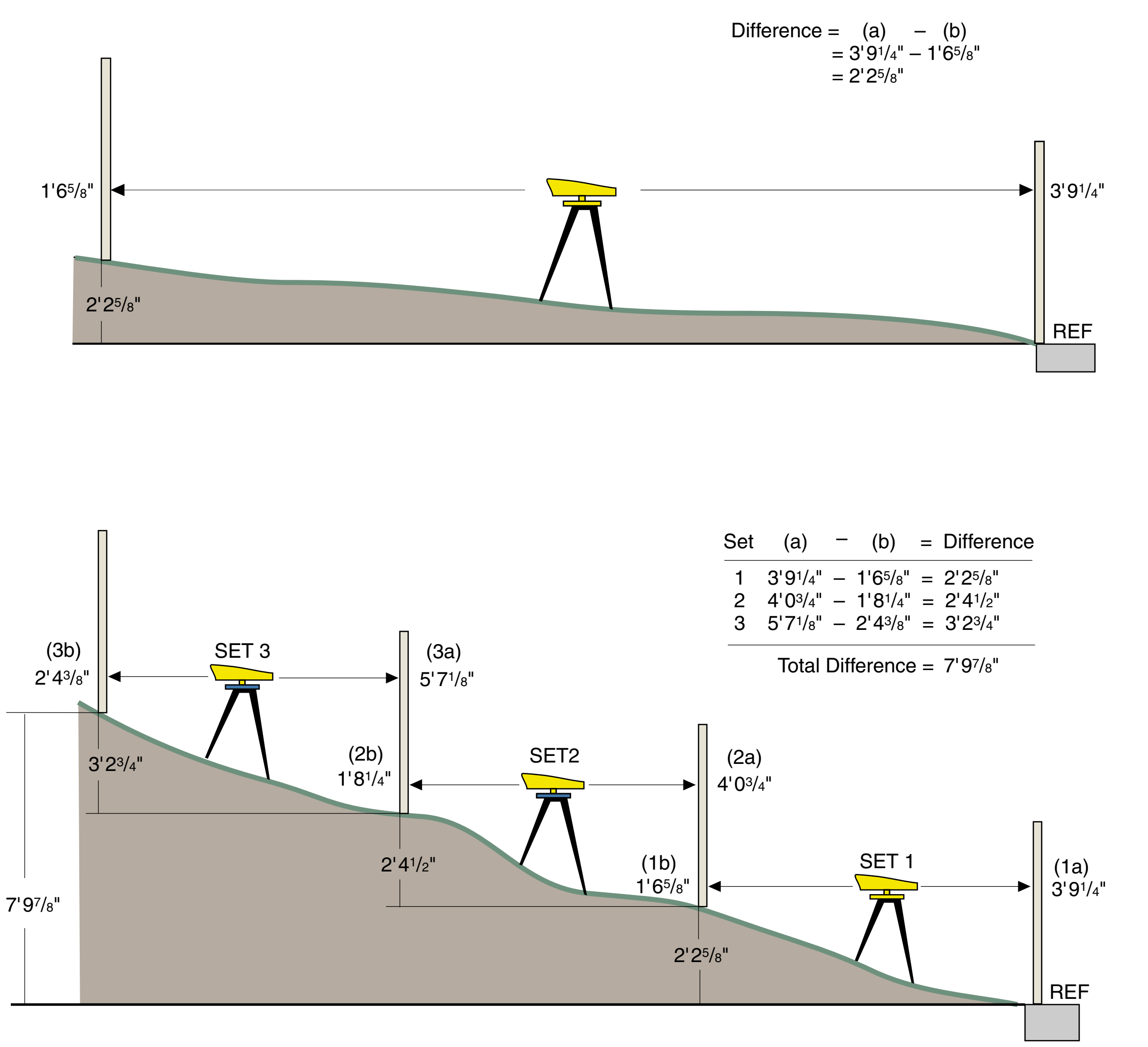


Determining Elevations

Relative elevations are important in laying out foundations, driveways, and leach fields. Preliminary measurements can be made with a pocket sighting level, sometimes referred to as a "pop level." More precise measurements on the order of ¼ inch per 100 feet can be made with a builder's level or transit.

The method below requires two people: one to sight through the level; the other to hold and operate the grade pole. If the two are not too far apart, the person sighting may be able to read the feet and inches on the grade pole directly. At greater distances the grade pole operator slides a target up and down the scale and reads the level. More expensive automatic laser levels that project a rotating laser beam allow a single operator to hold the pole and read the level.

Measuring Relative Elevation



Driveways

In addition to drainage and, in northern states, ease of snow removal, issues to consider in planning a driveway include:

- Permission to enter a public way
- Grade limits
- Vehicle turning radii

Entering a Public Way

Where and how a private drive enters a public road is a safety issue. You must obtain a permit from the town, city, or state that maintains the road or street. The key consideration is the safe sight distance at the highway's posted speed limit.

Safe Sight Distances for Passenger Cars Entering Two-Lane Highways

Speed, mph	Distance to Left	Distance to Right
30	350	260
40	530	440
50	740	700
60	950	1050

In the illustration below, the permit will depend on the visibility for traffic in the lane being entered. Entrances may be denied in the shaded areas.

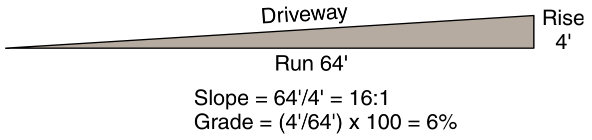
Grade Limits

The *slope* of a surface is defined as the ratio of horizontal run to vertical rise. *Grade* is the percentage ratio of vertical rise to horizonal run. The table below shows recommended minimum and maximum grades for traffic surfaces.

Minimum grades are for the purpose of drainage; maximum grades are related to traction.

Slope versus Grade

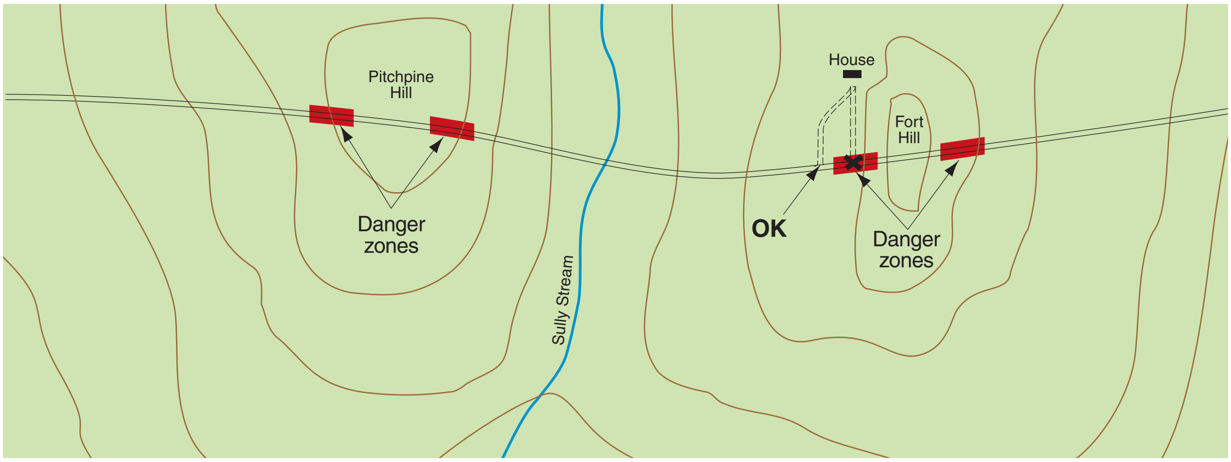
Example



Grades for Traffic Surfaces

Surface	Minimum	Maximum
Driveways in the North	1%	10%
Driveways in the South	1%	15%
Walks	1%	4%
Ramps	—	15%
Wheelchair ramps	—	8%

Danger Zones for Driveway Entrances

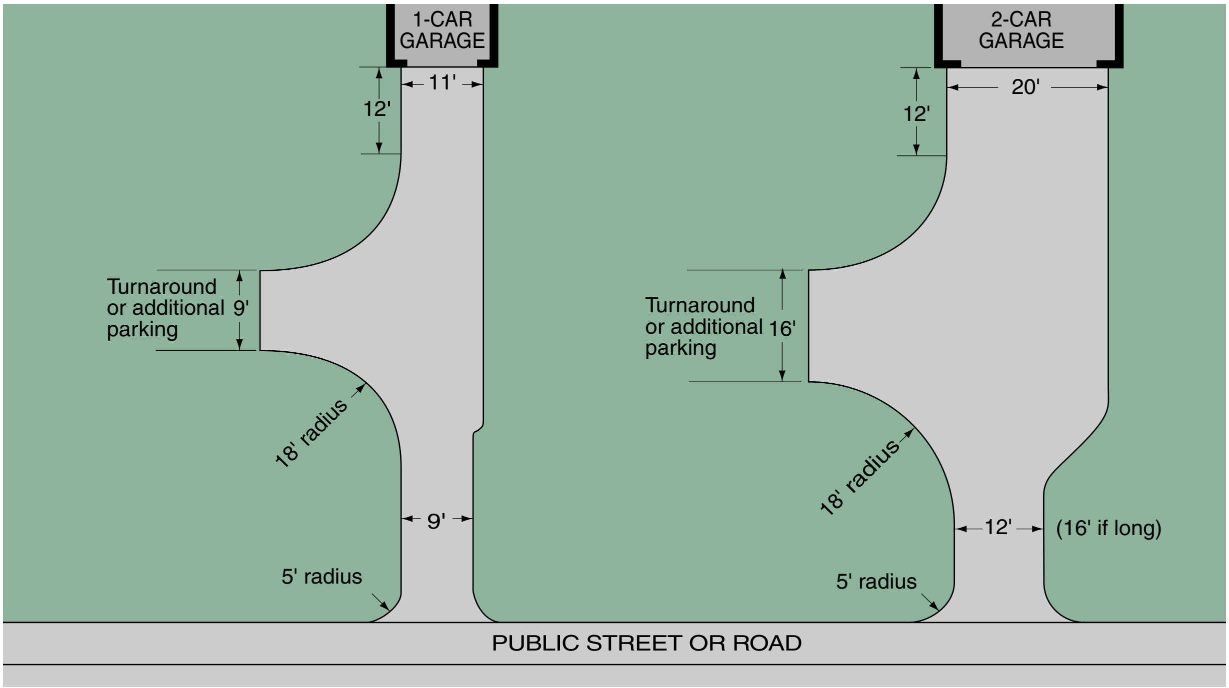


Turning Radii

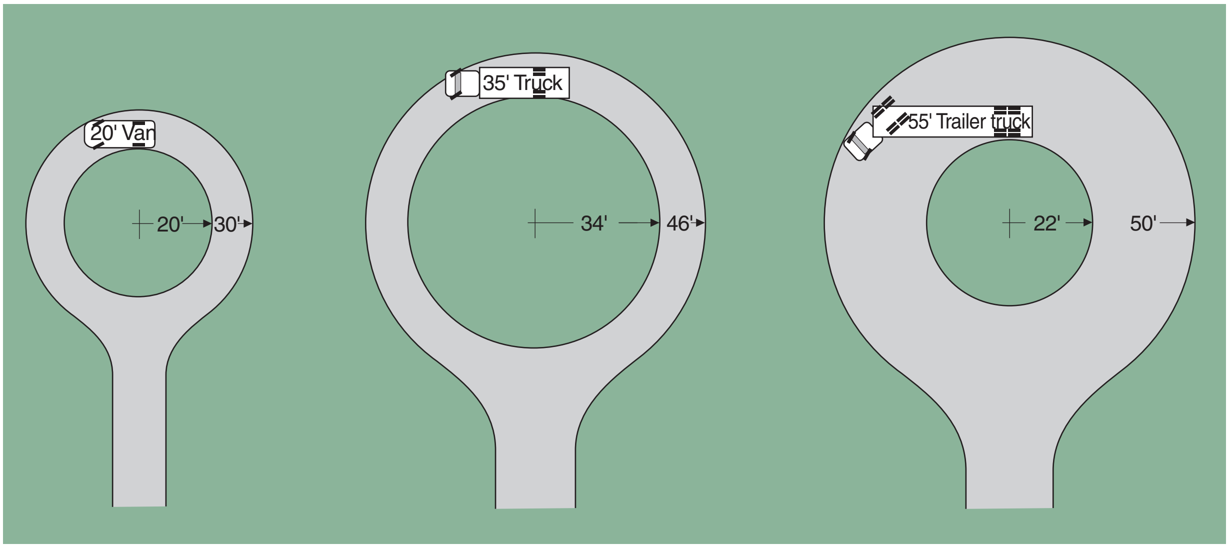
The illustration at top shows the recommended minimum dimensions of driveways and parking turnarounds for one- and two-car garages.

At bottom are the minimum required inside and outside diameters of circular drives for small to large vehicles.

Minimum Turning Radii for Driveways and Turnarounds



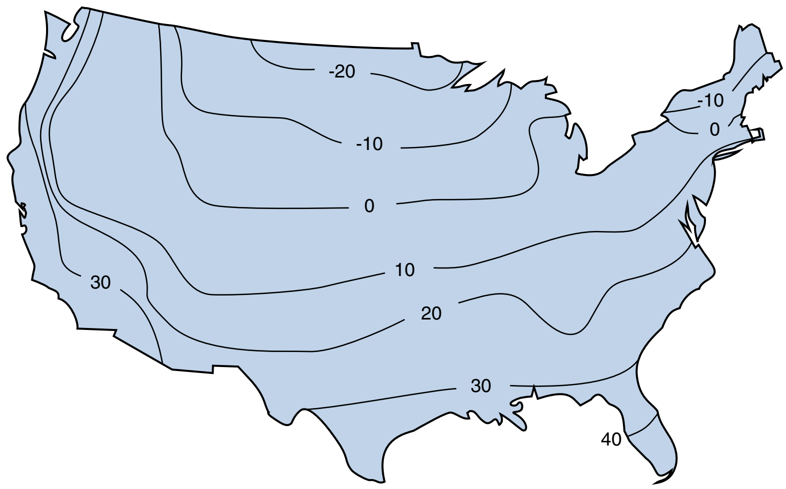
Circular Drive Radii



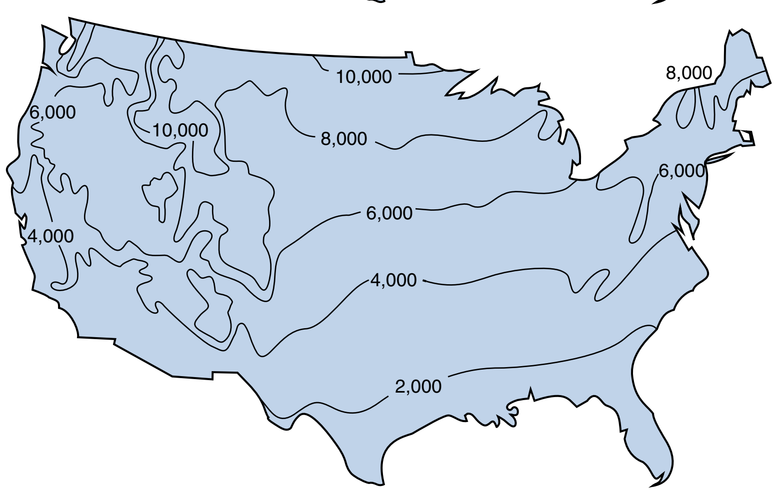
Climate Data

Heating Season

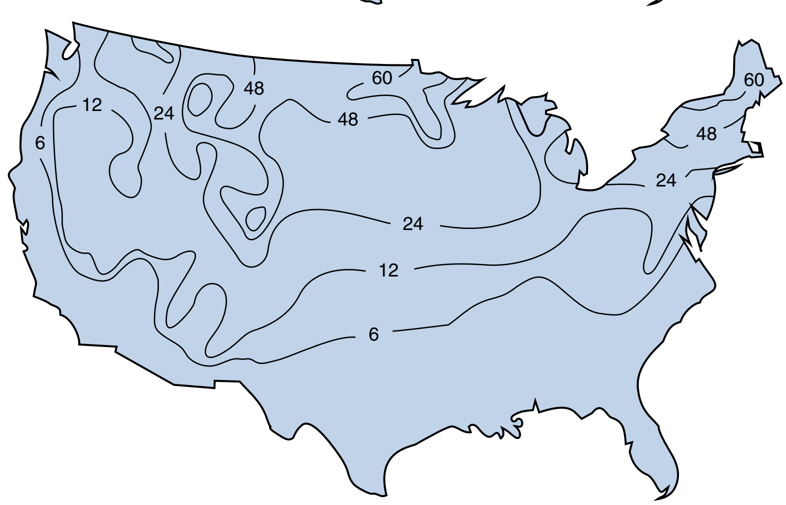
Winter Design Temperature, °F (colder 2.5% of hours)



Heating Degree-Days (base 65°F)

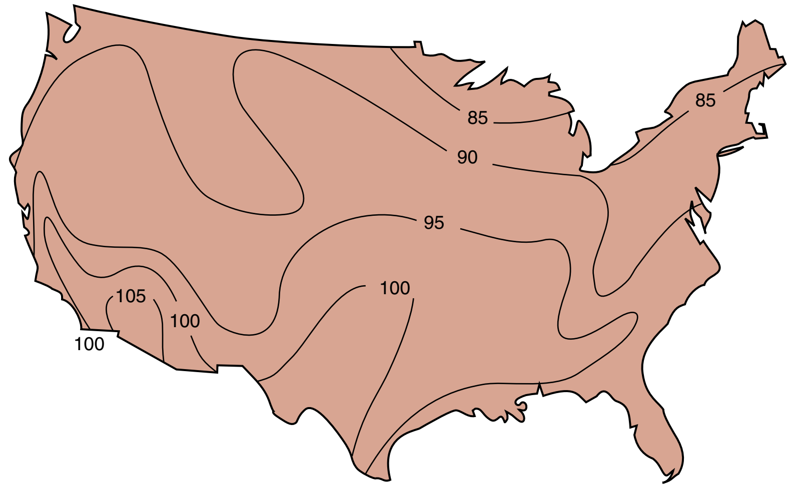


Average Frost Penetration (inches)

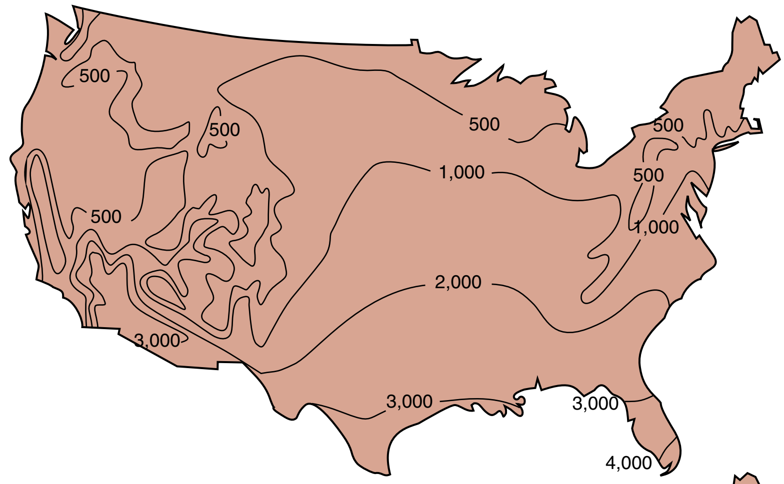


Cooling Season

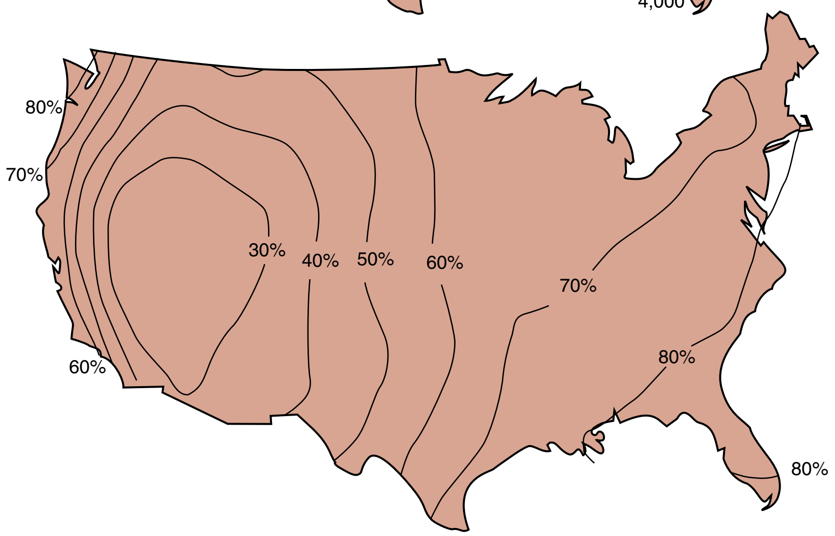
Summer Design Temperature, °F (warmer 2.5% of hours)



Cooling Degree-Days (base 65°F)
The accumulated difference between the average daily temperature and 65°F for the cooling season



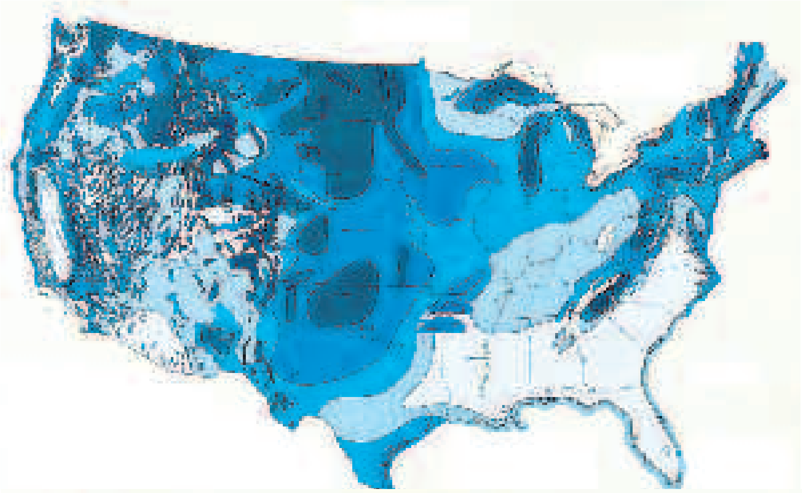
Mean Relative Humidity, July



Wind Speed and Direction

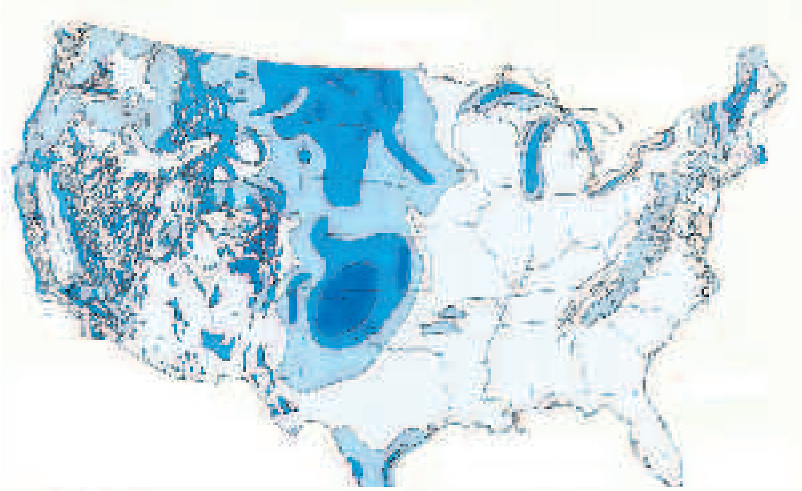
Mean Wind Speed and Power in Spring

	W/m^2	mph	knots
☐	50	7.8	6.8
■	100	9.8	8.5
■	150	11.5	10.0
■	200	12.5	10.9
■	300	14.3	12.4
■	400	15.7	13.6



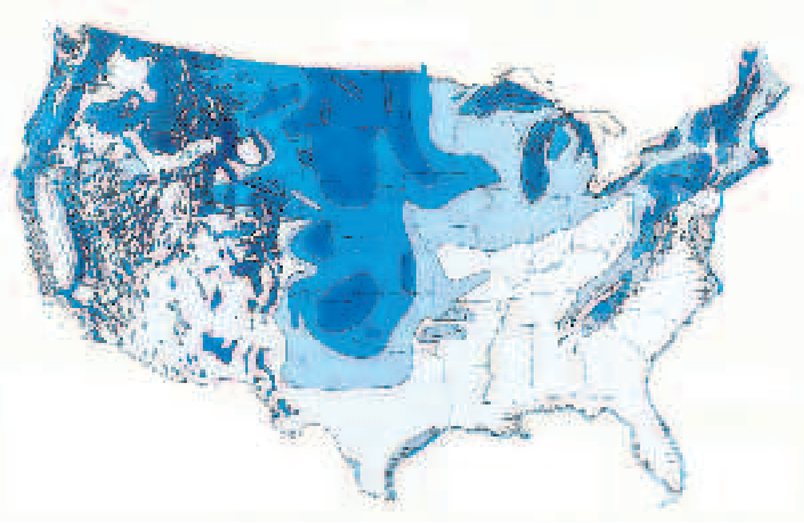
Mean Wind Speed and Power in Summer

	W/m^2	mph	knots
☐	50	7.8	6.8
■	100	9.8	8.5
■	150	11.5	10.0
■	200	12.5	10.9
■	300	14.3	12.4
■	400	15.7	13.6



Mean Wind Speed and Power in Fall

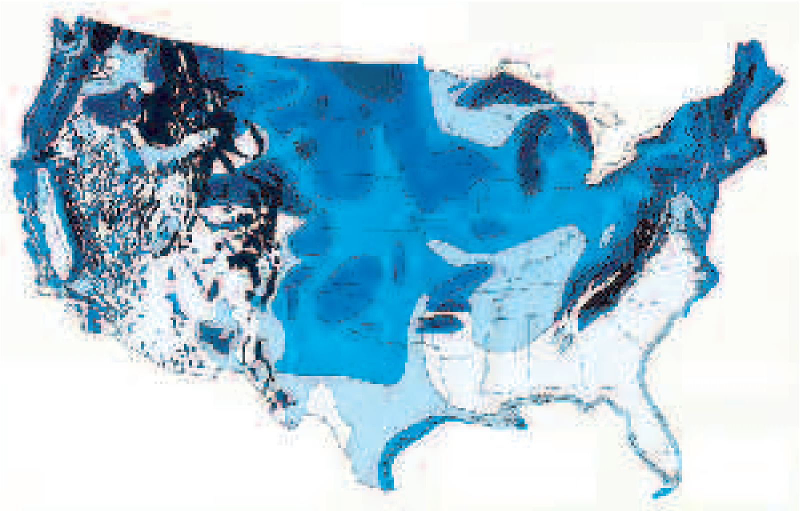
	W/m^2	mph	knots
☐	50	7.8	6.8
■	100	9.8	8.5
■	150	11.5	10.0
■	200	12.5	10.9
■	300	14.3	12.4
■	400	15.7	13.6



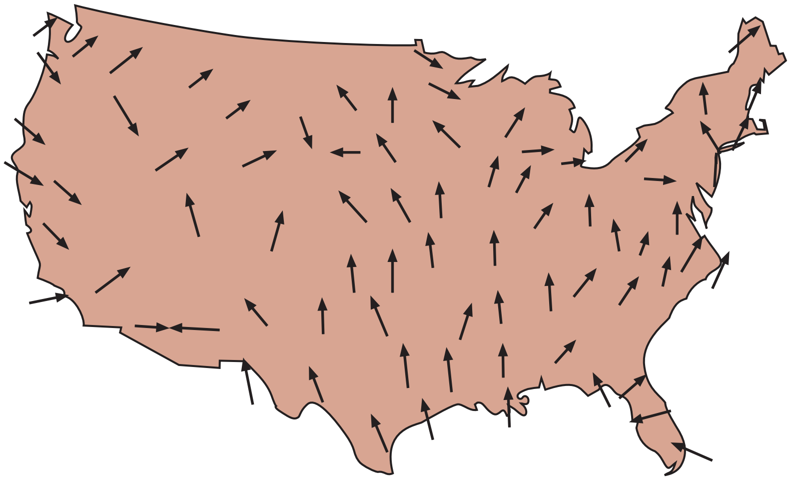
Wind Speed and Direction—*Continued*

Mean Wind Speed and Power in Winter

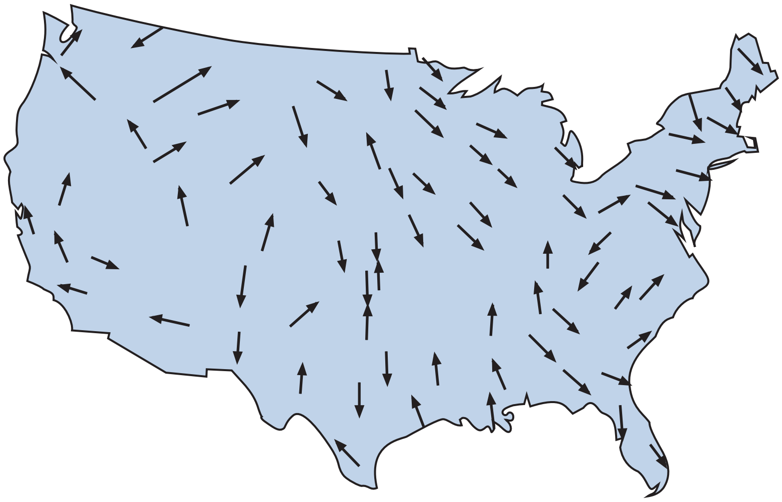
W/m^2	mph	knots
50	7.8	6.8
100	9.8	8.5
150	11.5	10.0
200	12.5	10.9
300	14.3	12.4
400	15.7	13.6



Mean Wind Direction in Summer

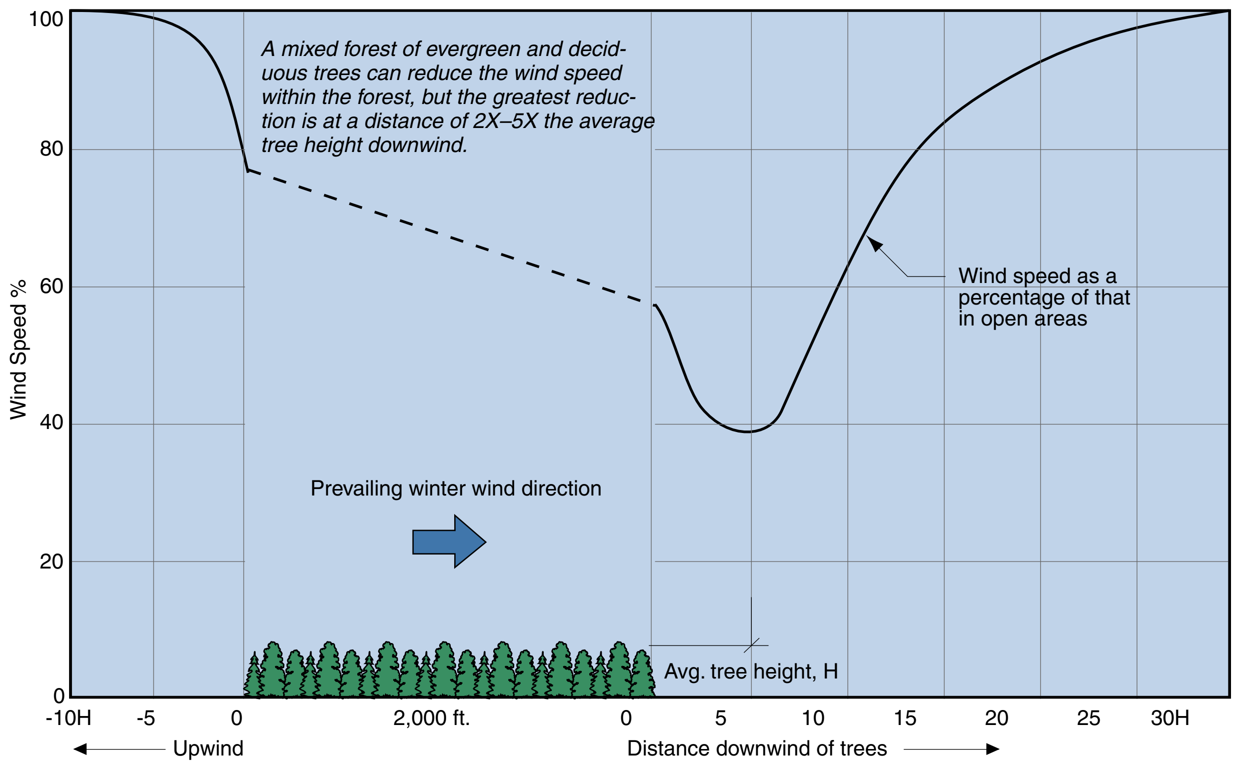


Mean Wind Direction in Winter

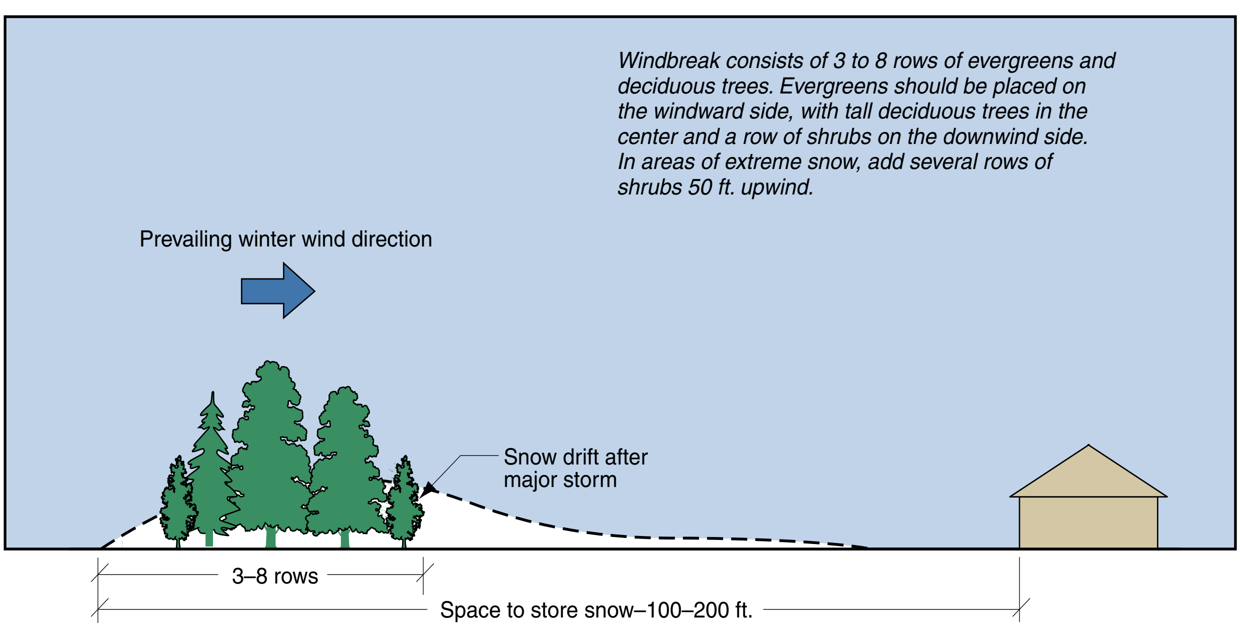


Shelterbelts

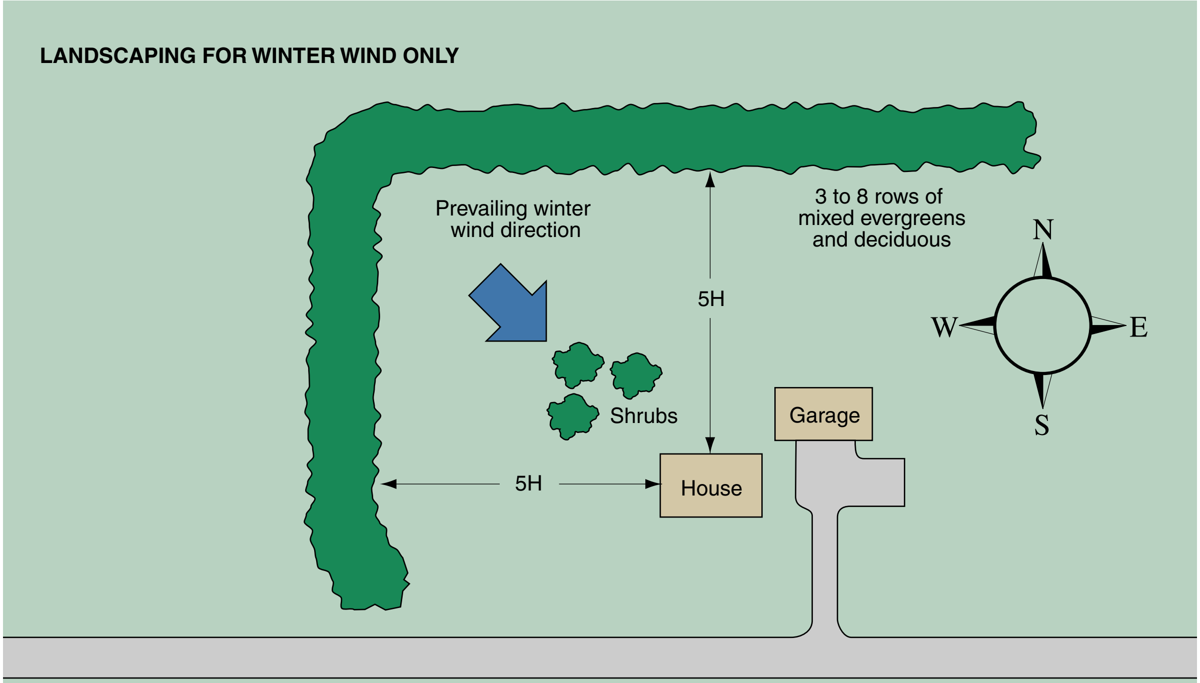
Effect of Shelterbelt on Wind Speed

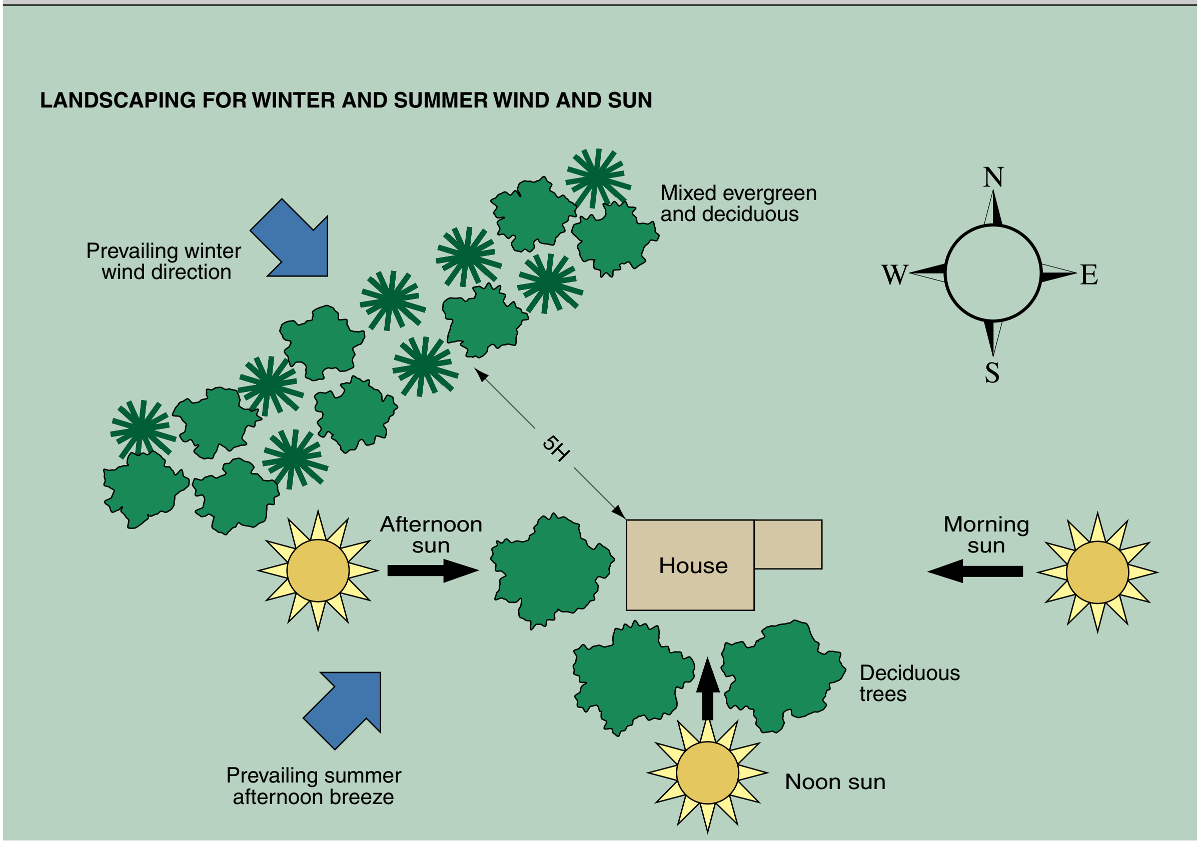


Effect of Shelterbelt on Snow Accumulation



Landscaping Strategies for Winter and Summer





Trees

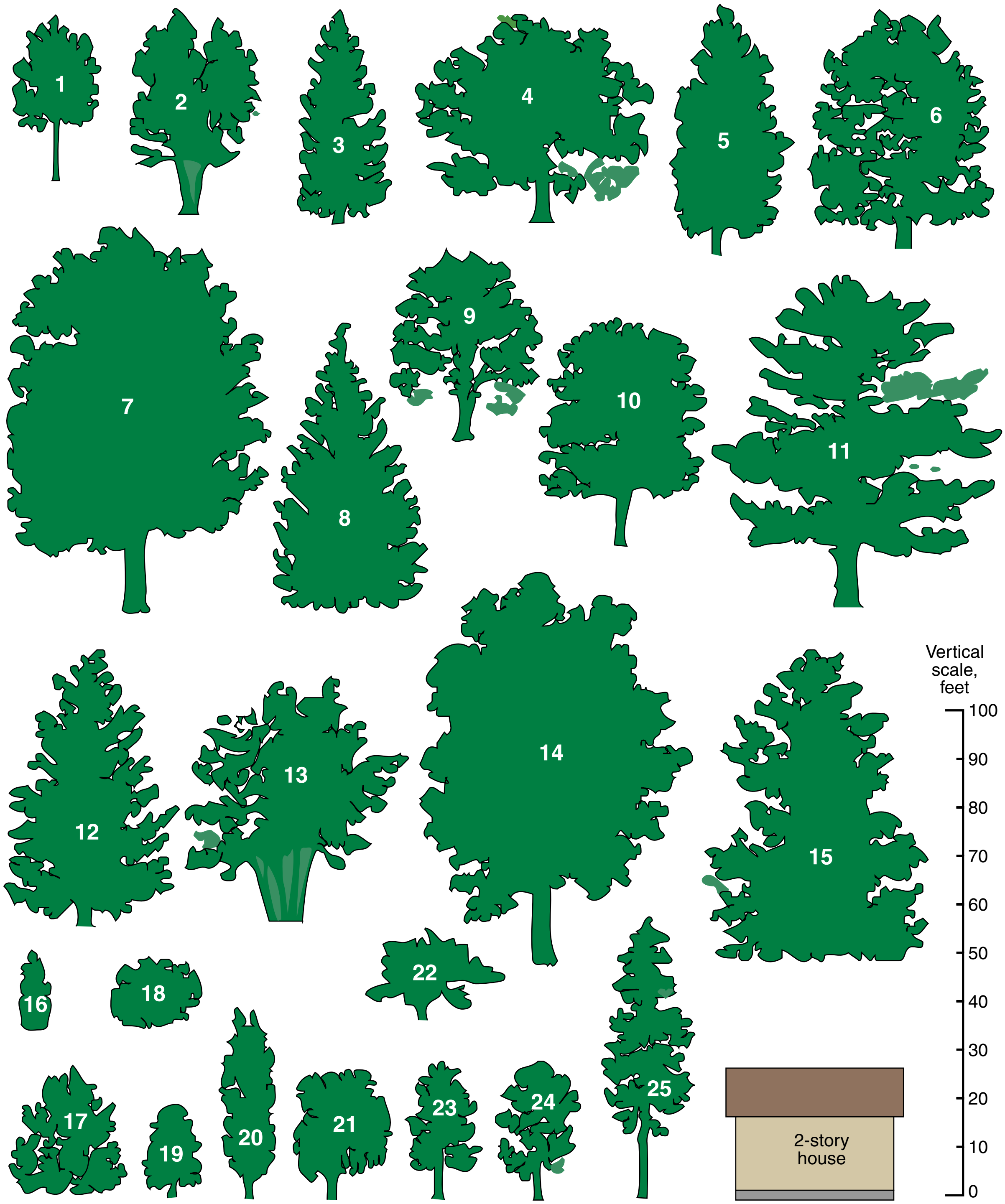
Trees for Shade and Shelter

Common Name	Hardiness Zones	Type[1]	Height feet	Width feet	Spacing feet	Features
1. Quaking aspen	2–5	D	35	5	7	Excellent visual screen
2. Paper birch	2-5	D	45	20	15	White bark, very hardy
3. White spruce	2-5	E	45	20	10	Good for windbreak
4. Bur oak	2-5	D	45	20	15	Requires good soil for full size
5. Eastern red cedar	2-8	E	50	10	7	Good screen, tolerates dry soil
6. Norway maple	3-6	D	50	30	25	Grows in city, grows fast
7. Sugar maple	3-6	D	80	50	40	Beautiful foliage, sugar sap
8. Norway spruce	3-5	E	60	25	14	Grows fast, prefers sun
9. Red maple	3-6	D	40	30	25	Brilliant foliage, grows fast
10. Green ash	3-6	D	50	30	25	Grows fast in most soils
11. Eastern white pine	3-6	E	70	40	12	Grows very fast in most soils
12. Eastern hemlock	3-7	E	60	30	8	Good screen, grows in shade
13. White poplar	3-5	D	50	12	10	Grows very fast, short life
14. Pin oak	4-7	D	80	50	30	Keeps leaves in winter
15. Japanese cryptomeria	6-8	E	70	20	10	Good screen, grows fast
16. Oriental arborvitae	7–9	E	16	6	3	Grows fast in most soils
17. Rocky Mountain juniper	4-7	E	25	10	6	In West only, dry soils
18. Black haw	4-7	D	15	15	5	White flowers, red berries
19. American holly	6-9	E	20	8	8	Spined leaves, red berries
20. Lombardy poplar	6.8	D	40	6	4	Grows fast, all soils
21. Weeping willow	6-8	D	30	30	30	Drooping branches, wet soils
22. Sea grape	10	E	20	8	4	Very decorative
23. Northern white cedar	3-6	E	30	12	8	Good screen, loamy soil
24. Southern magnolia	8-9	E	30	10	5	Large white flowers
25. Douglas fir	4-6	E	60	25	12	Grows fast, up to 200'

Source: W. R. Nelson, Jr., *Landscaping Your Home* (Urbana-Champaign: University of Illinois, 1975).

[1] D = deciduous, E = evergreen.

Typical Mature Tree Heights



Lawns

Use the map below to select grass seed for your area. The table on the facing page lists the characteristics of each of the grasses listed.

Grass Seed Zones

1. Best adapted to this cool zone are fine fescues, Kentucky bluegrass, and creeping bentgrass. Winter kill can be the limiting factor for tall fescue and perennial ryegrass.

2. Warmer than Zone 1. Perennial ryegrass and tall fescues do well here, either alone or mixed.

3. Zone characterized by high heat and humidity. Best grasses would be tall fescue, perennial ryegrass, Bermudagrass, and zoysiagrass.

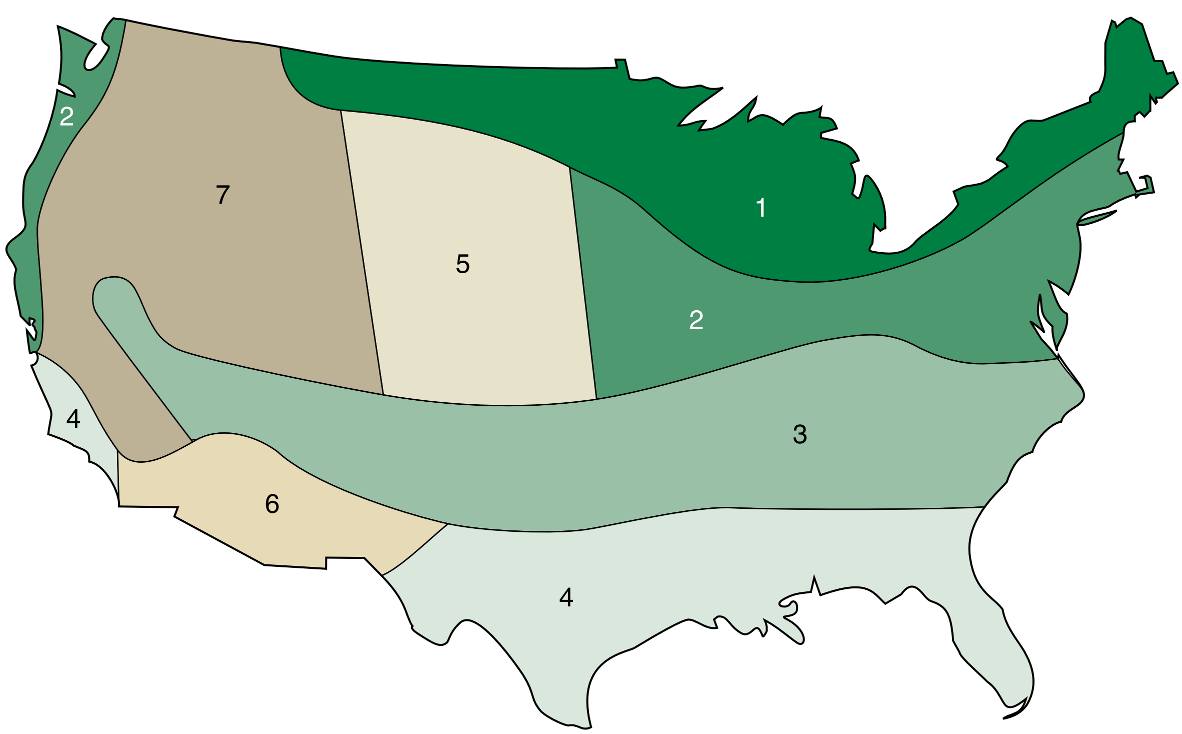
4. Even warmer and more humid than Zone 3. Best grasses in sunlight are Bermudagrass, zoysiagrass, and Bahiagrass. Tall fescue does well here in shade.

5. This zone is characterized by cold winters and hot and dry summers. Bluegrass, perennial ryegrass, tall and fine fescues, bentgrass, Bermudagrass, and zoysiagrass do well here. Irrigation is required. If irrigation is not possible, use either tall or fine fescue.

6. Zone is extremely hot and dry during summer. In areas of full sun use Bermudagrass and zoysiagrass. In shady locations, especially where irrigation is possible, plant tall fescue. Overseeding with annual or perennial ryegrass during the dormant season is recommended for golf courses and other high-use areas.

7. Climate is extremely variable in this mountainous zone. Bluegrass is most popular in the northern areas. Tall fescue is more common in the southern areas of the zone.

Grass Seed Zones



Grasses for Lawns

Seed Name	Appearance	Texture	Common Applications	Relative Cost	Relative Maintenance	Planting Depth, in	Spread Rate lb/1,000 sq ft
Bahiagrass Argentine	Good	Coarse to medium	Lawns and traffic areas	Low	Low	¼–½	5–10
Bahiagrass Pensacola	Average	Medium	Lawns and roadways	Low	Low	¼–½	5–10
Bentgrass	Excellent	Fine	Putting greens	High	High	¼–½	½–1
Bermuda Common	Average	Fine	Lawns and sports fields	Low	Medium	¼	2–3
Bermuda Improved	Excellent	Fine	Lawns and traffic areas	Medium	High	¼	2–3
Bluegrass Kentucky	Good	Medium to fine	Lawns	Low	Low	¼–½	1–3
Bluegrass Rough	Good	Medium	Lawns and roadways	Low	Low	¼–½	1–3
Carpetgrass	Poor	Medium	Wet areas	Low	Low	¼–½	4–5
Centipede	Poor to medium	Medium	Lawns	Medium	Low	¼	¼–1
Fescue Fine	Excellent	Fine	Lawns	Medium	Medium	¼–½	3–5
Fescue Tall	Good	Medium	Lawns and sports fields	Medium	Medium	¼–½	5–10
Ryegrass Annual	Poor	Fine	In conservation seed mixes	Low	Low	¼–½	5–10
Ryegrass Perennial	Poor	Medium	Lawns and sports fields	Medium	Low	¼–½	1–10
St Augustine	Good	Coarse	Lawns	High	Medium	¼–½	½–1
Zoysiagrass	Excellent	Medium to fine	Lawns	High	High	¼–½	2–3

3

Masonry

Masonry constitutes man's oldest building material. Remnants of masonry structures more than 3,000 years old still exist, bearing witness to the material's resistance to the elements.

Chief among masonry materials are *concrete*, which can be poured into forms, and *mortar*, which is the glue used to fasten solid masonry units together.

Aside from floor slabs, most concrete in residential construction is used in concrete masonry units (CMU). We begin with the details of typical *CMU wall construction.* In addition to the ubiquitous 8×8×16 concrete block, there is a wide variety of other *typical CMU sizes*. In addition to walls, driveways, walks, and patios are often constructed of *concrete pavers*.

A second whole class of masonry consists of brick. As with concrete, there is a wide range of standard *brick sizes*. More than with CMU, brick is used in a variety of *wall positions and patterns* to achieve architectural designs.

Walls consisting entirely of brick are rare today. Instead, cost and practical considerations have led to the development of three hybrid systems: *brick masonry cavity walls*, *brick veneer/steel stud walls*, and *brick veneer/wood stud walls*.

In both design and construction, our tables for *brick wall heights* and for *estimating brick and mortar* will prove time savers. And as with concrete, bricks are often used in walks and patios as *brick pavement*.

The last type of masonry is stone. Stone is a very difficult and expensive material for residential construction. However, cultured stone—concrete cast and colored to resemble a variety of natural stones—makes possible *stone veneer construction*.

Finally, we provide another handy crib sheet to make sure your masonry design will *meet the code*.

Concrete

Concrete is reconstituted stone. Consisting of gravel aggregate, sand, and portland cement, it is as strong as most naturally occurring rock and will last as long. Made improperly, it cracks and crumbles and may have to be replaced within a few years.

Properly made concrete has four characteristics:

1. Correct ratio of clean and well-sized materials. The proper ratios of materials ensure that all sand grains are surrounded by cement and that all gravel pebbles are surrounded by sand.

2. Correct amount of water. Portland cement chemically combines with the water (the cement hydrates). Too little water results in unhydrated cement; too much water leaves voids when the water eventually escapes.

3. Long curing time. Complete hydration requires many days. To prevent evaporation of the water, the surface of the concrete should be kept damp for up to a week.

4. Air entrainment. When concrete is exposed to freezing, water within the cured concrete can freeze and expand and crack the concrete. Air-entraining admixtures form billions of microscopic air bubbles, which act as pressure relief valves for freezing water.

Recommended Concrete Mixes

Application	Cement 94-lb Sacks	Sand cu ft	Gravel cu ft	Gal. Water if Dry	Sand Wet	Makes cu ft
Severe weather, heavy wear, slabs < 3″ thick	1.0	2.0	2.2	5.0	4.0	3.5
Slabs > 3″ thick, sidewalks, driveways, patios	1.0	2.2	3.0	6.0	5.0	4.1
Footings, foundation walls, retaining walls	1.0	3.0	4.0	7.0	5.5	5.0

Estimating Concrete for Slabs, Walks, and Drives (cubic yards)

Slab Area	Slab Thickness, inches							
sq ft	2	3	4	5	6	8	10	12
10	0.1	0.1	0.1	0.2	0.2	0.3	0.3	0.4
50	0.3	0.5	0.6	0.7	0.9	1.2	1.4	1.9
100	0.6	0.9	1.2	1.5	1.9	2.5	3.0	3.7
300	1.9	2.8	3.7	4.7	5.6	7.4	9.4	11.1
500	3.1	4.7	6.2	7.2	9.3	12.4	14.4	18.6

Estimating Concrete for Footings and Walls (cubic yards per linear foot)

Depth/Height	Width or Thickness, inches				
inches	6	8	12	18	24
8	0.012	0.017	0.025	0.037	0.049
12	0.019	0.025	0.037	0.056	0.074
24	0.037	0.049	0.074	0.111	0.148
72	0.111	0.148	0.222	0.333	0.444
96	0.148	0.198	0.296	0.444	0.593

Mortar

Mortar is a mixture of cement, lime, and sand for the bonding together of unit masonry (bricks, blocks, or stone). It differs from concrete in two ways: 1) because it is used in thin layers, it contains no gravel aggregate, and 2) because brick and block laying is a slow process, it contains hydrated lime to retain water and retard setup.

Availability

For small jobs requiring up to 1 cubic foot of mortar (about thirty 8×8×16-inch blocks or seventy 2×4×8-inch bricks), purchase a bag of mortar mix that requires only the addition of water. For larger jobs, buy sacks of masonry cement. To each sack add 3 cubic feet of clean, sharp sand and enough water to make the mix plastic. Precolored mortar mixes are also available through masonry supply outlets.

Mixing

Unless you are a professional mason, or more than one bricklayer is at work, mix small batches of mortar by hand, because it must be used within approximately 1 hour. Do not lay masonry when there is any danger of freezing. Calcium chloride accelerator is sometimes used to speed setup and lessen the chances of freezing, but it can later cause efflorescence (a white, powdery deposit) on wall surfaces. Use the bottom table below to estimate quantities of mortar for various masonry wall constructions.

Recommended Mortar Mixes

Mortar Type	Compressive Strength @ 28 days	Portland Cement	Masonry Cement	Sand
M	2,500 psi	1 Bag	1 Bag	6 cu ft
S	1,800 psi	1/2 Bag	1 Bag	4.5 cu ft
N, S, or M	750 psi	0	1 Bag	3 cu ft

Estimating Mortar (per 1,000 masonry units)

Masonry Unit Dimensions, inches	Mortar Type	Portland Cement, lb	Masonry Cement, lb
3⁵/₈×2¹/₄×8 standard brick	M	329	245
3⁵/₈×2¹/₄×8 standard brick	S	219	327
3⁵/₈×2¹/₄×8 standard brick	N, S, or M	0	490
3⁵/₈×3⁵/₈×8 utility brick	M	423	315
3⁵/₈×3⁵/₈×8 utility brick	S	260	420
3⁵/₈×3⁵/₈×8 utility brick	N, S, or M	0	700
3⁵/₈×2¹/₄×8 Norman	M	329	245
3⁵/₈×2¹/₄×8 Norman	S	235	350
3⁵/₈×2×8 Norman	N, S, or M	0	560
8×8×16 block	M	1,034	770
8×8×16 block	S	705	1,050
8×8×16 block	N, S, or M	0	1,750

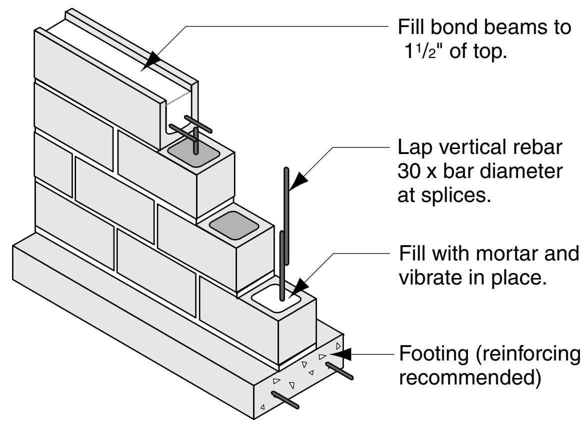
CMU Wall Construction

Exterior residential walls up to 35 feet in height may be constructed of 8-inch-thick concrete masonry units (blocks). Interior load-bearing walls may be the same, or they may be 6-inch-thick up to 20 feet in height.

Unless protected by shallow-foundation insulation (see Chapter 4), footings must be poured beneath the local frost depth. Mortar should be applied only to the perimeter of the block, except on all faces of blocks to be filled.

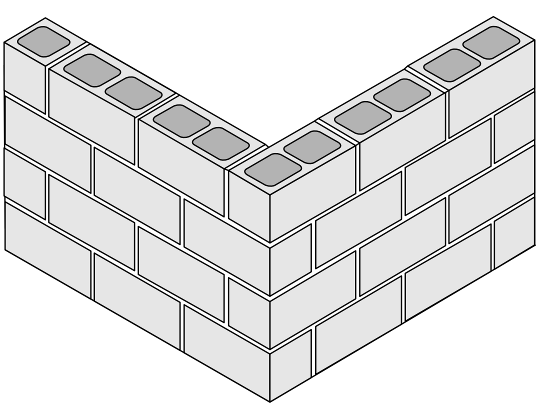
The top course of the wall should be made solid, preferably by filling and reinforcing a continuous bond beam. Vertical rebar should be placed 16 or 24 inches on-center.

Typical CMU Wall Construction

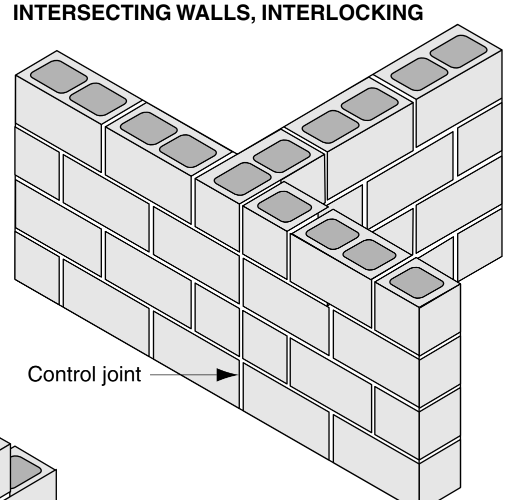


Corners and Intersections

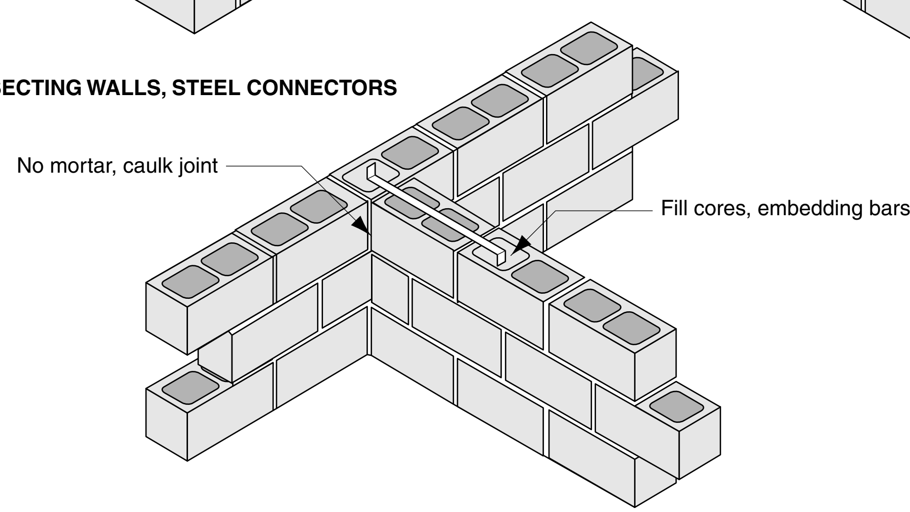
OUTSIDE CORNER, INTERLOCKING



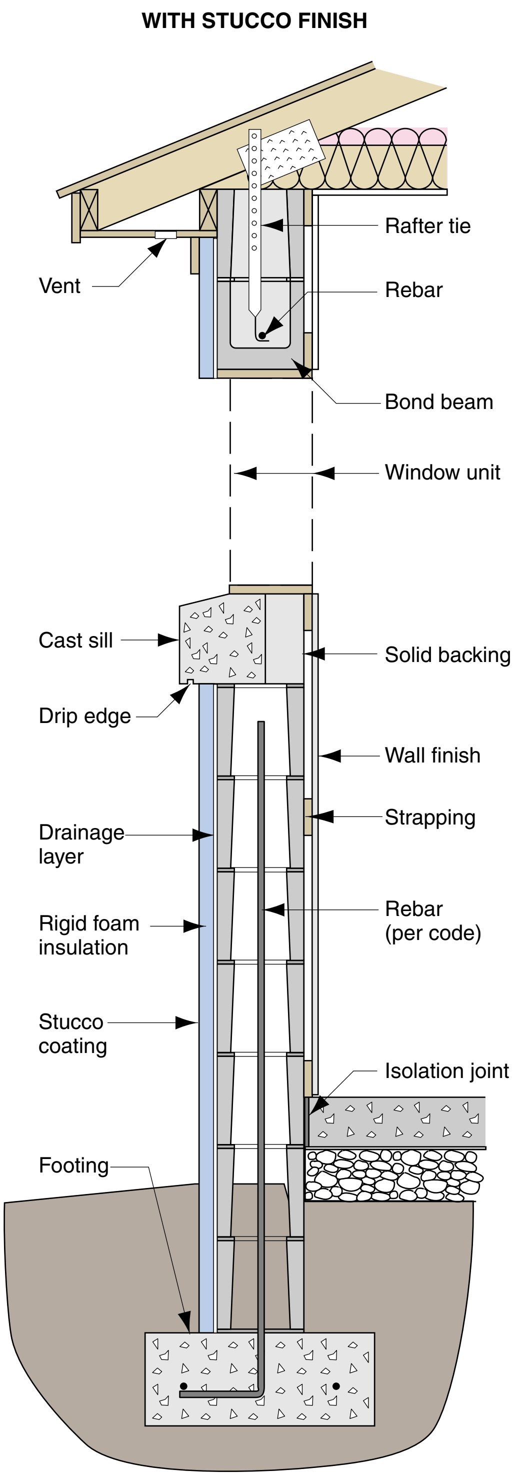
INTERSECTING WALLS, INTERLOCKING

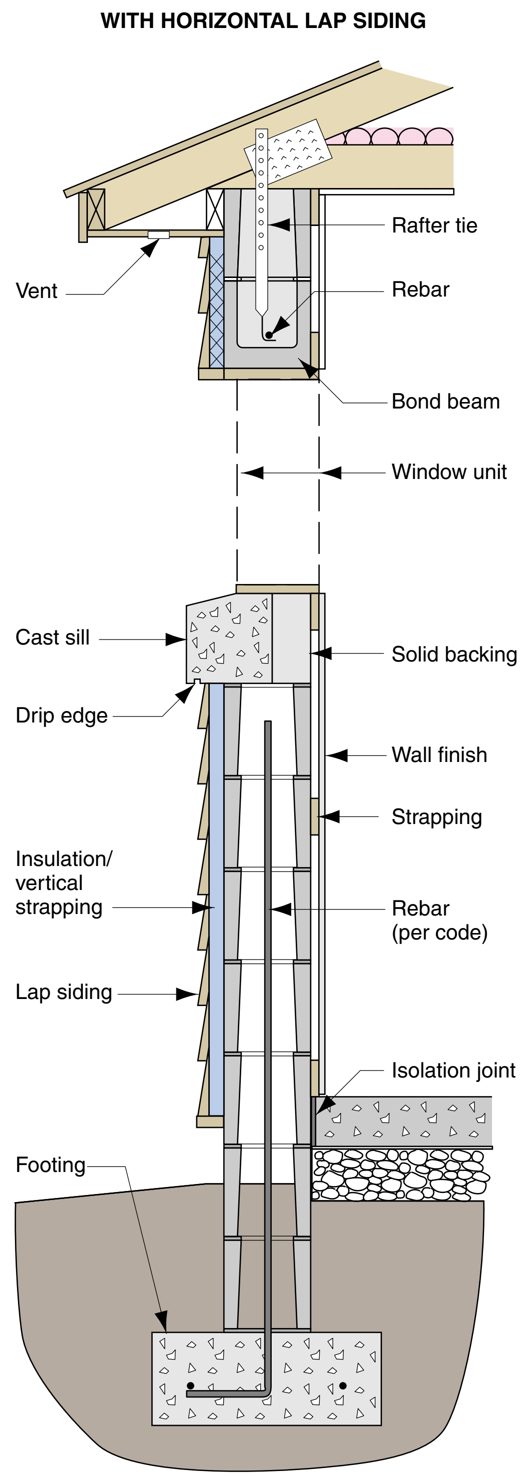


INTERSECTING WALLS, STEEL CONNECTORS



Typical Walls with Exterior Insulation

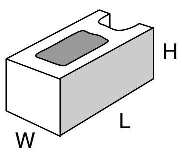




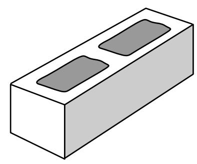
Typical CMU Sizes

Dimensions of Typical CMU

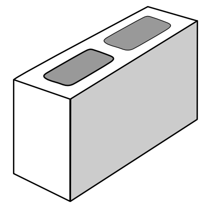
Dimensions actual WxLxH



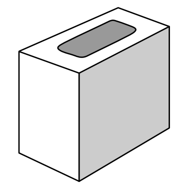
Partition
3 5/8"x7 5/8"x3 5/8"



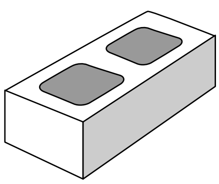
Half partition
3 5/8"x15 5/8"x3 5/8"



Partition
3 5/8"x15 5/8"x7 5/8"



Double ends
3 5/8"x7 5/8"x7 5/8"



Double ends
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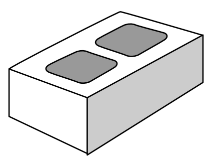

Double ends
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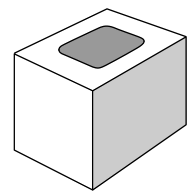

Double ends
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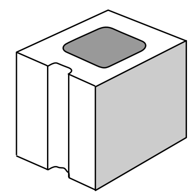
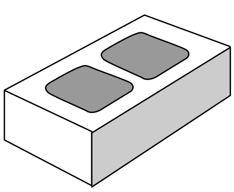
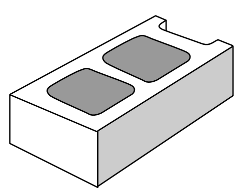


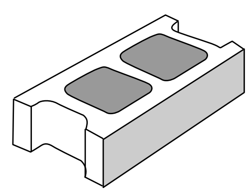
Half jamb
5 5/8"x7 5/8"x7 5/8"



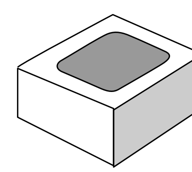
Half-high double end
7 5/8"x15 5/8"x3 5/8"



Half-high
7 5/8"x15 5/8"x3 5/8"



Half-high stretcher
7 5/8"x15 5/8"x3 5/8"



Half-high
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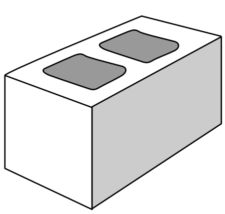
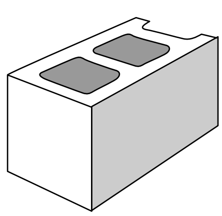
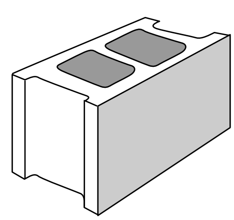


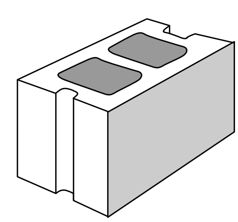
Double end
7 5/8"x15 5/8"x7 5/8"



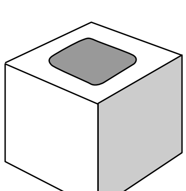
Regular
7 5/8"x15 5/8"x7 5/8"



Stretcher
7 5/8"x15 5/8"x7 5/8"



Steel sash jamb
7 5/8"x15 5/8"x7 5/8"



Plain ends
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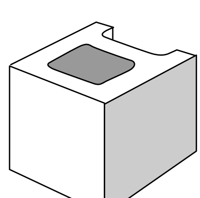
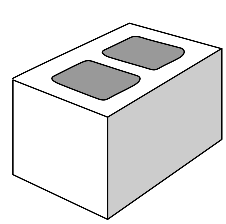
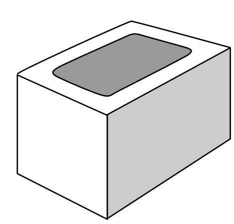


Half block
7 5/8"x7 5/8"x7 5/8"



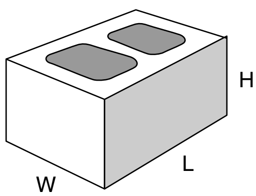
Double ends
7 5/8"x11 5/8"x7 5/8"



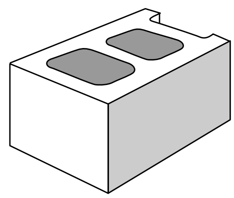
Plain ends
7 5/8"x11 5/8"x7 5/8"

Dimensions of Typical CMU—*Continued*

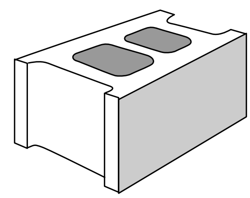
Dimensions actual WxLxH



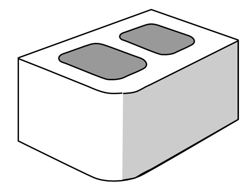
Double ends
$11^{5}/_{8}$"x$15^{5}/_{8}$"x$7^{5}/_{8}$"



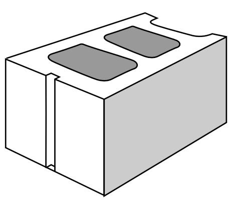
Regulars
$11^{5}/_{8}$"x$15^{5}/_{8}$"x$7^{5}/_{8}$"



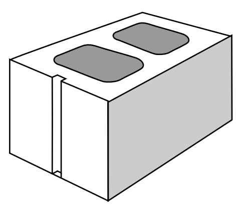
Stretcher
$11^{5}/_{8}$"x$15^{5}/_{8}$"x$7^{5}/_{8}$"



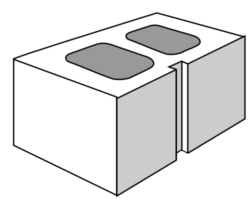
Single bull-nose
$11^{5}/_{8}$"x$15^{5}/_{8}$"x$7^{5}/_{8}$"



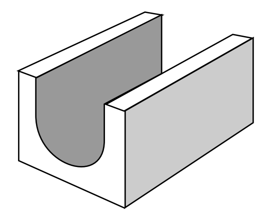
Steel sash jamb
$11^{5}/_{8}$"x$15^{5}/_{8}$"x$7^{5}/_{8}$"



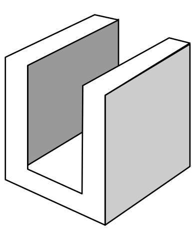
Jamb
$11^{5}/_{8}$"x$15^{5}/_{8}$"x$7^{5}/_{8}$"



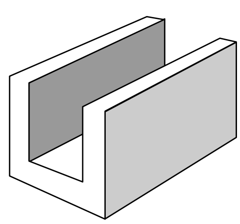
Twin
$11^{5}/_{8}$"x$15^{5}/_{8}$"x$7^{5}/_{8}$"



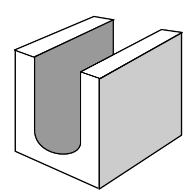
Solid bottom U block
$11^{5}/_{8}$"x$15^{5}/_{8}$"x$7^{5}/_{8}$"



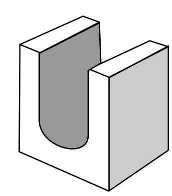
Beam
$7^{5}/_{8}$"x$7^{5}/_{8}$"x$11^{5}/_{8}$"



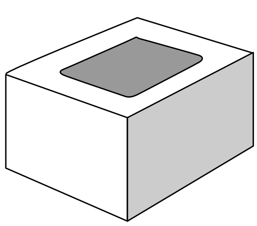
U lintel
$7^{5}/_{8}$"x$15^{5}/_{8}$"x$7^{5}/_{8}$"



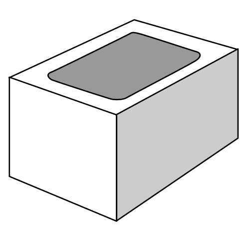
U lintel
$7^{5}/_{8}$"x$7^{5}/_{8}$"x$7^{5}/_{8}$"



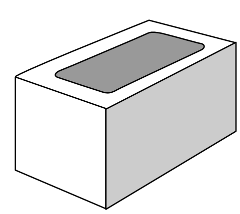
U lintel
$7^{5}/_{8}$"x$3^{5}/_{8}$"x$7^{5}/_{8}$"



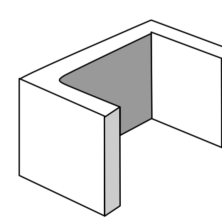
Pilaster & chimney block
$15^{5}/_{8}$"x$15^{5}/_{8}$"x$7^{5}/_{8}$"



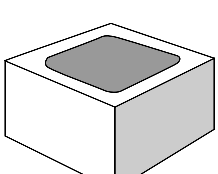
Pilaster
$11^{5}/_{8}$"x$15^{5}/_{8}$"x$7^{5}/_{8}$"



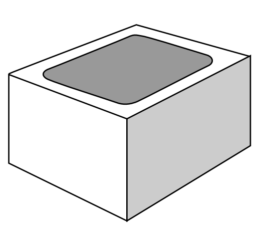
Pilaster
$7^{5}/_{8}$"x$15^{5}/_{8}$"x$7^{5}/_{8}$"



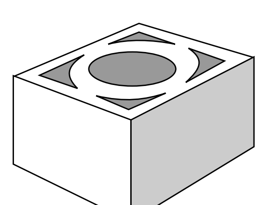
Pilaster
$7^{5}/_{8}$"x$15^{5}/_{8}$"x$7^{5}/_{8}$"



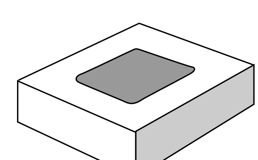
Chimney block
14"x14"x$7^{5}/_{8}$"



Column style no. 1
$15^{5}/_{8}$"x$15^{5}/_{8}$"x$7^{5}/_{8}$"



Flue block
$15^{5}/_{8}$"x$15^{5}/_{8}$"x$7^{5}/_{8}$"

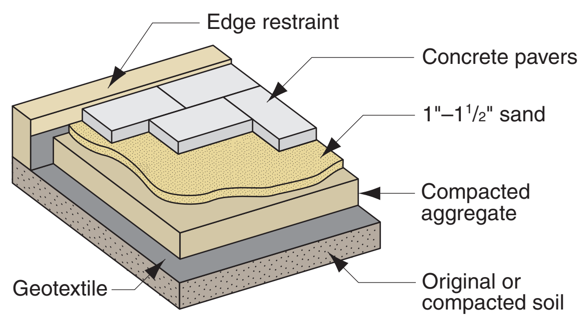


Flue block
$15^{5}/_{8}$"x$15^{5}/_{8}$"x$3^{5}/_{8}$"

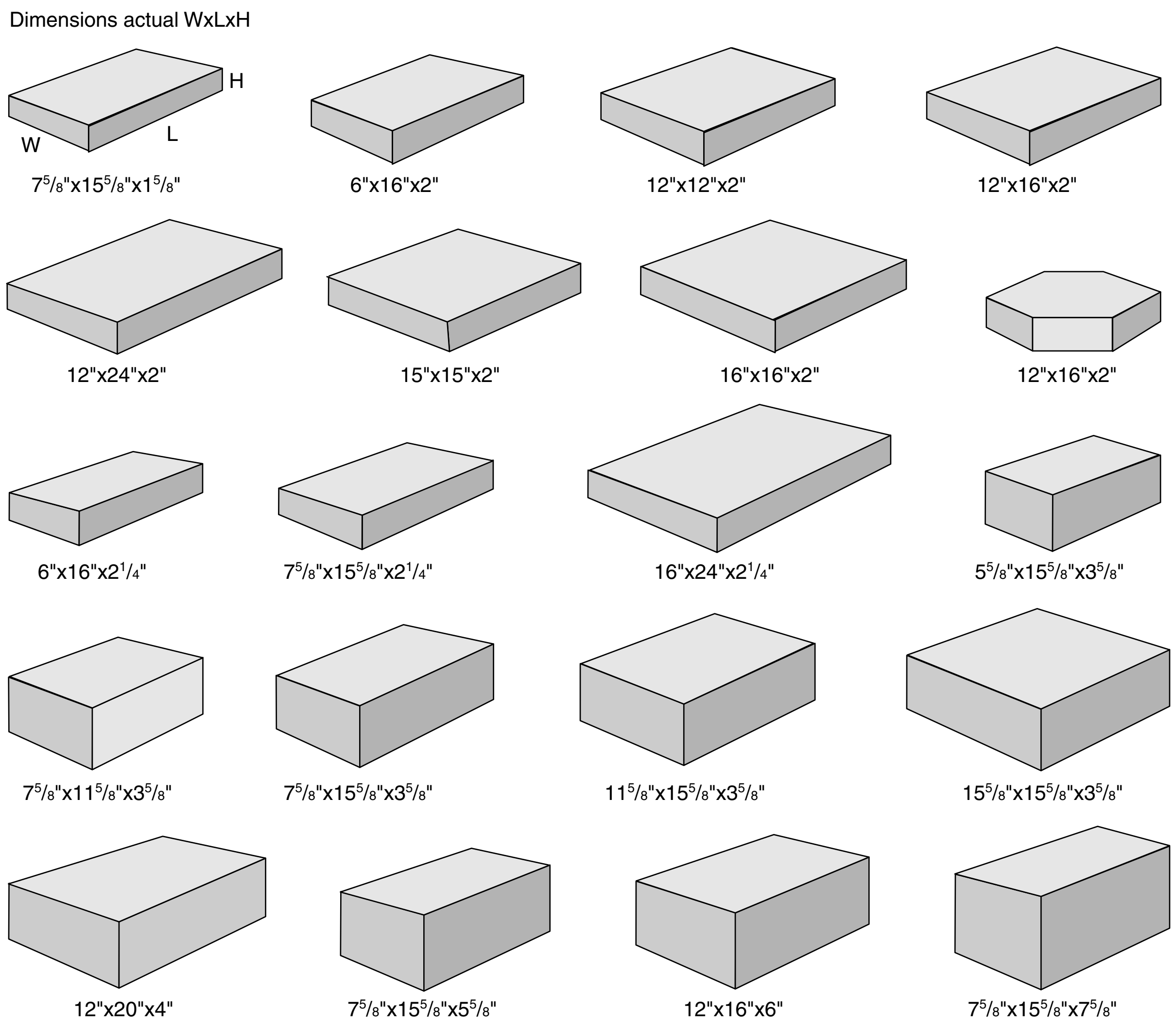
Concrete Pavers

The details for paving patios, walks, and drives with CMU pavers are similar to those for brick pavers (see "Brick Pavement" on p. 70). There is an almost infinite variety of shapes and sizes of CMU pavers. Some of the most common are shown below. Many of the shapes are available in several earthtone colors. Check with local suppliers before designing your project.

Common CMU Paver Sizes

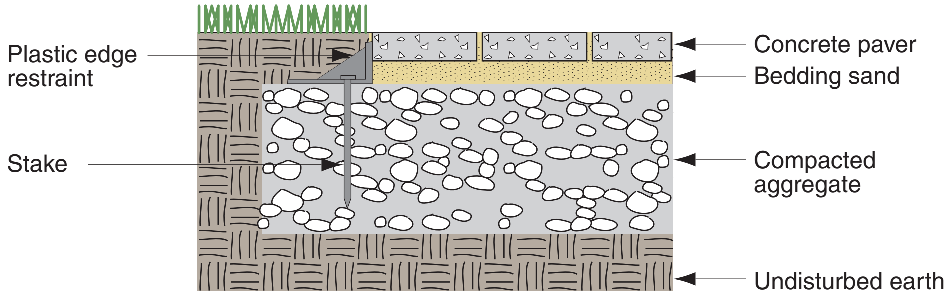


Common CMU Paver Sizes

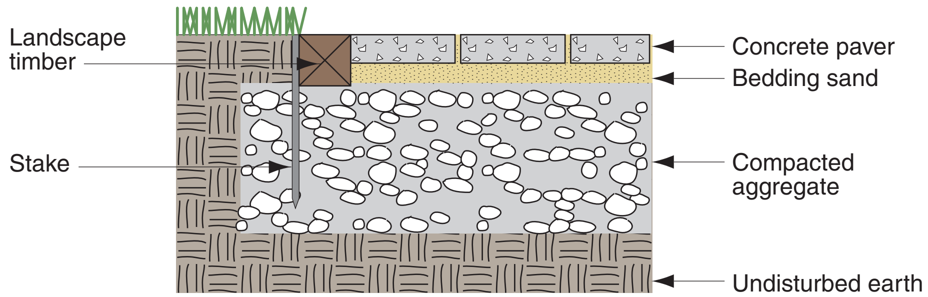


Edge Restraints

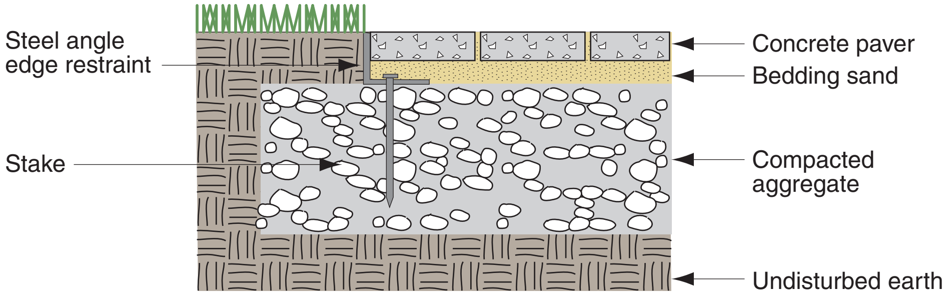
PLASTIC EDGE RESTRAINT



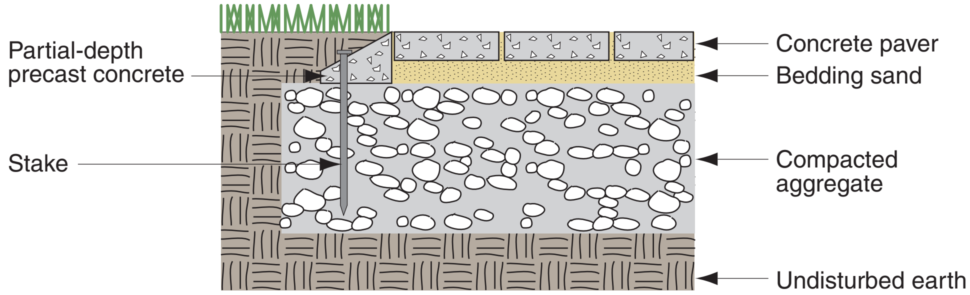
LANDSCAPE TIMBER RESTRAINT



STEEL ANGLE RESTRAINT



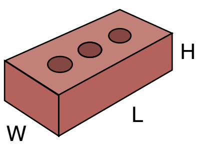
PRECAST CONCRETE RESTRAINT



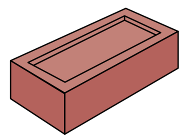
Brick Sizes

Dimensions of Common Bricks

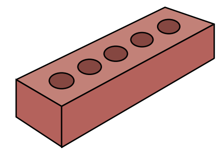
NON-MODULAR BRICK
(dimensions actual WxLxH)



Standard
$3\frac{3}{4}$"x8"x$2\frac{1}{4}$"

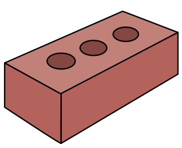


Oversize
$3\frac{3}{4}$"x8"x$2\frac{3}{4}$"

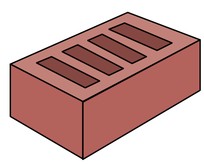


Three inch
3"x$9\frac{3}{4}$"x$2\frac{3}{4}$"

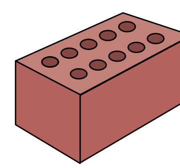
MODULAR BRICK
(dimensions nominal WxLxH)



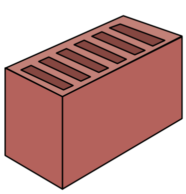
Standard
4"x8"x$2\frac{2}{3}$"



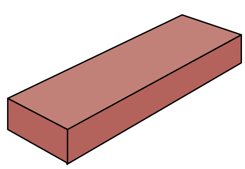
Engineer
4"x8"x$3\frac{1}{5}$"



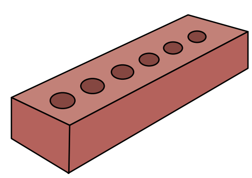
Jumbo closure
4"x8"x4"



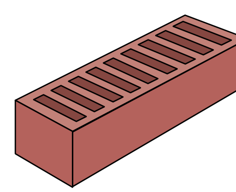
Double
4"x8"x$5\frac{1}{3}$"



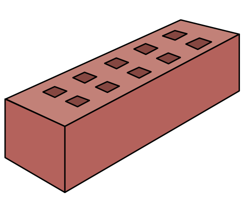
Roman
4"x12"x2"



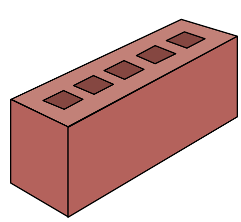
Norman
4"x12"x$2\frac{2}{3}$"



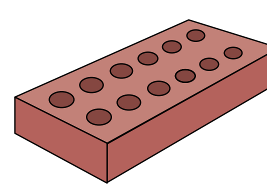
Norwegian
4"x12"x$3\frac{1}{5}$"



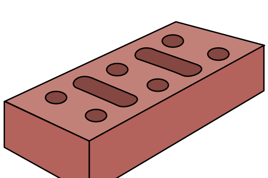
Jumbo utility
4"x12"x4"



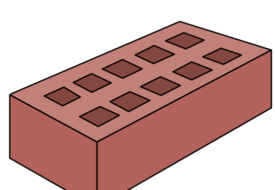
Triple
4"x12"x$5\frac{1}{3}$"



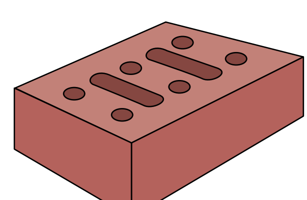
SCR brick
6"x12"x$2\frac{2}{3}$"



6" Norwegian
6"x123"x$3\frac{1}{5}$"



6" Jumbo
6"x12"x4"

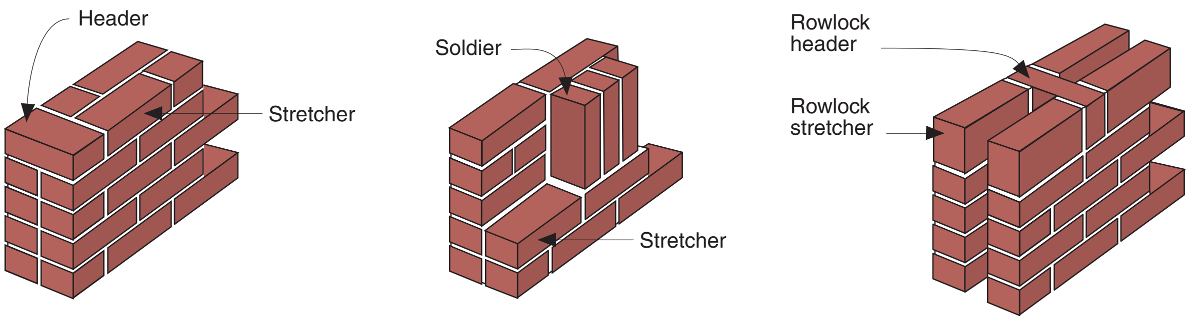


8" Jumbo
8"x12"x4"

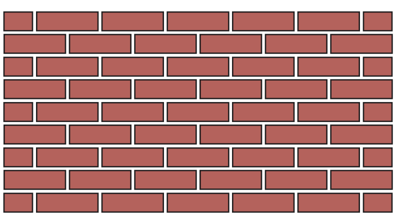
Brick Wall Positions and Patterns

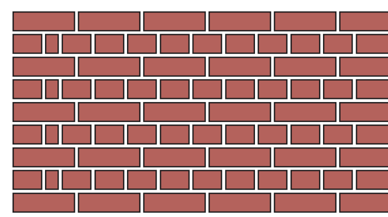
Brick Position and Pattern Terminology

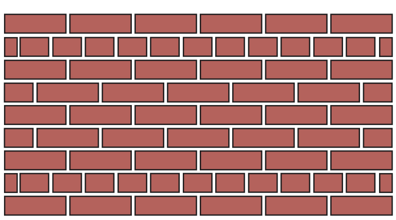
BRICK POSITIONS

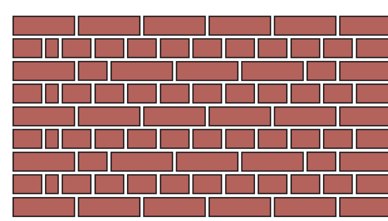


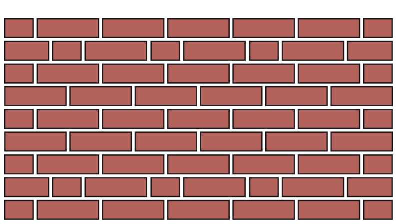
BRICK PATTERNS

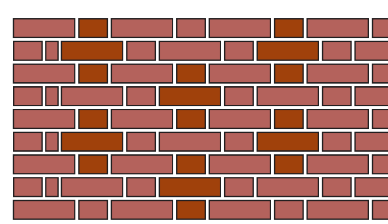

RUNNING

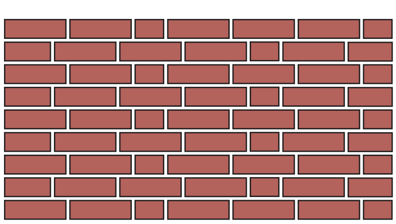

ENGLISH

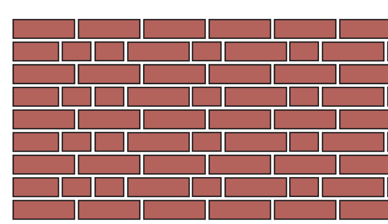

COMMON


DUTCH


COMMON WITH FLEMISH HEADERS


FLEMISH CROSS


GARDEN WALL


FLEMISH

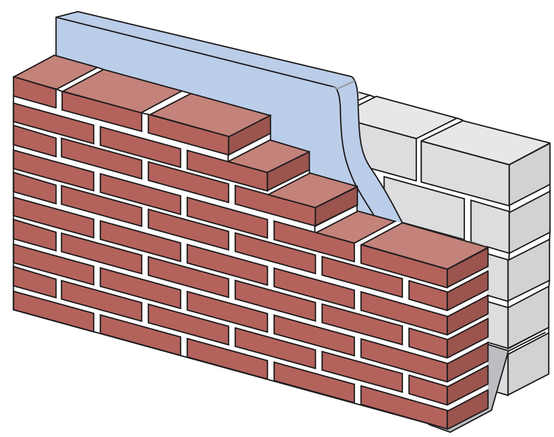
Brick Masonry Cavity Walls

Brick and concrete masonry unit cavity wall construction is common in commercial and southern residential building. Best building practice requires the use of durable brick (grade SW in ground contact and freeze areas) and adherence to proper detailing.

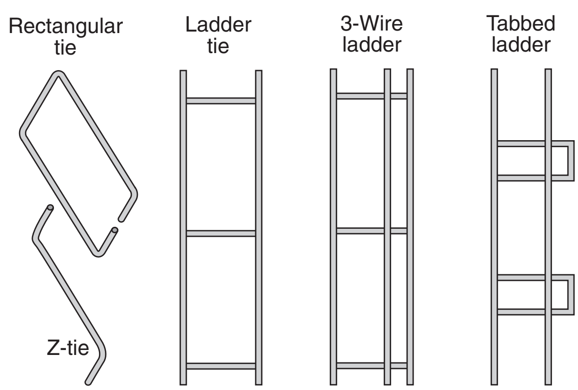
Proper detailing requires the use of drips at sills, flashing at wall top and bottom, flashing at window and door heads and sills, provision for weep holes at all flashings, and caulking at the junctions of masonry and nonmasonry materials.

Insulation is required in most locations, and a draining cavity is recommended in areas of wind-driven rain.

Brick/Masonry Cavity Construction



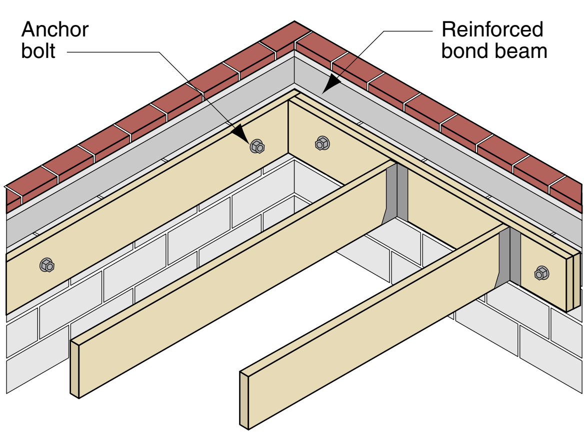
Wall Ties



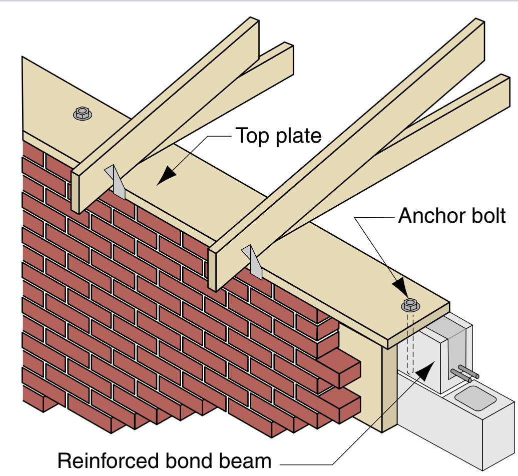
Wall Tie Spacing Requirements

Tie Wire Size in. (mm)	Wall Area per Tie No. per ft² (m²)	Max. Tie Spacing Horizontal × Vertical
W1.7 (MW11) 0.125 (3.06)	22/3 (0.25)	36 × 24 (914 × 610)
W2.8 (MW18) 0.188 (4.76)	41/2 (0.42)	36 × 24 (914 × 610)
Adjustable, with 2 W2.8 (MW18) 1.88 (4.76) legs	1.77 (0.16)	16 × 16 (406 × 406)

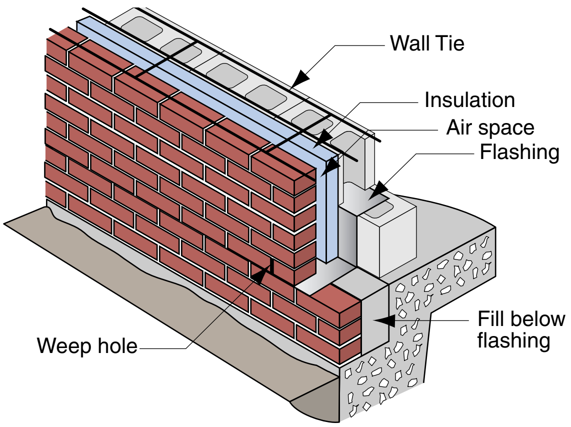
Floor Load Bearing

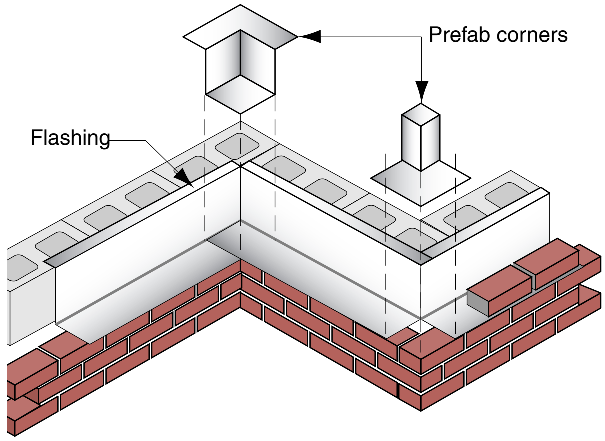


Roof Load Bearing

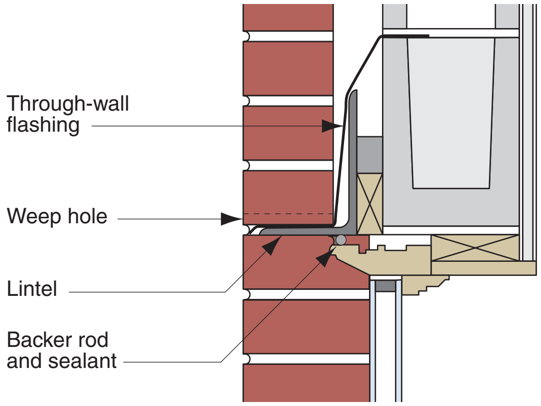


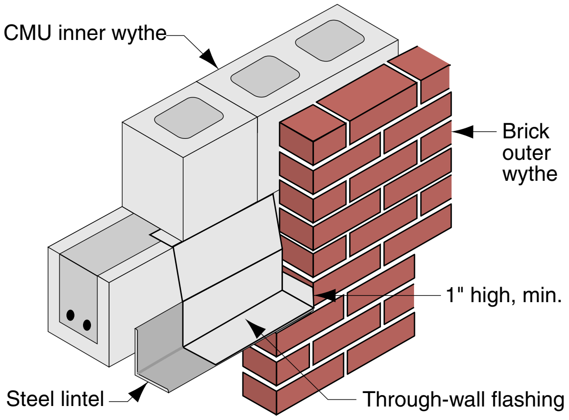
Flashing at Bottom of Wall



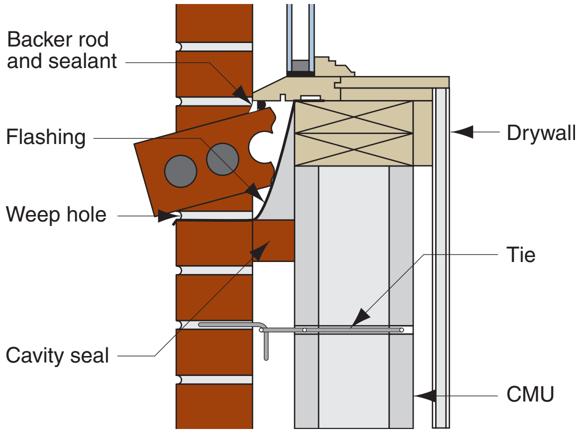


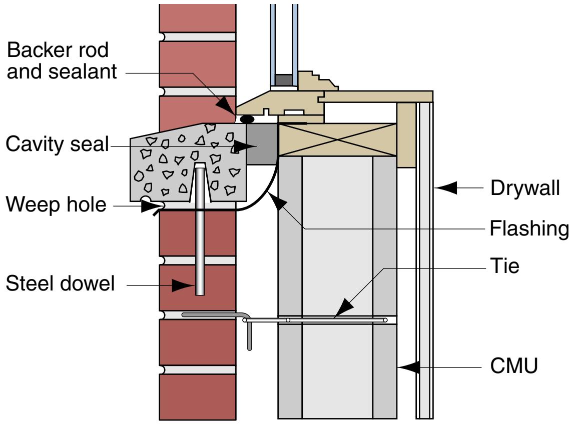
Flashing at Heads





Flashing at Sills





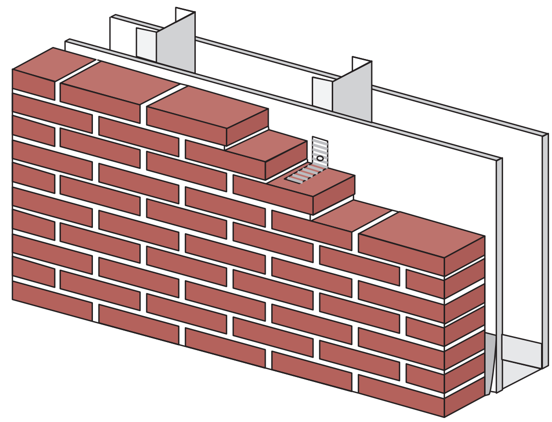
Brick Veneer/Steel Stud Walls

The brick veneer/steel stud wall system has grown, from its introduction in the 1960s, to one of the most widely used in commercial, industrial, and institutional building.

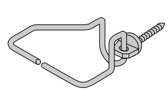
Because this style of building rarely has overhangs or gutters, the wall is not as well protected from rain, and the resulting incursion of water has required careful detailing of windscreen and flashings. The illustrations below detail flashings at wall bottoms, heads over doors and windows, and window sills.

As with all brick construction, best practice requires the use of durable brick (grade SW) in ground contact and freeze areas.

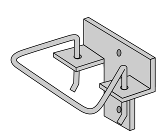
Brick Veneer and Steel Framing



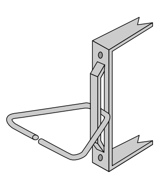
Wall Ties



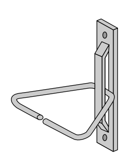
Wire and screw tie



Eye and pintle tie

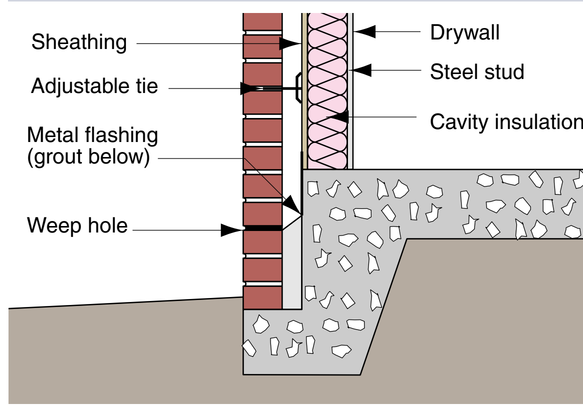


Base and tee
with prongs

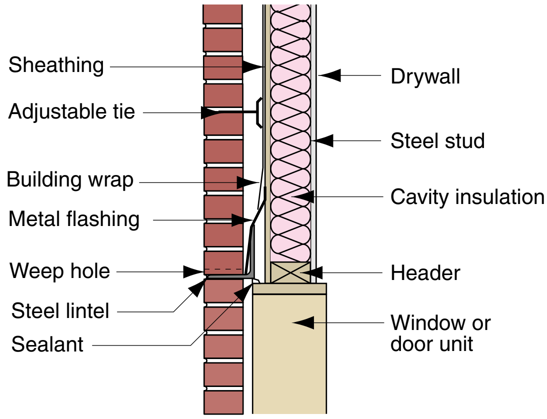


Base and tee tie

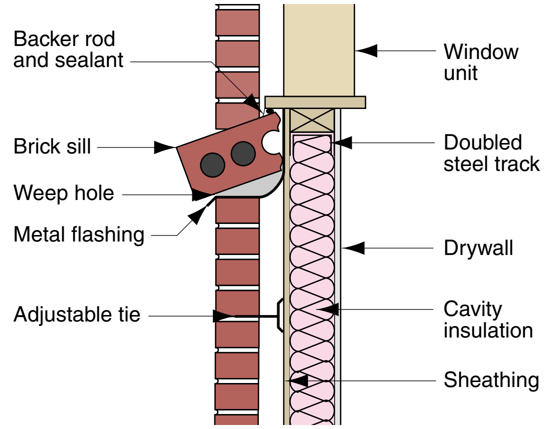
Flashing at Bottom of Wall



Flashing at Heads



Flashing at Sills

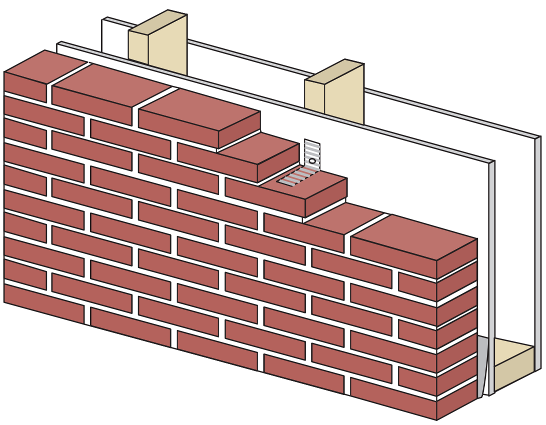


Brick Veneer/Wood Stud Walls

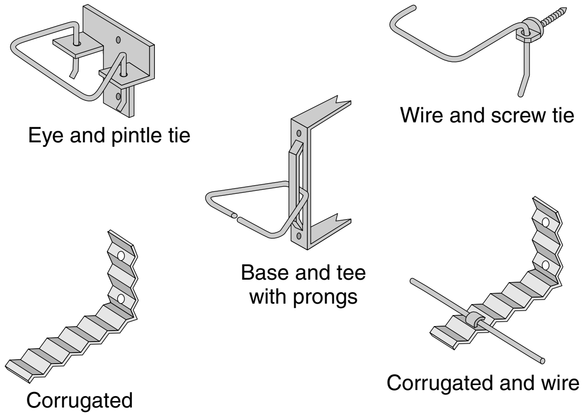
Despite its obvious strength in compression, brick veneer over a wood frame wall functions as a low-maintenance exterior finish only and not as a structural element. This is because brick and wood expand and contract with moisture and temperature differently and so cannot be rigidly bonded in the vertical plane. Because a thin brick wythe has little bending strength against wind and earthquake, however, it must be tied to the stronger wood stud wall horizontally.

The illustrations below show the most common connecting wall ties and detail the recommended flashing at wall bottoms, heads, and sills.

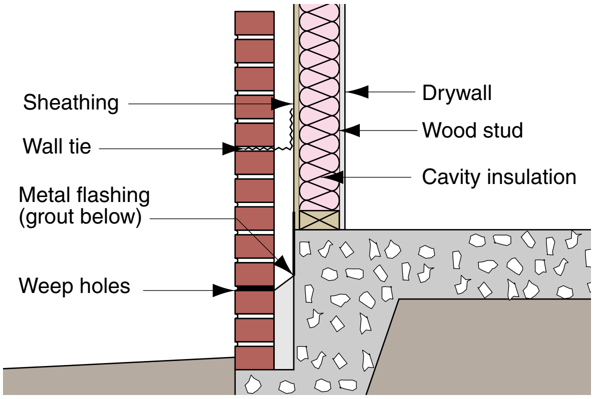
Brick Veneer and Wood Framing



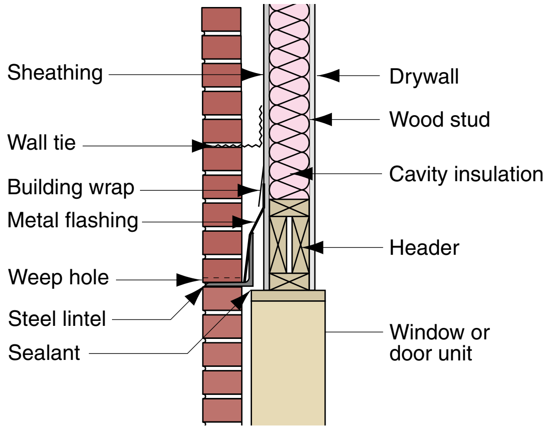
Wall Ties



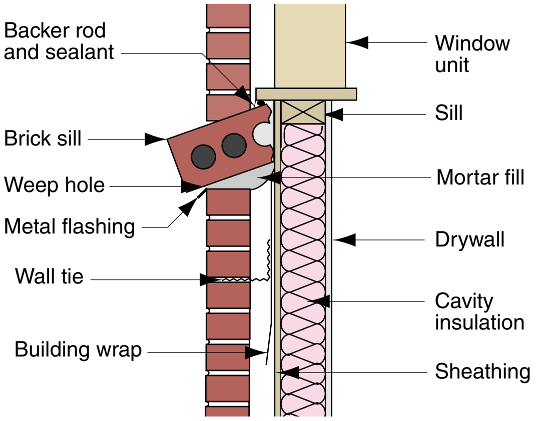
Flashing at Bottom of Wall



Flashing at Heads



Flashing at Sills



Brick Wall Heights

Heights of Nonmodular Brick Walls

Number of Courses	2 1/4-in-thick Bricks 3/8-in Joint	2 1/4-in-thick Bricks 1/2-in Joint	2 5/8-in-thick Bricks 3/8-in Joint	2 5/8-in-thick Bricks 1/2-in Joint	2 3/4-in-thick Bricks 3/8-in Joint	2 3/4-in-thick Bricks 1/2-in Joint
1	0'2 5/8"	0'2 3/4"	0'3"	0'3 1/8"	0'3 1/8"	0'3 1/4"
2	0'5 1/4"	0'5 1/2"	0'6"	0'6 1/4"	0'6 1/4"	0'6 1/2"
3	0'7 7/8"	0'8 1/4"	0'9"	0'9 3/8"	0'9 3/8"	0'9 3/4"
4	0'10 1/2"	0'11"	1'0"	1'0 1/2"	1'0 1/2"	1'1"
5	1'1 1/8"	1'1 3/4"	1'3"	1'3 5/8"	1'3 5/8"	1'4 1/4"
6	1'3 3/4"	1'4 1/2"	1'6"	1'6 3/4"	1'6 3/4"	1'7 1/2"
7	1'6 3/8"	1'7 1/4"	1'9"	1'9 7/8"	1'9 7/8"	1'10 3/4"
8	1'9"	1'10"	2'0$_8$"	2'1"	2'1"	2'2"
9	1'11 5/8"	2'0 3/4"	2'3"	2'4 1/8"	2'4 1/8"	2'5 1/4"
10	2'2 1/4"	2'3 1/2"	2'6"	2'7 1/4"	2'7 1/4"	2'8 1/2"
11	2'4 7/8"	2'6 1/4"	2'9"	2'10 3/8"	2'10 3/8"	2'11 3/4"
12	2'7 1/2"	2'9"	3'0"	3'1 1/2"	3'1 1/2"	3'3"
13	2'10 1/8"	2'11 3/4"	3'3"	3'4 5/8"	3'4 5/8"	3'6 1/4"
14	3'0 3/4"	3'2 1/2"	3'6"	3'7 3/4"	3'7 3/4"	3'9 1/2"
15	3'3 3/8"	3'5 1/4"	3'9"	3'10 7/8"	3'10 7/8"	4'0 3/4"

Heights of Modular Brick Walls

Number of Courses	Nominal Height (thickness) of Brick: 2-in	2 2/3-in	3 1/5-in	4-in	5 1/3-in
1	0'2"	0'2 11/16"	0'3 3/16"	0'4"	0'5 5/16"
2	0'4"	0'5 5/16"	0'6 3/8"	0'8"	0'10 11/16"
3	0'6"	0'8"	0'9 5/8"	1'0"	1'4"
4	0'8"	0'10 11/16"	1'0 13/16"	1'4"	1'9 5/16"
5	0'10"	1'1 5/16"	1'4"	1'8"	2'2 11/16"
6	1'0"	1'4"	1'7 3/16"	2'0"	2'8"
7	1'2"	1'6 11/16"	1'10 3/8"	2'4"	3'1 5/16"
8	1'4"	1'9 5/16"	2'1 5/8"	2'8"	3'6 11/16"
9	1'6"	2'0"	2'4 13/16"	3'0"	4'0"
10	1'8"	2'2 11/16"	2'8"	3'4"	4'5 5/16"
11	1'10"	2'5 5/16"	2'11 3/16"	3'8"	4'10 11/16"
12	2'0"	2'8"	3'2 3/8"	4'0"	5'4"
13	2'2"	2'10 11/16"	3'5 5/8"	4'4"	5'9 5/16"
14	2'4"	3'1 5/16"	3'8 13/16"	4'8"	6'2 11/16"
15	2'6"	3'4"	4'0"	5'0"	6'8"

Estimating Brick and Mortar

Nonmodular Brick[1] and Mortar[2] Required for Single-Wythe Walls in Running Bond

Size of Brick, in T×H×L	With 3/8-in Joints			With 1/2-in Joints		
	Number of Brick/ 100 sq ft	Cubic Feet of Mortar/ 100 sq ft	Cubic Feet of Mortar/ 1,000 Brick	Number of Brick/ 100 sq ft	Cubic Feet of Mortar/ 100 sq ft	Cubic Feet of Mortar/ 1,000 Brick
2 3/4×2 3/4×9 3/4	455	3.2	7.1	432	4.5	10.4
2 5/8×2 3/4×8 3/4	504	3.4	6.8	470	4.1	8.7
3 3/4×2 1/4×8	655	5.8	8.8	616	7.2	11.7
3 3/4×2 3/4×8	551	5.0	9.1	522	6.4	12.2

[1] Add at least 5% for breakage.

[2] Add 10% to 25% for waste.

Modular Brick[1] and Mortar[2] Required for Single-Wythe Walls in Running Bond

Nominal Size of Brick, in T×H×L	Number of Brick/ 100 sq ft	Cubic Feet of Mortar/ 100 sq ft		Cubic Feet of Mortar/ 1,000 Brick	
		3/8-in Joints	1/2-in Joints	3/8-in Joints	1/2-in Joints
4×2 2/3×8	675	5.5	7.0	8.1	10.3
4×3 1/5×8	563	4.8	6.1	8.6	10.9
4×4×8	450	4.2	5.3	9.2	11.7
4×5 1/3×8	338	3.5	4.4	10.2	12.9
4×2×12	600	6.5	8.2	10.8	13.7
4×2 2/3×12	450	5.1	6.5	11.3	14.4
4×3 1/5×12	375	4.4	5.6	11.7	14.9
4×4×12	300	3.7	4.8	12.3	15.7
4×5 1/3×12	225	3.0	3.9	13.4	17.1
6×2 2/3×12	450	7.9	10.2	17.5	22.6
6×3 1/5×12	375	6.8	8.8	18.1	23.4
6×4×12	300	5.6	7.4	19.1	24.7

[1] Add at least 5% for breakage.

[2] Add 10% to 25% for waste.

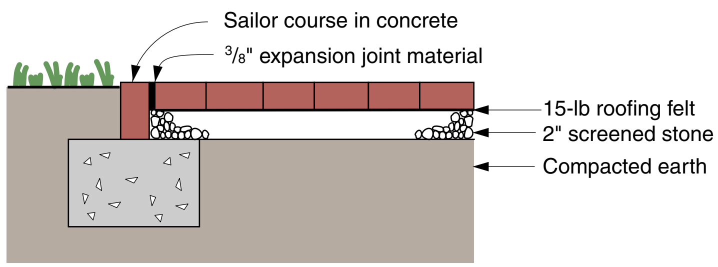
Brick Pavement

Compared with asphalt and concrete paving, brick paving is more attractive, will not crack (the cracks are part of the design), and is easy to repair.

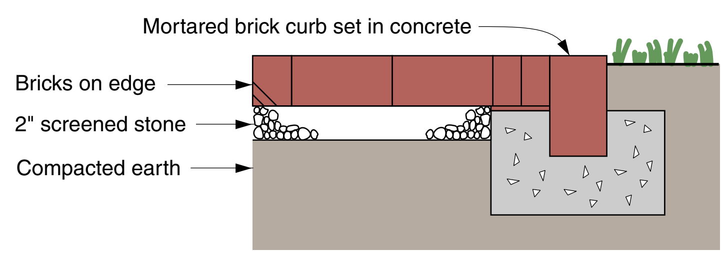
Below are designs for a walkway, a driveway, and two patios. The use of Severe Weather (SW) grade brick is recommended in all cases. All should incorporate a slope for drainage. Walks and drives should slope at least $^1/_4$ inch per foot (2% grade), but no more than $1^3/_4$ inches per foot (15% grade).

Patios should slope from $^1/_8$ to $^1/_4$ inch per foot (1% to 2% percent grade). The slopes can be from one edge to the other or from the center to the edges.

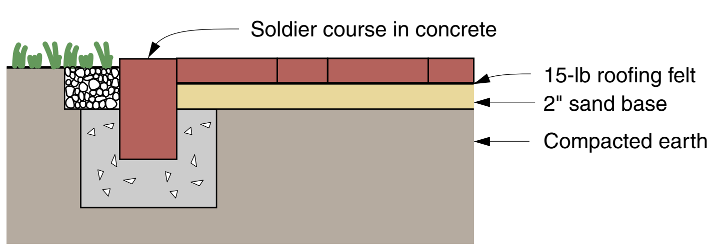
Bases for Brick Pavement



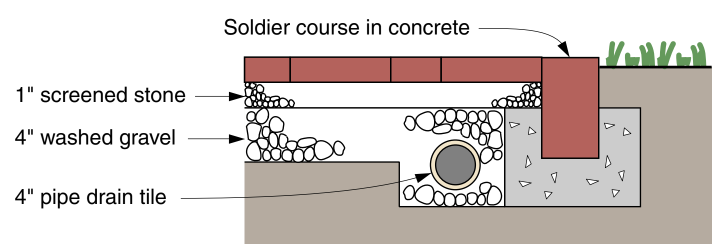
WALKWAY–GRAVEL BASE



DRIVEWAY–BRICK ON EDGE



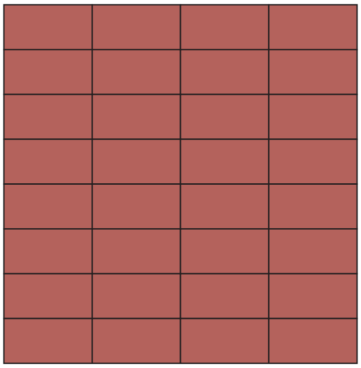
PATIO–SAND BASE



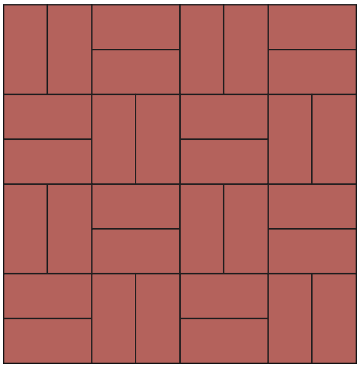
PATIO–GRAVEL BASE

Brick Pavement Patterns

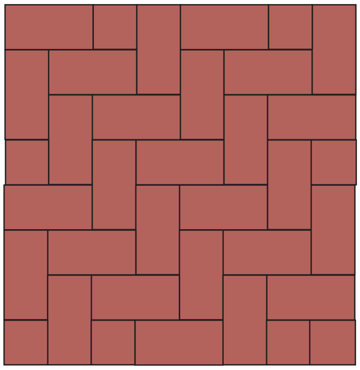
STACK BOND



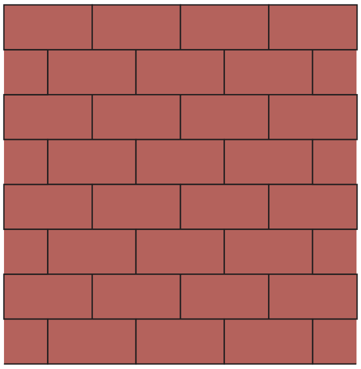
BASKET WEAVE



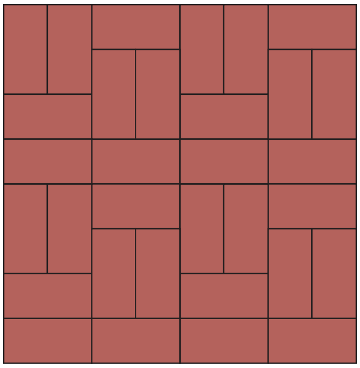
HERRINGBONE



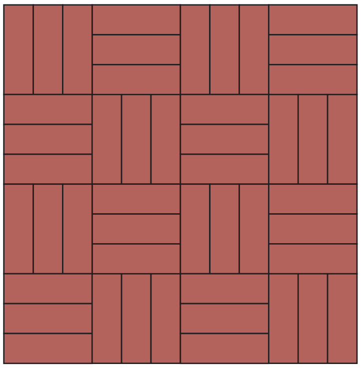
RUNNING BOND



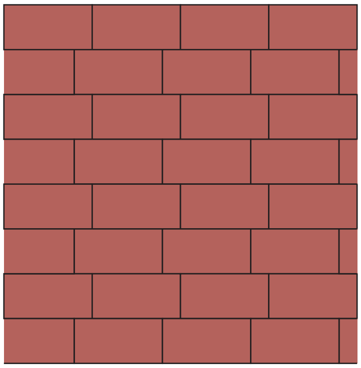
HALF-BASKET



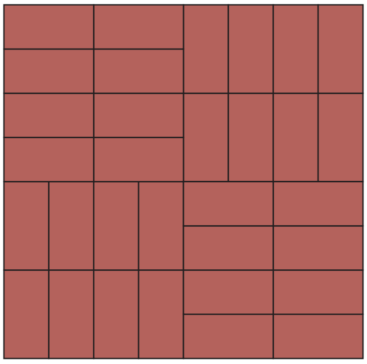
BASKET ON EDGE



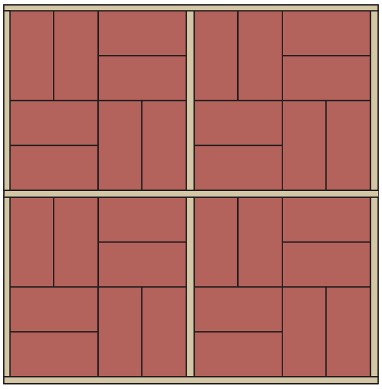
OFFSET BOND



DOUBLE-BASKET



BASKET/WOOD GRID



Stone Veneer Construction

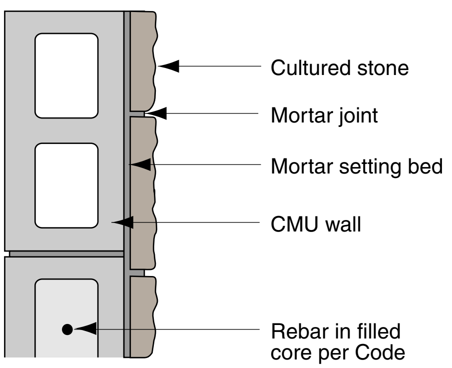
Stone walls may be built entirely of stone or they may be cultured stone (cast concrete) over a base wall of solid concrete, concrete masonry units, or wood frame and sheathing. Cultured stone is preferred today as it allows for thermal insulation.

Mortar joints should be $\frac{1}{2}$ to 1 inch thick for rubble and $\frac{3}{8}$ to $\frac{3}{4}$ inch thick for ashlar patterns.

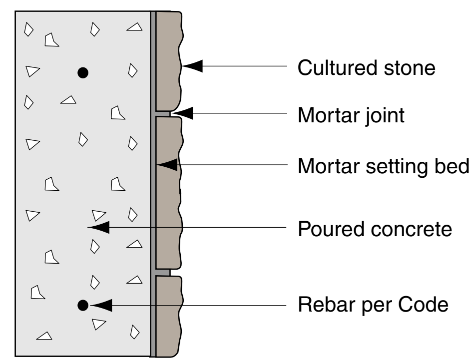
To prevent staining, all fasteners should be stainless; flashing should be either stainless or hot-dipped galvanized steel; and mortar should be nonstaining.

Construction Details

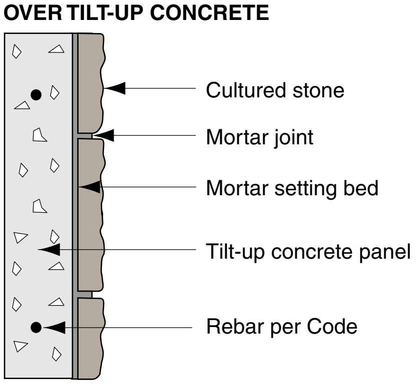
OVER CONCRETE BLOCK



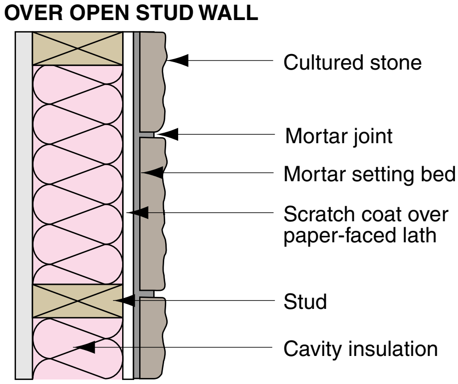
OVER POURED CONCRETE



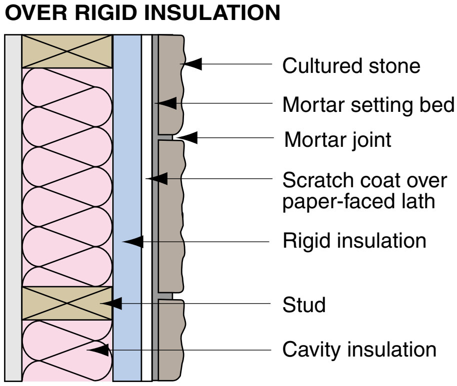
OVER TILT-UP CONCRETE



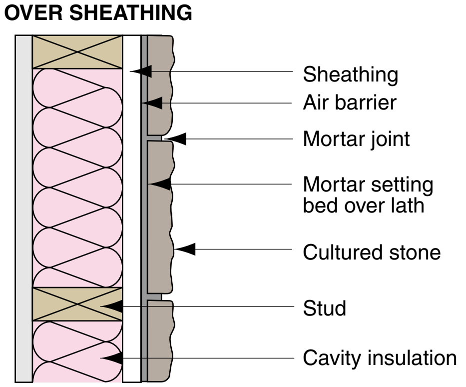
OVER OPEN STUD WALL



OVER RIGID INSULATION

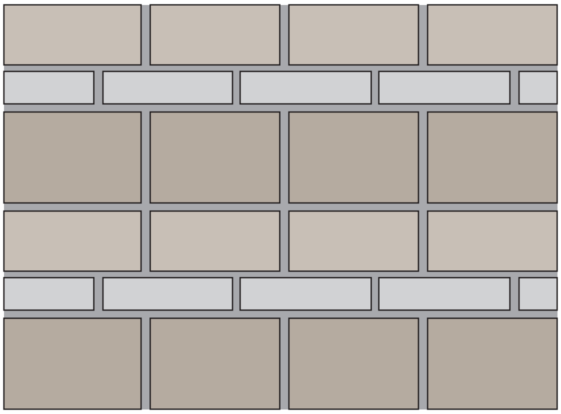


OVER SHEATHING

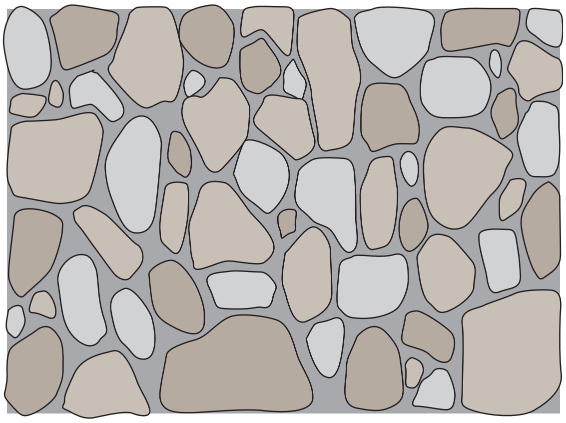


Stone Patterns

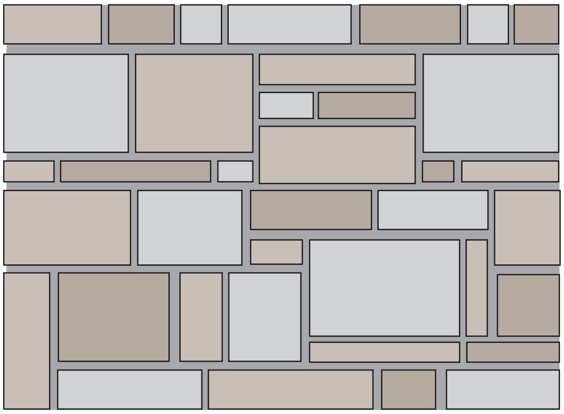
COURSED ASHLAR



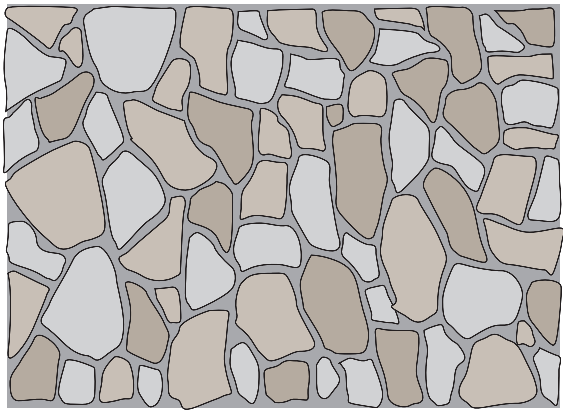
FIELDSTONE



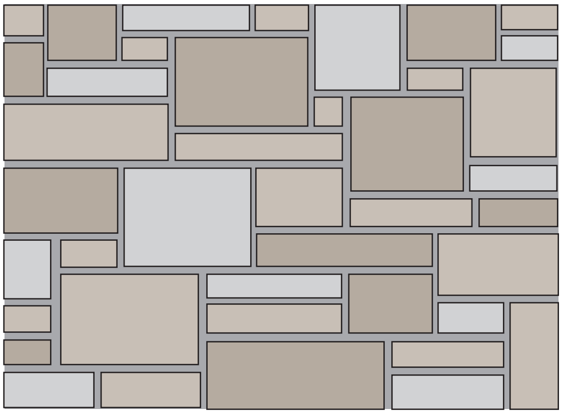
RANDOM ASHLAR



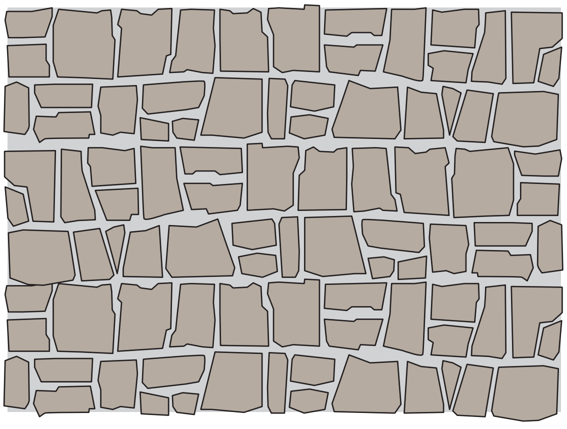
MOSAIC



THREE-HEIGHT RANDOM ASHLAR



COURSED RUBBLE



Meet the Code (IRC)

The following is a partial list of requirements from the *2015 International Residential Code (IRC) for One- and Two-Family Dwellings.* Consult the publication for the full text and additional provisions.

Concrete Floors on Ground (R506)

- slab thickness: ≥$3^1/_2$ inches
- where provided, reinforcement should be supported at center to upper third of slab during pour

Compressive strength:

- exposed to negligible or no weathering, 2,500 psi
- exposed to moderate weathering, 3,000 psi
- porches, steps, and garage floor slabs exposed to severe weathering, 3,500 psi

Base preparation:

- vegetation, top soil, and foreign material removed
- fill free of vegetation and foreign material
- fill compacted to ensure uniform support
- fill depths ≤24 inches for clean sand and gravel and ≤8 inches for earth
- 4-inch base course of clean sand, gravel, or crushed stone when the slab is below grade
- base course not required if slab on well-drained or sand-gravel mixture soils classified as Group I
- 6-mil vapor retarder with joints lapped ≥6 inches between slab and base course or prepared subgrade

Exceptions—may be omitted from:

1. garages, carports, other unheated structures
2. driveways, walks, and patios
3. unheated storage rooms of ≤70 sq.ft.

Masonry Wall Construction (R606)

- minimum thickness of masonry bearing walls more than one story high 8 inches
- minimum thickness of solid masonry walls ≤9 feet high in 1-story dwellings and garages 6 inches, except an additional 6 feet is permitted to a gable peak
- rubble stone masonry wall thickness ≥16 inches
- a course of solid masonry is required where hollow unit walls decrease in thickness

Support considerations:

- beams/girders must have bearing of ≥3" on a solid wall or column ≥4" thick or on a metal plate
- joists must have bearing of ≥$1^1/_2$"
- interior nonload-bearing walls must be anchored at intersections with ≥9-gauge or $^1/_4$-inch galvanized mesh at vertical intervals of ≤16"
- other intersecting walls must be anchored at intersections with ≥9-gauge galvanized mesh at vertical intervals of ≤8" extending ≥30" in both directions
- masonry walls to be laterally supported at intervals shown in Table R606.6.4

Table R606.6.4

Construction	Max. Wall Length/Thickness or Wall Height/Thickness
Bearing walls:	
Solid or solid grouted	20
All other	18
Nonbearing walls:	
Exterior	18
Interior	36

Mortar placement:

- unless otherwise required, head and bed joints $^3/_8$ inch thick, except bed of starting course over foundations shall be $^1/_4$ – $^3/_4$ inch
- mortar joint thickness shall be within the following tolerances from the specified dimensions:
  1. Bed joint: + $^1/_8$ inch
  2. Head joint: $^1/_4$ inch + $^3/_8$ inch
  3. Collar joints: $^1/_4$ inch + $^3/_8$ inch

Exception: Nonload-bearing and masonry veneers

- mortar plasticity and pressure sufficient to extrude mortar from the joint and produce a tight joint
- no furrowing of bed joints producing voids
- if bond broken after initial placement, unit must be relaid in fresh mortar
- mortared surfaces clean and free of deleterious materials
- solid masonry units laid with full head, bed, and interior vertical joints filled

- hollow masonry unit head and bed mortar joints not less than the thickness of the face shell
- wall tie ends embedded in mortar joints
- wall tie ends to engage outer face shells of hollow units by at least $^5/_8$ inch
- wire wall ties embedded at least $1^1/_2$ inches into mortar bed of solid masonry units or solid grouted hollow units
- wall ties must not be bent after embedment

Grouted masonry:

- grout to consist of cementitious material and aggregate in accordance with ASTM C476
- Type M or Type S mortar with pouring consistency can be used as grout
- if grout pour stopped for 1 hour, horizontal joints shall be formed by stopping all tiers at same elevation with grout 1 inch below top
- mortar projecting $>^1/_2$ inch into grout space to be removed before inspection and grouting
- grout to be placed before any initial set and $<1^1/_2$ hours after water added
- maximum pour heights and minimum spaces for grout placement to conform to Table R606.3.5.1
- grout poured continuously in lifts ≤5 feet
- grout to be consolidated by puddling or vibration during placement
- no grout pumping through aluminum pipes
- grout cleanouts may be required by official
- cleanouts to be sealed before pour
- cleanouts required at bottom course at each pour of grout, where pour exceeds 4 feet in height
- fine grout required if vertical space ≤2 inches
- vertical grout barriers of solid masonry entire height of wall to control horizontal flow of grout
- grout barriers to be >25 feet apart
- grouting between vertical barriers to be completed in one day with no interruptions >1 hour

Reinforcement of hollow unit masonry:

- horizontal grout or mortar between units and reinforcement $\geq^1/_4$ inch

Exceptions:

1. $^1/_4$-inch bar in horizontal mortar of thickness $\geq^1/_2$ inch
2. steel wire reinforcement in mortar ≥2× the wire diameter

- reinforced hollow-unit masonry must preserve unobstructed vertical continuity of cells to be filled
- walls and cross webs forming filled cells to be full-bedded in mortar to prevent leakage of grout
- head and end joints to be filled with mortar not less than the thickness of the longitudinal face shells
- bond provided by lapping units in successive vertical courses
- align filled cells to maintain an unobstructed vertical cell of dimensions prescribed in Table R606.3.5.1.
- vertical rebar held in position at top and bottom and at intervals of ≤200 reinforcement diameter
- cells containing rebar filled solidly with grout
- grout to be poured in lifts of ≤8 feet, except if pour >8 feet, grout to be placed in lifts of ≤5 feet and inspection during pour required
- horizontal steel to be fully embedded in grout in an uninterrupted pour

Table R606.3.5.1

Grout Type	Max. Pour Height, ft	Min. Space[a,b] Width, in	Min Space[b,c] Hollow Units, in
Fine	1	0.75	1.5×2
	5	2	2×3
	12	2.5	2.5×3
	24	3	3×3
Coarse	1	1.5	1.5×3
	5	2	2.5×3
	12	2.5	3×3
	24	3	3×4

[a] For grouting between masonry wythes.

[b] Grout space dimension is the clear dimension between any masonry protrusion and shall be increased by the horizontal projection of the diameters of the horizontal bars within the cross section of the grout space.

[c] Area of vertical reinforcement shall not exceed 6 percent of the area of the grout space.

4

Foundations

Many homeowners—even builders—think the words ”foundation” and “basement” are synonymous. In northern states this is understandable, since about 90 percent of homes there have basements. But as the *foundation design* section shows, there are many other options for foundations. Your choice should be determined by the functions you want the foundation to perform.

After you choose the style (*full basement*, *crawl space*, or *slab on grade*), you must choose the material (poured concrete, masonry, or all-weather wood).

In this age of energy conservation, foundations must be insulated against heat loss. Each of the 18 detailed foundation designs indicate the placement of insulation, but recommended types and R-values are shown in greater detail in Chapter 14, “Best Practice Insulating.”

Additional sections cover the details of *ground moisture control*, *termite control*, and *radon mitigation*.

Finally, we provide you with a checklist of requirements so that your foundation will *meet the code (IRC)*.

Foundation Design

Vitruvius (80 BC to 25 BC), in his *De architecture,* had it right, "Durability will be assured when foundations are carried down to the solid ground and materials wisely and liberally selected."

Functions of Foundations

The longevity of many Roman public buildings is testimony to Vitruvius having identified that most important function of the foundation—transferring the weight of the building to stable ground. Since his day, however, we have added considerably to the foundation's list of duties. In selecting or designing an appropriate building foundation, one must now keep in mind all these possibilities:

- transfer building loads to the ground
- anchor the building against wind
- anchor the building against earthquakes
- isolate the building from frost heaving
- isolate the building from expansive soil
- support the building above ground moisture
- retard heat loss from the conditioned space
- provide dry storage space
- provide possible comfortable living space
- house the mechanical systems

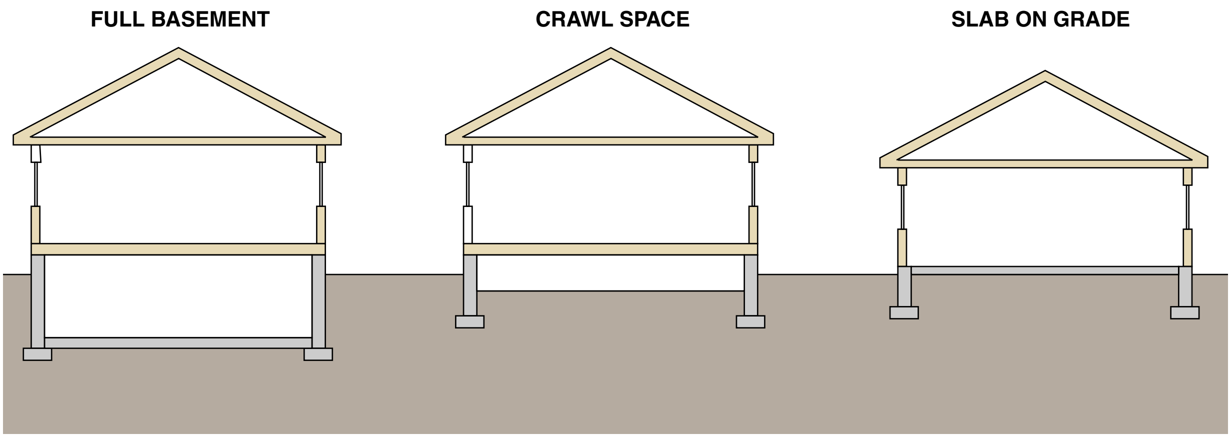
Designing the Foundation

The design (decision-making) process should involve these eight steps:

1. Select the basic foundation style.
2. Select the material of which the foundation will be constructed (poured concrete, masonry units, or pressure-treated wood).
3. Decide if it is to be unconditioned or conditioned (heated to 65°F and cooled to 75°F).
4. Select the type and R-value of its insulation.
5. Detail its structure, insulation application, and possible finish.
6. Detail its control of moisture (including surface runoff, groundwater, and water vapor).
7. Detail its barriers against termites.
8. Detail its built-in radon mitigation.

The illustration below shows the three basic foundation types (full basement, crawl space, and slab on grade), each of which will be detailed in a number of variations in the following pages. Regardless of foundation type, however, all designs should conform, where applicable, to the list of best practices described on the facing page and the illustrations in Chapter 14.

The Three Basic Foundation Types



Foundation Best Practices

Surface Drainage The surface next to the foundation should slope downward at least 6 inches in 10 feet to steer surface runoff away from the building. If practical, gutters should be used to collect roof runoff.

Backfill Foundation backfill should be topped with low permeability soil to divert surface runoff. Porous sand or gravel should be placed against the walls to provide an easy path to the drain tile. In place of porous backfill, a drainage mat or insulating board with drainage channels may be placed against the foundation wall.

Dampproofing A dampproof coating covered by a 4- or 6-mil layer of polyethylene is recommended to reduce water vapor transmission from the soil to the basement. Parging is recommended over masonry unit (CMU) walls before dampproofing. Waterproofing applied directly to the foundation surface from grade level to drain tile is recommended for soils with poor drainage.

Filter Fabric A filter fabric over (and ideally around) the gravel bed and drainpipe is recommended to prevent clogging of the drain pipe.

Drainage System Where drainage problems are possible, a 4-inch-diameter perforated drainpipe should be installed in a gravel bed either outside or inside the footing. The pipe should be placed with holes facing downward and sloping 1 inch in 20 feet to an outfall or sump. The pipe should be below the level of the underside of the floor slab. Surface or roof drainage systems should not be connected to the foundation drainage system.

Exterior Insulation Acceptable materials include: extruded polystyrene boards, molded polystyrene boards when porous backfill and adequate drainage are provided, and fiberglass drainage boards when drainage is provided at the footing. Insulation materials should be protected to at least 6 inches below grade by a material such as fiberglass panel, latex-modified cementitious coating, or other rigid weatherproof board—extending at least 6 inches below grade.

Footings All footings must be beneath the maximum frost depth or insulated to prevent frost penetration. They must be sized to distribute the load uniformly and have a minimum compressive strength of 2,500 psi.

Crack Control Two No. 4 bars running continuously 2 inches below the top of the wall and above/below window openings are recommended to minimize shrinkage cracking.

Anchor Bolts ½-inch anchor bolts embedded at least 7 inches into concrete should be placed at a maximum spacing of 6 feet and no farther than 1 foot from any corner.

Isolation Joint An isolation joint between slab and foundation wall reduces cracking by allowing relative movement. In radon areas, a liquid sealant should be poured into the joint over backing rod.

Concrete Slabs A slab of at least 4 inches thickness compressive strength of 2,500 psi is recommended. Chopped fiberglass additive or welded wire reinforcement held in place 2 inches below the top of the slab is recommended in areas with radon and termites. To avoid cracking due to soil settlement, slabs should not rest on foundation walls. To maximize strength and minimize cracking, slabs poured directly over insulation board or plastic vapor barrier should have a minimum water/cement ratio. Alternatively, the slab may be poured on a layer of sand over the foam insulation or vapor barrier.

Sill The foundation sill should be at least 8 inches above grade and should be pressure-treated to resist decay.

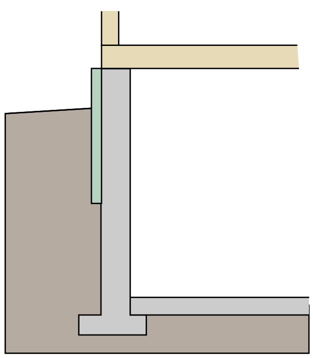
Caulking/Sealing Caulking against air leakage should include: foundation wall/sill plate, sill plate/rim joist, rim joist/subfloor, and subfloor/above-grade wall plate.

Full Basements

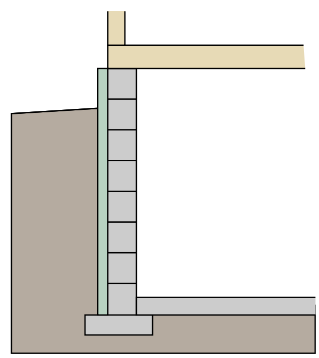
Six full basement foundation options are shown below. Details for placement of insulation, wall and floor vapor control, and drainage are shown in detailed drawings on the pages that follow.

Climate- and heating/cooling-specific insulation R-value recommendations are further detailed in Chapter 14, “Best Practice Insulating.”

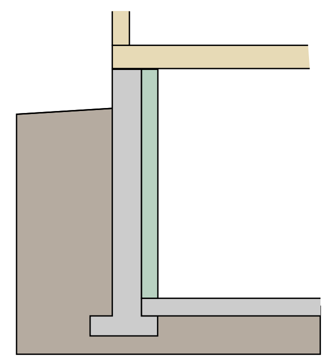
Basement Insulation Configurations



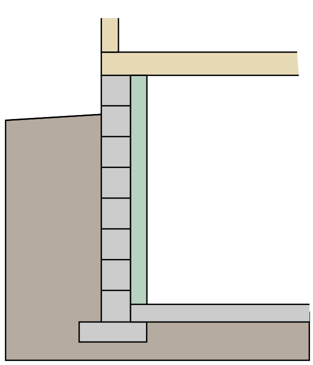
Concrete wall with partial-height exterior insulation



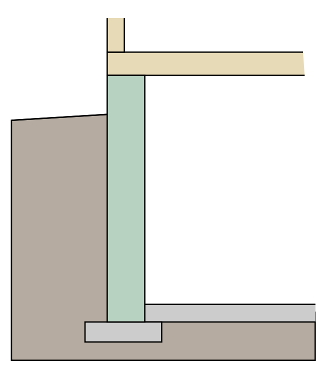
Masonry wall with full-height exterior insulation



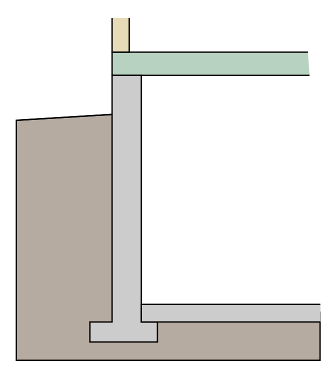
Concrete wall with full-height interior insulation



Masonry wall with full-height interior insulation

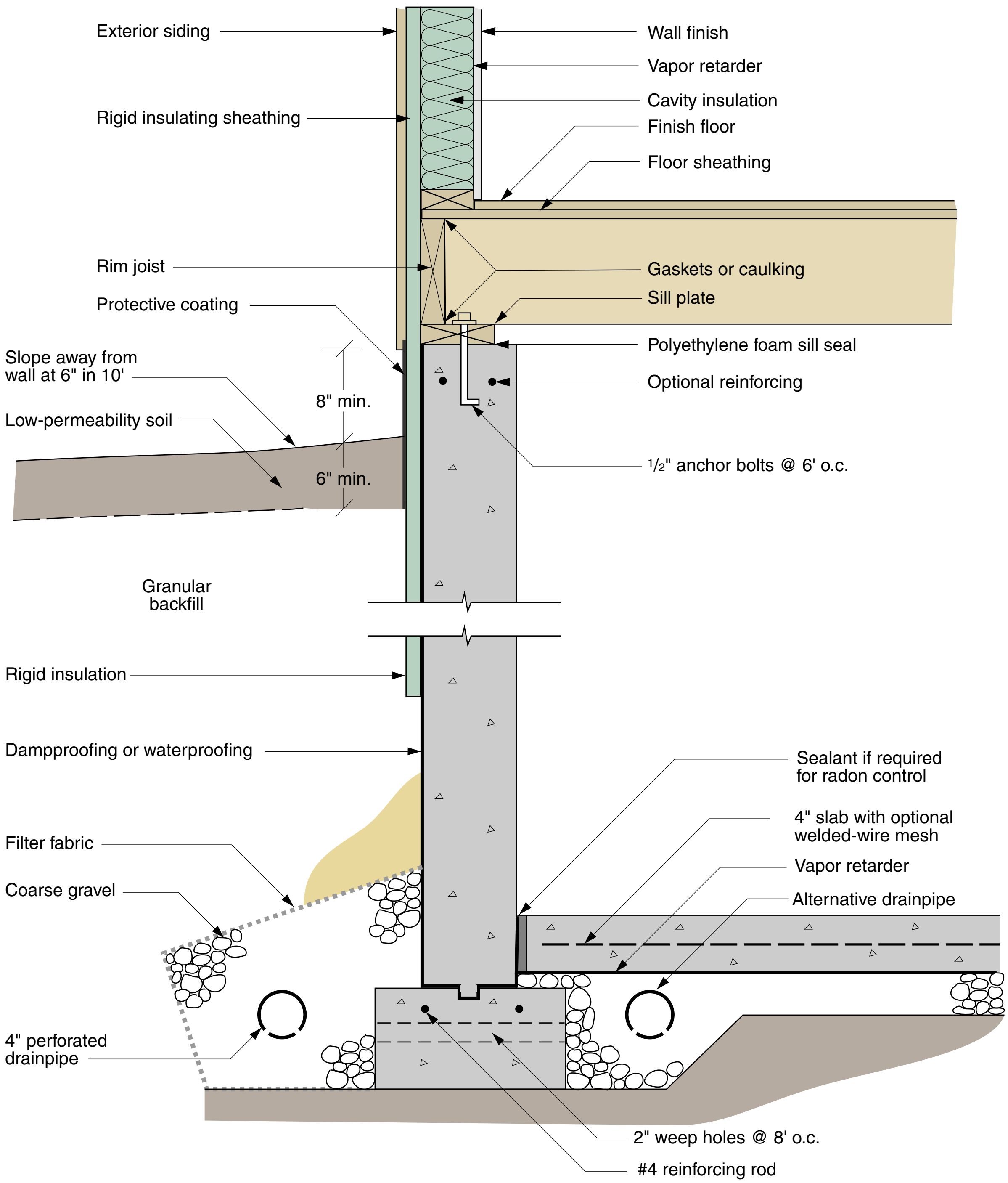


All-weather wood foundation with blanket insulation

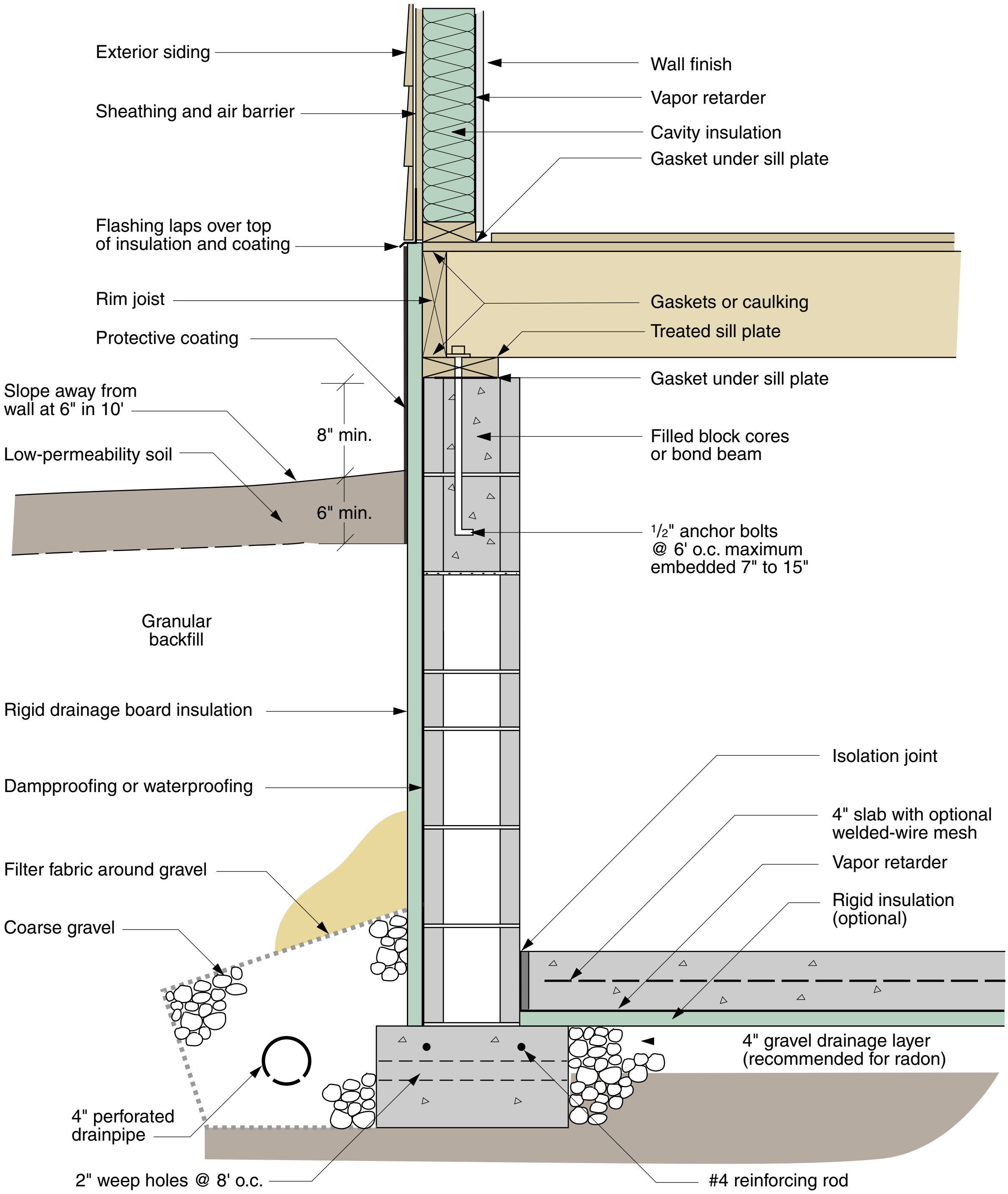


Concrete wall with ceiling insulation

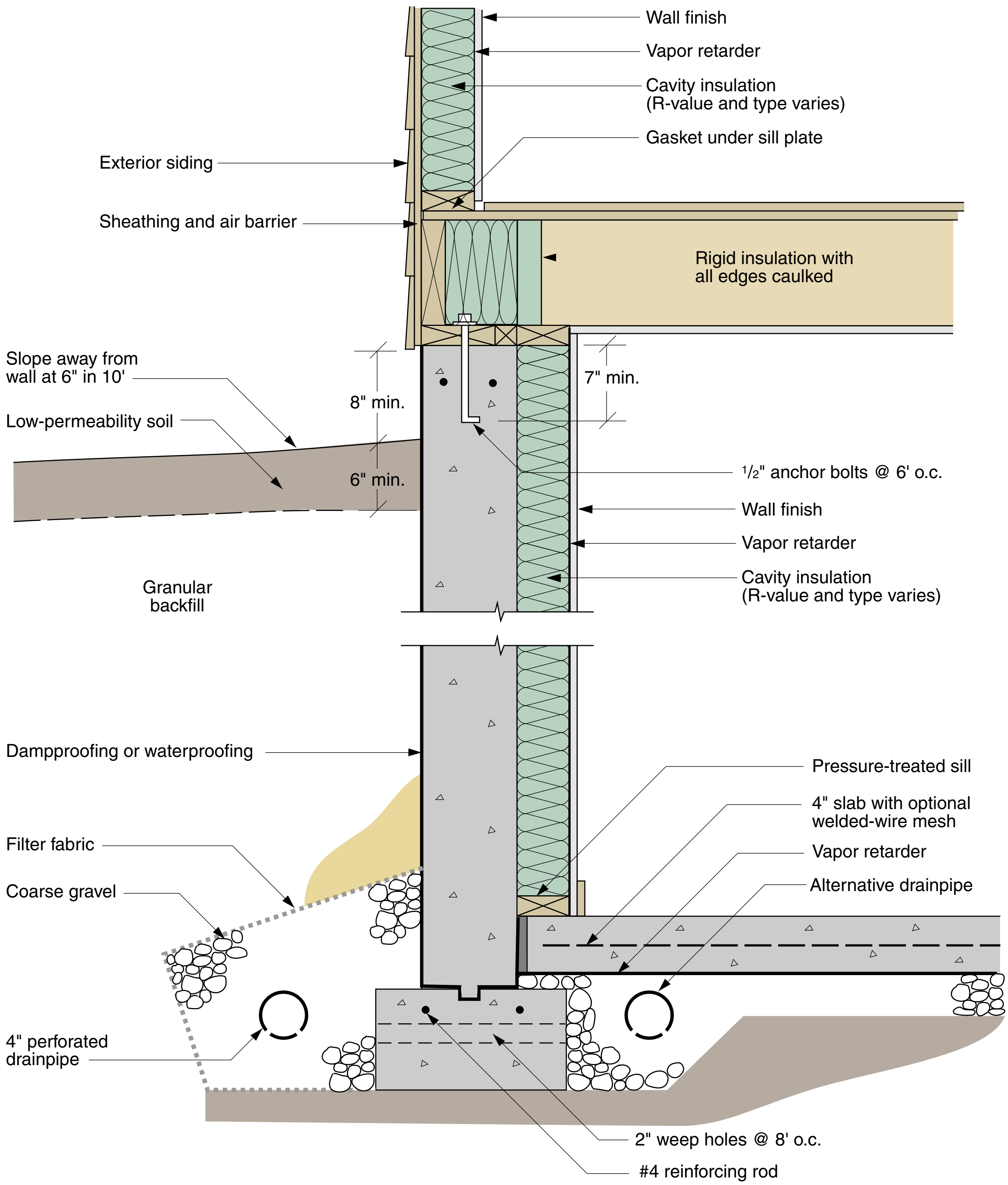
Concrete Basement Wall with Partial-Height Exterior Insulation



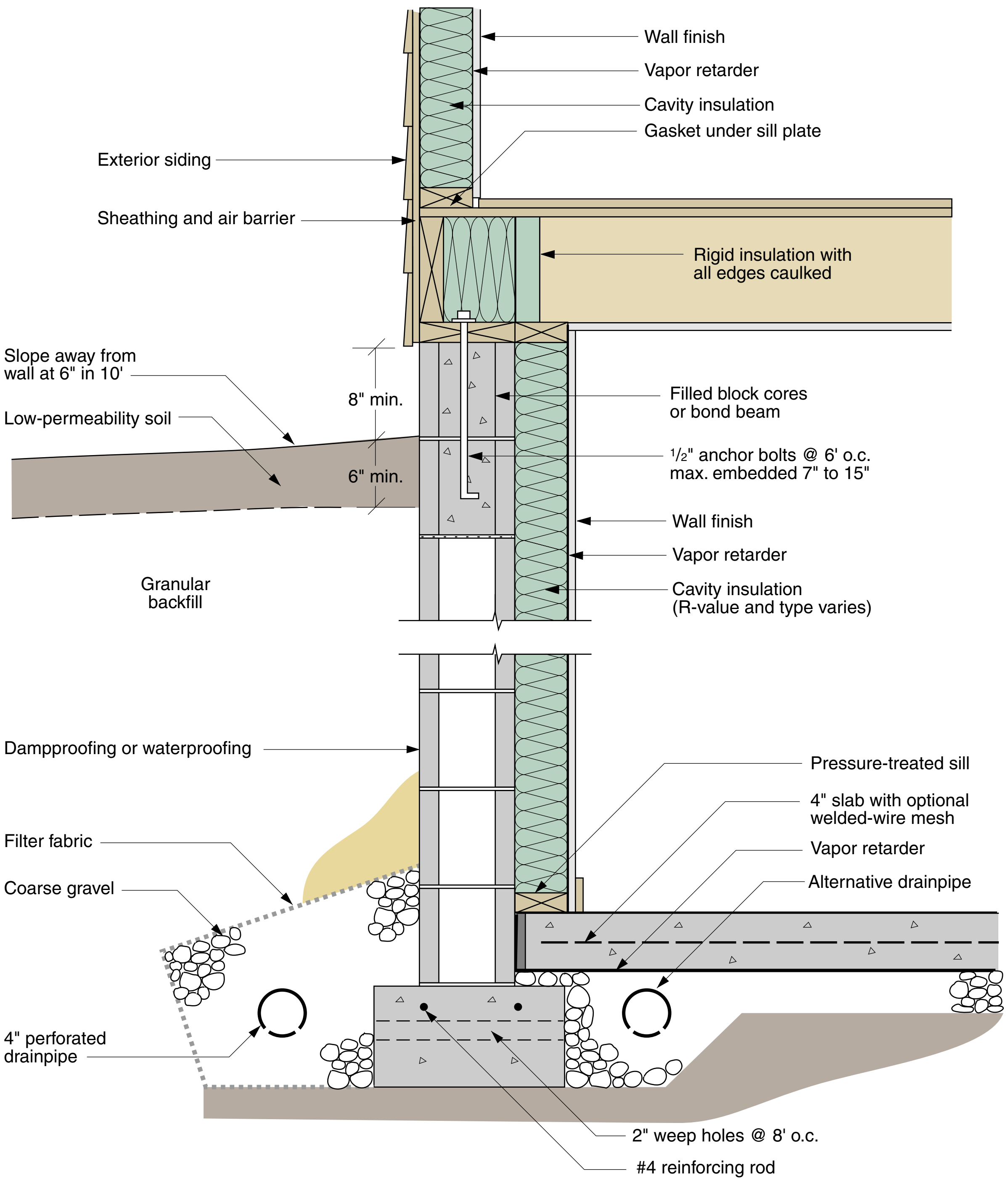
Masonry Basement Wall with Full-Height Exterior Insulation



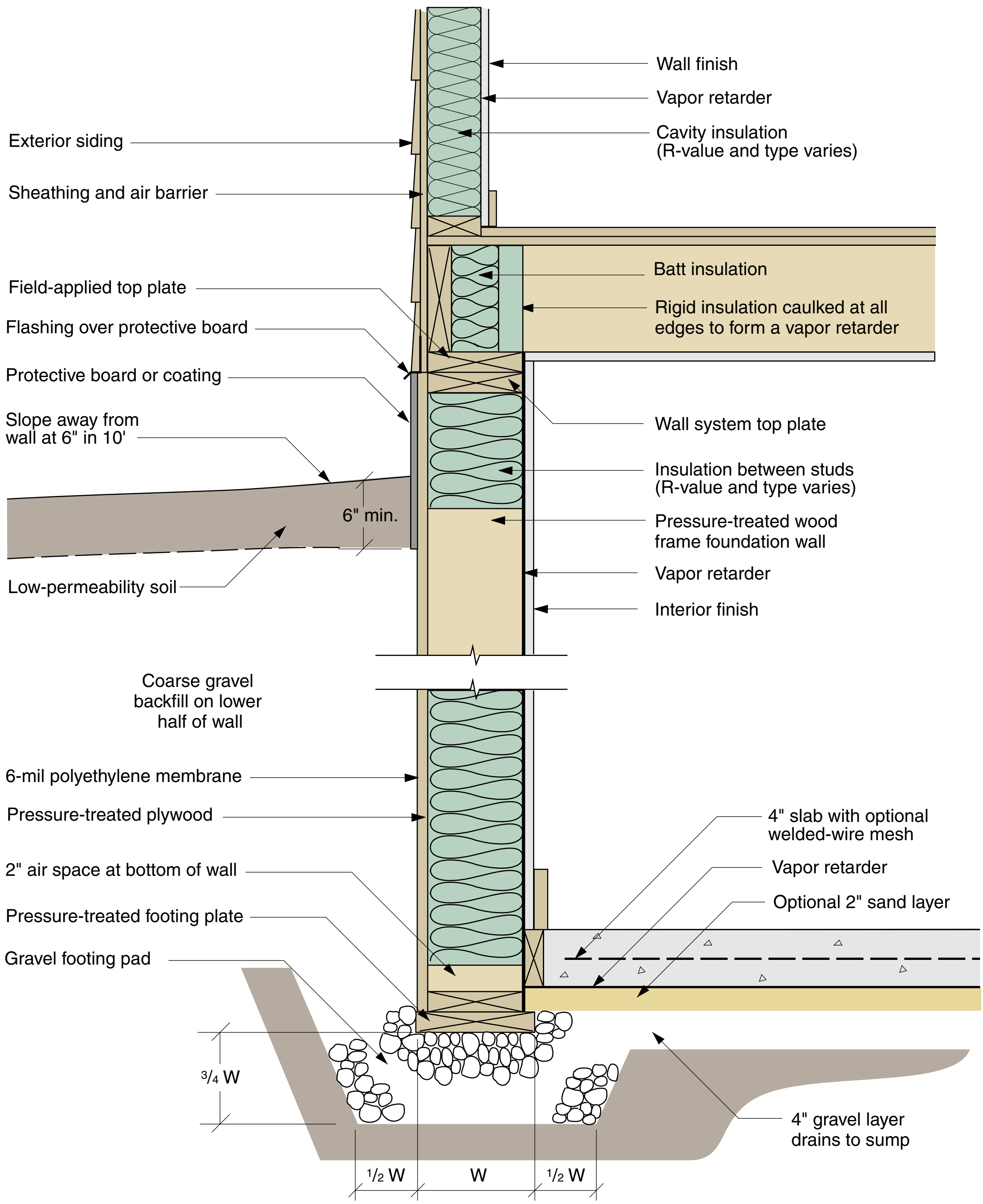
Concrete Basement Wall with Full-Height Interior Insulation



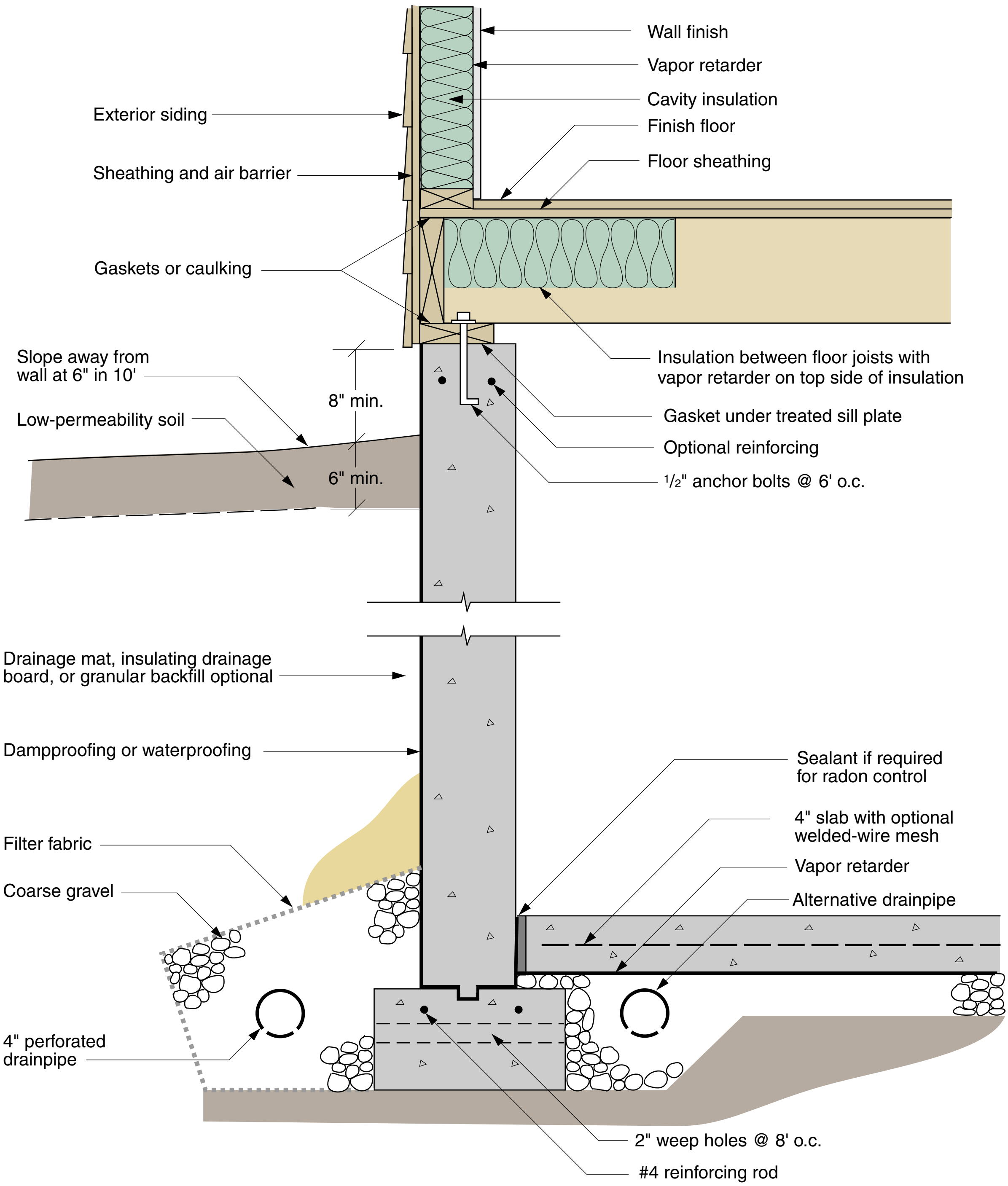
Masonry Basement Wall with Full-Height Interior Insulation



All-Weather Wood Foundation



Concrete Basement Wall with Ceiling Insulation

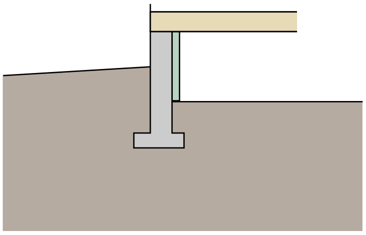


Crawl Spaces

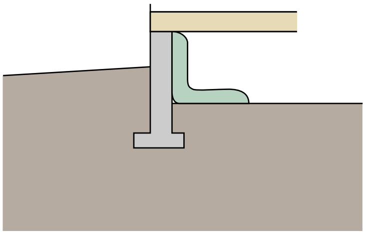
Five crawl-space foundation options are shown below. Details for placement of insulation, wall and floor vapor control, and drainage are shown in detailed drawings on the pages that follow.

Climate- and heating/cooling-specific insulation recommendations are further detailed in Chapter 14, “Best Practice Insulating.”

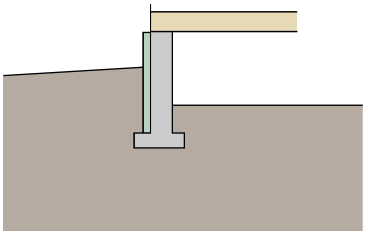
Crawl-Space Insulation Configurations



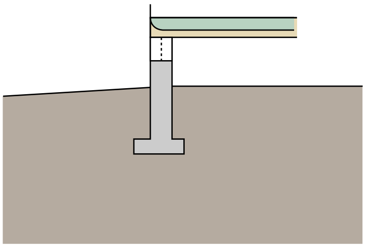
Unvented concrete with rigid interior insulation



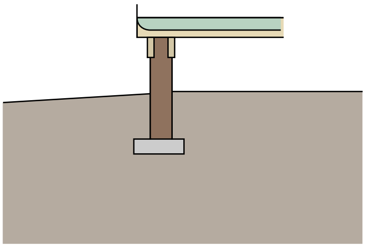
Unvented concrete with blanket interior insulation



Unvented concrete with rigid exterior insulation

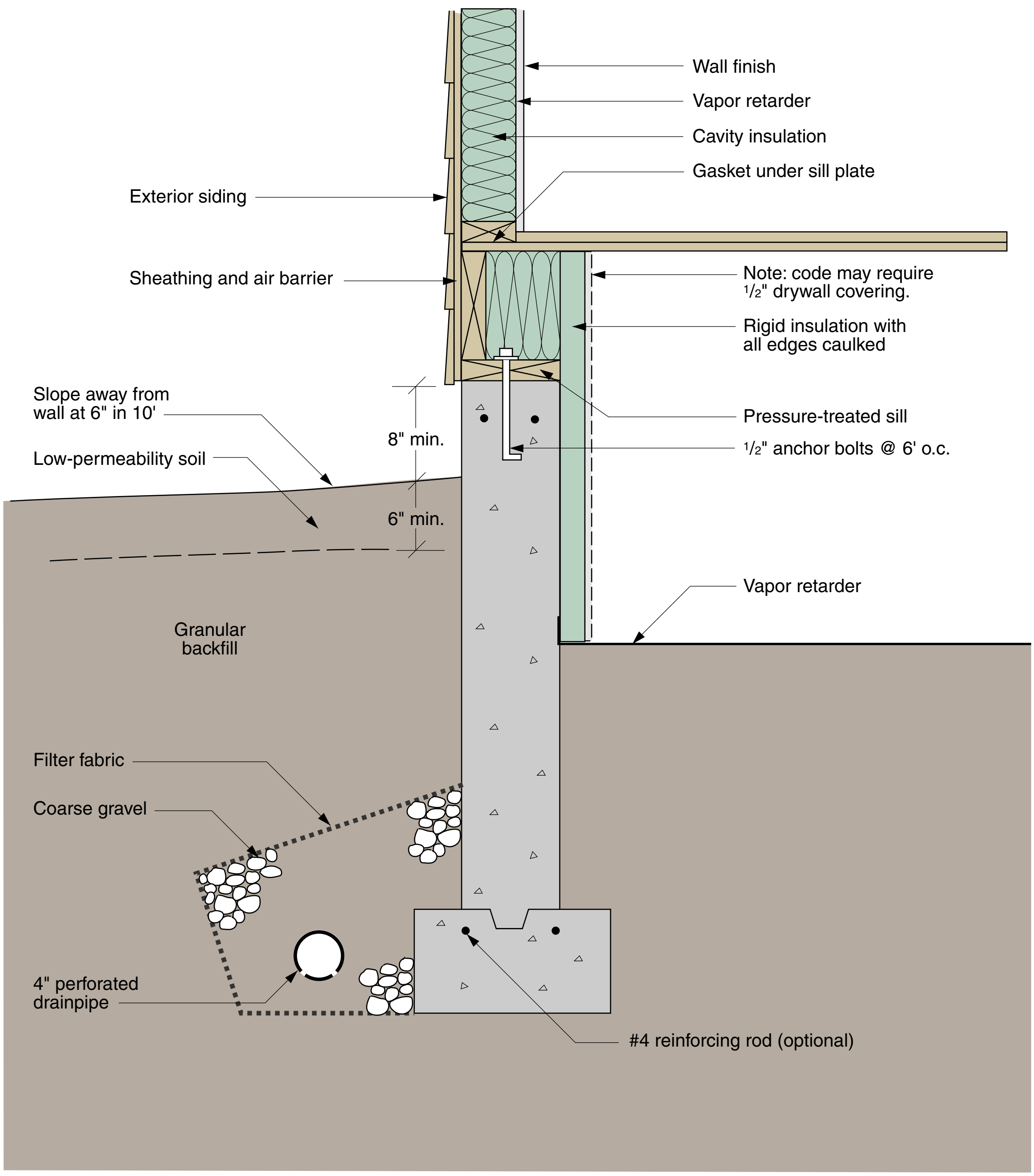


Vented concrete with floor insulation

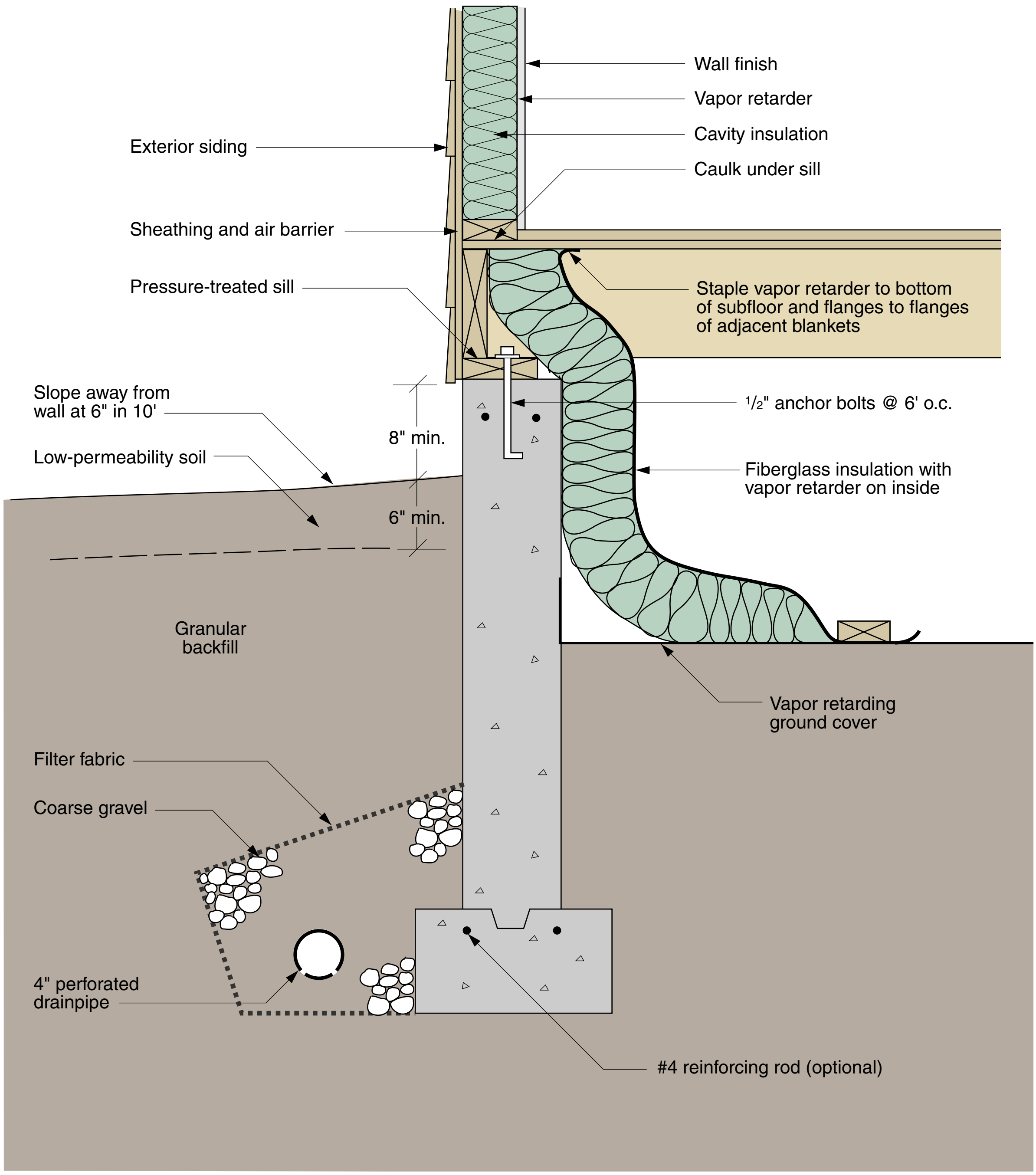


Open piers with floor insulation

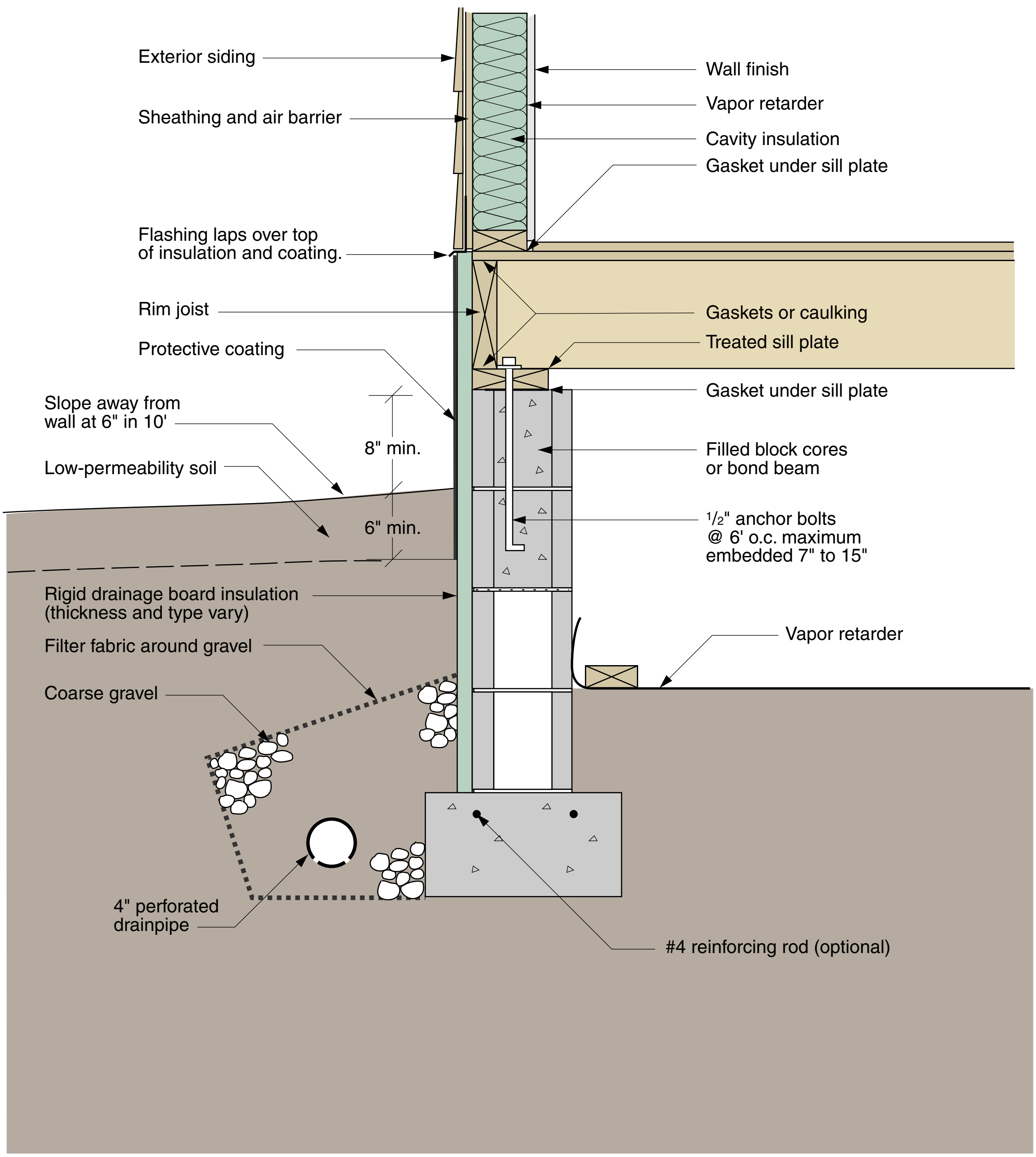
Unvented Concrete Crawl Space with Rigid Interior Insulation



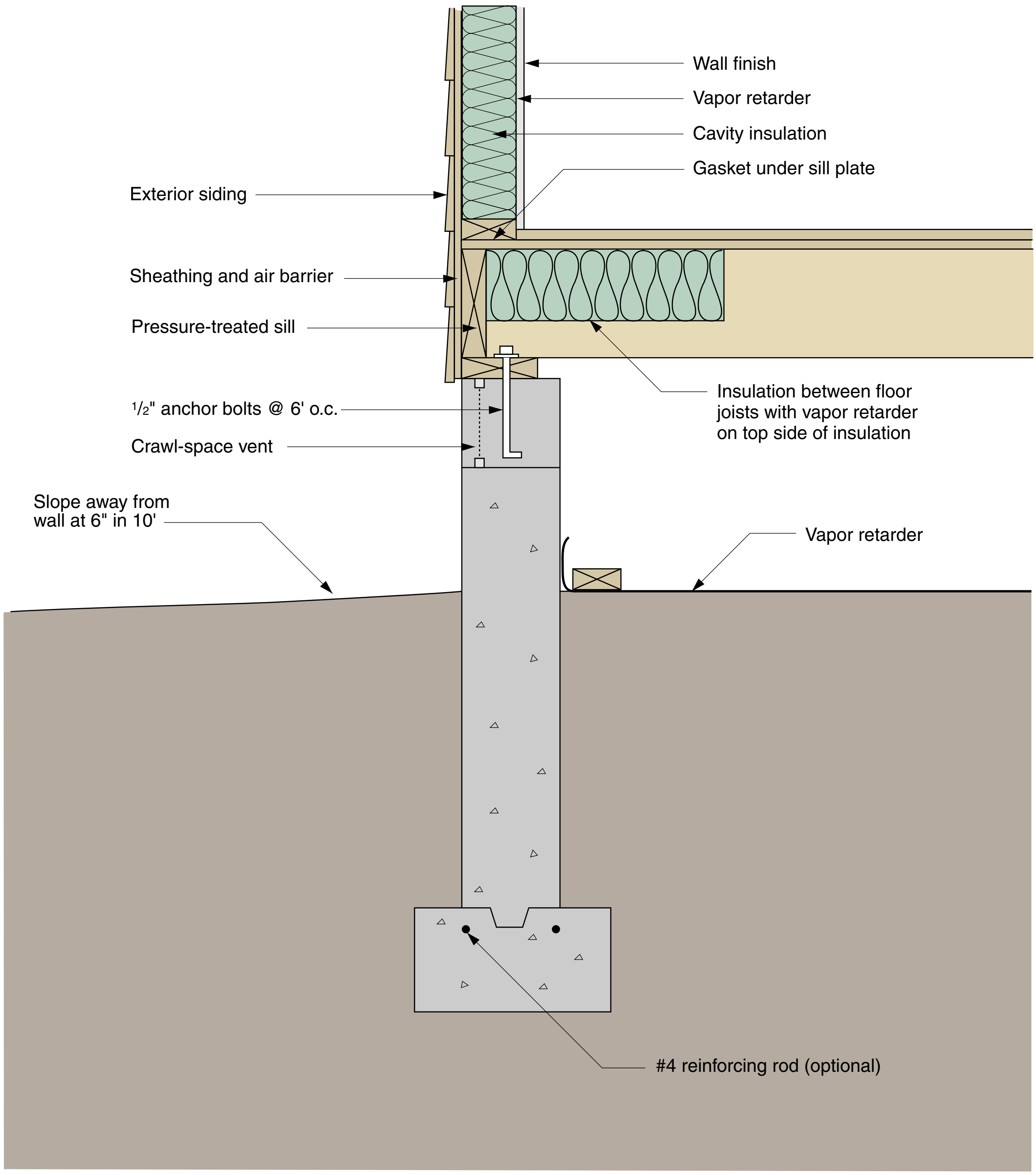
Unvented Concrete Crawl Space with Blanket Interior Insulation



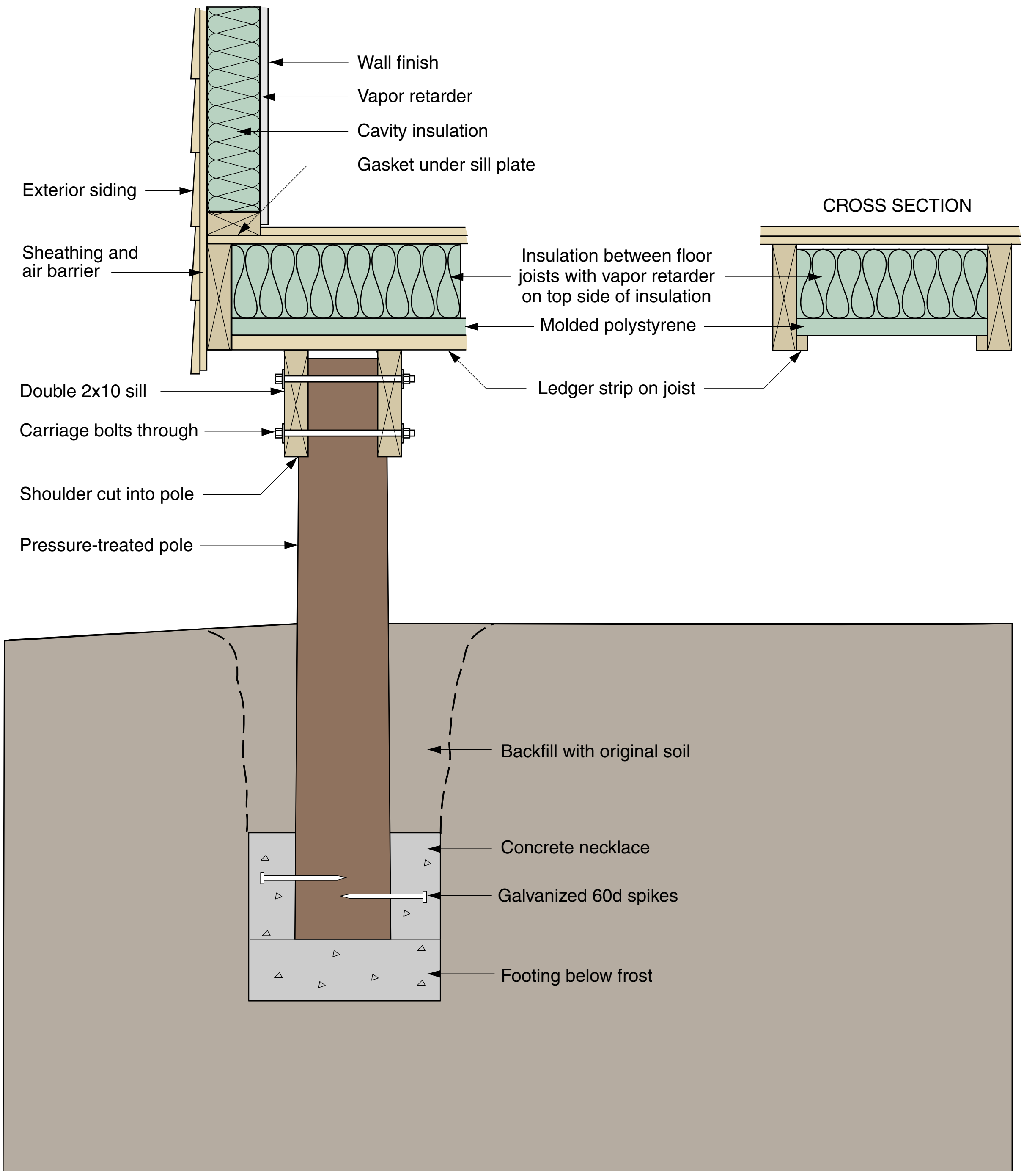
Unvented Masonry Crawl Space with Exterior Insulation



Vented Concrete Crawl Space with Floor Insulation



Open Piers with Floor Insulation

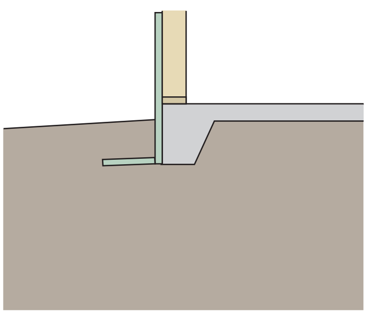


Slabs on Grade

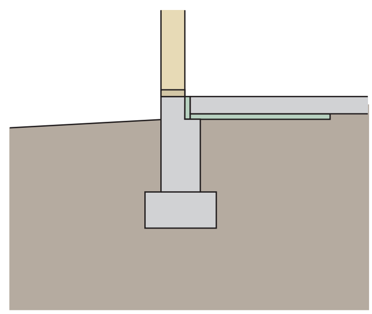
Six slab-on-grade foundation options are shown below. Details for placement of insulation, wall and floor vapor control, and drainage are shown in detailed drawings on the pages that follow.

Climate- and heating/cooling-specific insulation recommendations are further detailed in Chapter 14, “Best Practice Insulating.”

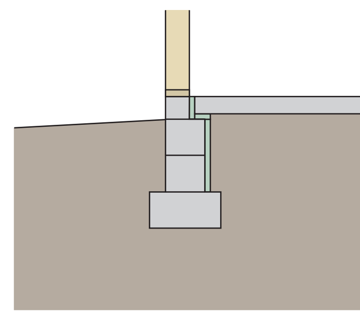
Slab-on-Grade Insulation Configurations



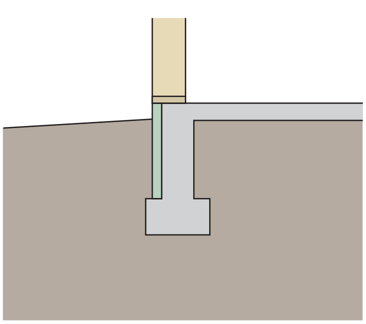
Shallow foundation with 2' horizontal exterior insulation



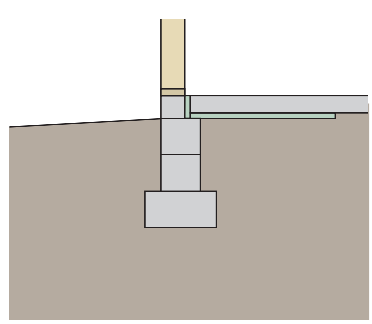
Concrete foundation with 4' horizontal interior insulation



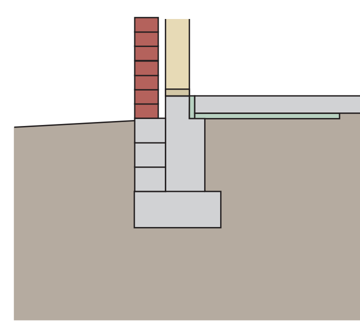
Masonry foundation with interior vertical insulation



Concrete foundation with vertical exterior insulation

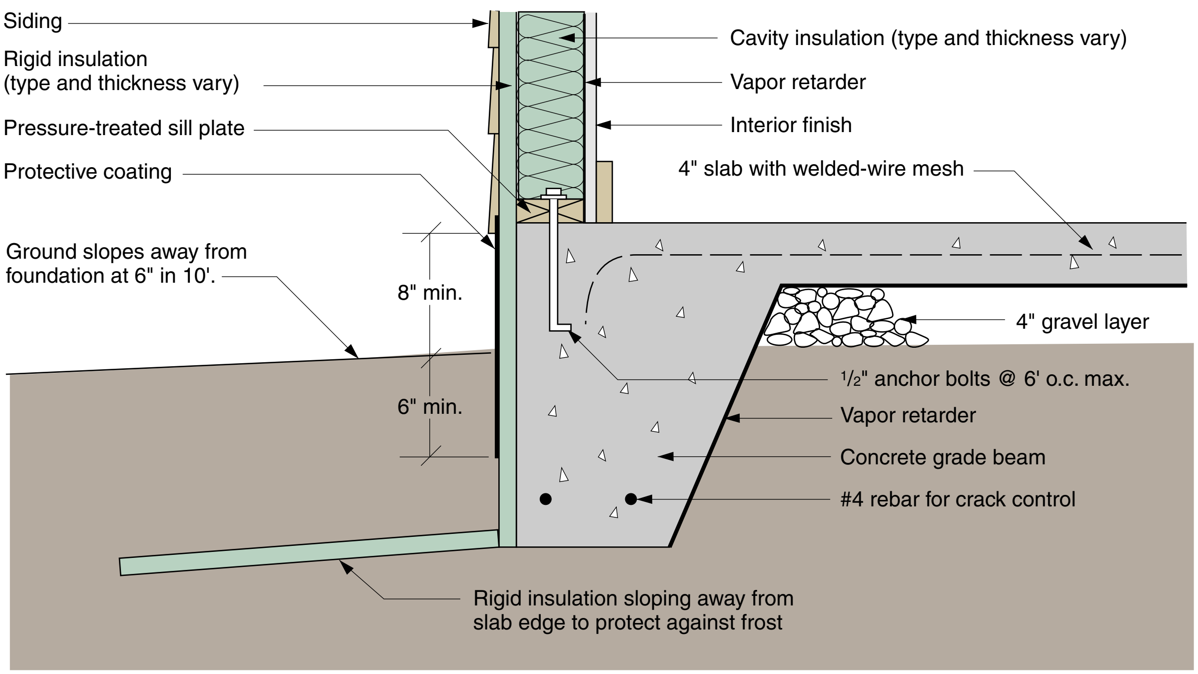


Masonry foundation with 4' horizontal interior insulation

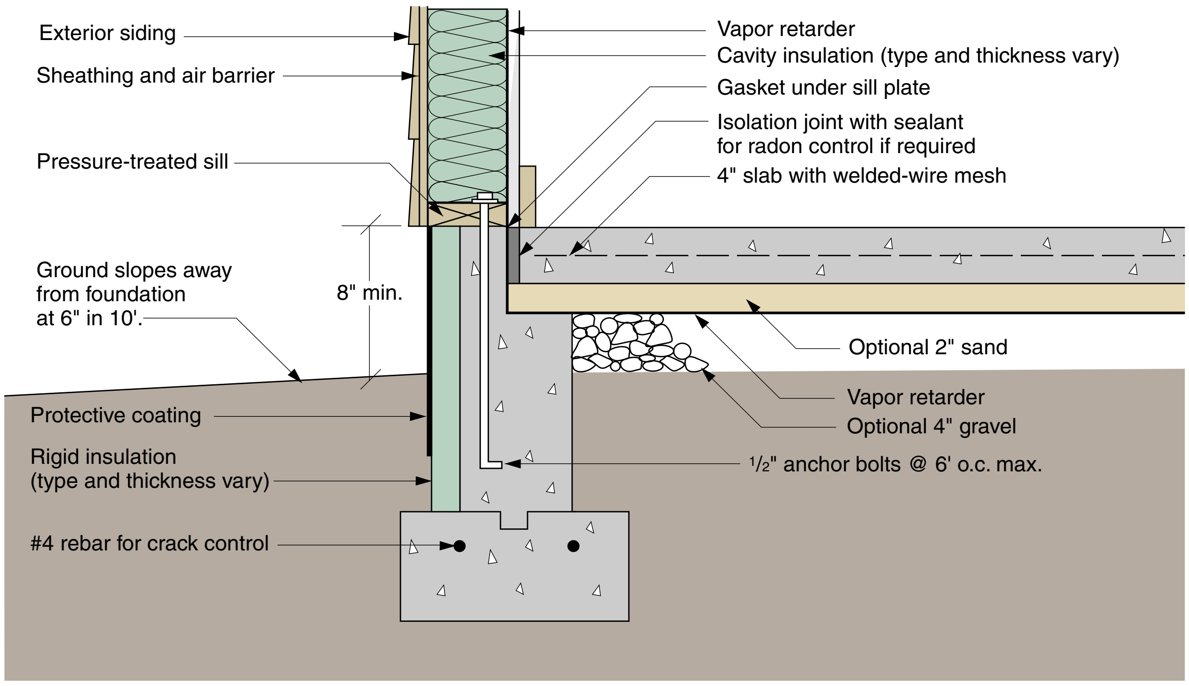


Concrete foundation with brick veneer and 4' interior horizontal insulation

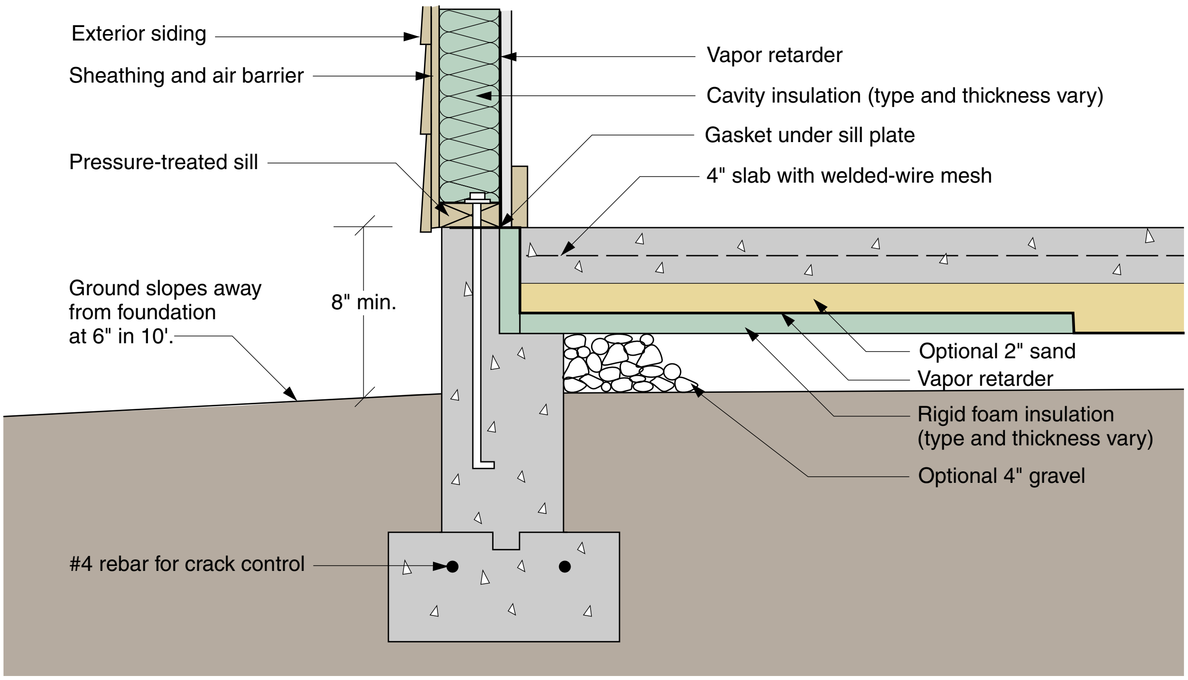
Shallow Foundation with Exterior Insulation (Frost-Protected Slab)



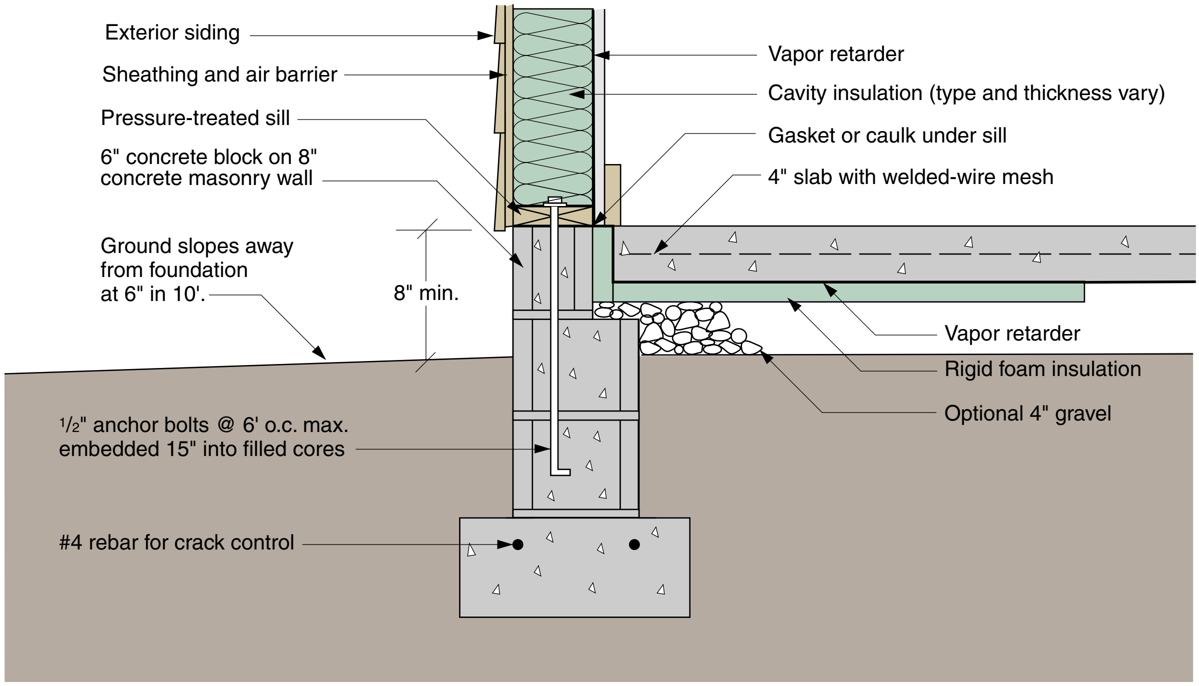
Slab-on-Grade and Concrete Foundation Wall with Exterior Edge Insulation



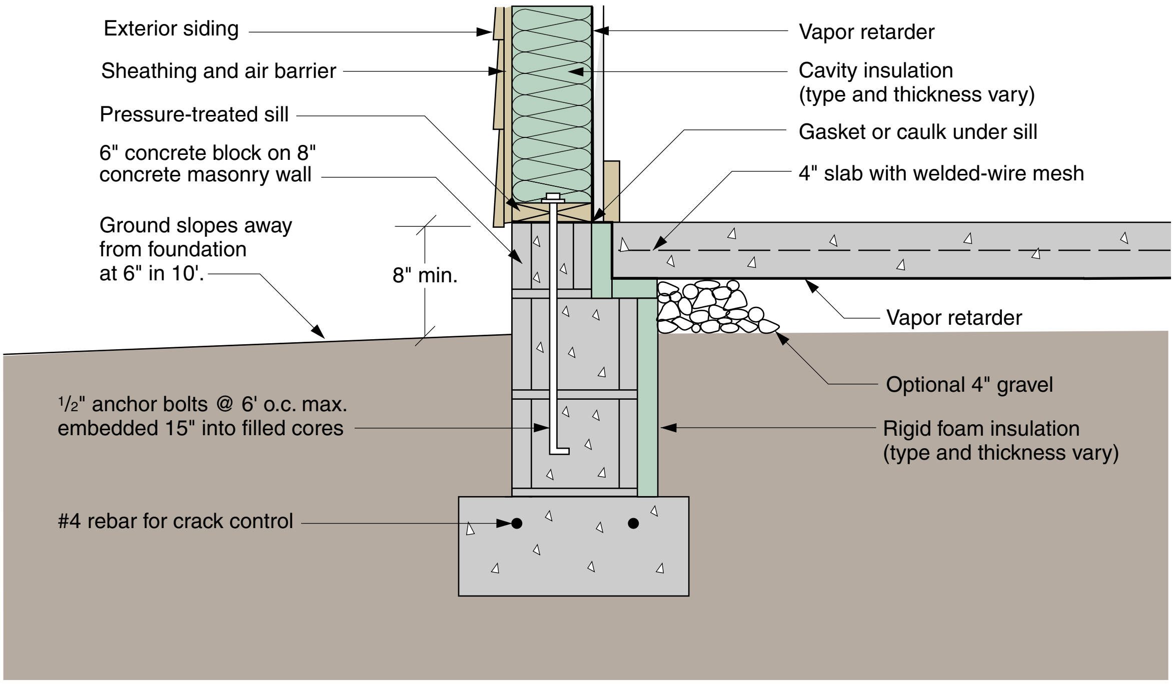
Slab-on-Grade and Concrete Foundation Wall with Interior Slab Insulation



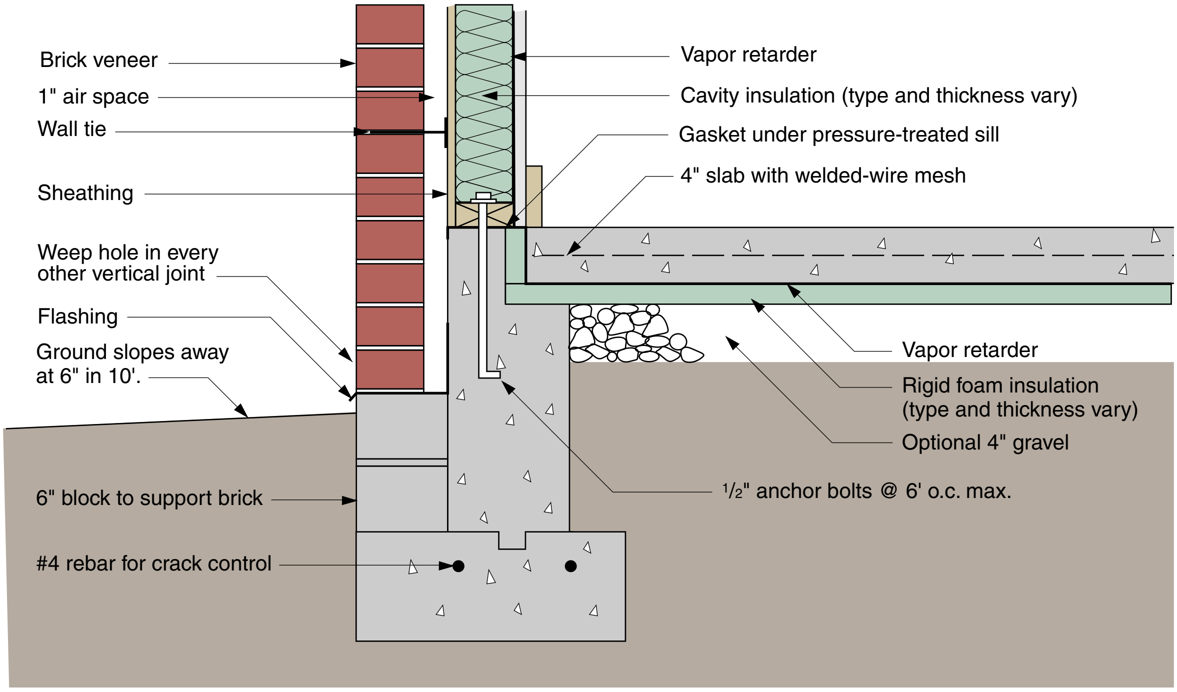
Slab-on-Grade and Masonry Foundation Wall with Interior Slab Insulation



Slab-on-Grade and Masonry Foundation Wall with Interior Edge Insulation



Slab-on-Grade and Concrete Foundation Wall with Interior Slab Insulation



Ground Moisture Control

Excessive moisture in a basement or crawl space gives rise to two sorts of problems:

1. The wood structure—particularly the sills and floor joists—can be infected by a fungus and, over time, destroyed by "dry rot."

2. Basement surfaces and wall stud cavities can support the growth of various molds that can seriously affect the health of occupants.

Prevention of excess moisture generally involves at least several of the following tactics:

1. Choose a site with permeable soil and a water table reliably below the foundation floor level.

2. Direct roof and ground-surface water away from the building with gutters and downspouts and by grading the surrounding ground surface away from the foundation.

3. Install a system of perforated drainage pipes around the foundation footing to lower the local water table to below the foundation floor.

4. Diminish the amount of water vapor evaporating from the soil into the foundation space with vapor-retarding ground covers.

5. Ventilate unconditioned foundation enclosures to remove excess water vapor from the air.

Drainage Systems

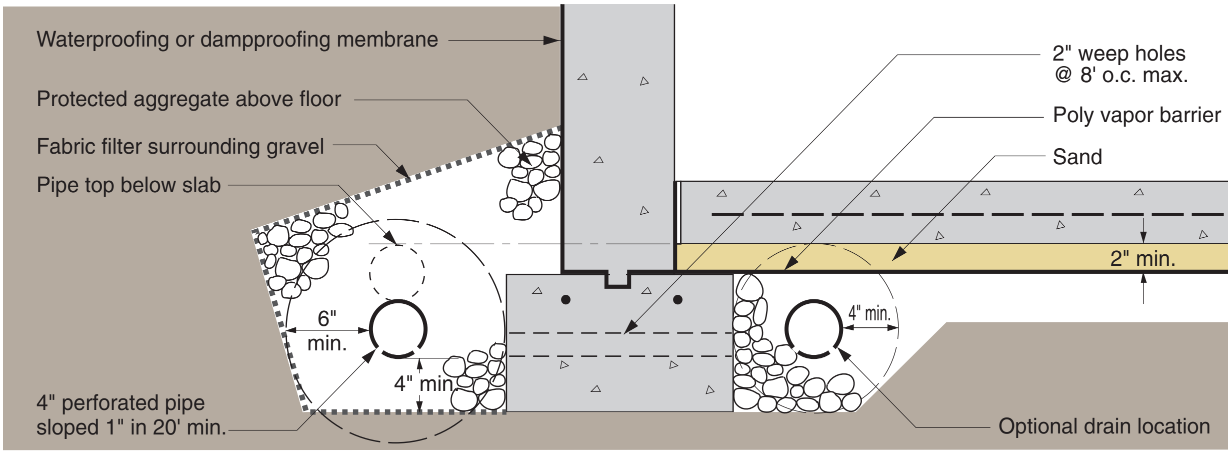
Footing drains (illustration below) have two functions. They draw down the groundwater level to below the basement walls and floor, and they collect and drain away water that seeps down through the backfill from rain and melting snow. They may be aided by vertical wall and underfloor drainage blankets and, especially in the case of exterior footing drains, by weep holes through the footing.

The drain must be placed so that the top of the pipe is beneath the bottom of the floor slab and the bottom of the pipe above the bottom of the footing. Drains can be located outside the foundation or inside next to the footing beneath the floor slab. When the drain line is inside, a gravel fill should still be provided at the outside, and weep holes should be provided through the footing every 8 feet.

Exterior placement beside the footing is more effective at drawing down the water table. Interior drains are more effective for collecting soil gas in radon-control systems.

The pipe is placed with the two rows of holes facing down. A fabric filter keeps coarse sediment from washing into the drain line. The pipe should be sloped at least 1 inch in 20 feet, although 1 inch in 10 feet compensates for settling after construction.

Perimeter Drain System



Ventilation Requirements

The IRC requires unconditioned crawl spaces to be ventilated to prevent moisture buildup. A rectangular crawl space requires a minimum of four vents, one on each wall, located no farther than 3 feet from each corner. The vents should be as high on the wall as possible to capture breezes, and landscaping should be planned to prevent obstruction. The free (open) area of all vents must total no less than 1⁄150 of the floor area. The gross area of vents depends on the type of vent cover. The gross area can be found by multiplying the vent's free area by one of the factors in the table at right.

Two exceptions to the passive ventilation requirement are as follows: 1) the ground surface is covered by a qualified ground cover, and 2) forced ventilation is provided.

Ground Covers

A ground cover (vapor retarder) that restricts evaporation of soil moisture is the most effective way to prevent condensation and wood decay problems in a crawl space, as well as in an unheated full basement.

The vapor retarder should have a permeability rating of 1.0 perm maximum and should be rugged enough to withstand foot traffic. Recommended materials include 6-mil polyethylene and 45-mil ethylene polymer diene monomer membranes (EPDM). Retarder sheet edges must overlap by 6 inches and be sealed or taped. The retarder must also extend at least 6 inches up the foundation walls and be fastened and sealed to the wall.

Forced Ventilation

It is not necessary to passively vent a crawl space if it is continuous with an adjacent basement or if its walls are insulated and a minimum of 1 cfm per 50 sq. ft. ventilating air is delivered by mechanical ventilation. Venting is also incompatible with crawl spaces that are used as heat distribution plenums (in which the foundation walls are insulated and the space acts as a giant warm-air duct).

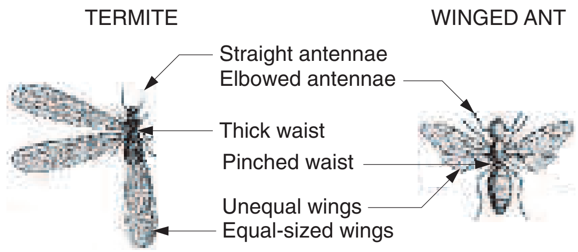
Crawl-Space Vent Area Requirements

Vent Cover Material	Multiply Free Vent Area By
¼″ mesh hardware cloth	1.0
⅛″ mesh screen	1.25
16-mesh insect screen	2.0
Louvers + ¼″ hardware cloth	2.0
Louvers + ⅛″ mesh screen	2.25
Louvers + 16-mesh insect screen	3.0

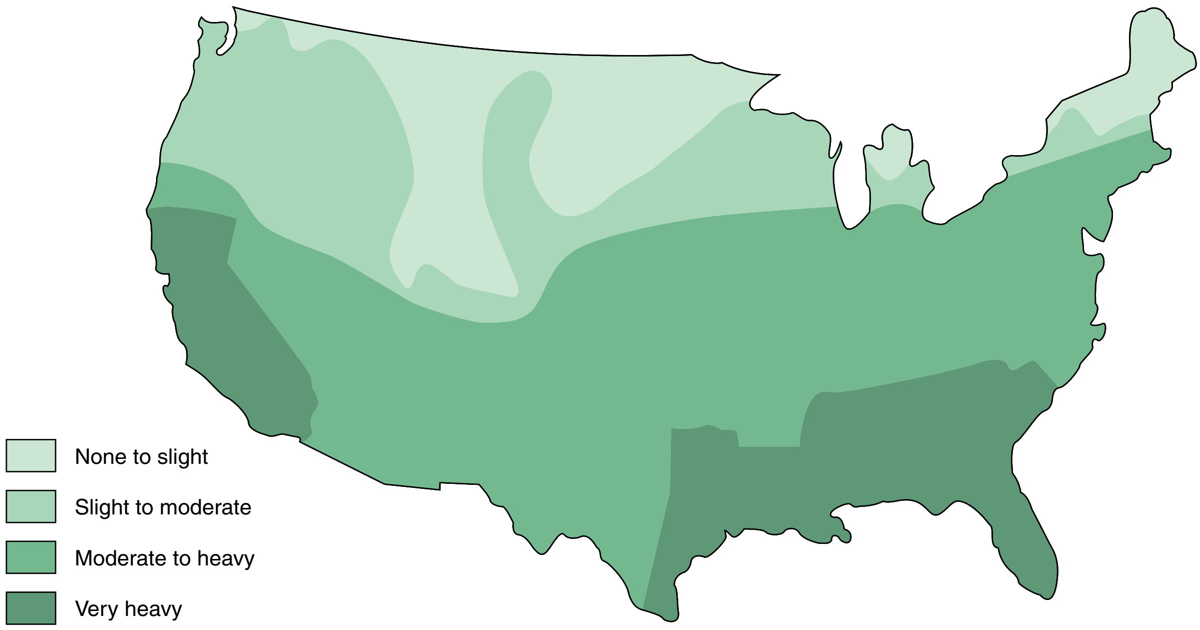
Termite Control

Termites occur naturally in woodlands, where they help break down dead plant material and play an important role in the nutrient cycle. The problem lies in the fact that termites don't distinguish between the wood in dead trees and the dead wood in structures. Subterranean termites, which account for 95% of all termite damage, are found throughout the United States wherever the average annual air temperature is 50°F or above and the ground is sufficiently moist (see map below).

Termite Identification



Termite Hazard Distribution



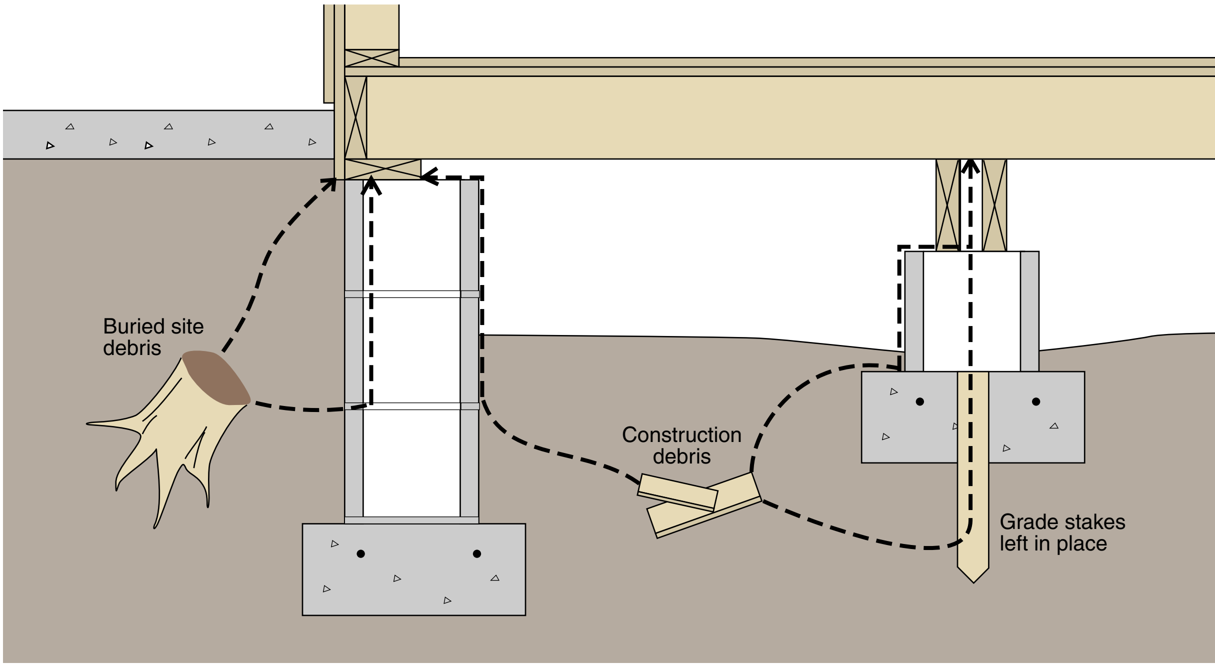
Points of Entry

Since termites occur naturally in forests and brushlands, clearing wooded sites robs them of their food supply. They adapt by feeding on the wood in structures. Termite control starts with blocking easy routes of entry from the soil to the wood in the structure. The most common points of entry are shown on p. 100.

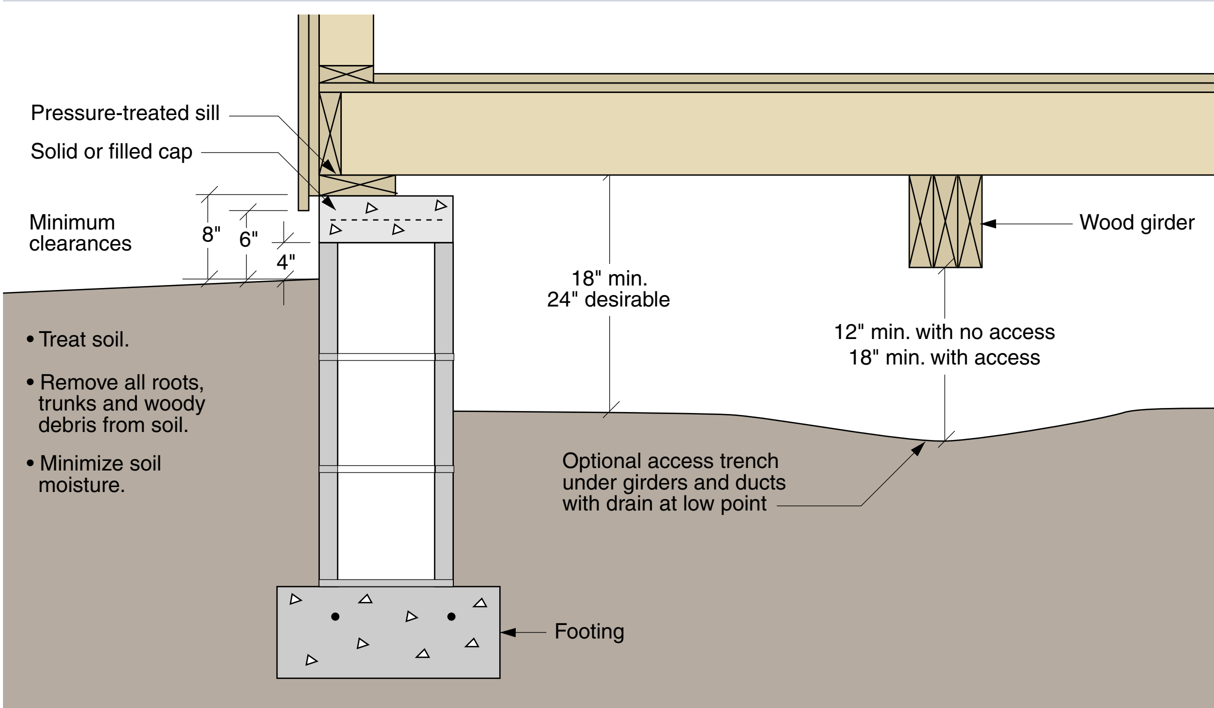
Control Measures

Termite control is simple in concept, but difficult in practice, since termites. can pass through cracks as narrow as $^1/_{32}$ inch. The major strategies of termite control include separating wood structures from the soil, minimizing cracks in slabs and walls, creating barriers to force termites into the open, treating soil with chemicals, and keeping the soil and foundation dry.

Points of Termite Entry



Preventive Steps



Radon Mitigation

Radon is a colorless, odorless, radioactive gas. It is produced in the natural decay of radium and exists at varying concentrations throughout the United States (see map below). Radon is emitted from the ground and diluted to an insignificant level in the atmosphere. Being a gas, radon can travel through the soil and into a building through cracks and other openings in the foundation. Radon from well water can also contribute to radon levels in indoor air.

Radon is drawn from the soil through the foundation when indoor pressure is less than that in the soil. Radon levels are generally higher in winter due to the buoyancy of warm indoor air, furnace and fireplace drafts, and power exhaust fans. There are two effective approaches to radon management. Neither cost much, so they should be standard practice in new construction.

The Barrier Approach

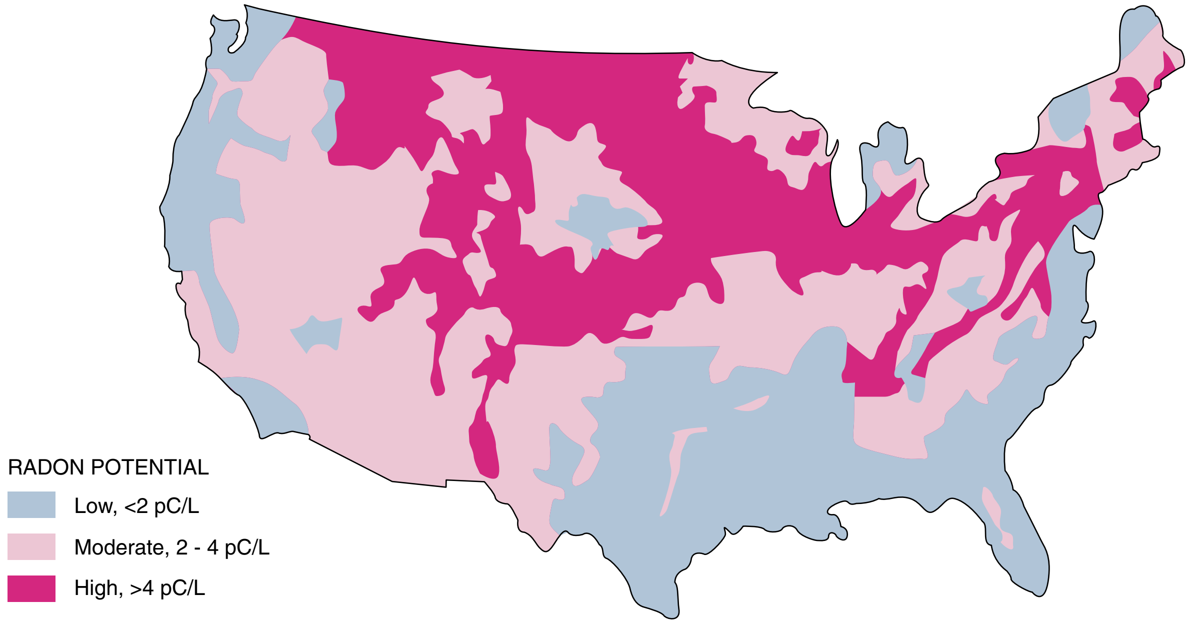
Like a boat in water, the barrier approach keeps radon out by making it difficult for it to get in. What works to keep a basement dry also works to keep radon out. Because radon is a gas, the approach relies on infiltration-control measures such as minimizing cracks, joints, and other openings through the foundation. Waterproofing and dampproofing membranes outside the wall and under the slab are excellent barriers.

The Suction Approach

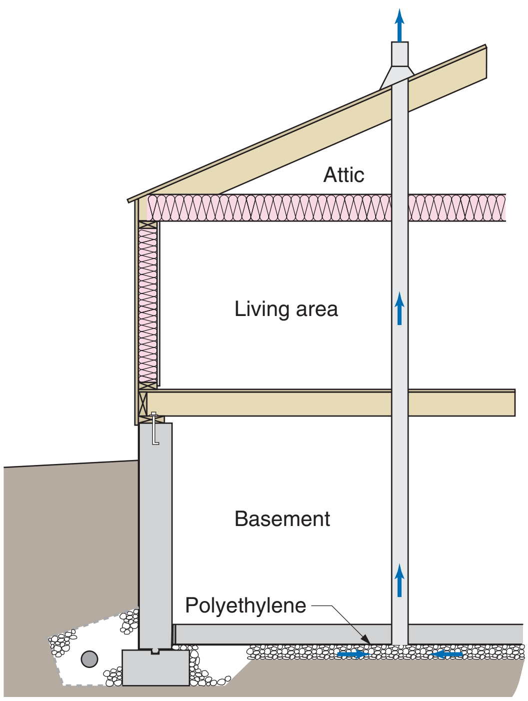
Suction systems collect radon from under the foundation and vent it to the outdoors. They do this by creating a stronger suction than that of the building itself. Suction systems are preferred where high potential for radon exists.

The systems have two parts: collection and discharge. A collection system adds little to construction cost, and the discharge system can be deferred until proven necessary. The collection system may utilize the existing moisture drainage system, or individual suction taps may be installed at the rate of one tap per 500 square feet of floor. A single tap, however, is adequate for a slab poured over a 4-inch layer of clean, coarse gravel.

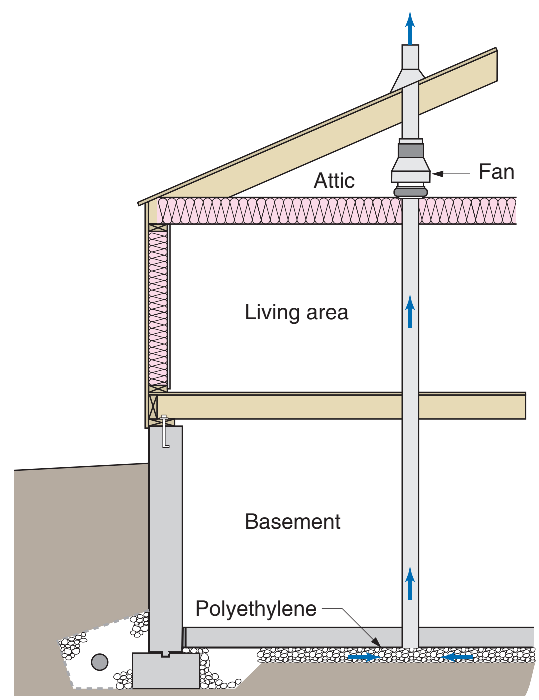
Geologic Radon Potential



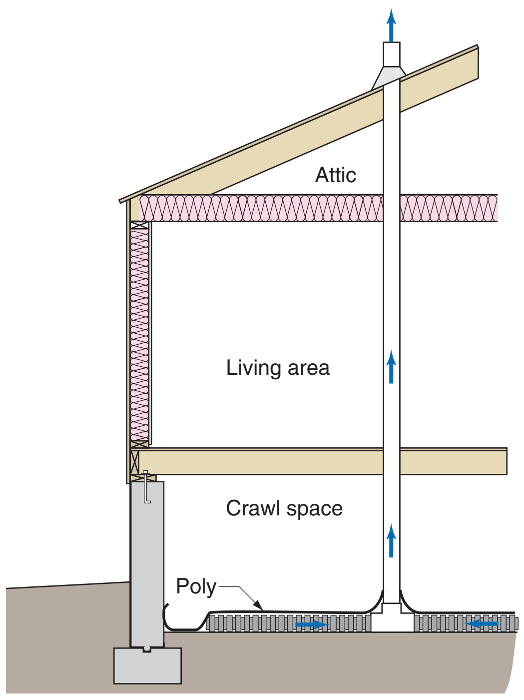
Passive Suction under Slabs



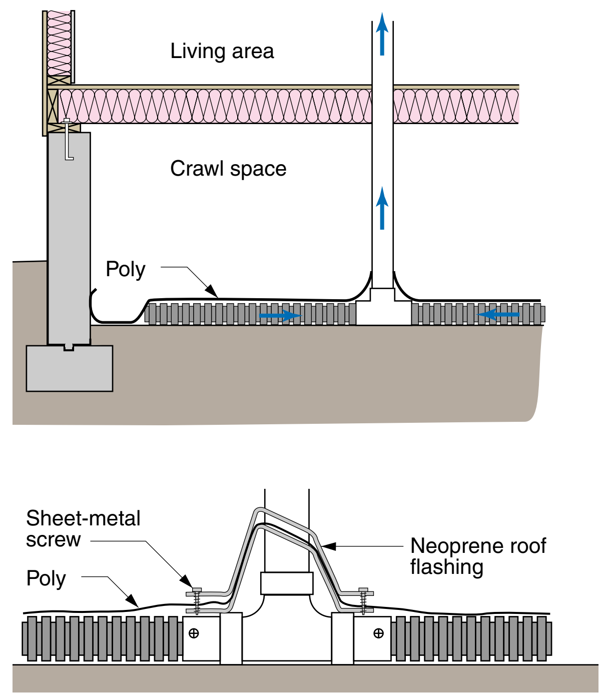
Active Suction under Slabs



Passive Suction in Crawl Space



Crawl-Space Groundcover Details



Meet the Code (IRC)

The following is a partial list of requirements from the *2015 International Residential Code (IRC) for One- and Two-Family Dwellings.* Consult the publication for the full text and additional provisions.

General (R401)

Drainage:

- diverted to a storm sewer or other collection point
- graded ≥6" within 10' of foundation

Exception: impervious surfaces within 10 feet of foundation slope a ≥2% percent away from building.

Materials (R402)

Concrete:

- minimum compressive strength in Table R402.2
- subject to moderate or severe weathering to be air-entrained

Table R402.2
Minimum Strength of Concrete, psi

	Weathering Potential		
Type or Location	**Negligible**	**Moderate**	**Severe**
Foundations & slabs (exc. garage)	2,500	2,500	2,500
Vertical walls exposed to weather	2,500	3,000	3,000
Porches, steps, garage & carport slabs exposed to weather	2,500	3,000	3,500

Fasteners for wood foundations:

- for below-grade plywood or in knee walls, 304 or 316 stainless steel
- for above-grade plywood and lumber, 304 or 316 stainless steel, silicon bronze, copper, hot-dipped galvanized steel or hot-tumbled galvanized steel
- electrogalvanized steel nails and galvanized steel staples not permitted

Wood for wood foundations:

- lumber and plywood treated to AWPA Std. U1
- lumber or plywood cut after treatment, to be field-treated with copper naphthenate until rejection

Footings R403

General:

- exterior walls supported on continuous concrete, fully grouted masonry, crushed stone, or wood footings, or approved systems to accommodate loads
- supported on undisturbed soil or engineered fill

Minimum size:

- minimum sizes per Table R403.1
- footings spread ≥6" thick
- footing projections ≥2" and <thickness of footing
- pier and column footings based on tributary load and allowable soil pressure

Table R403.1
Minimum Width of Footings, inches*

	Load-Bearing Value of Soil, psf			
	1,500	**2,000**	**3,000**	**4,000**
Conventional light-frame construction				
1-story	12	12	12	12
2-story	16	12	12	12
4" brick veneer over light frame or 8" hollow masonry				
1-story	12	12	12	12
2-story	20	15	12	12
8" solid or fully grouted masonry				
1-story	19	14	12	12
2-story	29	22	14	12

* For 20 psf snow or live roof load and crawl-space foundations

Reinforcement:

- foundations with stemwalls, one No. 4 bar within 12" of top of wall and one No. 4 bar 3"–4" from bottom of footing
- slabs on ground with turned-down footings, one No. 4 bar at top and bottom of footing, except if monolithic, 1 No. 5 bar or 2 No. 4 bars in middle third of footing depth

Frost protection:

- foundation walls, piers, and other supports to be protected by one or more of the following methods:
  1. extended below frost line
  2. frost-protected shallow foundation (R403.3)
  3. erected on solid rock

Exceptions:

1. freestanding light-framed structures of ≤600 sq. ft., with eave height ≤10'
2. other freestanding structures of ≤400 sq. ft., with eave height ≤10'
3. decks not supported by dwelling

Foundation/Retaining Walls (R404)

- height above finished grade ≥6"

Exception: ≥4" for masonry veneer walls

- no backfill until wall cured and anchored to floor above or braced to prevent damage, except bracing not required for <4' of unbalanced backfill

Anchor bolts:

- ≥1/2" bolts @ ≤6' o.c. and embedded ≥7"
- two bolts per plate section min.
- one bolt ≤12" from each end of plate section

Foundation Drainage (R405)

Concrete or masonry foundations:

- drains required around foundations enclosing usable space below grade
- drain tiles, gravel or crushed stone, or perforated pipe at or below area to be protected and discharged into approved drainage system
- gravel or crushed stone drains must extend ≥12" outside and ≥6" above footing and be covered with filter membrane
- drain tiles or perforated pipe on ≥2" and covered with ≥6" of washed gravel or crushed stone

Exception: drainage not required when foundation on well-drained ground (USC, Group I soils)

Wood foundations enclosing usable space:

- ≥4" gravel, stone or sand under basement floor
- automatic draining of subslab and wall footings
- 6-mil poly vapor retarder under basement floor
- unless USC Group I (well-drained) soil, a sump ≥24" in diameter or 20" square, extending ≥24" below bottom of basement floor, and discharging into approved sewer system or to daylight

Dampproofing (R406)

- basement walls enclosing usable space must be dampproofed from footing to grade
- masonry walls require ≥3/8" portland cement parging plus dampproofing

Exception: parging not required for material approved for direct application to masonry

- waterproofing required in areas of high water table or other severe soil-water conditions
- membrane joints to be sealed with compatible adhesive

Exception: organic-solvent-based waterproofing products such as hydrocarbons, chlorinated hydrocarbons, ketones, and esters shall not be used for ICF walls with expanded polystyrene (“beadboard”) forms

Crawlspace Ventilation (R408)

- net vent area with no vapor retarder covering ground ≥1 sq ft per 150 sq ft of floor
- net vent area with Class I vapor retarder covering ground ≥1 sq ft per 1,500 sq ft of floor
- 1 vent within 3' of each building corner
- ventilation not required where earth covered with continuous vapor retarder having lapped and sealed joints and edges, and there is continuous mechanical ventilation of ≥1 cfm/50 sq ft
- access to under-floor areas: ≥18"×24" through floor, or ≥16"×24" through perimeter wall

5

Wood

Wood is nature's must wonderful building material. Its combination of strength and beauty has never been surpassed in the laboratory. The first section of this chapter explores the *nature of wood.*

The beauty of wood, however, is partly due to its imperfections. So next the chapter looks at how *lumber defects* affect its *grading* and how lumber grade stamps are interpreted.

Wood is categorized as being either softwood (from evergreens) or hardwood (from deciduous trees). The *Properties of North American Species* table lists the qualities of 56 species. A second table compares *moisture and shrinkage* of 34 of the wood species.

And when is a 2×4 really a 2×4? Building projects often require that we know the exact dimensions of the lumber. The table of *standard finished lumber dimensions* lists both nominal and actual dimensions of all standard categories and sizes of lumber.

Wood will last a long time if kept dry. The building codes recognize that many outdoor and underground applications lead to decay, however. This chapter lists and illustrates the applications for which the codes call for *pressure-treated wood.*

The Nature of Wood

The fibrous nature of wood largely determines how it is used. Wood is primarily composed of hollow, elongate, spindle-shaped cells arranged parallel to each other along the trunk of a tree. When lumber and other products are cut from the tree, the characteristics of these fibrous cells and their arrangement affect such properties as strength and shrinkage as well as the grain pattern of the wood.

Reading a Tree Trunk

Bark is a thick layer of dead cells, similar in function to the outer layers of human skin, that protects the living parts of the tree from insects and fire. A tree is very resistant to insects as long as its bark forms a complete barrier.

Phloem is the inner bark, consisting of live cells that transmit nutrients, as do the cells of the sapwood.

The *cambium* is a single layer of cells where, remarkably, all tree growth occurs. The cells of the cambium continually divide, first adding a cell to the phloem outside and then a cell to the sapwood inside. As a result, a tree limb that first appears at a height of 5 feet aboveground will remain 5 feet high, even though the tree grows taller.

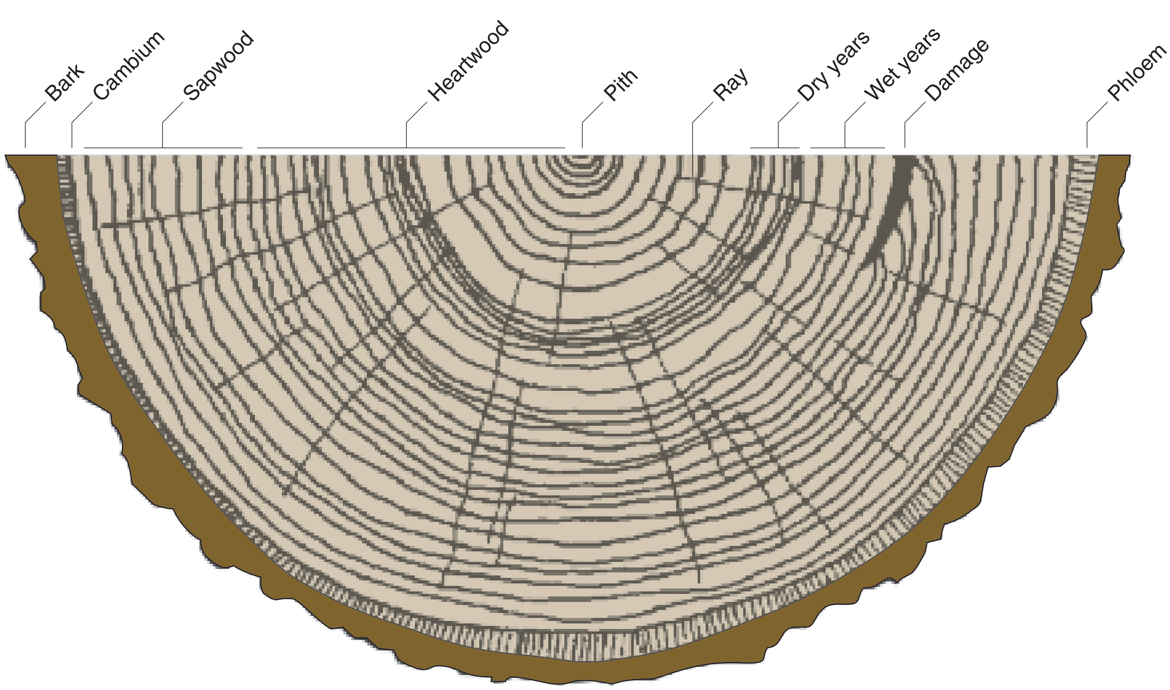
Sapwood consists of the most recently formed layers of wood, and, as its name implies, it carries sap up and down the tree. When the rate of growth varies throughout the year, or even ceases during cold winters, the sapwood shows annual growth rings. Wide rings are due to rapid growth in wet summers; narrow rings indicate dry summers.

Heartwood is formed of dead sapwood cells. Chemicals and minerals are deposited in and between the heartwood cells, making the wood more dense, strong, dark, and resistant to decay than the sapwood.

The *pith*. at the very center of the tree, is the overgrown remnant of the original shoot.

Rays are at right angles to the circular rings. Not defects or cracks, as they appear, rays are bundles of cells that transport and store food across the annual rings.

Reading a Tree Trunk



Growth Rings

In most species the difference between wood formed early in the growing season and that formed later produces well-marked annual growth rings. The age of a tree can be determined by counting these annual rings. However, if the growth is interrupted, by drought or defoliation by insects for example, more than one ring may be formed in the same season. In this case the inner rings do not have sharply defined boundaries and are called false rings.

The inner part of the growth ring formed early in the growing season is called earlywood, and the outer part formed later in the growing season, latewood. The actual time of formation of these two parts of a ring may vary with environmental and weather conditions. Earlywood is characterized by cells with relatively large cavities and thin walls. Latewood cells have smaller cavities and thicker walls.

Growth rings are most readily seen in species with sharp contrast between latewood formed in one year and earlywood formed in the following year, such as in the hardwoods ash and oak, and in softwoods like southern pine. In some species, such as water tupelo, aspen, and sweetgum, differentiation of earlywood and latewood is slight and the annual growth rings are difficult to recognize. In many tropical regions, growth is continuous throughout the year, and no well-defined growth rings are formed.

When growth rings are prominent, as in most softwoods and ring-porous hardwoods, earlywood differs markedly from latewood in physical properties. Earlywood is lighter in weight, softer, and weaker than latewood. Because of the greater density of latewood, the proportion of latewood is sometimes used to judge the strength of the wood. This method is useful with such species as the southern pines, Douglas fir, ash, hickory, and oak.

Wood Cells

Wood cells—the structural elements of wood tissue—are of various sizes and shapes and are firmly cemented together. Dry wood cells may be empty or partly filled with deposits, such as gums and resins. The majority of wood cells are considerably elongated and pointed at the ends; these cells are customarily called fibers. The length of wood fibers is highly variable within a tree and among species. Hardwood fibers average about $^{1}/_{25}$ inch in length; softwood fibers range from $^{1}/_{8}$ to $^{1}/_{3}$ inch in length.

In addition to fibers, hardwoods have cells of relatively large diameter known as vessels or pores. These cells form the main conduits in the movement of sap.

Both hardwoods and softwoods also have cells that are oriented radially from pith toward bark. These groups of cells conduct sap across the grain and are called rays. The rays are most easily seen on edge-grained or quartersawn surfaces, and they vary greatly in size in different species. In oaks the rays are very conspicuous and add to the decorative features of the wood. Rays also represent planes of weakness along which seasoning (drying) checks develop.

Chemical Composition

Dry wood is primarily composed of cellulose, lignin, hemicelluloses, and minor amounts (5% to 10%) of extraneous materials. Cellulose, the major component, constitutes approximately 50% of wood by weight. It is a high-molecular-weight linear polymer. During growth the cellulose molecules are arranged into ordered strands called fibrils, which in turn are organized into the larger structural elements that make up the cell wall of wood fibers. Most of the cell wall cellulose is crystalline. Delignified wood fibers, which consist mostly of cellulose, are used in making paper. Delignified fibers may also be chemically altered to form textiles, films, lacquers, and explosives.

Lignin constitutes 23% to 33% of the wood substance in softwoods and 16% to 25% in hardwoods. Although lignin occurs in wood throughout the cell wall, it is concentrated toward the outside of the cells and between cells. Lignin is the cementing agent that binds the cells together. It is necessary to remove lignin from wood to make high-grade paper.

Defects and Grading

Defects in Lumber

Lumber is sawn from trees, and trees grow in an ever changing environment. As a result, the material composition of trees and lumber varies. Some of the variations are valued for their beauty, whereas others reduce the strength or utility of the lumber. The most common "defects" are illustrated on the facing page and described below.

Bow is deviation from a flat plane of the wide face, end to end. It is caused by a change in moisture content after sawing and by fibers not being exactly parallel to the surfaces. It has no effect on strength. Therefore, feel free to use a piece wherever nailing will constrain it to a flat plane.

Cup is deviation from a flat plane of the narrow face, edge to edge. It is caused by a change in moisture content after surfacing. It tends to loosen fasteners.

Crook is deviation from a flat plane of the narrow face, end to end. It is caused by change of moisture content after sawing and by fibers not parallel to the surfaces. It makes wood unsuitable for framing.

Twist is deviation from a flat plane of all faces, end-to-end. It results from spiral wood grain and changes in moisture content. Twist also makes lumber unsuitable for framing.

Knots are the high-density roots of the limbs. Knots are very strong but not well connected to the surrounding wood. The rules for use in joists and rafters are 1) tight knots are allowed in the top third, 2) loose or missing knots are allowed in the middle third, and 3) no knots at all over 1" are allowed in the bottom third.

Check is the lumber version of a stretch mark, a rift in the surface caused when the surface of a timber dries more rapidly than the interior. End checks weaken a timber in shear; other checks are mostly cosmetic. The development of check can be very dramatic and unsightly in exposed beams that are dried rapidly in a warm house the first winter. Solutions include air drying for several years before use, or treatment of timber surfaces with oil to retard the drying process.

Split passes clear through the wood and is often the result of rough handling. It constitutes a serious structural weakness. Lumber with splits should not be used in bending (joists and rafters) or in compression as a post.

Shake is a separation of growth rings. Lumber with shake should not be used to support bending loads (beams, joists, and rafters), because it must be presumed that the zone of weakness extends the entire length of the piece.

Wane is the presence of bark or lack of wood at an edge. It results from a slight miscalculation on the part of the sawyer. It has very little effect on strength. The main drawback is the lack of a full-width nailing surface.

Cross grain occurs when a board is sawn from a crooked log. Since wood is ten times stronger in the direction of grain than across the grain, a cross-grain angle greater than one part in ten seriously weakens the wood in bending (beams, joists, and rafters).

Decay is destruction of the wood structure by fungi or insects. It prohibits structural use of the wood but may enhance its decorative value, provided the decay process has been halted.

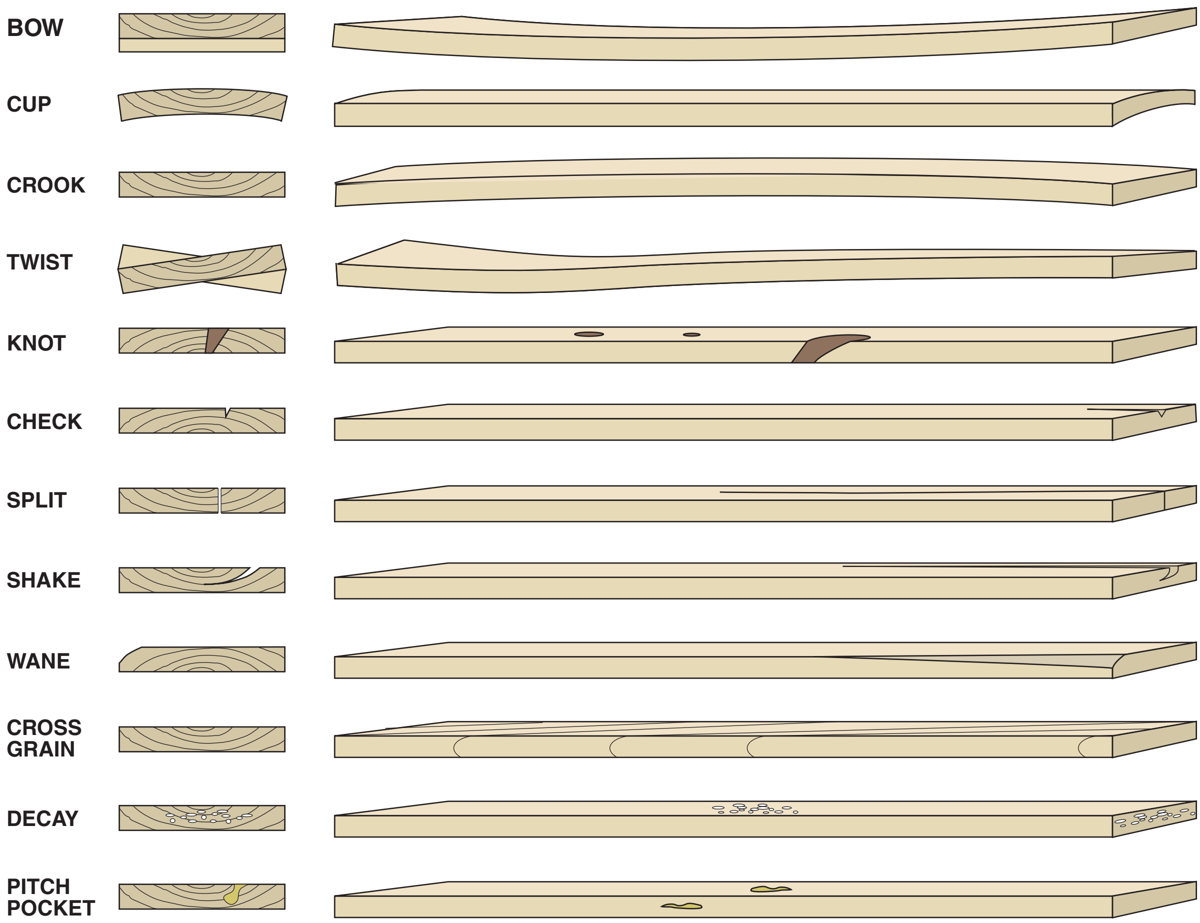
Pitch pockets are accumulations of natural resins. They have little effect on strength but will bleed through paint and should not be allowed in lumber that will be painted.

Lumber Grade Stamps

A grade stamp assures the lumber customer that the piece of lumber carrying the stamp meets the minimum standard for the stated purpose. Some stamps certify strength for use in framing, whereas others certify appearance for use in millwork.

There is a bewildering array of grade stamps, but all stamps from certified agencies conform to the guidelines set by the American Lumber Standard Committee Inc.SM Reading grade stamps is quite simple, as demonstrated by the example on the facing page.

Lumber Defects



Typical Lumber Grade Stamp

Properties of North American Species

Below is a table of properties of North American wood species. For all of the numerical ratings, 1 is best and 5 is worst.

Density is an indirect measure of strength. Refer to chapter 23 for tables of wood density versus the holding power of nails and screws.

Paintability refers to the relative ease of maintaining exterior painted surfaces such as clapboards, decking, and trim.

Cupping, or deviation of the wide face of a board from a flat plane, tends to loosen nails. Only species with cupping ratings of 1 or 2 should be considered for exterior siding and trim.

Checking is cracking of the exterior surface due to drying too quickly. It does not usually affect strength but is unsightly.

R/inch is the thermal resistance to heat flow, just as with insulation.

Physical Properties of Selected North American Hardwoods

Species	Density lb/cu ft	Paint-ability	Resistance to cupping	Resistance to Checking	R/inch Oven-dry	R/inch 12% MC	Color of Heartwood
Alder, red	25.6	3	–	–	–	–	Pale brown
Ash, white	37.4	–	–	–	1.0	0.84	Gray-brown
Aspen, quaking	24.3	3	2	1	1.5	1.2	Pale brown
Basswood, American	23.1	3	2	2	1.6	1.3	Cream
Beech. American	40.0	4	4	2	0.96	0.78	Pale brown
Birch, yellow	38.7	4	4	2	0.98	0.81	Light brown
Butternut	23.7	3–5	–	–	–	–	Light brown
Cherry, black	31.2	4	–	–	1.2	0.98	Brown
Chestnut, American	26.8	3–5	3	2	1.4	1.1	Light brown
Cottonwood, black	21.8	3	4	2	1.7	1.4	White
Cottonwood, eastern	26.8	3	4	2	1.4	1.2	White
Elm, American	31.2	4–5	4	2	1.2	0.96	Brown
Elm, rock	34.9	–	4	2	0.97	0.80	Brown
Elm, slippery	41.8	–	–	–	1.1	0.93	Brown
Hickory, pecan	41.2	4–5	4	2	0.95	0.77	Light brown
Locust, black	43.1	–	–	–	–	–	Golden brown
Magnolia, southern	31.2	3	2	–	1.2	1.0	Pale brown
Maple, sugar	39.3	4	4	2	0.98	0.81	Light brown
Oak, red	39.3	4	4	2	1.0	0.82	Light brown
Oak, white	42.4	4–5	4	2	0.91	0.75	Brown
Poplar, yellow	26.2	3	2	1	1.3	1.1	Pale brown
Sycamore, American	30.6	4	–	–	1.2	0.96	Pale brown
Walnut, black	34.3	3–5	3	2	–	–	Dark brown

Physical Properties of Selected North American Softwoods

Species	Density lb/cu ft	Paint-ability	Resistance to cupping	Resistance to Checking	R/inch Oven-dry	R/inch 12% MC	Color of Heartwood
Baldcypress	32.0	–	–	1	1.3	1.1	Brown
Cedar, Alaska	27.5	1	1	1	–	–	Golden brown
Cedar, Atlantic white	21.2	1	1	1	1.7	1.4	–
Cedar, eastern red	30.0	1	1	1	1.3	1.1	Pale red
Cedar, Incense	23.1	1	–	–	–	–	Brown
Cedar, Port Orford	26.8	1	–	1	1.4	1.2	Cream
Cedar, western red	20.0	1	1	1	1.7	1.5	Brown
Cedar, white	19.3	1	1	–	1.7	1.4	Light brown
Cypress	28.7	1	1	1	1.3	1.1	Light brown
Fir, balsam	23.0	–	–	–	1.6	1.3	–
Fir, Douglas	30.0	4	2	2	1.2	1.0	Pale red
Fir, white	24.3	3	2	2	1.5	1.2	White
Hemlock, eastern	25.0	3	2	2	1.4	1.2	Pale brown
Hemlock, western	28.1	3	2	2	1.3	1.1	Pale brown
Larch	32.4	4	2	2	1.1	0.93	Brown
Pine, eastern white	21.8	2	2	2	1.6	1.3	Cream
Pine, loblolly	33.7	–	–	–	1.2	0.96	–
Pine, lodgepole	33.7	–	–	–	1.4	1.2	–
Pine, longleaf	38.7	–	–	–	1.0	0.87	–
Pine, Norway	–	2	2	2	1.3	1.1	Light brown
Pine, pitch	33.1	–	–	–	1.2	0.98	–
Pine, ponderosa	25.0	3	2	2	1.4	1.2	Cream
Pine, red	28.7	–	–	–	1.3	1.1	–
Pine, shortleaf	33.7	–	–	–	1.2	0.96	–
Pine, southern	34.3	4	2	2	1.2	0.96	Light brown
Pine, sugar	22.5	2	2	2	1.6	1.3	Cream
Pine, western white	23.7	2	2	2	15	1.2	Cream
Redwood	22.5	1	1	1	1.5	1.2	Dark brown
Spruce, black	26.8	3	2	2	1.4	1.2	–
Spruce, Engelmann	23.1	3	2	2	1.4	1.2	–
Spruce, sitka	26.2	3	2	2	1.4	1.2	–
Spruce, white	21.8	3	2	2	1.6	1.3	White
Tamarack	33.1	4	2	2	–	–	Brown

Moisture and Shrinkage

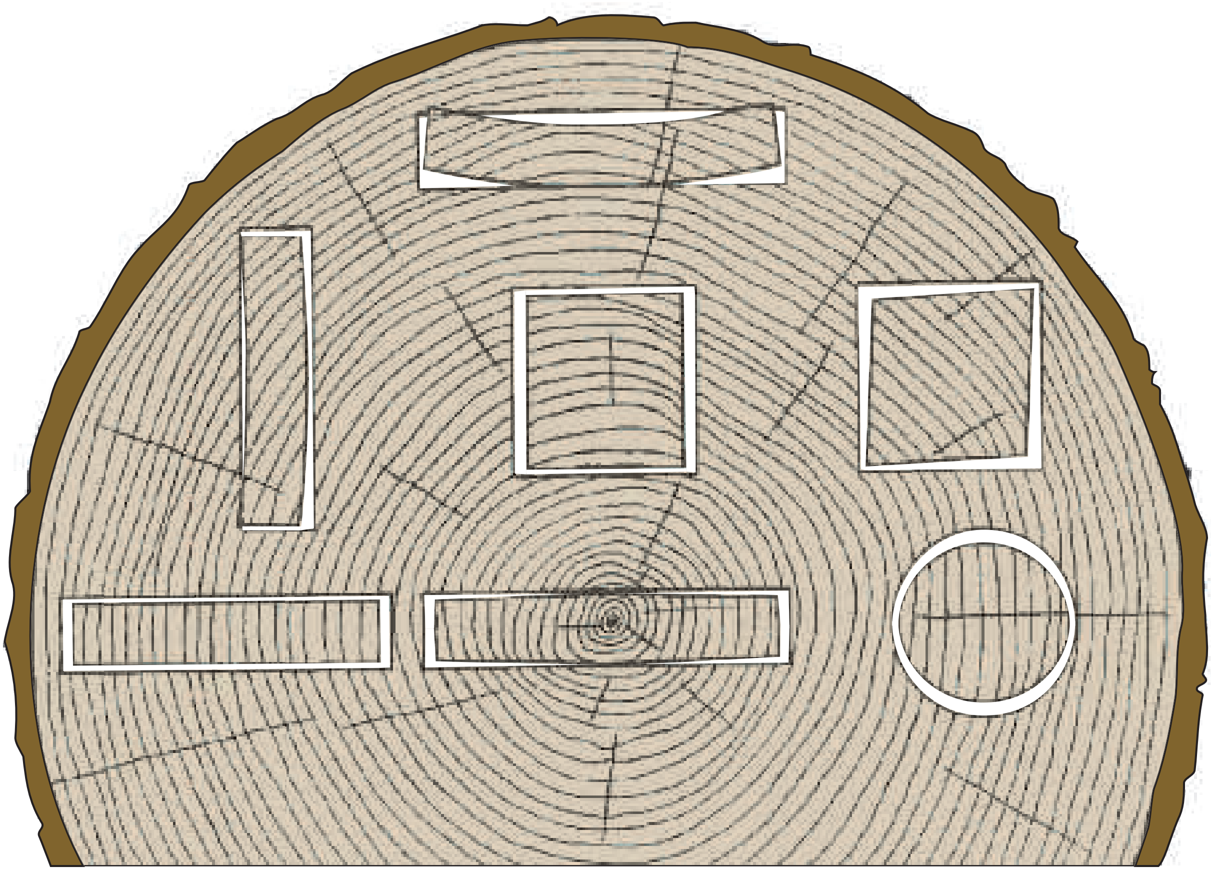
The amount of water in wood is expressed as a percentage of its oven-dry (dry as possible) weight. For example, 1 cubic foot of oven-dry red oak weighs 39.3 pounds. In drying from the just-cut, or green, stage, the sapwood loses 69% of 39.3, or 27.1 pounds of water.

As wood dries, it first loses moisture from within its cells without shrinking; after reaching the fiber saturation point (cells empty), further drying results in shrinkage. Eventually wood comes to dynamic equilibrium with the relative humidity of the surrounding air—interior wood typically shrinking in winter and swelling in summer. Average summer indoor equilibrium moisture content (EMC) ranges from 6% in the southwest to 11% in the south and east coastal states. Indoor EMC can drop to 4% in northern states in winter.

In the table on the facing page, the terms *radial* and *tangential* refer to orientation relative to the growth rings. Because shrinkage tangential to growth rings averages twice that in the radial direction, lumber tends to distort in cross section in drying.

As shown in the illustration below, the pattern of distortion depends on the direction of the rings in the lumber. The greatest distortion occurs in plainsawn lumber; the least in radial-sawn, or edge-grained lumber.

Shrinkage Patterns of Lumber from Green to Oven-Dry



Moisture Content and Shrinkage of Hardwoods and Softwoods

	Moisture Content Green (%)[1]		Shrinkage, from Green to Oven-Dry (%)		
Species	**Heartwood**	**Sapwood**	**Radial**	**Tangential**	**Volume**
HARDWOODS					
Ash, white	46	44	4.9	7.8	13.3
Aspen, quaking	95	113	3.5	6.7	11.5
Basswood, American	81	133	6.6	9.3	15.8
Beech. American	55	72	5.5	11.9	17.2
Birch, yellow	74	72	7.3	9.5	16.8
Cherry, black	58	—	3.7	7.1	11.5
Chestnut, American	120	—	3.4	6.7	11.6
Elm, American	95	92	4.2	9.5	14.6
Hickory, pecan	80	54	4.9	8.9	13.6
Locust, black	—	—	4.6	7.2	10.2
Magnolia, southern	80	104	5.4	6.6	12.3
Maple, sugar	65	72	4.8	9.9	14.7
Oak, red	80	69	4.0	8.6	13.7
Oak, white	64	78	5.6	10.5	16.3
Poplar, yellow	83	106	4.6	8.2	12.7
Walnut, black	90	73	5.5	7.8	12.8
SOFTWOODS					
Cedar, Alaska	32	166	2.8	6.0	9.2
Cedar, Port Orford	50	98	4.6	6.9	10.1
Cedar, western red	58	249	2.4	5.0	6.8
Cedar, white	–	–	2.2	4.9	7.2
Cypress	121	171	3.8	6.2	10.5
Fir, Douglas	37	115	4.8	7.6	12.4
Fir, white	98	160	3.3	7.0	9.8
Hemlock, eastern	97	119	3.0	6.8	9.7
Hemlock, western	85	170	4.2	7.8	12.4
Larch, western	54	110	4.5	9.1	14.0
Pine, eastern white	—	—	2.1	6.1	8.2
Pine, lodgepole	41	120	4.3	6.7	11.1
Pine, longleaf	31	106	5.1	7.5	12.2
Pine, sugar	98	219	2.9	5.6	7.9
Pine, western white	62	148	4.1	7.4	11.8
Redwood	86	210	2.6	4.4	6.8
Spruce, sitka	41	142	4.3	7.5	11.5
Tamarack	49	–	3.7	7.4	13.6

[1] Moisture content is expressed as percentage of oven-dry weight. When the moisture in the wood weighs more than oven-dry wood, this percentage will be more than 100%.

Standard Finished Lumber Dimensions

Standard Lumber Dimensions by Western Wood Products Association Rules

Product	Nominal Dimensions, inches		Dressed Dimensions, inches	
	Thickness	Width	Dry	Green
Dimension	2	2	1 1/2	1 9/16
	3	3	2 1/2	2 9/16
	4	4	3 1/2	3 9/16
		5	4 1/2	4 5/8
		6	5 1/2	5 5/8
		8	7 1/4	7 1/2
		10	9 1/4	9 1/2
		12	11 1/4	11 1/2
Scaffold plank	1 1/4 and thicker	8 and wider	Same as for "dimension"	
Timbers	5 and larger	5 and larger	Nominal less ½"	
			Thickness	Width
Decking	2	5	1 1/2	4
		6		5
		8		6 3/4
		10		8 3/4
		12		10 3/4
	3	6	2 1/2	5 1/4
	4		3 1/2	
Flooring	3/8	2	5/16	1 1/8
	1/2	3	7/16	2 1/8
	5/8	4	9/16	3 1/8
	1	5	3/4	4 1/8
	1 1/4	6	1	5 1/8
	1 1/2		1 1/4	
Ceiling and partition	3/8	3	5/16	2 1/8
	1/2	4	7/16	3 1/8
	5/8	5	9/16	4 1/8
	3/4	6	11/16	5 1/8
Factory and shop lumber	1 (4/4)	5 and wider	3/4	random width
	1 1/4 (5/4)		1 5/32	
	1 1/2 (6/4)		1 13/32	
	1 3/4 (7/4)		1 19/32	
	2 (8/4)		1 13/16	
	2 1/2 (10/4)		2 3/8	
	3 (12/4)		2 3/4	
	4 (16/4)		3 3/4	

Standard Lumber Dimensions by Western Wood Products Association Rules

	Nominal Dimensions, inches		Dressed Dimensions, inches	
Product	Thickness	Width	Thickness	Width
Selects and commons	1 (4/4)	2	$3/4$	$1\,1/2$
	$1\,1/4$ (5/4)	3	$1\,5/32$	$2\,1/2$
	$1\,1/2$ (6/4)	4	$1\,13/32$	$3\,1/2$
	$1\,3/4$ (7/4)	5	$1\,19/32$	$4\,1/2$
	2 (8/4)	6	$1\,13/16$	$5\,1/2$
	$2\,1/4$ (9/4)	7	$2\,3/32$	$6\,1/2$
	$2\,1/2$ (10/4)	8 and wider	$2\,3/8$	nominal – $3/4$
	$2\,3/4$ (11/4)		$2\,9/16$	
	3 (12/4)		$2\,3/4$	
Finish and boards	$3/8$	2	$5/16$	$1\,1/2$
	$1/2$	3	$7/16$	$2\,1/2$
	$5/8$	4	$9/16$	$3\,1/2$
	$3/4$	5	$5/8$	$4\,1/2$
	1	6	$3/4$	$5\,1/2$
	$1\,1/4$	7	1	$6\,1/2$
	$1\,1/2$	8 and wider	$1\,1/4$	nominal – $3/4$
	$1\,3/4$		$1\,3/8$	
	2		$1\,1/2$	
	$2\,1/2$		2	
	3		$2\,1/2$	
	$3\,1/2$		3	
	4		$3\,1/2$	
Rustic and drop siding	1	6	$23/32$	$5\,3/8$
		8		$7\,1/8$
		10		$9\,1/8$
		12		$11\,1/8$
Paneling and siding	1	6	$23/32$	$5\,7/16$
		8		$7\,1/8$
		10		$9\,1/8$
		12		$11\,1/8$
Ceiling and partition	$5/8$	4	$9/16$	$3\,3/8$
	1	6	$23/32$	$5\,3/8$
Bevel siding	$1/2$	4	$15/32$ butt, $3/16$ tip	$3\,1/2$
		5		$4\,1/2$
		6		$5\,1/2$
	$3/4$	8	$3/4$ butt, $3/16$ tip	$7\,1/4$
		10		$9\,1/4$
		12		$11\,1/4$

Pressure-Treated Wood

Pressure-treated lumber is softwood that has been treated by forcing chemicals into the wood cells. The result is lumber that is nearly immune to decay.

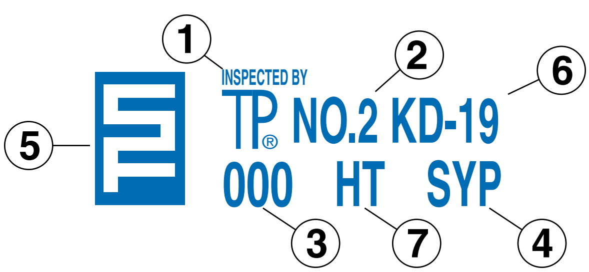
Most pressure-treated wood used in residential applications is southern yellow pine framing lumber. Because it must meet the structural requirements of framing, and because it is also pressure-treated, each piece carries two separate quality stamps or tags, typical examples of which are illustrated below:

1. An inked grade mark conforming to the rules of the Southern Pine Inspection Bureau.

2. A stamp or tag conforming to the rules of the American Wood Protection Association.

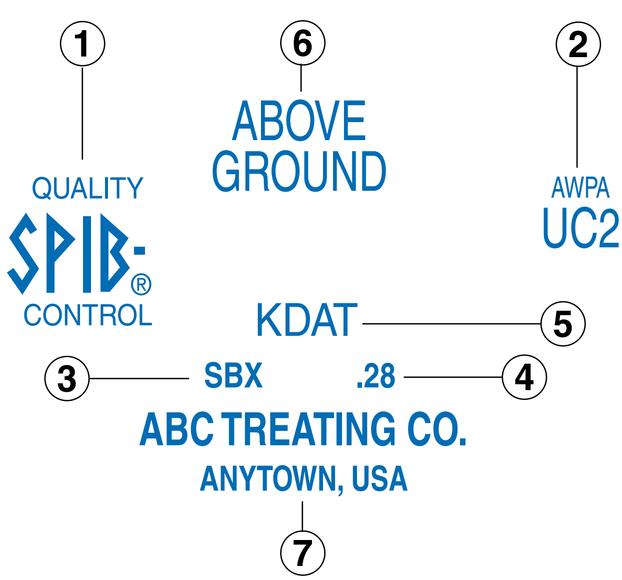
Building codes generally require the use of pressure-treated wood in the applications shown in the illustrations on the facing page.

Typical Southern Pine Lumber Grade Stamp



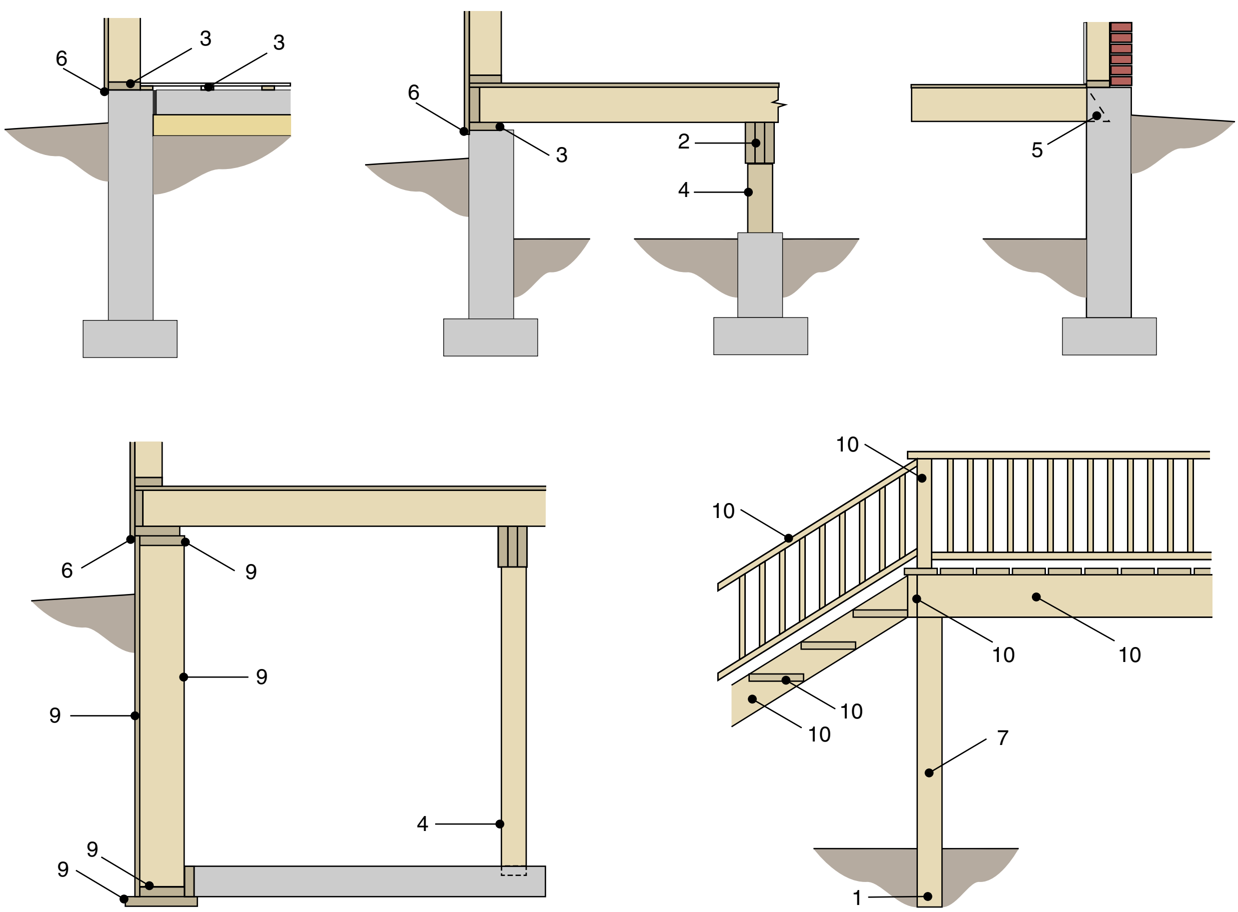
1 Inspection service: Timber Products Inspection (TPS℠)
2 Lumber grade
3 Mill identification number
4 Lumber species
5 Southern Forest Products Association℠ logo (optional)
6 Moisture content: Kiln dried (KD) to 19% maximum
7 Heat treated

Typical Quality Stamp for Treated Lumber



1 Trademark of inspection agency accredited by American Lumber Standard Committee (ALSC)
2 American Wood Protection Association (AWPA) use category
3 Preservative used for treatment
4 Retention level
5 Dry or kiln dried after treatment (KDAT)
6 Exposure category
7 Treating company and location

Applications Where Code Requires Pressure-Treated Wood



KEY:

1. Wood embedded in, or in direct contact with, earth for support of permanent structures

2. Floor joists less than 18 inches and girders less than 12 inches from the ground

3. Foundation plates, sills, or sleepers on a masonry slab or foundation in earth contact

4. Posts or columns placed directly on masonry exposed to weather, or in basements

5. Ends of girders entering concrete or masonry walls without a 1/2-inch air space

6. Wood in permanent structures and located less than 6 inches from earth

7. Wood structural members supporting moisture-permeable floors or roofs exposed to the weather unless separated by an impervious moisture barrier

8. Earth-retaining walls (not illustrated)

9. All-weather wood foundations (see details in chapter 4)

10. In hot and humid areas, structural supports of buildings, balconies, porches, etc., when exposed to the weather without protection from a roof, overhang, or other covering to prevent moisture accumulation

6

Framing

To make a human analogy, the frame of a building is its skeleton. To ensure that this skeleton is strong enough, we need to specify how much weight it will support—the *building loads*. Using *wood beam design* formulae, the loads, and the design values for structural lumber, we can calculate *span tables for rough-sawn lumber*. Alternatively, we can consult *joist and rafter span tables for U.S. species* and *joist and rafter span tables for Canadian species*.

Builders are increasingly turning to engineered-wood *I-joists* and *wood trusses*, so span tables for both are included here. Span tables are also given for *plank floors and roofs*, which are often used with the greater-than-usual joist and rafter spacing that results from timber framing. When loads become too large for ordinary lumber, you can turn to *glued laminated (glulam) beams, panel and lumber beams,* and even *steel beams*. This chapter includes simple span tables for all three.

The section on *timber framing* traces the origins of this revitalized art and illustrates the joinery that many find so beautiful. If you are remodeling an older home, you may be dealing with *balloon framing*. If your home is less than 60 years old, you will probably recognize its *platform framing*. If building a new home, you should take advantage of the energy- and cost-efficiencies of *advanced (OVE) framing*.

Many of the code requirements for stairways are covered in Chapter 1, "Design." *Stair framing*, however, is covered in this chapter.

Finally, we provide you with a checklist so your framing will *meet the code (IRC)*.

Building Loads

In this chapter we will consider the variety of forces acting on a building's frame. Understanding these forces (*loads* in building parlance), we can calculate the total load on an individual framing member. Being able to calculate loads is a powerful tool. It is the key that allows us to use span tables.

Building loads are the forces a building frame must support or resist. Building codes recognize five types of load:

- Dead—the weight of the building materials
- Live—the weight due to occupancy; i.e., the weight of people, furnishings, and stored materials
- Snow—the weight of snow on the roof
- Wind—the force of the wind against exterior building surfaces, including the roof
- Seismic—the force of the reaction of the building to the acceleration of the earth beneath

Dead Loads

For a floor or roof, the dead load in pounds per square foot (psf) is found by adding the weights of the materials of which it is constructed using the table at right.

Example 1: A first floor framed with 2×8 joists, spaced 16 inches on-center, and covered with ⅝-inch plywood and wall-to-wall carpet weighs 2.2 psf + 1.8 psf + 0.6 psf = 4.6 psf.

Example 2: A second floor framed with 2×6 joists, spaced 16 inches on-center, with ½-inch drywall ceiling below and floored with ½-inch plywood and ¾-inch hardwood above, weighs 1.7 psf + 2.2 psf + 1.5 psf + 3.0 psf = 8.4 psf.

Example 3: A roof with 2×8 joists 16 inches on-center, 6-inch fiberglass batts, ½-inch plywood sheathing, and asphalt shingles weighs 2.2 psf + 1.8 psf + 1.5 psf + 2.5 psf = 8.0 psf.

Weights of Building Materials

Component	Material	psf
Framing	2×4 @ 16″ o.c.	1.1
	2×4 @ 24″ o.c.	0.7
	2×6 @ 16″ o.c.	1.7
	2×6 @ 24″ o.c.	1.1
	2×8 @ 16″ o.c.	2.2
	2×8 @ 24″ o.c.	1.5
	2×10 @ 16″ o.c.	2.8
	2×10 @ 24″ o.c.	1.9
Flooring	Softwood, per inch	3.0
	Hardwood, per inch	4.0
	½″ Plywood	1.5
	⅝″ Plywood	1.8
	¾″ Plywood	2.3
	1⅛″ Plywood	3.4
	Sheet vinyl	1.5
	Carpet and pad	0.6
	¾″ Tile	10.0
	¾″ Gypcrete	6.5
	Concrete, per inch	12.0
	Stone, per inch	13.0
Ceiling	½″ Drywall	2.2
	Plaster. per inch	8.0
	Acoustic tile	1.0
Roofing	Asphalt shingles	2.5
	Asphalt roll roofing	1.2
	Asphalt, built-up	6.0
	Wood shingles	3.0
	Wood shakes	6.0
	Roman tile	12.0
	Spanish tile	19.0
	Slate, ⅜″	12.0
	Steel	2.0
Insulation	Fiberglass wool, per inch	0.3
	Fiberglass board, per inch	1.5
	Foam. per inch	0.2

Live Loads

Live loads are specified by building code. The table at right lists the International Residential Code (IRC) requirements for one- and two-family residential construction. The roof loads shown assume a maximum tributary loaded area of 200 square feet per rafter.

Snow Loads

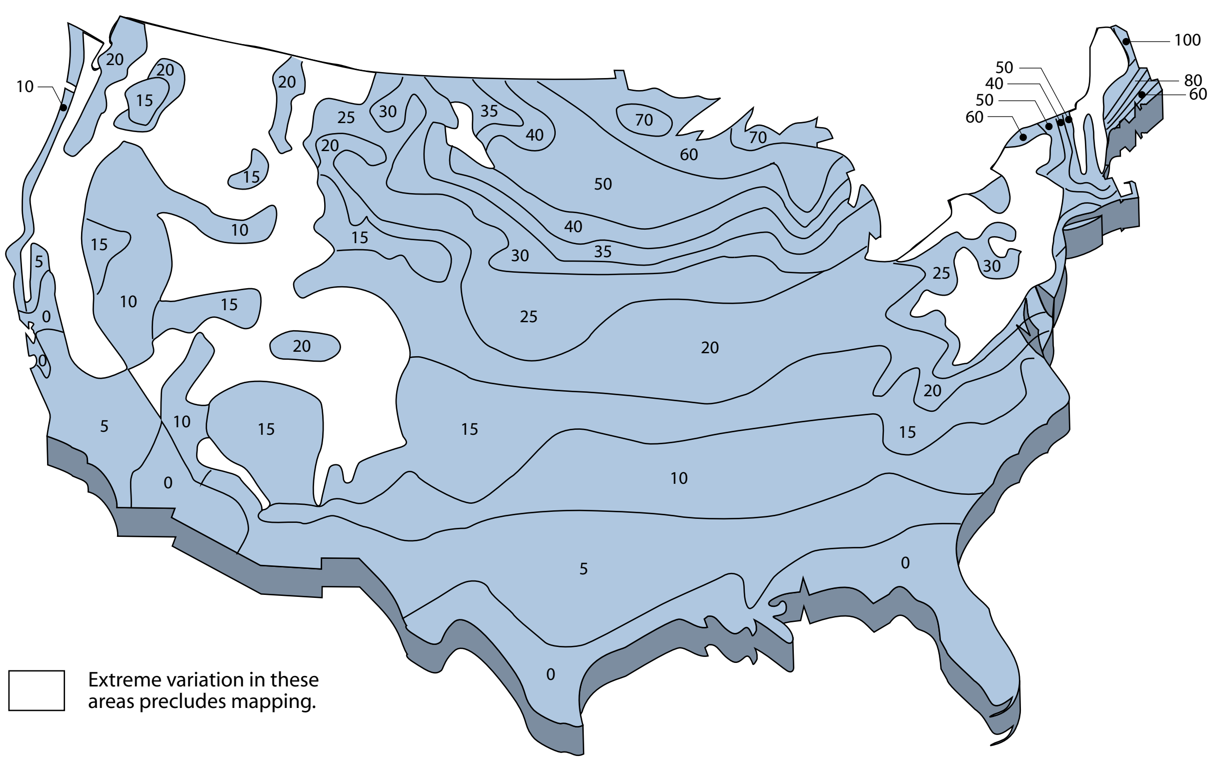
The snow load on a roof is taken over its horizontal projection; i.e. its span. It is thus the same as the ground snow load. The map below is simplified from the Ground Snow Load in the International Residential Code.

Important: if you live in one of the unshaded (mountainous) areas, consult your code official.

Minimum Live Loads (IRC)

Area	psf
Attics with storage	20
Attics without storage	10
Decks	40
Exterior balconies	60
Fire escapes	40
Passenger vehicle garages	50
Rooms other than sleeping rooms	40
Sleeping rooms	30
Stairs	40
Roof, rise < 4" per foot	20
rise 4"–12" per foot	16
rise > 12" per foot	12

Ground Snow Loads, PSF



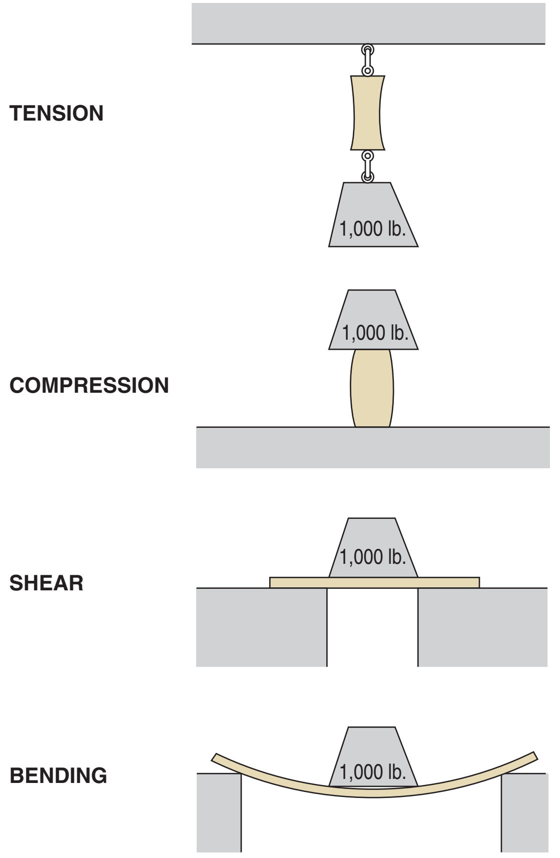
Wood Beam Design

Wood has different strengths depending on whether it is oak or pine; whether it has knots; how big it is in cross section; how long it is, etc. We have three choices in framing: 1) be supercautious and overspecify (not overdesign, for no real design is involved); 2) use graded dressed lumber and span tables provided by grading associations; or 3) use roughsawn ungraded lumber. Method #3 can save 50% of the cost of framing a house, but it also requires calculating the sizes of beams. The following six pages show how to size rough wood beams.

Forces in Wood

We are concerned with four types of forces in wood, each with a different name according to what it tends to do (see the illustration below).

Forces in Wood Framing Members



Stress and Strain

Stress in a wood member is the measure of internal force resulting from an external force. The larger the member, the more external force it can resist. To be able to compare wood members of varying size, unit stress is defined:

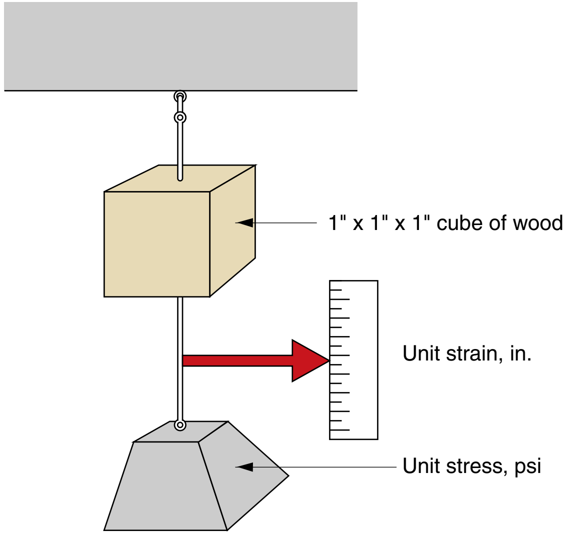
$$f = F/A$$

where:
f = unit stress in psi
F = total force in lb.
A = area of cross section in sq.in.

According to atomic theory, all matter consists almost entirely of empty space. Whenever a stress is applied to a solid object, no matter how slight, there is a resulting strain. What follows is true of any material, be it wood, glass, steel, or stone. If we had an extremely sensitive measuring device, we could perform the following experiment:

We fashion a cube of material exactly 1 inch on a side. Starting from zero, we slowly increase the stress by adding weight and measure the corresponding strain, or movement, of the pointer. The cross-sectional area, A, of the cube is 1 sq.in.

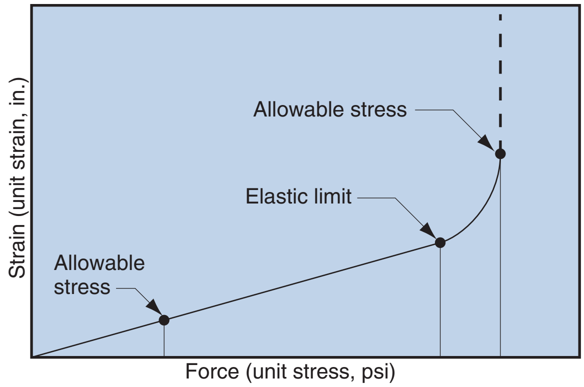
Stress/Strain Experiment



The results of our experiment plotted on a graph would demonstrate Hooke's Law: As stress increases from zero, strain increases proportionately, giving us a straight line. That is:

Change in stress/Change in strain = E

Results of Stress/Strain Experiment



E is a measure of stiffness or rigidity and has the engineering name *modulus of elasticity*, modulus being a fancy term for ratio. In the straight-line region where Hooke's Law applies, removal of the stress results in the return of strain to zero. That is what *elastic* means. However, if we continue to increase stress, we reach a point where not only does the strain increase more rapidly, but removal of the stress also results in a permanent strain, or *set*. We have at this point exceeded the elastic limit. Increasing the stress even further, we ultimately reach a point where strain increases without limit and without requiring further stress (the material breaks). This point is the material's *ultimate strength*.

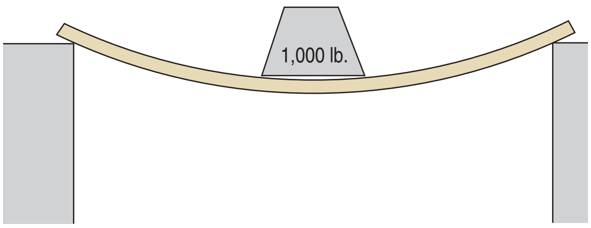
Inhomogeneities and imperfections lower the strength of wood. Visual grading of lumber for framing purposes consists of specifying an allowable stress due to visible defects. The ratio of *ultimate strength* to *allowable stress* is called the *safety factor*. The reason why flimsy carports sometimes withstand extreme winter snows in spite of violating the building code is that the safety factor for graded lumber is about eight!

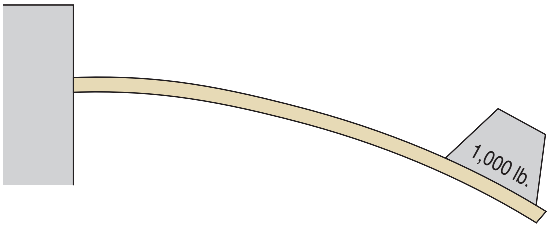
Bending

Framing members subjected to forces that make them bend are generally known as *beams*. Specific examples of beams are *joists* and *rafters*. We are interested in two aspects of bending in beams: 1) Will the beam break? 2) How much will the beam deflect (bend) under a given load?

Experience tells us that beams supported at both ends (top illustration below) are most likely to break when the load is placed at the midpoint. Similarly, cantilevered beams (bottom illustration below) are most likely to break when the load is placed at the unsupported end.

Force, Distance, and Bending





Obviously, force and distance are both important in bending. A quantity that combines the effects of both force and distance is the *bending moment*, measured in inch-pounds. But what are the properties of a beam that resists bending? Suppose there are two identical 2×6 planks bridging a stream, one of oak and one of pine. Which would you choose to keep your feet dry? Which would be less likely to break? Experience points to the oak plank. In other words, there seems to be an inherent difference in strength in bending between wood species. The quantity that expresses this difference is known as the material's (wood's) *extreme fiber stress in bending*, f, measured in psi.

There is also a geometric quality to strength. Disregarding the question of balance, which way would you lay the plank: on its edge or on its face? Rafters and joists are used on edge because they are stronger that way. The quantity that expresses geometric strength is *section modulus*, S. Calculating S for our example shows that the 2×6 is three times stronger on edge than on its face.

section modulus, $S = b \times d^2 / 6$
where b = breadth, d = depth in inches

On face: $S = 6\text{ in.} \times 2\text{ in.} \times 2\text{ in.} / 6 = 4\text{ in.}^3$

On edge: $S = 2\text{ in.} \times 6\text{ in.} \times 6\text{ in.} / 6 = 12\text{ in.}^3$

The way in which the three bending factors combine is simple. Imagine a tug-of-war between the breaking factor, M, and the strength factors, f and S.

M	=	f	×	S
bending moment		extreme fiber stress in bending		section modulus

The equality represents the point of breaking. The beam is unsafe when the left-hand side, M, is larger numerically.

Deflection

We are concerned with deflection less than with bending because deflection is not a safety issue. However, the usual criterion for "bounciness" of a floor is that the ratio of deflection to span of the beam be less than 1/360 for first floors, 1/240 for second and above floors, and 1/180 for roofs under maximum live load.

Example: 1/360 translates into 1 inch of vertical deflection at the center of a 30-foot (360-inch) beam; ½ inch over 15 feet, etc. The quantities determining deflection are the total load on the beam, the span, the modulus of elasticity, E (stiffness), and a quantity similar to section modulus but called *moment of inertia*:

$I = b \times d^3 / 12$

Shear

When a beam bends under a vertical load, its upper fibers shorten in compression, whereas the lower fibers elongate in tension. These opposing shearing stresses are maximum at the beam's ends. If the opposing forces exceed a certain limit, the beam will attempt to relieve the shear by splitting into two beams. Since the combined section moduli of the two smaller beams are less that the section modulus of the original intact beam, the beam may subsequently fail (break) in bending.

There are two shear variables:

Vertical shear, V, is generally half of the total load (W/2) on a beam supported at both ends and the total load (W) on a cantilevered beam. Tables of beam formule usually give the formula for computing V.

Horizontal shear, H, is computed from vertical shear and the beam's cross-section dimensions, b and d:

$H = {}^3/_2 V / (b \times d)$

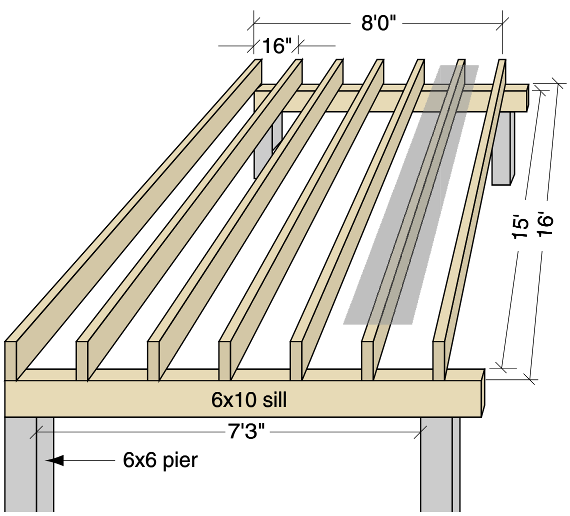
H must not exceed the horizontal shear unit stress value for the beam species.

Shear is rarely the cause of failure in a beam but can occur when a beam carries a large load over a short span. An example would be a cantilevered floor joist supporting a wall post that, in turn, supports a second-floor load plus a roof load.

Calculating the Load on a Beam

Loads are usually placed on beams in one of two simple ways: distributed uniformly or concentrated at one or more points. An example of a uniformly distributed load is the live load of 40 psf on a residential floor. A single post bearing upon a sill is a concentrated load. Before calculating the bending strength of beams in various situations we must learn to calculate the load(s) carried by each beam. The illustration below shows a conventional floor with joists spaced 16 inches o.c. resting on a pair of sills, in turn supported by posts 8 feet o.c.

Conventional Floor



Each joist carries one-half of the uniformly distributed weight of the floor area on each side (shaded area in illustration). For interior joists, this is equivalent to each joist carrying the weight of an entire space. The weight carried by end joists is only half as great, but because they also carry the end walls they are usually doubled in practice. The sills support the joists, and if there are more than two uniformly spaced joists, the weight is assumed to be uniformly distributed on the sill.

Example: The clear span, L, of the joists, is the length unsupported from beneath. In the illustration, L = 15'0", and the clear span of the sills is 7'3". The uniformly distributed load on a floor is the dead load of 5 psf plus the live load. The total load carried by a first-floor joist is, therefore, (5 + 40) psf times the area of the clear span times the o.c. spacing.

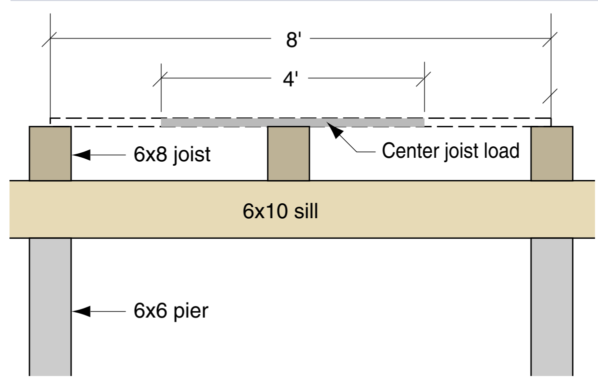
Load W = 45 psi × 15 ft. × $1^1/_3$ ft. = 900 lb.

The distributed load on a sill is 45 psf times the area of the rectangle formed by the sill clear span and one-half the joist length.

Load W = 45 psi × $7^1/_4$ ft. × 8 ft. = 2,610 lb.

If the floor joists comprise an exposed design element such as those carrying the second floor in a post-and-beam building, they tend to be heavier and more widely spaced. Because there are so few it is often more accurate to treat each as a concentrated load.

Post-and-Beam Floor



Example: In the post-and-beam floor illustrated above we have substituted one 6×8 joist for every three 2×8 joists. The o.c. spacing is now 48 inches instead of 16 inches.

As before, the center joist carries the load of the floor halfway to each of the adjacent joists:

W = 45 psi × 16 ft. × 4 ft. = 2,880 lb.

Bending force is applied to each sill now at a single point—the center joist. This is clearly a concentrated load. The point load on each sill is one-half of the total load on the joist:

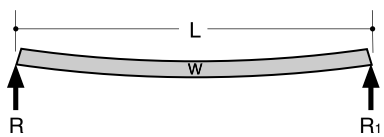
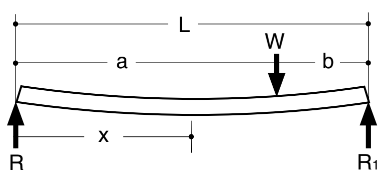
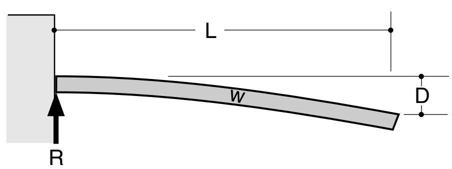
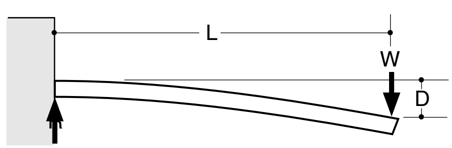
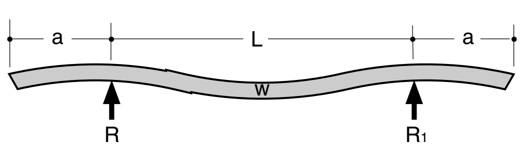
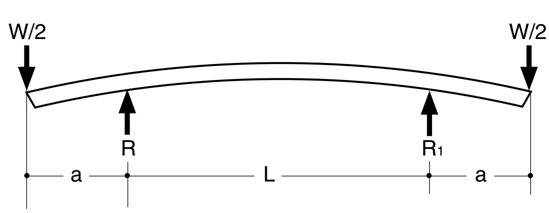
W = $^1/_2$ × 2,880 lb. = 1,440 lb.

Beam Design Cases

The majority of cases are like the foregoing example. The table below gives the formulae for six design cases covering uniform loads, point loads, simple beams, overhanging beams, and cantilevered beams.

When a design involves a combination of cases loading a single beam, the solution is simple: solve each case separately, and then add the reactions, bending moments, deflections, and shears for the total solution.

Beam Formulae

Case 1 ***Simple Beam*** ***Uniform Load***		$R = R_1 = W/2$ $M_{max} = WL/8$ $D_{max} = 5WL^3/384EI$ $V_{max} = W/2$
Case 2 ***Simple Beam*** ***Point Load***		$R = Wb/L$, $R_1 = Wa/L$ $M_{max} = Wab/L$ (at point of load) $V_{max} = R$ or R_1 (whichever greater) $M_{at\ x} = Wbx/L$
Case 3 ***Cantilever*** ***Uniform Load***		$R = W$ $M_{max} = WL/2$ $D = WL^3/8EI$ $V_{max} = -W$
Case 4 ***Cantilever*** ***Point Load***		$R = W$ $M_{max} = WL$ $D = WL^3/3EI$ $V_{max} = W$
Case 5 ***Overhanging*** ***Uniform Load***		$R = R_1 = W/2$ $M_{max} = WL/8 - Wa/4$ (within L) $M = Wa^2/(2L + 4a)$ (at R, R_1) $M_{at\ x} = Wbx/L$
Case 6 ***Overhanging*** ***Point Loads***		$R = R_1 = W/2$ $M_{max} = Wa/2$ (within L) $D = WaL^2/16EI$ (at center) $V_{max} = W/2$

W = total weight, lb.	***M = bending moment, in.lb.***	***I = moment of inertia, in.^{4}***
L = clear span, in.	***V = vertical shear, lb.***	***D = deflection, in.***
R, R_1 = reactions, lb.	***E = modulus of elasticity, psi***	

Strengths of Wood Species

The table below lists values of *f*, extreme fiber stress in bending, *S*, shear stress, and *E*, modulus of elasticity, for nine common North American species. Columns 2–4 are laboratory-measured values from clear, perfect samples. Columns 5–7 are allowable 10-year values for ungraded joists, rafters, and beams reflecting average real-world lumber imperfections. Recognizing the fact that lumber is stronger over shorter periods, the last column lists allowable values of *f* for durations of one month.

Average Strength Values of Ungraded North American Species

	Clear Specimen			Allowable, 10 Year			1 Month
Species	Fiber Stress in Bending f(psi)	Unit Shear Stress S(psi)	Modulus of Elasticity E(10^6 psi)	Fiber Stress in Bending f(psi)	Unit Shear Stress S(psi)	Modulus of Elasticity E(10^6 psi)	f(psi)
Northern white pine	8,600	900	1.24	900	80	1.0	1,200
Eastern hemlock	8,900	1,060	1.20	1,200	80	1.2	1,400
Eastern spruce	9,800	1,080	1.34	1,200	100	1.2	1,400
Douglas fir	12,400	1,130	1.95	1,500	120	1.6	1,700
Red or white oak	15,200	2,000	1.78	1,800	190	1.5	2,100
Sugar maple	15,800	2,330	1.83	2,000	190	1.6	2,300
Eastern red cedar	8,800	–	0.88	1,200	60	0.8	1,400
American elm	11,800	1,510	1.34	1,400	150	1.2	1,600
Paper birch	12,300	1,210	1.59	1,600	190	1.6	1,800

Ungraded Wood Beam Design

1. Pick a species and its values of f, E, and S.
2. Pick the beam design and write its formulae.
3. Define the clear span, L, and o.c. spacing.
4. Calculate the total load, W.
5. Calculate maximum bending moment, M_{max}.
6. Calculate beam section modulus, $S = M_{max}/f$.
7. Find the required breadth, b, and depth, d, from the formula $S = b \times d^2/6$ or $d^2 = 6S/b$.
8. Calculate moment of inertia, $I = b \times d^2/12$.
9. Calculate deflection, D_{max}. If greater than 1/360 (or 1/240 or 1/180), recycle, increasing d or b.
10. Compute vertical shear, V, from beam formula, then horizontal unit shear stress, $H = {}^3/_2 V/(b \times d)$. If H exceeds the allowable 10-year unit shear stress for the species, S, pick another species or increase b or d.

Example: design a joist for the floor on page 125.

1. Eastern hemlock f = 1.200, E = 1,200,000 psi, S = 80 psi.
2. Simple beam with uniform load, Case 1.
3. L = 15', o.c. spacing = $1^1/_3$ ft.
4. W = 45 psf×15'×$1^1/_3$' = 900 lb.
5. M_{max} = 900 lb.×15'×12"/8 = 20,250 in.lb.
6. S = 20,250 in.lb./1,200 psi = 16.875 in^3.
7. Let b = 2". $S = b \times d^2/6$, or $d = (6S/b)^{1/2}$ =7.1". The joist needs to be a 2 × 8.
8. $I = b \times d^2/12 = 2 \times 8 \times 8 \times 8/12 = 85.33$.
9. $D_{max.} = 5WL^3/384EI$ $=5 \times 900 \times 15^3 \times 12^3/(384 \times 1{,}200{,}000 \times 85.33) = 0.67$". L/360 = 15'×12"/360 = 0.5", so D_{max} is too great.
10. V = W/2 = 450 lb.
$H = {}^3/_2 V/(b \times d) = 1.5 \times 450/(2 \times 8) = 42.2$
H (42.2) is less than S(80) so is ok.

Span Tables for Rough-Sawn Lumber

Uniformly Distributed 20 PSF Live Load + 5 PSF Dead Load

Member b×d	Section Modulus, S	Spacing inches o.c.	Maximum Allowable Span (feet-inches)						
			Extreme Fiber Stress in Bending, f						
			900	1,000	1,100	1,200	1,300	1,400	1,500
2×4	5.33	16	9-10	10-4	10-10	11-4	11-9	12-3	12-8
		24	8-0	8-5	8-10	9-3	9-7	10-0	10-4
2×6	12.0	16	14-8	15-6	16-3	17-0	17-8	18-4	19-0
		24	12-0	12-8	13-3	13-10	14-5	15-0	15-6
2×8	23.1	16	19-7	20-8	21-8	22-8	23-6	>24	>24
		24	16-0	16-10	17-8	18-6	19-3	20-0	20-8
2×10	33.3	16	>24	>24	>24	>24	>24	>24	>24
		24	20-0	21-1	22-1	23-1	24-0	>24	>24
4×6	24.0	24	17-0	17-11	18-9	19-7	20-5	21-2	21-11
		48	12-0	12-8	13-3	13-10	14-5	15-0	15-6
4×8	42.7	24	22-8	23-10	>24	>24	>24	>24	>24
		48	16-0	16-10	17-8	18-6	19-3	20-0	20-8
4×10	66.7	24	>24	>24	>24	>24	>24	>24	>24
		48	20-0	21-1	22-1	23-1	24-0	>24	>24
6×6	36.0	48	14-9	15-6	16-3	17-0	17-8	18-4	19-0
6×8	64.0	48	19-7	20-8	21-8	22-8	23-6	>24	>24
6×10	100	48	>24	>24	>24	>24	>24	>24	>24
8×8	85.3	48	22-7	23-10	>24	>24	>24	>24	>24
8×10	133	48	>24	>24	>24	>24	>24	>24	>24
8×12	192	48	>24	>24	>24	>24	>24	>24	>24

Uniformly Distributed 30 PSF Live Load + 5 PSF Dead Load

Member b×d	Section Modulus, S	Spacing inches o.c.	Maximum Allowable Span (feet-inches)						
			Extreme Fiber Stress in Bending, f						
			900	1,000	1,100	1,200	1,300	1,400	1,500
2×4	5.33	16	8-3	8-9	9-2	9-6	9-11	10-4	10-8
		24	6-9	7-1	7-6	7-10	8-1	8-5	8-9
2×6	12.0	16	12-5	13-1	13-9	14-4	14-11	15-6	16-0
		24	10-2	10-8	11-3	11-9	12-2	12-8	13-1
2×8	23.1	16	16-7	17-6	18-4	19-2	19-11	20-8	21-4
		24	13-6	14-3	14-11	15-7	16-3	16-10	17-5
2×10	33.3	16	20-9	21-10	22-11	23-11	>24	>24	>24
		24	16-11	17-10	18-8	19-6	20-4	21-1	21-10
4× 6	24.0	24	14-4	15-1	15-10	16-7	17-3	17-11	18-6
		48	10-2	10-8	11-3	11-9	12-2	12-8	13-1
4×8	42.7	24	19-1	20-2	21-2	22-1	23-0	23-10	>24
		48	13-6	14-3	15-0	15-7	16-3	16-10	17-6
4×10	66.7	24	23-11	>24	>24	>24	>24	>24	>24
		48	16-11	17-10	18-8	19-6	20-4	21-1	21-10
6×6	36.0	48	12-5	13-1	13-9	14-4	14-11	15-6	16-0
6×8	64.0	48	16-7	17-5	18-4	19-1	19-11	20-8	21-4
6×10	100	48	20-8	21-10	22-11	23-11	>24	>24	>24
8×8	85.3	48	19-1	20-2	21-2	22-1	23-0	23-10	>24
8×10	133	48	23-11	>24	>24	>24	>24	>24	>24
8×12	192	48	>24	>24	>24	>24	>24	>24	>24

Uniformly Distributed 40 PSF Live Load + 5 PSF Dead Load

Member b×d	Section Modulus, S	Spacing inches o.c.	Maximum Allowable Span (feet-inches) Extreme Fiber Stress in Bending, f						
			900	1,000	1,100	1,200	1,300	1,400	1,500
2×4	5.33	16	7-4	7-9	8-1	8-5	8-9	9-1	9-5
		24	6-0	6-3	6-7	6-11	7-2	7-5	7-8
2×6	12.0	16	11-0	11-6	12-1	12-8	13-2	13-8	14-2
		24	8-11	9-5	9-11	10-4	10-9	11-2	11-6
2×8	23.1	16	14-7	15-5	16-2	16-10	17-6	18-3	18-10
		24	11-1	12-7	13-2	13-9	14-4	14-10	15-5
2×10	33.3	16	18-3	19-3	20-2	21-1	21-11	22-9	23-7
		24	14-11	15-9	16-6	17-3	17-11	18-7	19-3
4×6	24.0	24	12-8	13-4	14-0	14-7	15-2	15-9	16-4
		48	8-11	9-5	9-11	10-4	10-9	11-2	11-6
4×8	42.7	24	16-10	17-9	18-8	19-6	20-3	21-0	21-9
		48	11-11	12-7	13-2	13-9	14-4	14-11	15-5
4×10	66.7	24	21-11	22-3	23-3	>24	>24	>24	>24
		48	14-11	15-9	16-6	17-3	17-11	18-7	19-3
6×6	36.0	48	11-0	11-6	12-1	12-8	13-2	13-8	14-2
6×8	64.0	48	14-7	15-4	16-2	16-10	17-6	18-3	18-10
6×10	100	48	18-3	19-3	20-2	21-1	21-11	22-9	23-7
8×8	85.3	48	16-10	17-9	18-8	19-6	20-3	21-0	21-9
8×10	133	48	21-1	22-3	23-4	>24	>24	>24	>24
8×12	192	48	>24	>24	>24	>24	>24	>24	>24

Uniformly Distributed 40 PSF Live Load + 7.5 PSF Dead Load

Member b×d	Section Modulus, S	Spacing inches o.c.	Maximum Allowable Span (feet-inches) Extreme Fiber Stress in Bending, f						
			900	1,000	1,100	1,200	1,300	1,400	1,500
2×4	5.33	16	7-1	7-6	7-10	8-2	8-6	8-10	9-2
		24	5-10	6-1	6-5	6-8	7-0	7-3	7-6
2×6	12.0	16	10-9	11-3	11-9	12-3	12-10	13-4	13-9
		24	8-8	9-2	9-8	10-0	10-6	10-10	11-3
2×8	23.1	16	14-3	15-6	15-9	16-5	17-1	17-9	18-4
		24	11-7	12-3	12-10	13-5	13-11	14-6	15-6
2×10	33.3	16	17-9	18-9	19-8	20-6	21-4	22-1	22-11
		24	14-6	15-4	16-0	16-9	17-5	18-1	18-9
4×6	24.0	24	12-4	13-0	13-7	14-3	14-9	15-4	15-11
		48	8-8	9-2	9-8	10-0	10-6	10-10	11-3
4×8	42.7	24	16-5	17-4	18-2	19-0	19-9	20-6	21-2
		48	11-7	12-3	12-10	13-5	13-11	14-6	15-0
4×10	66.7	24	20-6	21-8	22-8	23-8	>24	>24	>24
		48	14-6	15-4	16-0	16-9	17-5	18-1	18-9
6×6	36.0	48	10-8	11-3	11-9	12-4	12-10	13-4	13-9
6×8	64.0	48	14-3	15-0	15-9	16-5	17-1	17-9	18-4
6×10	100	48	17-9	18-9	19-8	20-6	21-4	22-2	22-11
8×8	85.3	48	16-5	17-4	18-2	19-0	19-9	20-6	21-2
8×10	133	48	20-6	21-8	22-8	23-8	>24	>24	>24
8×12	192	48	23-7	>24	>24	>24	>24	>24	>24

Joist & Rafter Span Tables for U.S. Species

The span tables on pp. 131–139 are adapted from *The U.S. Span Book for Major Lumber Species.* The book, available from the Canadian Wood Council, was created in conformance with the procedures of U.S. grading and building authorities and with the design methods of the American Wood Council's *National Design Specification® for Wood Construction.*

The book provides a convenient reference for the common species of U.S. and Canadian dimension lumber, fully in accord with U.S. building codes and Federal Housing Authority (FHA) requirements. It is important to note, however, that the tables apply only to construction in the United States.

On-Line Span Calculator

For those who prefer computers to books, the Canadian Wood Council offers a handy on-line span calculator. The free and user-friendly calculator allows even more dead-and-live load combinations than contained in this book. To access *SpanCalc*, go to: *www.awc.org/codes-standards/calculators-software/spancalc*

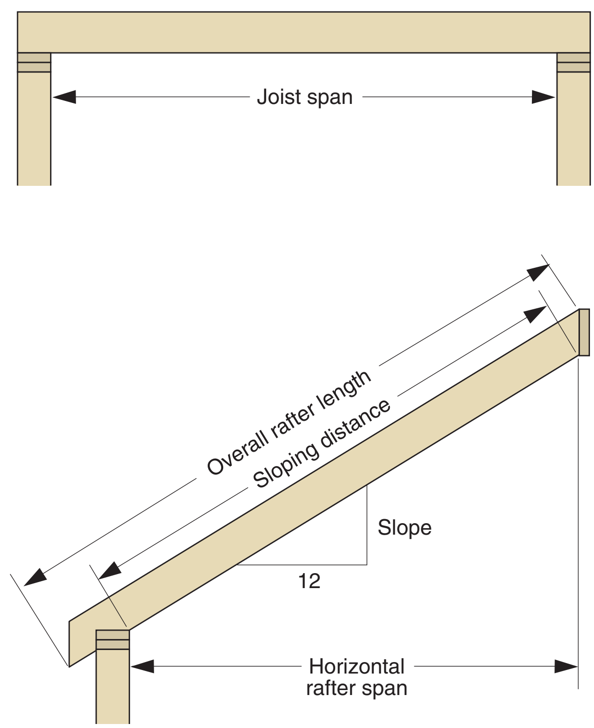
Allowable Span

The allowable span is the maximum clear horizontal distance between supports. For horizontal members such as joists, the clear span is the actual length between supports (see illustration at right). For sloping members such as roof rafters, a factor must be applied to the horizontal rafter span to determine the actual clear length or sloping distance. The table at right provides a method for converting horizontal span to sloping distance, and vice versa.

Spans are based on the use of lumber in dry conditions, as in most covered structures. They have been calculated using strength and stiffness values adjusted for size, repetitive member use, and appropriate duration of load.

Allowable spans in some cases (e.g., ceiling joists) may exceed available lengths. Availability should be confirmed before specification for a project.

Definition of Span



Conversion Factors for Rafters

Slope in 12	Slope Factor	Slope in 12	Slope Factor
1	1.003	13	1.474
2	1.014	14	1.537
3	1.031	15	1.601
4	1.054	16	1.667
5	1.083	17	1.734
6	1.118	18	1.803
7	1.158	19	1.873
8	1.202	20	1.944
9	1.250	21	2.016
10	1.302	22	2.088
11	1.357	23	2.162
12	1.414	24	2.236

Floor Joists

Sleeping Rooms and Attics: 30 PSF Live, 10 PSF Dead

Species Group	Spacing inches o.c.	Maximum Allowable Span (feet-inches): 2×6 Sel Str	2×6 Grade No.1	2×6 Grade No.2	2×6 Grade No.3	2×8 Sel Str	2×8 Grade No.1	2×8 Grade No.2	2×8 Grade No.3	2×10 Sel Str	2×10 Grade No.1	2×10 Grade No.2	2×10 Grade No.3	2×12 Sel Str	2×12 Grade No.1	2×12 Grade No.2	2×12 Grade No.3
Douglas fir-larch	12	12-6	12-0	11-10	9-11	16-6	15-10	15-7	12-7	21-0	20-3	19-10	15-5	25-7	24-8	23-4	17-10
	16	11-4	10-11	10-9	8-7	15-0	14-5	14-2	10-11	19-1	18-5	17-5	13-4	23-3	21-4	20-3	15-5
	19.2	10-8	10-4	10-1	7-10	14-1	13-7	13-0	10-0	18-0	16-9	15-11	12-2	21-10	19-6	18-6	14-1
	24	9-11	9-7	9-3	7-0	13-1	12-4	11-8	8-11	16-8	15-0	14-3	10-11	20-3	17-5	16-6	12-7
Hem-fir	12	11-10	11-7	11-0	9-8	15-7	15-3	14-6	12-4	19-10	19-5	18-6	15-0	24-2	23-7	22-6	17-5
	16	10-9	10-6	10-0	8-5	14-2	13-10	13-2	10-8	18-0	17-8	16-10	13-0	21-11	21-1	19-8	15-1
	19.2	10-1	9-10	9-5	7-8	13-4	13-0	12-5	9-9	17-0	16-7	15-6	11-10	20-8	19-3	17-11	13-9
	24	9-4	9-2	8-9	6-10	12-4	12-1	11-4	8-8	15-9	14-10	13-10	10-7	19-2	17-2	16-1	12-4
Southern pine	12	12-3	12-0	11-10	10-5	16-2	15-10	15-7	13-3	20-8	20-3	19-10	15-8	25-1	24-8	24-2	18-8
	16	11-2	10-11	10-9	9-0	14-8	14-5	14-2	11-6	18-9	18-5	18-0	13-7	22-10	22-5	21-1	16-2
	19.2	10-6	10-4	10-1	8-3	13-10	13-7	13-4	10-6	17-8	17-4	16-5	12-5	21-6	21-1	19-3	14-9
	24	9-9	9-7	9-4	7-4	12-10	12-7	12-4	9-5	16-5	16-1	14-8	11-1	19-11	19-6	17-2	13-2

All Rooms Except Sleeping Rooms and Attics: 40 PSF Live, 10 PSF Dead

Species Group	Spacing inches o.c.	Maximum Allowable Span (feet-inches): 2×6 Sel Str	2×6 Grade No.1	2×6 Grade No.2	2×6 Grade No.3	2×8 Sel Str	2×8 Grade No.1	2×8 Grade No.2	2×8 Grade No.3	2×10 Sel Str	2×10 Grade No.1	2×10 Grade No.2	2×10 Grade No.3	2×12 Sel Str	2×12 Grade No.1	2×12 Grade No.2	2×12 Grade No.3
Douglas fir-larch	12	11-4	10-11	10-9	8-11	15-0	14-5	14-2	11-3	19-1	18-5	18-0	13-9	23-3	22-0	20-11	16-0
	16	10-4	9-11	9-9	7-8	13-7	13-1	12-9	9-9	17-4	16-5	15-7	11-11	21-1	19-1	18-1	13-10
	19.2	9-8	9-4	9-2	7-0	12-10	12-4	11-8	8-11	16-4	15-0	14-3	10-11	19-10	17-5	16-6	12-7
	24	9-0	8-8	8-3	6-3	11-11	11-0	10-5	8-0	15-2	13-5	12-9	9-9	18-5	15-7	14-9	11-3
Hem-fir	12	10-9	10-6	10-0	8-8	14-2	13-10	13-2	11-0	18-0	17-8	16-10	13-5	21-11	21-6	20-4	15-7
	16	9-9	9-6	9-1	7-6	12-10	12-7	12-0	9-6	16-5	16-0	15-2	11-8	19-11	18-10	17-7	13-6
	19.2	9-2	9-0	8-7	6-10	12-1	11-10	11-3	8-8	15-5	14-10	13-10	10-7	18-9	17-2	16-1	12-4
	24	8-6	8-4	7-11	6-2	11-3	10-10	10-2	7-9	14-4	13-3	12-5	9-6	17-5	15-5	14-4	11-0
Southern pine	12	11-2	10-11	10-9	9-4	14-8	14-5	14-2	11-11	18-9	18-5	18-0	14-0	22-10	22-5	21-9	16-8
	16	10-2	9-11	9-9	8-1	13-4	13-1	12-10	10-3	17-0	16-9	16-1	12-2	20-9	20-4	18-10	14-6
	19.2	9-6	9-4	9-2	7-4	12-7	12-4	12-1	9-5	16-0	15-9	14-8	11-1	19-6	19-2	17-2	13-2
	24	8-10	8-8	8-6	6-7	11-8	11-5	11-0	8-5	14-11	14-7	13-1	9-11	18-1	17-5	15-5	11-10

Ceiling Joists

Drywall—No Future Rooms and No Attic Storage: 10 PSF Live, 5 PSF Dead

		Maximum Allowable Span (feet-inches)															
		2×4				2×6				2×8				2 ×10			
		Sel	Grade			Sel	Grade			Sel	Grade			Sel	Grade		
Species Group	Spacing inches o.c.	Str	No.1	No.2	No.3	Str	No.1	No.2	No.3	Str	No.1	No.2	No.3	Str	No.1	No.2	No.3
Douglas fir-larch	12	13-2	12-8	12-5	11-1	20-8	19-11	19-6	16-3	27-2	26-2	25-8	20-7	34-8	33-5	32-9	25-2
	16	11-11	11-6	11-3	9-7	18-9	18-1	17-8	14-1	24-8	23-10	23-4	17-10	31-6	30-0	28-6	21-9
	19.2	11-3	10-10	10-7	8-9	17-8	17-0	16-8	12-10	23-3	22-5	21-4	16-3	29-8	27-5	26-0	19-10
	24	10-5	10-0	9-10	7-10	16-4	15-9	15-0	11-6	21-7	20-1	19-1	14-7	27-6	24-6	23-3	17-9
Hem-fir	12	12-5	12-2	11-7	10-10	19-6	19-1	18-2	15-10	25-8	25-2	24-0	20-1	32-9	32-1	30-7	24-6
	16	11-3	11-0	10-6	9-5	17-8	17-4	16-6	13-9	23-4	22-10	21-9	17-5	29-9	29-2	27-8	21-3
	19.2	10-7	10-4	9-11	8-7	16-8	16-4	15-7	12-6	21-11	21-6	20-6	15-10	28-0	27-1	25-3	19-5
	24	9-10	9-8	9-2	7-8	15-6	15-2	14-5	11-2	20-5	19-10	18-6	14-2	26-0	24-3	22-7	17-4
Southern pine	12	12-11	12-8	12-5	11-6	20-3	19-11	19-6	17-0	26-9	26-2	25-8	21-8	34-1	33-5	32-9	25-7
	16	11-9	11-6	11-3	10-0	18-5	18-1	17-8	14-9	24-3	23-10	23-4	18-9	31-0	30-5	29-4	22-2
	19.2	11-0	10-10	10-7	9-1	17-4	17-0	16-8	13-6	22-10	22-5	21-11	17-2	29-2	28-7	26-10	20-3
	24	10-3	10-0	9-10	8-2	16-1	15-9	15-6	12-0	21-2	20-10	20-1	15-4	27-1	26-6	23-11	18-1

Drywall—No Future Rooms and Limited Attic Storage: 20 PSF Live, 10 PSF Dead

		Maximum Allowable Span (feet-inches)															
		2×4				2×6				2×8				2 ×10			
		Sel	Grade			Sel	Grade			Sel	Grade			Sel	Grade		
Species Group	Spacing inches o.c.	Str	No.1	No.2	No.3	Str	No.1	No.2	No.3	Str	No.1	No.2	No.3	Str	No.1	No.2	No.3
Douglas fir-larch	12	10-5	10-0	9-10	7-10	16-4	15-9	15-0	11-6	21-7	20-1	19-1	14-7	27-6	24-6	23-3	17-9
	16	9-6	9-1	8-11	6-10	14-11	13-9	13-0	9-11	19-7	17-5	16-6	12-7	25-0	21-3	20-2	15-5
	19.2	8-11	8-7	8-2	6-2	14-0	12-6	11-11	9-1	18-5	15-10	15-1	11-6	23-7	19-5	18-5	14-1
	24	8-3	7-8	7-3	5-7	13-0	11-2	10-8	8-1	17-2	14-2	13-6	10-3	21-3	17-4	16-5	12-7
Hem-fir	12	9-10	9-8	9-2	7-8	15-6	15-2	14-5	11-2	20-5	19-10	18-6	14-2	26-0	24-3	22-7	17-4
	16	8-11	8-9	8-4	6-8	14-1	13-7	12-8	9-8	18-6	17-2	16.0	12-4	23-8	21-0	19-7	15-0
	19.2	8-5	8-3	7-10	6-1	13-3	12-4	11-7	8-10	17-5	15-8	14-8	11-3	22-3	19-2	17-10	13-8
	24	7-10	7-7	7-1	5-5	12-3	11-1	10-4	7-11	16-2	14-0	13-1	10-0	20-6	17-1	16-0	12-3
Southern pine	12	10-3	10-0	9-10	8-2	16-1	15-9	15-6	12-0	21-2	20-10	20-1	15-4	27-1	26-6	23-11	18-1
	16	9-4	9-1	8-11	7-1	14-7	14-4	13-6	10-5	19-3	18-11	17-5	13-3	24-7	23-1	20-9	15-8
	19.2	8-9	8-7	8-5	6-5	13-9	13-6	12-3	9-6	18-2	17-9	15-10	12-1	23-2	21-1	18-11	14-4
	24	8-1	8-0	7-8	5-9	12-9	12-6	11-0	8-6	16-10	15-10	14-2	10-10	21-6	18-10	16-11	12-10

Rafters

Snow Region, Light Roof, Drywall, No Attic Space: 20 PSF Live, 10 PSF Dead

Species Group	Spacing inches o.c.	2×6 Sel Str	2×6 No.1	2×6 No.2	2×6 No.3	2×8 Sel Str	2×8 No.1	2×8 No.2	2×8 No.3	2×10 Sel Str	2×10 No.1	2×10 No.2	2×10 No.3	2×12 Sel Str	2×12 No.1	2×12 No.2	2×12 No.3
Douglas fir-larch	12	16-4	15-9	15-6	12-4	21-7	20-10	20-5	15-7	27-6	26-4	24-11	19-1	33-6	30-6	28-11	22-1
	16	14-11	14-4	14-0	10-8	19-7	18-8	17-8	13-6	25-0	22-9	21-7	16-6	30-5	26-5	25-1	19-2
	19.2	14-0	13-5	12-9	9-9	18-5	17-0	16-2	12-4	23-7	20-9	19-9	15-1	28-8	24-1	22-10	17-6
	24	13-0	12-0	11-5	8-9	17-2	15-3	14-5	11-0	21-10	18-7	17-8	13-6	26-5	21-7	20-5	15-7
Hem-fir	12	15-6	15-2	14-5	12-0	20-5	19-11	19-0	15-3	26-0	25-5	24-3	18-7	31-8	30-1	28-1	21-7
	16	14-1	13-9	13-1	10-5	18-6	18-2	17-2	13-2	23-8	22-6	21-0	16-1	28-9	26-1	24-4	18-8
	19.2	13-3	12-11	12-4	9-6	17-5	16-10	15-8	12-0	22-3	20-6	19-2	14-8	27-1	23-10	22-3	17-1
	24	12-3	11-10	11-1	8-6	16-2	15-0	14-0	10-9	20-8	18-4	17-2	13-2	25-1	21-3	19-11	15-3
Southern pine	12	16-1	15-9	15-6	12-11	21-2	20-10	20-5	16-5	27-1	26-6	25-8	19-5	32-11	32-3	30-1	23-1
	16	14-7	14-4	14-1	11-2	19-3	18-11	18-6	14-3	24-7	24-1	22-3	19-10	29-11	29-4	26-1	20-0
	19.2	13-9	13-6	13-2	10-2	18-2	17-9	17-0	13-0	23-2	22-7	20-4	15-4	28-1	26-11	23-10	18-3
	24	12-9	12-6	11-9	9-2	16-10	16-6	15-3	11-8	21-6	20-3	18-2	13-9	26-1	24-1	21-3	16-4

Maximum Allowable Span (feet-inches)

Snow Region, Light Roof, Drywall, No Attic Space: 30 PSF Live, 10 PSF Dead

Species Group	Spacing inches o.c.	2×6 Sel Str	2×6 No.1	2×6 No.2	2×6 No.3	2×8 Sel Str	2×8 No.1	2×8 No.2	2×8 No.3	2×10 Sel Str	2×10 No.1	2×10 No.2	2×10 No.3	2×12 Sel Str	2×12 No.1	2×12 No.2	2×12 No.3
Douglas fir-larch	12	14-4	13-9	13-6	10-8	18-10	18-2	17-8	13-6	24-1	22-9	21-7	16-6	29-3	26-5	25-1	19-2
	16	13-0	12-6	12-1	9-3	17-2	16-2	15-4	11-8	21-10	19-9	18-9	14-3	26-7	22-10	21-8	16-7
	19.2	12-3	11-8	11-0	8-5	16-1	14-9	14-0	10-8	20-7	18-0	17-1	13-1	25-0	20-11	19-10	15-2
	24	11-4	10-5	9-10	7-7	15-0	13-2	12-6	9-7	19-1	16-1	15-3	11-8	22-10	18-8	17-9	13-6
Hem-fir	12	13-6	13-3	12-7	10-5	17-10	17-5	16-7	13-2	22-9	22-3	21-0	16-1	27-8	26-1	24-4	18-8
	16	12-3	12-0	11-5	9-0	16-2	15-10	14-11	11-5	20-8	19-6	18-2	13-11	25-1	22-7	21-1	16-2
	19.2	11-7	11-4	10-9	8-3	15-3	14-7	13-7	10-5	19-5	17-9	16-7	12-9	23-7	20-7	19-3	14-9
	24	10-3	10-3	9-7	7-4	14-2	13-0	12-2	9-4	18-0	15-11	14-10	11-5	21-11	18-5	17-3	13-2
Southern pine	12	14-1	13-9	13-6	11-2	18-6	18-2	17-10	14-3	23-8	23-2	22-3	16-10	28-9	28-2	26-1	20-0
	16	12-9	12-6	12-3	9-8	16-10	16-6	16-2	12-4	21-6	21-1	19-3	14-7	26-1	25-7	22-7	17-4
	19.2	12-0	11-9	11-5	8-10	15-10	15-6	14-9	11-3	20-2	19-7	17-7	13-4	24-7	23-4	20-7	15-10
	24	11-2	10-11	10-2	7-11	14-8	14-5	13-2	10-1	18-9	17-6	15-9	11-11	22-10	20-11	18-5	14-2

Maximum Allowable Span (feet-inches)

Rafters

Snow Region, Light Roof, Drywall, No Attic Space: 40 PSF Live, 10 PSF Dead

		Maximum Allowable Span (feet-inches)															
		2×6				2×8				2×10				2×12			
		Sel	Grade			Sel	Grade			Sel	Grade			Sel	Grade		
Species Group	Spacing inches o.c.	Str	No.1	No.2	No.3	Str	No.1	No.2	No.3	Str	No.1	No.2	No.3	Str	No.1	No.2	No.3
Douglas fir-larch	12	13-2	12-6	12-3	9-6	17-2	16-6	15-10	12-1	21-10	20-4	19-4	14-9	26-7	23-7	22-5	17-1
	16	11-10	11-5	10-10	8-3	15-7	14-5	13-8	10-6	19-10	17-8	16-9	12-9	24-2	20-5	19-5	14-10
	19.2	11-1	10-5	9-10	7-7	14-8	13-2	12-6	9-7	18-8	16-1	15-3	11-8	22-9	18-8	17-9	13-6
	24	10-4	9-4	8-10	6-9	13-7	11-9	11-2	8-7	17-4	14-5	13-8	10-5	20-5	16-8	15-10	12-1
Hem-fir	12	12-3	12-0	11-5	9-4	16-2	15-10	15-1	11-9	20-8	20-1	18-9	14-5	25-1	23-4	21-9	16-8
	16	11-2	10-11	10-5	8-1	14-8	14-3	13-4	10-3	18-9	17-5	16-3	12-6	22-10	20-2	18-10	14-6
	19.2	10-6	10-3	9-7	7-4	13-10	13-0	12-2	9-4	17-8	15-11	14-10	11-5	21-6	18-5	17-3	13-2
	24	9-9	9-2	8-7	6-7	12-10	11-8	10-10	8-4	16-5	14-3	13-3	10-2	19-9	16-6	15-5	11-10
Southern pine	12	12-9	12-6	12-3	10-0	16-10	16-6	16-2	12-9	21-6	21-1	19-11	15-1	26-1	25-7	23-4	17-11
	16	11-7	11-5	11-2	8-8	15-3	15-0	14-5	11-0	19-6	19-2	17-3	13-0	23-9	22-10	20-2	15-6
	19.2	10-11	10-8	10-2	7-11	14-5	14-1	13-2	10-1	18-4	17-6	15-9	11-11	22-4	20-11	18-5	14-2
	24	10-2	9-11	9-2	7-1	13-4	13-1	11-9	9-0	17-0	15-8	14-1	10-8	20-9	18-8	16-6	12-8

Snow Region, Light Roof, Drywall, No Attic Space: 50 PSF Live, 10 PSF Dead

		Maximum Allowable Span (feet-inches)															
		2×6				2×8				2×10				2×12			
		Sel	Grade			Sel	Grade			Sel	Grade			Sel	Grade		
Species Group	Spacing inches o.c.	Str	No.1	No.2	No.3	Str	No.1	No.2	No.3	Str	No.1	No.2	No.3	Str	No.1	No.2	No.3
Douglas fir-larch	12	12-1	11-8	11-5	8-9	15-11	15-3	14-5	11-0	20-3	18-7	17-8	13-6	24-8	21-7	20-5	15-7
	16	11-0	10-5	9-10	7-7	14-5	13-2	12-6	9-7	18-5	16-1	15-3	11-8	22-5	18-8	17-9	13-6
	19.2	10-4	9-6	9-0	6-11	13-7	12-0	11-5	8-9	17-4	14-8	13-11	10-8	20-11	17-1	16-2	12-4
	24	9-7	8-6	8-1	6-2	12-7	10-9	10-3	7-10	16-1	13-2	12-6	9-6	18-8	15-3	14-6	11-1
Hem-fir	11-5	11-5	11-2	10-8	8-6	15-0	14-8	14-0	10-9	19-2	18-4	17-2	13-2	23-4	21-3	19-11	15-3
	16	10-4	10-2	9-7	7-4	13-8	13-0	12-2	9-4	17-5	15-11	14-10	11-5	21-2	18-5	17-3	13-2
	19.2	9-9	9-5	8-9	6-9	12-10	11-11	11-1	8-6	16-5	14-6	13-7	10-5	19-11	16-10	15-9	12-1
	24	9-1	8-5	7-10	6-0	11-11	10-8	9-11	7-7	15-2	13-0	12-1	9-4	18-0	15-1	14-1	10-9
Southern pine	12	11-10	11-8	11-5	9-2	15-7	15-4	15-0	11-8	19-11	19-7	18-2	13-9	24-3	23-9	21-3	16-4
	16	10-9	10-7	10-2	7-11	14-2	13-11	13-2	10-1	18-1	17-6	15-9	11-11	22-0	20-11	18-5	14-2
	19.2	10-2	9-11	9-4	7-3	13-4	13-1	12-0	9-2	17-0	16-0	14-4	10-10	20-9	19-1	16-10	12-11
	24	9-5	9-3	8-4	6-5	12-5	12-0	10-9	8-3	15-10	14-4	12-10	9-9	19-3	17-1	15-1	11-7

Rafters

Snow Region, Heavy Roof, Drywall, No Attic Space: 20 PSF Live, 20 PSF Dead

		Maximum Allowable Span (feet-inches)															
		2×6				2×8				2×10				2×12			
			Grade				Grade				Grade				Grade		
Species Group	Spacing inches o.c.	Sel Str	No.1	No.2	No.3	Sel Str	No.1	No.2	No.3	Sel Str	No.1	No.2	No.3	Sel Str	No.1	No.2	No.3
Douglas fir-larch	12	16-4	14-9	14-0	10-8	21-7	18-8	17-8	13-6	27-6	22-9	21-7	16-6	32-4	26-5	25-1	19-2
	16	14-11	12-9	12-1	9-3	19-7	16-2	15-4	11-8	24-2	19-9	18-9	14-3	28-0	22-10	21-8	16-7
	19.2	14-0	11-8	11-0	8-5	18-1	14-9	14-0	10-8	22-1	18-0	17-1	13-1	25-7	20-11	19-10	15-2
	24	12-9	10-5	9-10	7-7	16-2	13-2	12-6	9-7	19-9	16-1	15-3	11-8	22-10	18-8	17-9	13-6
Hem-fir	12	15-6	14-6	13-7	10-5	20-5	18-5	17-2	13-2	26-0	22-6	21-0	16-1	31-3	26-1	24-4	18-8
	16	14-1	12-7	11-9	9-0	18-6	15-11	14-11	11-5	23-4	19-6	18-2	13-11	27-1	22-7	21-1	16-2
	19.2	13-3	11-6	10-9	8-3	17-5	14-7	13-7	10-5	21-4	17-9	16-7	12-9	24-8	20-7	19-3	14-9
	24	12-3	10-3	9-7	7-4	15-7	13-0	12-2	9-4	19-1	15-11	14-10	11-5	22-1	18-5	17-3	13-2
Southern pine	12	16-1	15-9	14-5	11-2	21-2	20-10	18-8	14-3	27-1	24-9	22-3	16-10	32-11	29-6	26-1	20-0
	16	14-7	14-4	12-6	9-8	19-3	18-1	16-2	12-4	24-7	21-5	19-3	14-7	29-11	25-7	22-7	17-4
	19.2	13-9	13-1	11-5	8-10	18-2	16-6	14-9	11-3	23-2	19-7	17-7	13-4	28-1	23-4	20-7	15-10
	24	12-9	11-9	10-2	7-11	16-10	14-9	13-2	10-1	21-6	17-6	15-9	11-11	25-9	20-11	18-5	14-2

Snow Region, Heavy Roof, Drywall, No Attic Space: 30 PSF Live, 20 PSF Dead

		Maximum Allowable Span (feet-inches)															
		2×6				2×8				2×10				2×12			
			Grade				Grade				Grade				Grade		
Species Group	Spacing inches o.c.	Sel Str	No.1	No.2	No.3	Sel Str	No.1	No.2	No.3	Sel Str	No.1	No.2	No.3	Sel Str	No.1	No.2	No.3
Douglas fir-larch	12	14-4	13-2	12-6	9-6	18-10	16-8	15-10	12-1	24-1	20-4	19-4	14-9	28-11	23-7	22-5	17-1
	16	13-0	11-5	10-10	8-3	17-2	14-5	13-8	10-6	21-7	17-8	16-9	12-9	25-1	20-5	19-5	14-10
	19.2	12-3	10-5	9-10	7-7	16-1	13-2	12-6	9-7	19-9	16-1	15-3	11-8	22-10	18-8	17-9	13-6
	24	11-4	9-4	8-10	6-9	14-5	11-9	11-2	8-7	17-8	14-5	13-8	10-5	20-5	16-8	15-10	12-1
Hem-fir	12	13-6	13-0	12-2	9-4	17-10	16-6	15-4	11-9	22-9	20-1	18-9	14-5	27-8	23-4	21-9	16-8
	16	12-3	11-3	10-6	8-1	16-2	14-3	13-4	10-3	20-8	17-5	16-3	12-6	24-2	20-2	18-10	14-6
	19.2	11-7	10-3	9-7	7-4	15-3	13-0	12-2	9-4	19-1	15-11	14-10	11-5	22-1	18-5	17-3	13-2
	24	10-9	9-2	8-7	6-7	13-11	11-8	10-10	8-4	17-1	14-3	13-3	10-2	19-9	16-6	15-5	11-10
Southern pine	12	14-1	13-9	12-11	10-0	18-6	18-2	16-8	12-9	23-8	22-2	19-11	15-1	28-9	26-5	23-4	17-11
	16	12-9	12-6	11-2	8-8	16-10	16-2	14-5	11-0	21-6	19-2	17-3	13-0	26-1	22-10	20-2	15-6
	19.2	12-0	11-9	10-2	7-11	15-10	14-9	13-2	10-1	20-2	17-6	15-9	11-11	24-7	20-11	18-5	14-2
	24	11-2	10-6	9-2	7-1	14-8	13-2	11-9	9-0	18-9	15-8	14-1	10-8	22-10	18-8	16-6	12-8

Rafters

Snow Region, Light Roof, No Ceiling, 20 PSF Live, 10 PSF Dead

		Maximum Allowable Span (feet-inches)															
		2×4				2×6				2×8				2 ×10			
Species Group	Spacing inches o.c.	Sel Str	Grade No.1	No.2	No.3	Sel Str	Grade No.1	No.2	No.3	Sel Str	Grade No.1	No.2	No.3	Sel Str	Grade No.1	No.2	No.3
Douglas fir-larch	12	11-6	11-1	10-10	8-5	18-0	17-0	16-2	12-4	23-9	21-6	20-5	15-7	30-4	26-4	24-11	19-1
	16	10-5	10-0	9-7	7-3	16-4	14-9	14-0	10-8	21-7	18-8	17-8	13-6	27-6	22-9	21-7	16-6
	19.2	9-10	9-2	8-9	6-8	15-5	13-5	12-9	9-9	20-4	17-0	16-2	12-4	25-6	20-9	19-9	15-1
	24	9-1	8-3	7-10	5-11	14-4	12-0	11-5	8-9	18-8	15-3	14-5	11-0	22-9	18-7	17-8	13-6
Hem-fir	12	10-10	10-7	10-1	8-3	17-0	16-8	15-8	12-0	22-5	21-3	19-10	15-3	28-7	26-0	24-3	18-7
	16	9-10	9-8	9-2	7-1	15-6	14-6	13-7	10-5	20-5	18-5	17-2	13-2	26-0	22-6	21-0	16-1
	19.2	9-3	9-1	8-6	6-6	14-7	13-3	12-5	9-6	19-2	16-10	15-8	12-0	24-6	20-6	19-2	14-8
	24	8-7	8-1	7-7	5-10	13-6	11-10	11-1	8-6	17-10	15-0	14-0	10-9	22-0	18-4	17-2	13-2
Southern pine	12	11-3	11-1	10-10	8-9	17-8	17-4	16-8	12-11	23-4	22-11	21-6	16-5	29-9	28-7	25-8	19-5
	16	10-3	10-0	9-10	7-7	16-1	15-9	14-5	11-2	21-2	20-10	18-8	14-3	27-1	24-9	22-3	16-10
	19.2	9-8	9-5	9-2	6-11	15-2	14-10	13-2	10-2	19-11	19-0	17-0	13-0	25-5	22-7	20-4	15-4
	24	8-11	8-9	8-2	6-2	14-1	13-6	11-9	9-2	18-6	17-0	15-3	11-8	23-8	20-3	18-2	13-9

Snow Region, Light Roof, No Ceiling: 30 PSF Live, 10 PSF Dead

		Maximum Allowable Span (feet-inches)															
		2×4				2×6				2×8				2 ×10			
Species Group	Spacing inches o.c.	Sel Str	Grade No.1	No.2	No.3	Sel Str	Grade No.1	No.2	No.3	Sel Str	Grade No.1	No.2	No.3	Sel Str	Grade No.1	No.2	No.3
Douglas fir-larch	12	10-0	9-8	9-6	7-3	15-9	14-9	14-0	10-8	20-9	18-8	17-8	13-6	26-6	22-9	21-7	16-6
	16	9-1	8-9	8-3	6-4	14-4	12-9	12-1	9-3	18-10	16-2	15-4	11-8	24-1	19-9	18-9	14-3
	19.2	8-7	7-11	7-7	5-9	13-6	11-8	11-0	8-5	17-9	14-9	14-0	10-8	22-1	18-0	17-1	13-1
	24	7-11	7-1	6-9	5-2	12-6	10-5	9-10	7-7	16-2	13-2	12-6	9-7	19-9	16-1	15-3	11-8
Hem-fir	12	9-6	9-3	8-10	7-1	14-10	14-6	13-7	10-5	19-7	18-5	17-2	13-2	25-0	22-6	21-0	16-1
	16	8-7	8-5	8-0	6-2	13-6	12-7	11-9	9-0	17-10	15-11	14-11	11-5	22-9	19-6	18-2	13-11
	19.2	8-1	7-10	7-4	5-8	12-9	11-6	10-9	8-3	16-9	14-7	13-7	10-5	21-4	17-9	16-7	12-9
	24	7-6	7-0	6-7	5-0	11-10	10-3	9-7	7-4	15-7	13-0	12-2	9-4	19-1	15-11	14-10	11-5
Southern pine	12	9-10	9-8	9-6	7-7	15-6	15-2	14-5	11-2	20-5	20-0	18-8	14-3	26-0	24-9	22-3	16-10
	16	8-11	8-9	8-7	6-7	14-1	13-9	12-6	9-8	18-6	18-0	16-2	12-4	23-8	21-5	19-3	14-7
	19.2	8-5	8-3	7-11	6-0	13-3	13-0	11-5	8-10	17-5	16-6	14-9	11-3	22-3	19-7	17-7	13-4
	24	7-10	7-8	7-1	5-4	12-3	11-9	10-2	7-11	16-2	14-9	13-2	10-1	20-8	17-6	15-9	11-11

Rafters

Snow Region, Light Roof, No Ceiling: 40 PSF Live, 10 PSF Dead

		Maximum Allowable Span (feet-inches)															
		2×4				2×6				2×8				2 ×10			
Species Group	Spacing inches o.c.	Sel Str	Grade No.1	No.2	No.3	Sel Str	Grade No.1	No.2	No.3	Sel Str	Grade No.1	No.2	No.3	Sel Str	Grade No.1	No.2	No.3
Douglas fir-larch	12	9-1	8-9	8-6	6-6	14-4	13-2	12-6	9-6	18-10	16-8	15-10	12-1	24-1	20-4	19-4	14-9
	16	8-3	7-10	7-5	5-8	13-0	11-5	10-10	8-3	17-2	14-5	13-8	10-6	21-7	17-8	16-9	12-9
	19.2	7-9	7-1	6-9	5-2	12-3	10-5	9-10	7-7	16-1	13-2	12-6	9-7	19-9	16-1	15-3	11-8
	24	7-3	6-4	6-0	4-7	11-4	9-4	8-10	6-9	14-5	11-9	11-2	8-7	17-8	14-5	13-8	10-5
Hem-fir	12	8-7	8-5	8-0	6-4	13-6	13-0	12-2	9-4	17-10	16-6	15-4	11-9	22-9	20-1	18-9	14-5
	16	7-10	7-8	7-2	5-6	12-3	11-3	10-6	8-1	16-2	14-3	13-4	10-3	20-8	17-5	16-3	12-6
	19.2	7-4	7-0	6-7	5-0	11-7	10-3	9-7	7-4	15-3	13-0	12-2	9-4	19-1	15-11	14-10	11-5
	24	6-10	6-3	5-10	4-6	10-9	9-2	8-7	6-7	13-11	11-8	10-10	8-4	17-1	14-3	13-3	10-2
Southern pine	12	8-11	8-9	8-7	6-9	14-1	13-9	12-11	10-0	18-6	18-2	16-8	12-9	23-8	22-2	19-11	15-1
	16	8-1	8-0	7-10	5-10	12-9	12-6	11-2	8-8	16-10	16-2	14-5	11-0	21-6	19-2	17-3	13-0
	19.2	7-8	7-6	7-1	5-4	12-0	11-9	10-2	7-11	15-10	14-9	13-2	10-1	20-2	17-6	15-9	11-11
	24	7-1	7-0	6-4	4-9	11-2	10-6	9-2	7-1	14-8	13-2	11-9	9-0	18-9	15-8	14-1	10-8

Snow Region, Light Roof, No Ceiling: 50 PSF Live, 10 PSF Dead

		Maximum Allowable Span (feet-inches)															
		2×6				2×8				2×10				2×12			
Species Group	Spacing inches o.c.	Sel Str	Grade No.1	No.2	No.3	Sel Str	Grade No.1	No.2	No.3	Sel Str	Grade No.1	No.2	No.3	Sel Str	Grade No.1	No.2	No.3
Douglas fir-larch	12	8-5	8-2	7-8	5-10	13-3	12-0	11-3	8-6	17-6	15-3	14-3	10-9	22-4	18-7	17-5	13-2
	16	7-8	7-1	6-8	5-0	12-1	10-5	9-9	7-4	15-10	13-2	12-4	9-4	19-5	16-1	15-1	11-5
	19.2	7-3	6-6	6-1	4-7	11-4	9-6	8-11	6-9	14-6	12-0	11-3	8-6	17-8	14-8	13-9	10-5
	24	6-8	5-10	5-5	4-1	10-3	8-6	7-11	6-0	13-0	10-9	10-1	7-7	15-10	13-2	12-4	9-4
Hem-fir	12	8-0	7-10	7-5	5-10	12-6	11-9	11-1	8-6	16-6	14-10	14-0	10-9	21-1	18-1	17-2	13-2
	16	7-3	6-11	6-7	5-0	11-5	10-2	9-7	7-4	15-0	12-10	12-2	9-4	19-1	15-8	14-10	11-5
	19.2	6-10	6-4	6-0	4-7	10-9	9-3	8-9	6-9	14-2	11-9	11-1	8-6	17-5	14-4	13-7	10-5
	24	6-4	5-8	5-4	4-1	9-11	8-3	7-10	6-0	12-9	10-6	9-11	7-7	15-7	12-10	12-1	9-4
Southern pine	12	8-4	8-2	8-0	6-2	13-1	12-10	11-9	9-2	17-2	16-10	15-3	11-8	21-11	20-3	18-2	13-9
	16	7-6	7-5	7-1	5-4	11-10	11-8	10-2	7-11	15-7	14-9	13-2	10-1	19-11	17-6	15-9	11-11
	19.2	7-1	7-0	6-6	4-11	11-2	10-8	9-4	7-3	14-8	13-5	12-0	9-2	18-9	16-0	14-4	10-10
	24	6-7	6-5	5-10	4-4	10-4	9-7	8-4	6-5	13-8	12-0	10-9	8-3	17-5	14-4	12-10	9-9

Rafters

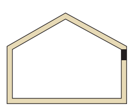
Snow Region, Heavy Roof, No Ceiling: 20 PSF Live, 20 PSF Dead

		Maximum Allowable Span (feet-inches)															
		2×4				2×6				2×8				2 ×10			
Species Group	Spacing inches o.c.	Sel Str	Grade No.1	No.2	No.3	Sel Str	Grade No.1	No.2	No.3	Sel Str	Grade No.1	No.2	No.3	Sel Str	Grade No.1	No.2	No.3
Douglas fir-larch	12	11-6	10-1	9-7	7-3	18-0	14-9	14-0	10-8	22-10	18-8	17-8	13-6	27-11	22-9	21-7	16-6
	16	10-5	8-9	8-3	6-4	15-7	12-9	12-1	9-3	19-9	16-2	15-4	11-8	24-2	19-9	18-9	14-3
	19.2	9-9	7-11	7-7	5-9	14-3	11-8	11-0	8-5	18-1	14-9	14-0	10-8	22-1	18-0	17-1	13-1
	24	8-9	7-1	6-9	5-2	12-9	10-5	9-10	7-7	16-2	13-2	12-6	9-7	19-9	16-1	15-3	11-8
Hem-fir	12	10-10	9-11	9-3	7-1	17-0	14-6	13-7	10-5	22-1	18-5	17-2	13-2	26-11	22-6	21-0	16-1
	16	9-10	8-7	8-0	6-2	15-1	12-7	11-9	9-0	19-1	15-11	14-11	11-5	23-4	19-6	18-2	13-11
	19.2	9-3	7-10	7-4	5-8	13-9	11-6	10-9	8-3	17-5	14-7	13-7	10-5	21-4	17-9	16-7	12-9
	24	8-5	7-0	6-7	5-0	12-4	10-3	9-7	7-4	15-7	13-0	12-2	9-4	19-1	15-11	14-10	11-5
Southern pine	12	11-3	11-1	10-1	7-7	17-8	16-7	14-5	11-2	23-4	20-10	18-8	14-3	29-9	24-9	22-3	16-10
	16	10-3	9-8	8-9	6-7	16-1	14-4	12-6	9-8	21-2	18-1	16-2	12-4	26-11	21-5	19-3	14-7
	19.2	9-8	8-10	7-11	6-0	15-2	13-1	11-5	8-10	19-11	16-6	14-9	11-3	24-7	19-7	17-7	13-4
	24	8-11	7-11	7-1	5-4	14-1	11-9	10-2	7-11	18-3	14-9	13-2	10-1	22-0	17-6	15-9	11-11

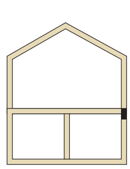
Snow Region, Heavy Roof, No Ceiling: 30 PSF Live, 20 PSF Dead

		Maximum Allowable Span (feet-inches)															
		2×4				2×6				2×8				2 ×10			
Species Group	Spacing inches o.c.	Sel Str	Grade No.1	No.2	No.3	Sel Str	Grade No.1	No.2	No.3	Sel Str	Grade No.1	No.2	No.3	Sel Str	Grade No.1	No.2	No.3
Douglas fir-larch	12	10-0	9-0	8-6	6-6	15-9	13-2	12-6	9-6	20-5	16-8	15-10	12-1	24-11	20-4	19-4	14-9
	16	9-1	7-10	7-5	5-8	14-0	11-5	10-10	8-3	17-8	14-5	13-8	10-6	21-7	17-8	16-9	12-9
	19.2	8-7	7-1	6-9	5-2	12-9	10-5	9-10	7-7	16-2	13-2	12-6	9-7	19-9	16-1	15-3	11-8
	24	7-10	6-4	6-0	4-7	11-5	9-4	8-10	6-9	14-5	11-9	11-2	8-7	17-8	14-5	13-8	10-5
Hem-fir	12	9-6	8-11	8-4	6-4	14-10	13-0	12-2	9-4	19-7	16-6	15-4	11-9	24-1	20-1	18-9	14-5
	16	8-7	7-8	7-2	5-6	13-6	11-3	10-6	8-1	17-1	14-3	13-4	10-3	20-10	17-5	16-3	12-6
	19.2	8-1	7-0	6-7	5-0	12-4	10-3	9-7	7-4	15-7	13-0	12-2	9-4	19-1	15-11	14-10	11-5
	24	7-6	6-3	5-10	4-6	11-0	9-2	8-7	6-7	13-11	11-8	10-10	8-4	17-1	14-3	13-3	10-2
Southern pine	12	9-10	9-8	9-0	6-9	15-6	14-10	12-11	10-0	20-5	18-8	16-8	12-9	26-0	22-2	19-11	15-1
	16	8-11	8-8	7-10	5-10	14-1	12-10	11-2	8-8	18-6	16-2	14-5	11-0	23-8	19-2	17-3	13-0
	19.2	8-5	7-11	7-1	5-4	13-3	11-9	10-2	7-11	17-5	14-9	13-2	10-1	22-0	17-6	15-9	11-11
	24	7-10	7-1	6-4	4-9	12-3	10-6	9-2	7-1	16-2	13-2	11-9	9-0	19-8	15-8	14-1	10-8

Headers In Exterior Bearing Walls



Header Supporting	Size	Maximum Allowable Span (feet-inches)											
Roof Live Load, psf		20			30			40			50		
		Building Width, ft			Building Width, ft			Building Width, ft			Building Width, ft		
		20	28	36	20	28	36	20	28	36	20	28	36
	2-2×4	3-6	3-2	2-10	3-3	2-10	2-7	3-0	2-7	2-4	2-10	2-6	2-2
	2-2×6	5-5	4-8	4-2	4-10	4-2	3-9	4-5	3-10	3-5	4-1	3-7	3-2
	2-2×8	6-10	5-11	5-4	6-2	5-4	4-9	5-7	4-10	4-4	5-2	4-6	4-0
	2-2×10	8-5	7-3	6-6	7-6	6-6	5-10	6-10	5-11	5-4	6-4	5-6	4-11
	2-2×12	9-9	8-5	7-6	8-8	7-6	6-9	7-11	6-10	6-2	7-4	6-4	5-8
	3-2×8	8-4	7-5	6-8	7-8	6-8	5-11	7-0	6-1	5-5	6-6	5-8	5-0
	3-2×10	10-6	9-1	8-2	9-5	8-2	7-3	8-7	7-5	6-8	7-11	6-10	6-2
	3-2×12	12-2	10-7	9-5	10-11	9-5	8-5	9-11	8-7	7-8	9-2	8-0	7-2
	4-2×8	9-2	8-4	7-8	8-6	7-8	6-11	8-0	7-0	6-3	7-6	6-6	5-10
	4-2×10	11-8	10-6	9-5	10-10	9-5	8-5	9-11	8-7	7-8	9-2	7-11	7-1
	4-2×12	14-1	12-2	10-11	12-7	10-11	9-9	11-6	9-11	8-11	10-8	9-2	8-3



Header Supporting	Size	Maximum Allowable Span (feet-inches)											
Roof Live Load, psf		20			30			40			50		
		Building Width, ft			Building Width, ft			Building Width, ft			Building Width, ft		
		20	28	36	20	28	36	20	28	36	20	28	36
	2-2×4	3-1	2-9	2-5	2-10	2-6	2-3	2-8	2-4	2-1	2-6	2-2	2-0
	2-2×6	4-6	4-0	3-7	4-2	3-8	3-3	3-11	3-5	3-1	3-8	3-2	2-11
	2-2×8	5-9	5-0	4-6	5-3	4-8	4-2	4-11	4-4	3-11	4-8	4-1	3-8
	2-2×10	7-0	6-2	5-6	6-5	5-8	5-1	6-0	5-3	4-9	5-8	4-11	4-5
	2-2×12	8-1	7-1	6-5	7-6	6-7	5-11	7-0	6-1	5-6	6-7	5-9	5-2
	3-2×8	7-2	6-3	5-8	6-7	5-10	5-3	6-2	5-5	4-10	5-10	5-1	4-7
	3-2×10	8-9	7-8	6-11	8-1	7-1	6-5	7-6	6-7	5-11	7-1	6-2	5-7
	3-2×12	10-2	8-11	8-0	9-4	8-2	7-5	8-9	7-8	6-11	8-3	7-2	6-6
	4-2×8	8-1	7-3	6-7	7-8	6-8	6-0	7-1	6-3	5-7	6-8	5-10	5-3
	4-2×10	10-1	8-10	8-0	9-4	8-2	7-4	8-8	7-7	6-10	8-2	7-2	6-5
	4-2×12	11-9	10-3	9-3	10-10	9-6	8-6	10-1	8-10	7-11	9-6	8-4	7-6

Joist & Rafter Span Tables for Canadian Species

Floor Joists

Sleeping Rooms and Attics: 30 PSF Live, 10 PSF Dead

		Maximum Allowable Span (feet-inches)											
		2×6			2×8			2×10			2×12		
Species Group	Spacing inches o.c.	Sel Str	No.1/ No.2	Grade No.3	Sel Str	No.1/ No.2	Grade No.3	Sel Str	No.1/ No.2	Grade No.3	Sel Str	No.1/ No.2	Grade No.3
Spruce-pine-fir	12	11-7	11-3	9-8	15-3	14-11	12-4	19-5	19-0	15-0	23-7	23-0	17-5
	16	10-6	10-3	8-5	13-10	13-6	10-8	17-8	17-2	13-0	21-6	19-11	15-1
	19.2	9-10	9-8	7-8	13-0	12-9	9-9	16-7	15-8	11-10	20-2	18-3	13-9
	24	9-2	8-11	6-10	12-1	11-6	8-8	15-5	14-1	10-7	18-9	16-3	12-4
Douglas Fir-L(N)	12	12-6	11-10	9-6	16-6	15-7	12-0	21-0	19-7	14-8	25-7	22-8	17-0
	16	11-4	10-9	8-2	15-0	13-11	10-5	19-1	16-11	12-8	23-3	19-8	14-8
	19.2	10-8	10-0	7-6	14-1	12-8	9-6	18-0	15-6	11-7	21-10	17-11	13-5
	24	9-11	8-11	6-8	13-1	11-4	8-6	16-8	13-10	10-4	20-3	16-1	12-0
Hem-Fir(N)	12	12-0	11-10	10-5	15-10	15-7	13-2	20-3	19-10	16-1	24-8	24-2	18-8
	16	10-11	10-9	9-0	14-5	14-2	11-5	18-5	18-0	13-11	22-5	21-4	16-2
	19.2	10-4	10-1	8-3	13-7	13-4	10-5	17-4	16-9	12-9	21-1	19-6	14-9
	24	9-7	9-4	7-4	12-7	12-4	9-4	16-1	15-0	11-5	19-7	17-5	13-2
Northern Species	12	10-5	10-5	8-1	13-9	13-6	10-3	17-6	16-5	12-7	21-4	19-1	14-7
	16	9-6	9-3	7-0	12-6	11-8	8-11	15-11	14-3	10-11	19-4	16-6	12-7
	19.2	8-11	8-5	6-5	11-9	10-8	8-2	15-0	13-0	9-11	18-3	15-1	11-6
	24	8-3	7-6	5-9	10-11	9-6	7-3	13-11	11-8	8-11	16-11	13-6	10-4

All Rooms Except Sleeping Rooms and Attics: 40 PSF Live, 10 PSF Dead

		Maximum Allowable Span (feet-inches)											
		2×6			2×8			2×10			2×12		
Species Group	Spacing inches o.c.	Sel Str	No.1/ No.2	Grade No.3	Sel Str	No.1/ No.2	Grade No.3	Sel Str	No.1/ No.2	Grade No.3	Sel Str	No.1/ No.2	Grade No.3
Spruce-pine-fir	12	10-6	10-3	8-8	13-10	13-6	11-0	17-8	17-3	13-5	21-6	20-7	15-7
	16	9-6	9-4	7-6	12-7	12-3	9-6	16-0	15-5	11-8	19-6	17-10	13-6
	19.2	9-0	8-9	6-10	11-10	11-6	8-8	15-1	14-1	10-7	18-4	16-3	12-4
	24	8-4	8-1	6-2	11-0	10-3	7-9	14-0	12-7	9-6	17-0	14-7	11-0
Douglas Fir-L(N)	12	11-4	10-9	8-6	15-0	14-2	10-9	19-1	17-6	13-1	23-3	20-4	15-2
	16	10-4	9-9	7-4	13-7	12-5	9-3	17-4	15-2	11-4	21-1	17-7	13-2
	19.2	9-8	8-11	6-8	12-10	11-4	8-6	16-4	13-10	10-4	19-10	16-1	12-0
	24	9-0	8-0	6-0	11-11	10-2	7-7	15-2	12-5	9-3	18-1	14-4	10-9
Hem-Fir(N)	12	10-11	10-9	9-4	14-5	14-2	11-9	18-5	18-0	14-5	22-5	21-11	16-8
	16	9-11	9-9	8-1	13-1	12-10	10-3	16-9	16-5	12-6	20-4	19-1	14-6
	19.2	9-4	9-2	7-4	12-4	12-1	9-4	15-9	15-0	11-5	19-2	17-5	13-2
	24	8-8	8-6	6-7	11-5	11-0	8-4	14-7	13-5	10-2	17-9	15-7	11-10
Northern Species	12	9-6	9-6	7-3	12-6	12-1	9-2	15-11	14-9	11-3	19-4	17-1	13-0
	16	8-7	8-3	6-3	11-4	10-5	8-0	14-6	12-9	9-9	17-7	14-9	11-3
	19.2	8-1	7-6	5-9	10-8	9-6	7-3	13-7	11-8	8-11	16-7	13-6	10-4
	24	7-6	6-9	5-2	9-11	8-6	6-6	12-8	10-5	7-11	15-4	12-1	9-3

Ceiling Joists

Drywall—No Future Rooms and No Attic Storage: 10 PSF Live, 5 PSF Dead

		Maximum Allowable Span (feet-inches)											
		2×4			2×6			2×8			2×10		
Species Group	Spacing inches o.c.	Sel Str	No.1/ No.2	Grade No.3	Sel Str	No.1/ No.2	Grade No.3	Sel Str	No.1/ No.2	Grade No.3	Sel Str	No.1/ No.2	Grade No.3
Spruce-pine-fir	12	12-2	11-10	10-10	19-1	18-8	15-10	25-2	24-7	20-1	32-1	31-4	24-6
	16	11-0	10-9	9-5	17-4	16-11	13-9	22-10	22-4	17-5	29-2	28-1	21-3
	19.2	10-4	10-2	8-7	16-4	15-11	12-6	21-6	21-0	15-10	27-5	25-8	19-5
	24	9-8	9-5	7-8	15-2	14-9	11-2	19-11	18-9	14-2	25-5	22-11	17-4
Douglas Fir-L(N)	12	13-2	12-5	10-7	20-8	19-6	15-5	27-2	25-8	19-7	34-8	32-0	23-11
	16	11-11	11-3	9-2	18-9	17-8	13-5	24-8	22-8	16-11	31-6	27-8	20-8
	19.2	11-3	10-7	8-4	17-8	16-4	12-3	23-3	20-8	15-6	29-8	25-3	18-11
	24	10-5	9-10	7-6	16-4	14-7	10-11	21-7	18-6	13-10	27-6	22-7	16-11
Hem-Fir(N)	12	12-8	12-5	11-7	19-11	19-6	17-0	26-2	25-8	21-6	33-5	32-9	26-4
	16	11-6	11-3	10-1	18-1	17-8	14-9	23-10	23-4	18-8	30-5	29-9	22-9
	19.2	10-10	10-7	9-2	17-0	16-8	13-5	22-5	21-11	17-0	28-7	27-5	20-9
	24	10-0	9-10	8-3	15-9	15-6	12-0	20-10	20-1	15-3	26-6	24-6	18-7
Northern Species	12	10-11	10-11	9-1	17-2	17-2	13-3	22-8	22-0	16-10	28-11	26-10	20-6
	16	9-11	9-11	7-10	15-7	15-0	11-6	20-7	19-1	14-7	26-3	23-3	17-9
	19.2	9-4	9-4	7-2	14-8	13-9	10-6	19-5	17-5	13-3	24-9	21-3	16-3
	24	8-8	8-5	6-5	13-8	12-3	9-5	18-0	15-7	11-11	22-11	19-0	14-6

Drywall—No Future Rooms, Limited Attic Storage: 20 PSF Live, 10 PSF Dead

		Maximum Allowable Span (feet-inches)											
		2×4			2×6			2×8			2×10		
Species Group	Spacing inches o.c.	Sel Str	No.1/ No.2	Grade No.3	Sel Str	No.1/ No.2	Grade No.3	Sel Str	No.1/ No.2	Grade No.3	Sel Str	No.1/ No.2	Grade No.3
Spruce-pine-fir	12	9-8	9-5	7-8	15-2	14-9	11-2	19-11	18-9	14-2	25-5	22-11	17-4
	16	8-9	8-7	6-8	13-9	12-10	9-8	18-2	16-3	12-4	23-2	19-10	15-0
	19.2	8-3	8-0	6-1	12-11	11-9	8-10	17-1	14-10	11-3	21-8	18-2	13-8
	24	7-8	7-2	5-5	12-0	10-6	7-11	15-10	13-3	10-0	19-5	16-3	12-3
Douglas Fir-L(N)	12	10-5	9-10	7-6	16-4	14-7	10-11	21-7	18-6	13-10	27-6	22-7	16-11
	16	9-6	8-8	6-6	14-11	12-8	9-6	19-7	16-0	12-0	24-8	19-7	14-8
	19.2	8-11	7-11	5-11	14-0	11-7	8-8	18-5	14-8	10-11	22-6	17-10	13-4
	24	8-3	7-1	5-3	13-0	10-4	7-9	16-6	13-1	9-9	20-2	16-0	11-11
Hem-Fir(N)	12	10-0	9-10	8-3	15-9	15-6	12-0	20-10	20-1	15-3	26-6	24-6	18-7
	16	9-1	8-11	7-1	14-4	13-9	10-5	18-11	17-5	13-2	24-1	21-3	16-1
	19.2	8-7	8-5	6-6	13-6	12-6	9-6	17-9	15-10	12-0	22-1	19-5	14-8
	24	8-0	7-8	5-10	12-6	11-2	8-6	16-2	14-2	10-9	19-9	17-4	13-2
Northern Species	12	8-8	8-5	6-5	13-8	12-3	9-5	18-0	15-7	11-11	22-11	19-0	14-6
	16	7-11	7-3	5-7	12-5	10-8	8-1	16-4	13-6	10-3	20-10	16-5	12-7
	19.2	7-5	6-8	5-1	11-8	9-8	7-5	15-5	12-4	9-5	19-5	15-0	11-6
	24	6-11	5-11	4-6	10-10	8-8	6-8	14-2	11-0	8-5	17-4	13-5	10-3

Rafters

Snow Region, Light Roof, Drywall, No Attic Space: 20 PSF Live, 10 PSF Dead

		Maximum Allowable Span (feet-inches)											
		2×6			2×8			2×10			2×12		
Species Group	Spacing inches o.c.	Sel Str	No.1/ No.2	Grade No.3	Sel Str	No.1/ No.2	Grade No.3	Sel Str	No.1/ No.2	Grade No.3	Sel Str	No.1/ No.2	Grade No.3
Spruce-pine-fir	12	15-2	14-9	12-0	19-11	19-6	15-3	25-5	24-7	18-7	30-11	28-6	21-7
	16	13-9	13-5	10-5	18-2	17-5	13-2	23-2	21-4	16-1	28-2	24-8	18-8
	19.2	12-11	12-7	9-6	17-1	15-11	12-0	21-9	19-5	14-8	26-6	22-7	17-1
	24	12-0	11-3	8-6	15-10	14-3	10-9	20-2	17-5	13-2	24-1	20-2	15-3
Douglas Fir-L(N)	12	16-4	15-6	11-9	21-7	19-10	14-10	27-6	24-3	18-1	33-6	28-1	21-0
	16	14-11	13-7	10-2	19-7	17-2	12-10	25-0	21-0	15-8	30-5	24-4	18-2
	19.2	14-0	12-5	9-3	18-5	15-8	11-9	23-7	19-2	14-4	28-0	22-3	16-7
	24	13-0	11-1	8-3	17-2	14-0	10-6	21-7	17-2	12-10	25-1	19-11	14-10
Hem-Fir(N)	12	15-9	15-6	12-11	20-11	20-5	16-4	26-6	26-0	19-11	32-3	30-6	23-1
	16	14-4	14-1	11-2	18-11	18-6	14-2	24-1	22-9	17-3	29-4	26-5	20-0
	19.2	13-6	13-3	10-2	17-9	17-0	12-11	22-8	20-9	15-9	27-6	24-1	18-3
	24	12-6	12-0	9-1	16-6	15-3	11-7	21-1	18-7	14-1	24-7	21-7	16-4
Northern Species	12	13-8	13-2	10-1	18-0	16-8	12-9	22-11	20-4	15-7	27-11	23-7	18-0
	16	12-5	11-5	8-9	16-4	14-5	11-0	20-10	17-8	13-6	25-4	20-5	15-7
	19.2	11-8	10-5	7-11	15-5	13-2	10-1	19-7	16-1	12-4	23-10	18-8	14-3
	24	10-10	9-4	7-1	14-3	11-9	9-0	18-1	14-5	11-0	21-7	16-8	12-9

Snow Region, Light Roof, Drywall, No Attic Space: 30 PSF Live, 10 PSF Dead

		Maximum Allowable Span (feet-inches)											
		2×6			2×8			2×10			2×12		
Species Group	Spacing inches o.c.	Sel Str	No.1/ No.2	Grade No.3	Sel Str	No.1/ No.2	Grade No.3	Sel Str	No.1/ No.2	Grade No.3	Sel Str	No.1/ No.2	Grade No.3
Spruce-pine-fir	12	13-3	12-11	10-5	17-5	17-0	13-2	22-3	21-4	16-1	27-1	24-8	18-8
	16	12-0	11-9	9-0	15-10	15-1	11-5	20-2	18-5	13-11	24-7	21-5	16-2
	19.2	11-4	10-11	8-3	14-11	13-9	10-5	19-0	16-10	12-9	23-1	19-6	14-9
	24	10-6	9-9	7-4	13-10	12-4	9-4	17-8	15-1	11-5	20-11	17-6	13-2
Douglas Fir-L(N)	12	14-4	13-6	10-2	18-10	17-2	12-10	24-1	21-0	15-8	29-3	24-4	18-2
	16	13-0	11-9	8-9	17-2	14-11	11-2	21-10	18-2	13-7	26-7	21-1	15-9
	19.2	12-3	10-9	8-0	16-1	13-7	10-2	20-7	16-7	12-5	24-3	19-3	14-5
	24	11-4	9-7	7-2	15-0	12-2	9-1	18-9	14-10	11-1	21-8	17-3	12-10
Hem-Fir(N)	12	13-9	13-6	11-2	18-2	17-10	14-2	23-2	22-9	17-3	28-2	26-5	20-0
	16	12-6	12-3	9-8	16-6	16-2	12-3	21-1	19-9	14-11	25-7	22-10	17-4
	19.2	11-9	11-7	8-10	15-6	14-9	11-2	19-10	18-0	13-8	23-10	30-11	15-10
	24	10-11	10-5	7-11	14-5	13-2	10-0	18-4	16-1	12-3	21-3	18-8	14-2
Northern Species	12	11-11	11-5	8-9	15-9	14-5	11-0	20-1	17-8	13-6	24-5	20-5	15-7
	16	10-10	9-10	7-7	14-3	12-6	9-7	18-3	15-3	11-8	22-2	17-9	13-6
	19.2	10-2	9-0	6-11	13-5	11-5	8-9	17-2	13-11	10-8	20-10	16-2	12-4
	24	9-6	8-1	6-2	12-6	10-3	7-10	15-11	12-6	9-6	18-8	14-6	11-1

Rafters

Snow Region, Light Roof, Drywall, No Attic Space: 40 PSF Live, 10 PSF Dead

		Maximum Allowable Span (feet-inches)											
		2×6			2×8			2×10			2×12		
Species Group	Spacing inches o.c.	Sel Str	No.1/ No.2	Grade No.3	Sel Str	No.1/ No.2	Grade No.3	Sel Str	No.1/ No.2	Grade No.3	Sel Str	No.1/ No.2	Grade No.3
Spruce-pine-fir	12	12-0	11-9	9-4	15-10	15-6	11-9	20-2	19-1	14-5	24-7	22-1	16-8
	16	10-11	10-8	8-1	14-5	13-6	10-3	18-4	16-6	12-6	22-4	19-2	14-6
	19.2	10-3	9-9	7-4	13-6	12-4	9-4	17-3	15-1	11-5	20-11	17-6	13-2
	24	9-6	8-9	6-7	12-7	11-0	8-4	16-0	13-6	10-2	18-8	15-7	11-10
Douglas Fir-L(N)	12	13-0	12-2	9-1	17-2	15-4	11-6	21-10	18-9	14-0	26-7	21-9	16-3
	16	11-10	10-6	7-10	15-7	13-4	9-11	19-10	16-3	12-2	23-9	18-10	14-1
	19.2	11-1	9-7	7-2	14-8	12-2	9-1	18-8	14-10	11-1	21-8	17-3	12-10
	24	10-4	8-7	6-5	13-7	10-10	8-2	16-9	13-3	9-11	19-5	15-5	11-6
Hem-Fir(N)	12	12-6	12-3	10-0	16-6	16-2	12-8	21-1	20-4	15-5	25-7	23-7	17-11
	16	11-5	11-2	8-8	15-0	14-5	10-11	19-2	17-8	13-5	23-3	20-5	15-6
	19.2	10-8	10-5	7-11	14-1	13-2	10-0	18-0	16-1	12-3	21-3	18-8	14-2
	24	9-11	9-4	7-1	13-1	11-9	8-11	16-5	14-5	10-11	19-1	16-8	12-8
Northern Species	12	10-10	10-2	7-9	14-3	12-11	9-10	18-3	15-9	12-1	22-2	18-4	14-0
	16	9-10	8-10	6-9	13-0	11-2	8-7	16-7	13-8	10-5	20-2	15-10	12-1
	19.2	9-3	8-1	6-2	12-2	10-3	7-10	15-7	12-6	9-6	18-8	14-6	11-1
	24	8-7	7-3	5-6	11-4	9-2	7-0	14-5	11-2	8-6	16-8	12-11	9-11

Snow Region, Light Roof, Drywall, No Attic Space: 50 PSF Live, 10 PSF Dead

		Maximum Allowable Span (feet-inches)											
		2×6			2×8			2×10			2×12		
Species Group	Spacing inches o.c.	Sel Str	No.1/ No.2	Grade No.3	Sel Str	No.1/ No.2	Grade No.3	Sel Str	No.1/ No.2	Grade No.3	Sel Str	No.1/ No.2	Grade No.3
Spruce-pine-fir	12	11-2	10-11	8-6	14-8	14-3	10-9	18-9	17-5	13-2	22-10	20-2	15-3
	16	10-2	9-9	7-4	13-4	12-4	9-4	17-0	15-1	11-5	20-9	17-6	13-2
	19.2	9-6	8-11	6-9	12-7	11-3	8-6	16-0	13-9	10-5	19-1	15-11	12-1
	24	8-10	7-11	6-0	11-8	10-1	7-7	14-8	12-4	9-4	17-1	14-3	10-9
Douglas Fir-L(N)	12	12-1	11-1	8-3	15-11	14-0	10-6	20-3	17-2	12-10	24-8	19-11	14-10
	16	11-0	9-7	7-2	14-5	12-2	9-1	18-5	14-10	11-1	21-8	17-3	12-10
	19.2	10-4	8-9	6-7	13-7	11-1	8-4	17-1	13-7	10-2	19-10	15-9	11-9
	24	9-7	7-10	5-10	12-6	9-11	7-5	15-3	12-1	9-1	17-9	14-1	10-6
Hem-Fir(N)	12	11-8	11-5	9-1	15-4	15-0	11-7	19-7	18-7	14-1	23-9	21-7	16-4
	16	10-7	10-4	7-11	13-11	13-2	10-0	17-9	16-1	12-3	21-3	18-8	14-2
	19.2	9-11	9-6	7-2	13-1	12-0	9-2	16-9	14-8	11-2	19-5	17-1	12-11
	24	9-3	8-6	6-5	12-2	10-9	8-2	15-0	13-2	10-0	17-5	15-3	11-7
Northern Species	12	10-1	9-4	7-1	13-3	11-9	9-0	16-11	14-5	11-0	20-7	16-8	12-9
	16	9-2	8-1	6-2	12-1	10-3	7-10	15-4	12-6	9-6	18-8	14-6	11-1
	19.2	8-7	7-4	5-7	11-4	9-4	7-1	14-6	11-5	8-8	17-1	13-2	10-1
	24	8-0	6-7	5-0	10-6	8-4	6-4	13-2	10-2	7-9	15-3	11-10	9-0

Rafters

Snow Region, Heavy Roof, Drywall, No Attic: 20 PSF Live, 20 PSF Dead

		Maximum Allowable Span (feet-inches)											
		2×6			2×8			2×10			2×12		
Species Group	Spacing inches o.c.	Sel Str	No.1/ No.2	Grade No.3	Sel Str	No.1/ No.2	Grade No.3	Sel Str	No.1/ No.2	Grade No.3	Sel Str	No.1/ No.2	Grade No.3
Spruce-pine-fir	12	15-2	13-9	10-5	19-11	17-5	13-2	25-5	21-4	16-1	29-6	24-8	18-8
	16	13-9	11-11	9-0	18-1	15-1	11-5	22-1	18-5	13-11	25-7	21-5	16-2
	19.2	12-11	10-11	8-3	16-6	13-9	10-5	20-2	16-10	12-9	23-4	19-6	14-9
	24	11-8	9-9	7-4	14-9	12-4	9-4	18-0	15-1	11-5	20-11	17-6	13-2
Douglas Fir-L(N)	12	16-4	13-7	10-2	21-7	17-2	12-10	26-6	21-0	15-8	30-8	24-4	18-2
	16	14-10	11-9	8-9	18-9	14-11	11-2	22-11	18-2	13-7	26-7	21-1	15-9
	19.2	13-6	10-9	8-0	17-1	13-7	10-2	20-11	16-7	12-5	24-3	19-3	14-5
	24	12-1	9-7	7-2	15-4	12-2	9-1	18-9	14-10	11-1	21-8	17-3	12-10
Hem-Fir(N)	12	15-9	14-9	11-2	20-10	18-8	14-2	26-0	22-9	17-3	30-1	26-5	20-0
	16	14-4	12-9	9-8	18-5	16-2	12-3	22-6	19-9	14-11	26-1	22-10	17-4
	19.2	13-3	11-8	8-10	16-10	14-9	11-2	20-6	18-0	13-8	23-10	20-11	15-10
	24	11-10	10-5	7-11	15-0	13-2	10-0	18-4	16-1	12-3	21-3	18-8	14-2
Northern Species	12	13-8	11-5	8-9	18-0	14-5	11-0	22-9	17-8	13-6	26-5	20-5	15-7
	16	12-5	9-10	7-7	16-2	12-6	9-7	19-9	15-3	11-8	22-10	17-9	13-6
	19.2	11-8	9-0	6-11	14-9	11-5	8-9	18-0	13-11	10-8	20-11	16-2	12-4
	24	10-5	8-1	6-2	13-2	10-3	7-10	16-1	12-6	9-6	18-8	14-6	11-1

Snow Region, Heavy Roof, Drywall, No Attic: 30 PSF Live, 20 PSF Dead

		Maximum Allowable Span (feet-inches)											
		2×6			2×8			2×10			2×12		
Species Group	Spacing inches o.c.	Sel Str	No.1/ No.2	Grade No.3	Sel Str	No.1/ No.2	Grade No.3	Sel Str	No.1/ No.2	Grade No.3	Sel Str	No.1/ No.2	Grade No.3
Spruce-pine-fir	12	13-3	12-4	9-4	17-5	15-7	11-9	22-3	19-1	14-5	26-5	22-1	16-8
	16	12-0	10-8	8-1	15-10	13-6	10-3	19-9	16-6	12-6	22-10	19-2	14-6
	19.2	11-4	9-9	7-4	14-9	12-4	9-4	18-0	15-1	11-5	20-11	17-6	13-2
	24	10-5	8-9	6-7	13-2	11-0	8-4	16-1	13-6	10-2	18-8	15-7	11-10
Douglas Fir-L(N)	12	14-4	12-2	9-1	18-10	15-4	11-6	23-8	18-9	14-0	27-5	21-9	16-3
	16	13-0	10-6	7-10	16-9	13-4	9-11	20-6	16-3	12-2	23-9	18-10	14-1
	19.2	12-1	9-7	7-2	15-4	12-2	9-1	18-9	14-10	11-1	21-8	17-3	12-10
	24	10-10	8-7	6-5	13-8	10-10	8-2	16-9	13-3	9-11	19-5	15-5	11-6
Hem-Fir(N)	12	13-9	13-2	10-0	18-2	16-8	12-8	23-2	20-4	15-5	26-11	23-7	17-11
	16	12-6	11-5	8-8	16-6	14-5	10-11	20-1	17-8	13-5	23-4	20-5	15-6
	19.2	11-9	10-5	7-11	15-0	13-2	10-0	18-4	16-1	12-3	21-3	18-8	14-2
	24	10-7	9-4	7-1	13-5	11-9	8-11	16-5	14-5	10-11	19-1	16-8	12-8
Northern Species	12	11-11	10-2	7-9	15-9	12-11	9-10	20-1	15-9	12-1	23-7	18-4	14-0
	16	10-10	8-10	6-9	14-3	11-2	8-7	17-8	13-8	10-5	20-5	15-10	12-1
	19.2	10-2	8-1	6-2	13-2	10-3	7-10	16-1	12-6	9-6	18-8	14-6	11-1
	24	9-4	7-3	5-6	11-9	9-2	7-0	14-5	11-2	8-6	16-8	12-11	9-11

Rafters

Snow Region, Light Roof, No Ceiling: 20 PSF Live, 10 PSF Dead

Species Group	Spacing inches o.c.	2×4 Sel Str	2×4 No.1/ No.2	2×4 Grade No.3	2×6 Sel Str	2×6 No.1/ No.2	2×6 Grade No.3	2×8 Sel Str	2×8 No.1/ No.2	2×8 Grade No.3	2×10 Sel Str	2×10 No.1/ No.2	2×10 Grade No.3
		Maximum Allowable Span (feet-inches)											
Spruce-pine-fir	12	10-7	10-4	8-3	16-8	15-11	12-0	21-11	20-2	15-3	28-0	24-7	18-7
	16	9-8	9-5	7-1	15-2	13-9	10-5	19-11	17-5	13-2	25-5	21-4	16-1
	19.2	9-1	8-7	6-6	14-3	12-7	9-6	18-9	15-11	12-0	23-3	19-5	14-8
	24	8-5	7-8	5-10	13-3	11-3	8-6	17-0	14-3	10-9	20-9	17-5	13-2
Douglas Fir-L(N)	12	11-6	10-9	8-0	18-0	15-8	11-9	23-9	19-10	14-10	30-4	24-3	18-1
	16	10-5	9-3	6-11	16-4	13-7	10-2	21-7	17-2	12-10	26-6	21-0	15-8
	19.2	9-10	8-6	6-4	15-5	12-5	9-3	19-9	15-8	11-9	24-2	19-2	14-4
	24	9-1	7-7	5-8	14-0	11-1	8-3	17-8	14-0	10-6	21-7	17-2	12-10
Hem-Fir(N)	12	11-1	10-10	8-10	17-4	17-0	12-11	22-11	21-6	16-4	29-2	26-4	19-11
	16	10-0	9-10	7-8	15-9	14-9	11-2	20-10	18-8	14-2	26-0	22-9	17-3
	19.2	9-5	9-2	7-0	14-10	13-5	10-2	19-5	17-0	12-11	23-8	20-9	15-9
	24	8-9	8-3	6-3	13-8	12-0	9-1	17-4	15-3	11-7	21-2	18-7	14-1
Northern Species	12	9-7	9-0	6-10	15-0	13-2	10-1	19-10	16-8	12-9	25-3	20-4	15-7
	16	8-8	7-10	5-11	13-8	11-5	8-9	18-0	14-5	11-0	22-9	17-8	13-6
	19.2	8-2	7-1	5-5	12-10	10-5	7-11	16-11	13-2	10-1	20-9	16-1	12-4
	24	7-7	6-4	4-10	11-11	9-4	7-1	15-3	11-9	9-0	18-7	14-5	11-0

Snow Region, Light Roof, No Ceiling: 30 PSF Live, 10 PSF Dead

Species Group	Spacing inches o.c.	2×4 Sel Str	2×4 No.1/ No.2	2×4 Grade No.3	2×6 Sel Str	2×6 No.1/ No.2	2×6 Grade No.3	2×8 Sel Str	2×8 No.1/ No.2	2×8 Grade No.3	2×10 Sel Str	2×10 No.1/ No.2	2×10 Grade No.3
		Maximum Allowable Span (feet-inches)											
Spruce-pine-fir	12	9-3	9-1	7-1	14-7	13-9	10-5	19-2	17-5	13-2	24-6	21-4	16-1
	16	8-5	8-2	6-2	13-3	11-11	9-0	17-5	15-1	11-5	22-1	18-5	13-11
	19.2	7-11	7-5	5-8	12-5	10-11	8-3	16-5	13-9	10-5	20-2	16-10	12-9
	24	7-4	6-8	5-0	11-7	9-9	7-4	14-9	12-4	9-4	18-0	15-1	11-5
Douglas Fir-L(N)	12	10-0	9-3	6-11	15-9	13-7	10-2	20-9	17-2	12-10	26-6	21-0	15-8
	16	9-1	8-0	6-0	14-4	11-9	8-9	18-9	14-11	11-2	22-11	18-2	13-7
	19.2	8-7	7-4	5-6	13-6	10-9	8-0	17-1	13-7	10-2	20-11	16-7	12-5
	24	7-11	6-7	4-11	12-1	9-7	7-2	15-4	12-2	9-1	18-9	14-10	11-1
Hem-Fir(N)	12	9-8	9-6	7-8	15-2	14-9	11-2	20-0	18-8	14-2	25-6	22-9	17-3
	16	8-9	8-7	6-7	13-9	12-9	9-8	18-2	16-2	12-3	22-6	19-9	14-11
	19.2	8-3	7-11	6-0	13-0	11-8	8-10	16-10	14-9	11-2	20-6	18-0	13-8
	24	7-8	7-1	5-5	11-10	10-5	7-11	15-0	13-2	10-0	18-4	16-1	12-3
Northern Species	12	8-4	7-10	5-11	13-1	11-5	8-9	17-4	14-5	11-0	22-1	17-8	13-6
	16	7-7	6-9	5-2	11-11	9-10	7-7	15-9	12-6	9-7	19-9	15-3	11-8
	19.2	7-2	6-2	4-8	11-3	9-0	6-11	14-9	11-5	8-9	18-0	13-11	10-8
	24	6-8	5-6	4-3	10-5	8-1	6-2	13-2	10-3	7-10	16-1	12-6	9-6

Rafters

Snow Region, Light Roof, No Ceiling: 40 PSF Live, 10 PSF Dead

		Maximum Allowable Span (feet-inches)											
		2×4			2×6			2×8			2×10		
Species Group	Spacing inches o.c.	Sel Str	No.1/ No.2	Grade No.3	Sel Str	No.1/ No.2	Grade No.3	Sel Str	No.1/ No.2	Grade No.3	Sel Str	No.1/ No.2	Grade No.3
Spruce-pine-fir	12	8-5	8-3	6-4	13-3	12-4	9-4	17-5	15-7	11-9	22-3	19-1	14-5
	16	7-8	7-3	5-6	12-0	10-8	8-1	15-10	13-6	10-3	19-9	16-6	12-6
	19.2	7-2	6-8	5-0	11-4	9-9	7-4	14-9	12-4	9-4	18-0	15-1	11-5
	24	6-8	5-11	4-6	10-5	8-9	6-7	13-2	11-0	8-4	16-1	13-6	10-2
Douglas Fir-L(N)	12	9-1	8-4	6-2	14-4	12-2	9-1	18-10	15-4	11-6	23-8	18-9	14-0
	16	8-3	7-2	5-4	13-0	10-6	7-10	16-9	13-4	9-11	20-6	16-3	12-2
	19.2	7-9	6-7	4-11	12-1	9-7	7-2	15-4	12-2	9-1	18-9	14-10	11-1
	24	7-3	5-10	4-5	10-10	8-7	6-5	13-8	10-10	8-2	16-9	13-3	9-11
Hem-Fir(N)	12	8-9	8-7	6-10	13-9	13-2	10-0	18-2	16-8	12-8	23-2	20-4	15-5
	16	8-0	7-10	5-11	12-6	11-5	8-8	16-6	14-5	10-11	20-1	17-8	13-5
	19.2	7-6	7-1	5-5	11-9	10-5	7-11	15-0	13-2	10-0	18-4	16-1	12-3
	24	7-0	6-4	4-10	10-7	9-4	7-1	13-5	11-9	8-11	16-5	14-5	10-11
Northern Species	12	7-7	7-0	5-4	11-11	10-2	7-9	15-9	12-11	9-10	20-1	15-9	12-1
	16	6-11	6-0	4-7	10-10	8-10	6-9	14-3	11-2	8-7	17-8	13-8	10-5
	19.2	6-6	5-6	4-3	10-2	8-1	6-2	13-2	10-3	7-10	16-1	12-6	9-6
	24	6-0	4-11	3-9	9-4	7-3	5-6	11-9	9-2	7-0	14-5	11-2	8-6

Snow Region, Light Roof, No Ceiling: 50 PSF Live, 10 PSF Dead

		Maximum Allowable Span (feet-inches)											
		2×4			2×6			2×8			2×10		
Species Group	Spacing inches o.c.	Sel Str	No.1/ No.2	Grade No.3	Sel Str	No.1/ No.2	Grade No.3	Sel Str	No.1/ No.2	Grade No.3	Sel Str	No.1/ No.2	Grade No.3
Spruce-pine-fir	12	7-10	7-8	5-10	12-3	11-3	8-6	16-2	14-3	10-9	20-8	17-5	13-2
	16	7-1	6-8	5-0	11-2	9-9	7-4	14-8	12-4	9-4	18-0	15-1	11-5
	19.2	6-8	6-1	4-7	10-6	8-11	6-9	13-5	11-3	8-6	16-5	13-9	10-5
	24	6-2	5-5	4-1	9-6	7-11	6-0	12-0	10-1	7-7	14-8	12-4	9-4
Douglas Fir-L(N)	12	8-5	7-7	5-8	13-3	11-1	8-3	17-6	14-0	10-6	21-7	17-2	12-10
	16	7-8	6-7	4-11	12-1	9-7	7-2	15-4	12-2	9-1	18-9	14-10	11-1
	19.2	7-3	6-0	4-6	11-0	8-9	6-7	14-0	11-1	8-4	17-1	13-7	10-2
	24	6-8	5-4	4-0	9-10	7-10	5-10	12-6	9-11	7-5	15-3	12-1	9-1
Hem-Fir(N)	12	8-2	8-0	6-3	12-10	12-0	9-1	16-10	15-3	11-7	21-2	18-7	14-1
	16	7-5	7-1	5-5	11-8	10-5	7-11	15-0	13-2	10-0	18-4	16-1	12-3
	19.2	7-0	6-6	4-11	10-10	9-6	7-2	13-9	12-0	9-2	16-9	14-8	11-2
	24	6-6	5-10	4-5	9-8	8-6	6-5	12-3	10-9	8-2	15-0	13-2	10-0
Northern Species	12	7-1	6-4	4-10	11-1	9-4	7-1	14-7	11-9	9-0	18-7	14-5	11-0
	16	6-5	5-6	4-3	10-1	8-1	6-2	13-2	10-3	7-10	16-1	12-6	9-6
	19.2	6-0	5-0	3-10	9-6	7-4	5-7	12-0	9-4	7-1	14-8	11-5	8-8
	24	5-7	4-6	3-5	8-6	6-7	5-0	10-9	8-4	6-4	13-2	10-2	7-9

Rafters

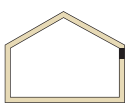
Snow Region, Heavy Roof, No Ceiling: 20 PSF Live, 20 PSF Dead

		Maximum Allowable Span (feet-inches)											
		2x4			2x6			2x8			2x10		
Species Group	Spacing inches o.c.	Sel Str	No.1/ No.2	Grade No.3	Sel Str	No.1/ No.2	Grade No.3	Sel Str	No.1/ No.2	Grade No.3	Sel Str	No.1/ No.2	Grade No.3
Spruce-pine-fir	12	10-7	9-5	7-1	16-5	13-9	10-5	20-10	17-5	13-2	25-6	21-4	16-1
	16	9-8	8-2	6-2	14-3	11-11	9-0	18-1	15-1	11-5	22-1	18-5	13-11
	19.2	8-11	7-5	5-8	13-0	10-11	8-3	16-6	13-9	10-5	20-2	16-10	12-9
	24	7-11	6-8	5-0	11-8	9-9	7-4	14-9	12-4	9-4	18-0	15-1	11-5
Douglas Fir-L(N)	12	11-6	9-3	6-11	17-1	13-7	10-2	21-8	17-2	12-10	26-6	21-0	15-8
	16	10-2	8-0	6-0	14-10	11-9	8-9	18-9	14-11	11-2	22-11	18-2	13-7
	19.2	9-3	7-4	5-6	13-6	10-9	8-0	17-1	13-7	10-2	20-11	16-7	12-5
	24	8-3	6-7	4-11	12-1	9-7	7-2	15-4	12-2	9-1	18-9	14-10	11-1
Hem-Fir(N)	12	11-1	10-1	7-8	16-9	14-9	11-2	21-3	18-8	14-2	26-0	22-9	17-3
	16	10-0	8-9	6-7	14-6	12-9	9-8	18-5	16-2	12-3	22-6	19-9	14-11
	19.2	9-1	7-11	6-0	13-3	11-8	8-10	16-10	14-9	11-2	20-6	18-0	13-8
	24	8-1	7-1	5-5	11-10	10-5	7-11	15-0	13-2	10-0	18-4	16-1	12-3
Northern Species	12	9-7	7-10	5-11	14-9	11-5	8-9	18-8	14-5	11-0	22-9	17-8	13-6
	16	8-8	6-9	5-2	12-9	9-10	7-7	16-2	12-6	9-7	19-9	15-3	11-8
	19.2	7-11	6-2	4-8	11-8	9-0	6-11	14-9	11-5	8-9	18-0	13-11	10-8
	24	7-1	5-6	4-3	10-5	8-1	6-2	13-2	10-3	7-10	16-1	12-6	9-6

Snow Region, Heavy Roof, No Ceiling: 30 PSF Live, 20 PSF Dead

		Maximum Allowable Span (feet-inches)											
		2x4			2x6			2x8			2x10		
Species Group	Spacing inches o.c.	Sel Str	No.1/ No.2	Grade No.3	Sel Str	No.1/ No.2	Grade No.3	Sel Str	No.1/ No.2	Grade No.3	Sel Str	No.1/ No.2	Grade No.3
Spruce-pine-fir	12	9-3	8-5	6-4	14-7	12-4	9-4	18-8	15-7	11-9	22-9	19-1	14-5
	16	8-5	7-3	5-6	12-9	10-8	8-1	16-2	13-6	10-3	19-9	16-6	12-6
	19.2	7-11	6-8	5-0	11-8	9-9	7-4	14-9	12-4	9-4	18-0	15-1	11-5
	24	7-1	5-11	4-6	10-5	8-9	6-7	13-2	11-0	8-4	16-1	13-6	10-2
Douglas Fir-L(N)	12	10-0	8-4	6-2	15-4	12-2	9-1	19-4	15-4	11-6	23-8	18-9	14-0
	16	9-1	7-2	5-4	13-3	10-6	7-10	16-9	13-4	9-11	20-6	16-3	12-2
	19.2	8-3	6-7	4-11	12-1	9-7	7-2	15-4	12-2	9-1	18-9	14-10	11-1
	24	7-5	5-10	4-5	10-10	8-7	6-5	13-8	10-10	8-2	16-9	13-3	9-11
Hem-Fir(N)	12	9-8	9-0	6-10	15-0	13-2	10-0	19-0	16-8	12-8	23-3	20-4	15-5
	16	8-9	7-10	5-11	13-0	11-5	8-8	16-6	14-5	10-11	20-1	17-8	13-5
	19.2	8-1	7-1	5-5	11-10	10-5	7-11	15-0	13-2	10-0	18-4	16-1	12-3
	24	7-3	6-4	4-10	10-7	9-4	7-1	13-5	11-9	8-11	16-5	14-5	10-11
Northern Species	12	8-4	7-0	5-4	13-1	10-2	7-9	16-8	12-11	9-10	20-4	15-9	12-1
	16	7-7	6-0	4-7	11-5	8-10	6-9	14-5	11-2	8-7	17-8	13-8	10-5
	19.2	7-1	5-6	4-3	10-5	8-1	6-2	13-2	10-3	7-10	16-1	12-6	9-6
	24	6-4	4-11	3-9	9-4	7-3	5-6	11-9	9-2	7-0	14-5	11-2	8-6

Headers In Exterior Bearing Walls

		Maximum Allowable Span (feet-inches)											
Roof Live Load, psf		**20**			**30**			**40**			**50**		
		Building Width, ft			**Building Width, ft**			**Building Width, ft**			**Building Width, ft**		
Header Supporting	**Size**	**20**	**28**	**36**	**20**	**28**	**36**	**20**	**28**	**36**	**20**	**28**	**36**
	2-2×4	3-7	3-2	2-10	3-4	2-10	2-7	3-0	2-7	2-4	2-10	2-5	2-2
	2-2×6	5-5	4-8	4-2	4-10	4-2	3-9	4-5	3-10	3-5	4-1	3-7	3-2
	2-2×8	6-10	5-11	5-4	6-2	5-4	4-9	5-7	4-10	4-4	5-2	4-6	4-0
	2-2×10	8-5	7-3	6-6	7-6	6-6	5-10	6-10	5-11	5-4	6-4	5-6	4-11
	2-2×12	9-9	8-5	7-6	8-8	7-6	6-9	7-11	6-10	6-2	7-4	6-4	5-8
	3-2×8	8-6	7-5	6-8	7-8	6-8	5-11	7-0	6-1	5-5	6-6	5-8	5-0
	3-2×10	10-6	9-1	8-2	9-5	8-2	7-3	8-7	7-5	6-8	7-11	6-10	6-2
	3-2×12	12-2	10-7	9-5	10-11	9-5	8-5	9-11	8-7	7-8	9-2	8-0	7-2
	4-2×8	9-4	8-6	7-8	8-8	7-8	6-11	8-1	7-0	6-3	7-6	6-6	5-10
	4-2×10	11-11	10-6	9-5	10-10	9-5	8-5	9-11	8-7	7-8	9-2	7-11	7-1
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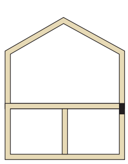	2-2×4	3-1	2-9	2-5	2-10	2-6	2-3	2-8	2-4	2-1	2-6	2-2	2-0
	2-2×6	4-6	4-0	3-7	4-2	3-8	3-3	3-11	3-5	3-1	3-8	3-2	2-11
	2-2×8	5-9	5-0	4-6	5-3	4-8	4-2	4-11	4-4	3-11	4-8	4-1	3-8
	2-2×10	7-0	6-2	5-6	6-5	5-8	5-1	6-0	5-3	4-9	5-8	4-11	4-5
	2-2×12	8-1	7-1	6-5	7-6	6-7	5-11	7-0	6-1	5-6	6-7	5-9	5-2
	3-2×8	7-2	6-3	5-8	6-7	5-10	5-3	6-2	5-5	4-10	5-10	5-1	4-7
	3-2×10	8-9	7-8	6-11	8-1	7-1	6-5	7-6	6-7	5-11	7-1	6-2	5-7
	3-2×12	10-2	8-11	8-0	9-4	8-2	7-5	8-9	7-8	6-11	8-3	7-2	6-6
	4-2×8	8-3	7-3	6-7	7-8	6-8	6-0	7-1	6-3	5-7	6-8	5-10	5-3
	4-2×10	10-1	8-10	8-0	9-4	8-2	7-4	8-8	7-7	6-10	8-2	7-2	6-5
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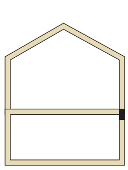
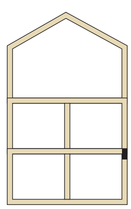
	2-2×4	2-8	2-4	2-1	2-8	2-3	2-0	2-6	2-2	2-0	2-5	2-1	1-10
	2-2×6	3-11	3-5	3-0	3-10	3-4	3-0	3-8	3-2	2-11	3-6	3-0	2-9
	2-2×8	5-0	4-4	3-10	4-10	4-3	3-9	4-8	4-1	3-8	4-5	3-10	3-5
	2-2×10	6-1	5-3	4-8	5-11	5-2	4-7	5-8	4-11	4-5	5-5	4-8	4-3
	2-2×12	7-1	6-1	5-5	6-11	6-0	5-4	6-7	5-9	5-2	6-3	5-5	4-11
	3-2×8	6-3	5-5	4-10	6-1	5-3	4-9	5-10	5-1	4-7	5-6	4-10	4-4
	3-2×10	7-7	6-7	5-11	7-5	6-5	5-9	7-1	6-2	5-7	6-9	5-10	5-3
	3-2×12	8-10	7-8	6-10	8-8	7-6	6-8	8-3	7-2	6-6	7-10	6-10	6-1
	4-2×8	7-2	6-3	5-7	7-1	6-1	5-6	6-9	5-10	5-3	6-4	5-7	5-0
	4-2×10	8-9	7-7	6-10	8-7	7-5	6-8	8-3	7-2	6-5	7-9	6-9	6-1
	4-2×12	10-2	8-10	7-11	10-0	8-8	7-9	9-6	8-4	7-6	9-0	7-10	7-1

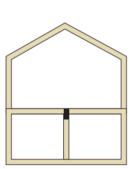
Headers In Exterior Bearing Walls



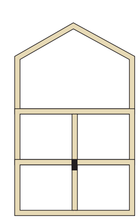
	Maximum Allowable Span (feet-inches)												
Roof Live Load, psf		20			30			40			50		
		Building Width, ft			Building Width, ft			Building Width, ft			Building Width, ft		
Header Supporting	Size	20	28	36	20	28	36	20	28	36	20	28	36
	2-2×4	2-7	2-3	2-0	2-6	2-2	2-0	2-5	2-1	1-11	2-3	2-0	1-10
	2-2×6	3-9	3-3	2-11	3-8	3-3	2-11	3-6	3-1	2-10	3-4	2-11	2-8
	2-2×8	4-9	4-2	3-9	4-8	4-1	3-8	4-5	3-11	3-6	4-3	3-9	3-4
	2-2×10	5-9	5-1	4-7	5-8	5-0	4-6	5-5	4-9	4-4	5-2	4-7	4-1
	2-2×12	6-8	5-10	5-3	6-7	5-9	5-2	6-4	5-7	5-0	6-0	5-3	4-9
	3-2×8	5-11	5-2	4-8	5-10	5-1	4-7	5-7	4-11	4-5	5-4	4-8	4-2
	3-2×10	7-3	6-4	5-9	7-1	6-3	5-7	6-10	6-0	5-5	6-6	5-8	5-2
	3-2×12	8-5	7-4	6-7	8-3	7-3	6-6	7-11	6-11	6-3	7-6	6-7	6-0
	4-2×8	6-10	6-0	5-5	6-8	5-11	5-4	6-5	5-8	5-1	6-1	5-5	4-10
	4-2×10	8-4	7-4	6-7	8-2	7-2	6-6	7-10	6-11	6-3	7-6	6-7	5-11
	4-2×12	9-8	8-6	7-8	9-6	8-4	7-6	9-1	8-0	7-3	8-8	7-7	6-11

Headers In Interior Bearing Walls

Maximum Allowable Span (feet-inches)



		Building Width, ft		
Header Supporting	Size	20	28	36
	2-2×4	3-5	2-10	2-6
	2-2×6	4-11	4-2	3-8
	2-2×8	6-3	5-4	4-8
	2-2×10	7-8	6-6	5-9
	2-2×12	8-11	7-6	6-7
	3-2×8	7-10	6-8	5-10
	3-2×10	9-7	8-1	7-2
	3-2×12	11-1	9-5	8-3
	4-2×8	9-1	7-8	6-9
	4-2×10	11-1	9-4	8-3
	4-2×12	12-10	10-10	9-7



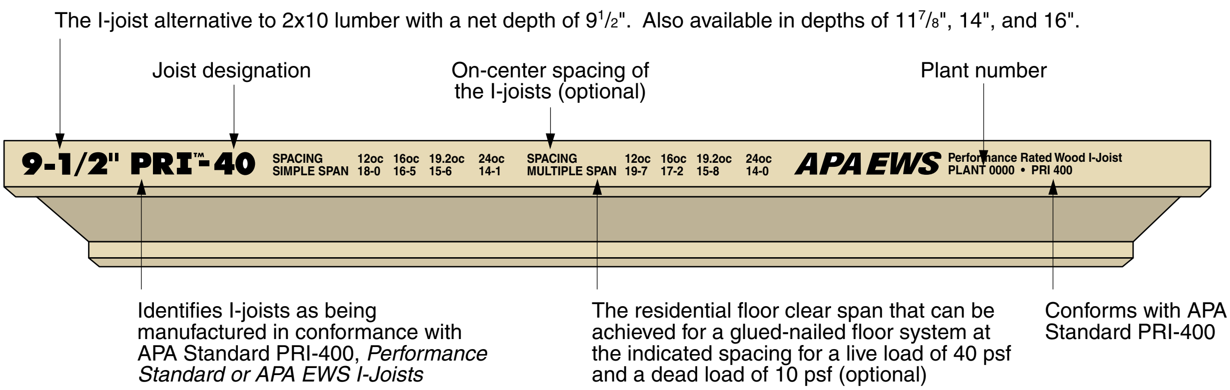
		Building Width, ft		
Header Supporting	Size	20	28	36
	2-2×4	2-3	1-11	1-9
	2-2×6	3-4	2-10	2-6
	2-2×8	4-3	3-7	3-3
	2-2×10	5-2	4-5	3-11
	2-2×12	6-0	5-2	4-7
	3-2×8	5-4	4-6	4-0
	3-2×10	6-6	5-5	4-11
	3-2×12	7-6	6-5	5-8
	4-2×8	6-1	5-3	4-8
	4-2×10	7-6	6-5	5-8
	4-2×12	8-8	7-5	6-7

I-Joists

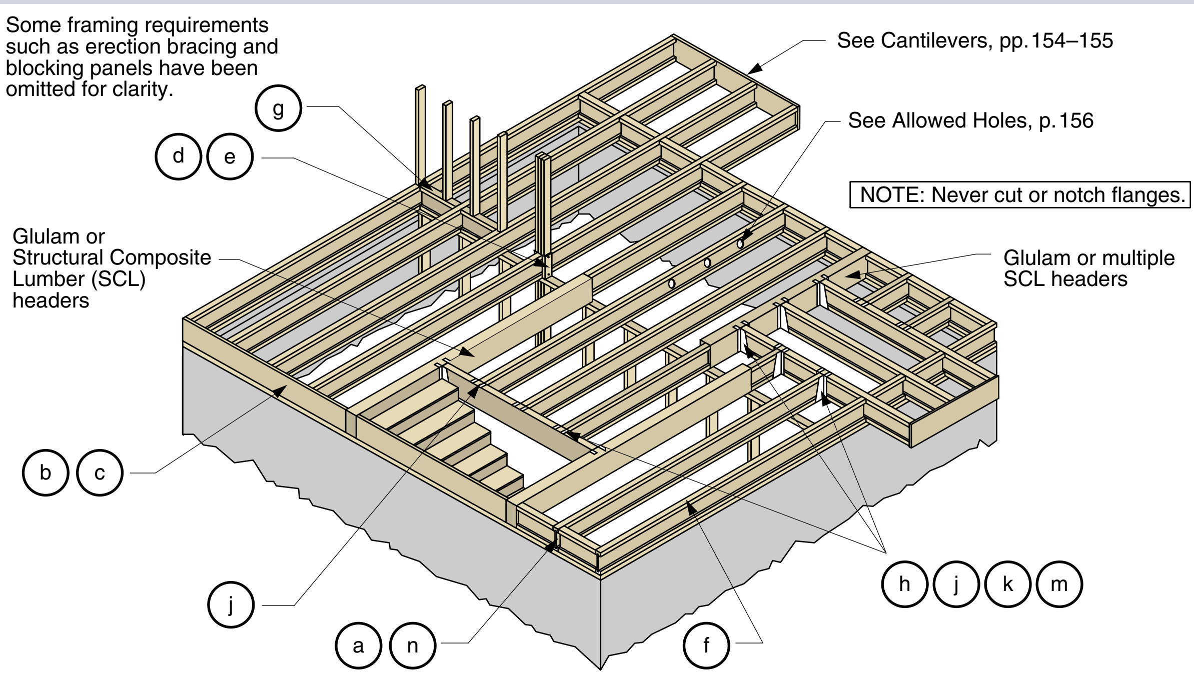
The APA Performance Rated™ I-Joist (PRI) is an engineered wood structural member, designed for residential floor framing, with the following characteristics:

- Flanges are either sawn lumber or structural composite lumber. Top and bottom flanges are of the same type and grade of material.
- Webs consist of wood structural panels, consisting of Exposure I or Exterior plywood or OSB.
- The four depths are: 9 1/2, 11 7/8, 14, and 16 inches. Flange widths vary with strength.
- PRIs are manufactured in lengths to 60 feet, then cut to standard lengths such as 16 to 36 feet.

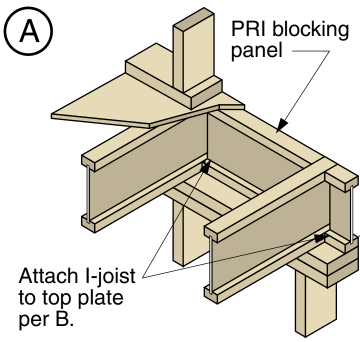
Sample Trademark



Typical Performance-Rated I-Joist Floor Framing (details on pp. 151–153)



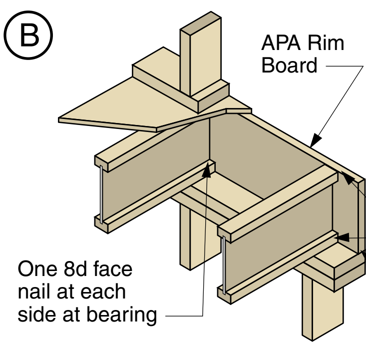
Floor Framing Details (letters refer to illustration at bottom of p. 150)



Blocking Panel or Rim Joist	Uniform Vertical Load Transfer Capacity* (plf)
PRI Joists	2000

*The uniform vertical load capacity is limited to a joist depth of 16 inches or less and is based on the normal (10-yr) load duration. It shall not be used in the design of a bending member, such as joist, header, or rafter. For concentrated vertical load transfer capacity, see D.

8d nails @ 6" o.c. to top plate (when used for lateral shear transfer, nail to bearing plate with same nailing as required for decking)



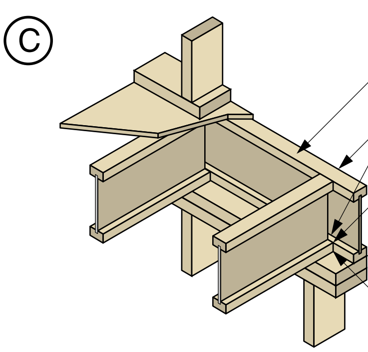
Blocking Panel or Rim Joist	Uniform Vertical Load Transfer Capacity* (plf)
$1^{1}/_{8}$" APA rim board plus	4850
$1^{1}/_{8}$" APA rim board	4400
1" APA rim board	3300

*The uniform vertical load capacity is limited to a rim board depth of 16 inches or less and is based on the normal (10-yr) load duration. It shall not be used in the design of a bending member, such as joist, header, or rafter. For concentrated vertical load transfer capacity, see D.

One 8d common or box nail at top and bottom flange

Attach APA rim board to top plate using 8d common or box toenails @ 6" o.c.

To avoid splitting flange, start nails at least $1^{1}/_{2}$" from end of I-joist. Nails may be driven at an angle to avoid splitting of bearing plate.



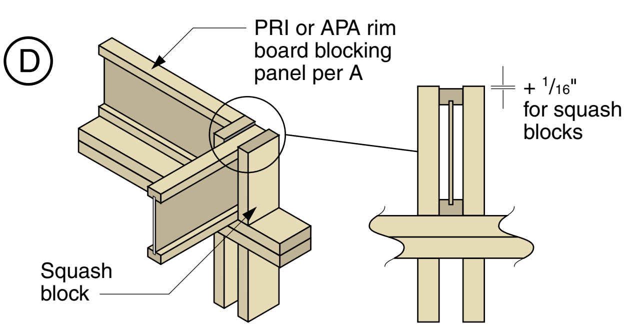
PRI rim joist per A

Attach rim joist to floor joist with one nail at top and bottom. Nail must provide 1" minimum penetration into floor joist. For $2^{1}/_{2}$" and $3^{1}/_{2}$" flange widths, toe nails may be used.

Attach I-joist per B.

Attach rim joist to top plate per A.

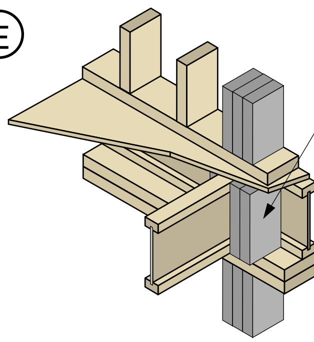
Minimum $1^{3}/_{4}$" bearing required



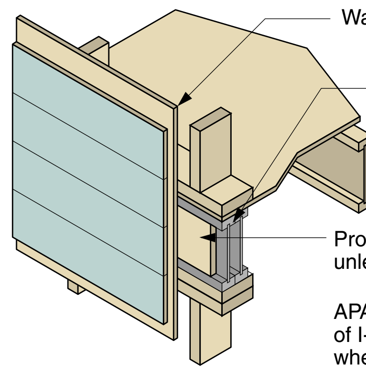
Pair of Squash Blocks	Vertical load transfer capacity per pair of squash blocks (lb) $3^{1}/_{2}$" wide	$5^{1}/_{2}$" wide
2x lumber	4000	7000
$1^{1}/_{8}$" APA rim board, rim board plus, or rated Sturd-I-Floor 48" o.c.	3000	3500
1" APA rim board or rated Sturd-I-Floor 32" o.c.	2700	3500

Provide lateral bracing per A, B, or C.

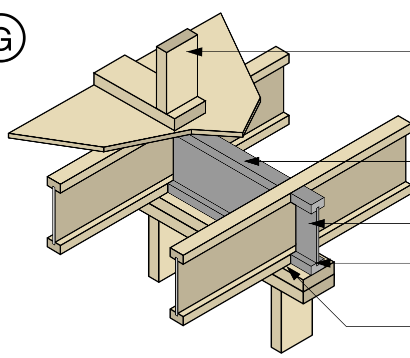
E



F



G

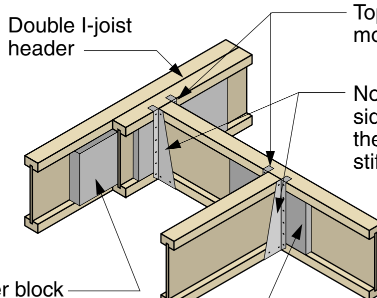


H

Backer block (use if hanger load exceeds 250 lb.) Before installing a backer block to a double I-joist, drive three additional 10d nails through the webs and filler block where the backer block will fit. Clinch. Install backer tight to top flange. Use twelve 10d nails, clinched when possible. Maximum capacity for hanger for this detail = 1,280 lb.

BACKER BLOCKS (Blocks must be long enough to permit required nailing without splitting)

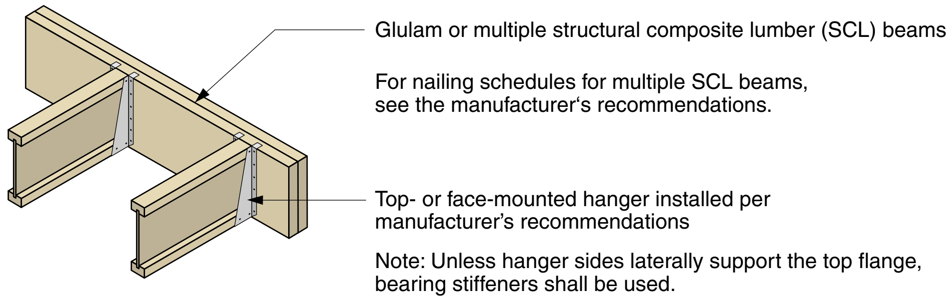
Flange Width	Material Thickness Required*	Minimum Depth**
$1\frac{1}{2}$"	$\frac{19}{32}$"	$5\frac{1}{2}$"
$1\frac{3}{4}$"	$\frac{23}{32}$"	$5\frac{1}{2}$"
$2\frac{5}{16}$"	1"	$7\frac{1}{4}$"
$2\frac{1}{2}$"	1"	$5\frac{1}{2}$"
$3\frac{1}{2}$"	$1\frac{1}{2}$"	$7\frac{1}{4}$"



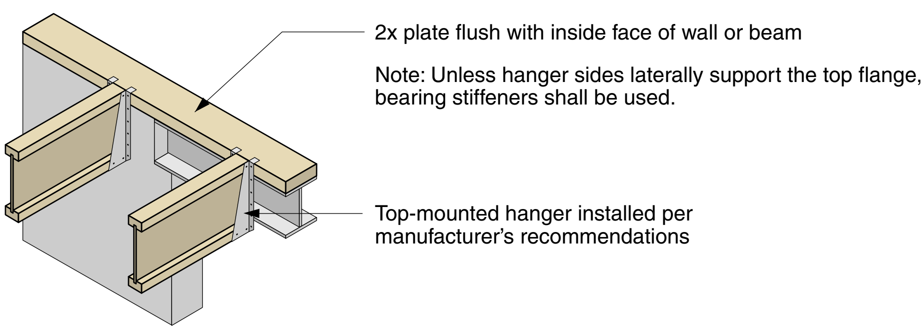
For hanger capacity see hanger manufacturer's recommendations. Verify double I-joist capacity to support concentrated loads.

* Minimum grade for backer block material shall be utility grade SPF (south) or better for solid sawn lumber and rated sheathing grade for wood structural panels.
** For face-mount hangers use net joist depth minus $3\frac{1}{4}$" for joists with $1\frac{1}{2}$" thick flanges. For $1\frac{5}{16}$" thick flanges use net depth minus $2\frac{7}{8}$".

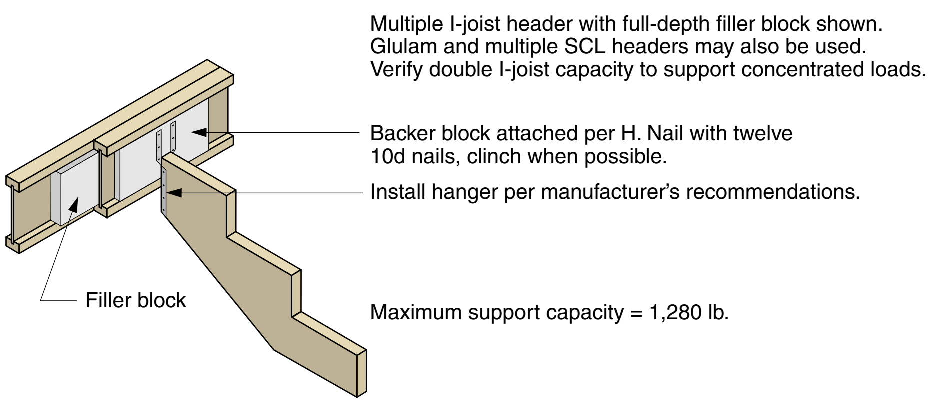
J


Glulam or multiple structural composite lumber (SCL) beams
For nailing schedules for multiple SCL beams, see the manufacturer's recommendations.
Top- or face-mounted hanger installed per manufacturer's recommendations
Note: Unless hanger sides laterally support the top flange, bearing stiffeners shall be used.

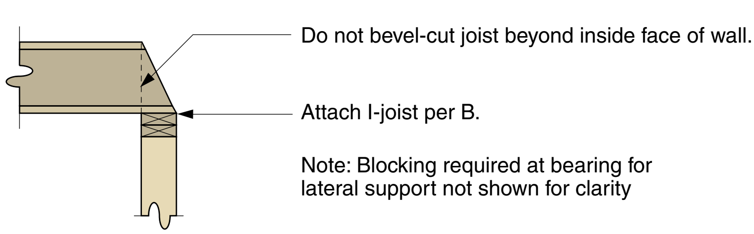
K


2x plate flush with inside face of wall or beam
Note: Unless hanger sides laterally support the top flange, bearing stiffeners shall be used.
Top-mounted hanger installed per manufacturer's recommendations

M


Multiple I-joist header with full-depth filler block shown. Glulam and multiple SCL headers may also be used. Verify double I-joist capacity to support concentrated loads.
Backer block attached per H. Nail with twelve 10d nails, clinch when possible.
Install hanger per manufacturer's recommendations.
Filler block
Maximum support capacity = 1,280 lb.

N


Do not bevel-cut joist beyond inside face of wall.
Attach I-joist per B.
Note: Blocking required at bearing for lateral support not shown for clarity

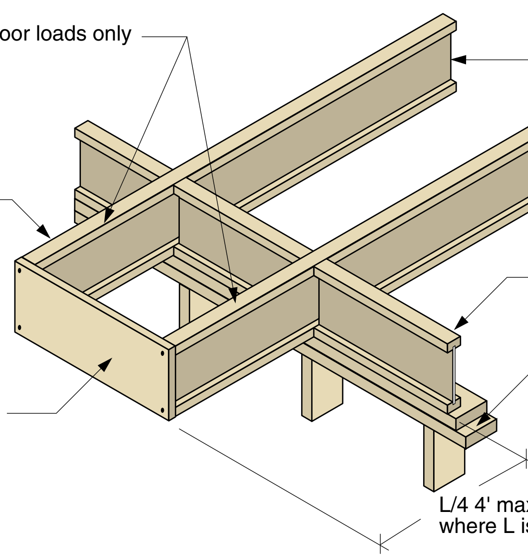
Cantilevers for Balconies

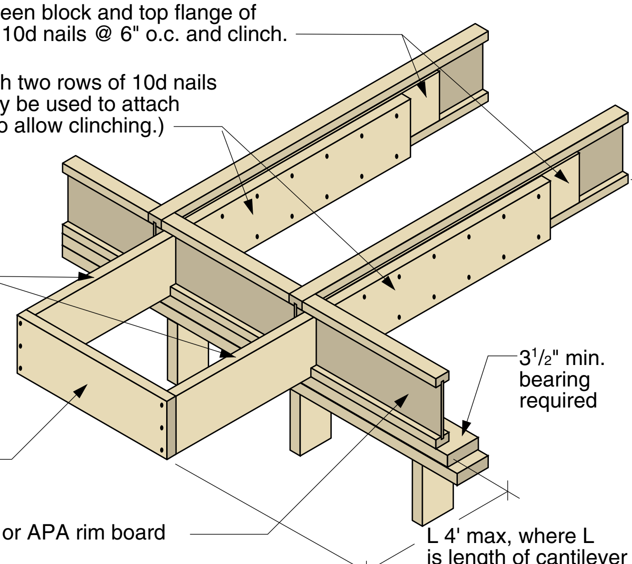
Balconies may be constructed using either continuous APA PRIs (first figure below) or by adding lumber extensions (second figure below) to the I-joist. Continuous I-joist cantilevers are limited to one-fourth the adjacent span when supporting uniform loads only. Applications supporting concentrated end loads, such as a wall, are shown on the facing page.

Unless otherwise engineered, cantilevers are limited to a maximum of 4 feet when supporting only uniform loads. Blocking is required at the cantilever support as shown in both figures.

Uniform floor load shall not exceed 40 psf live load and 10 psf dead load. The balcony load shall not exceed 60 psf live load and 10 psf dead load.

Cantilever Details for Balconies

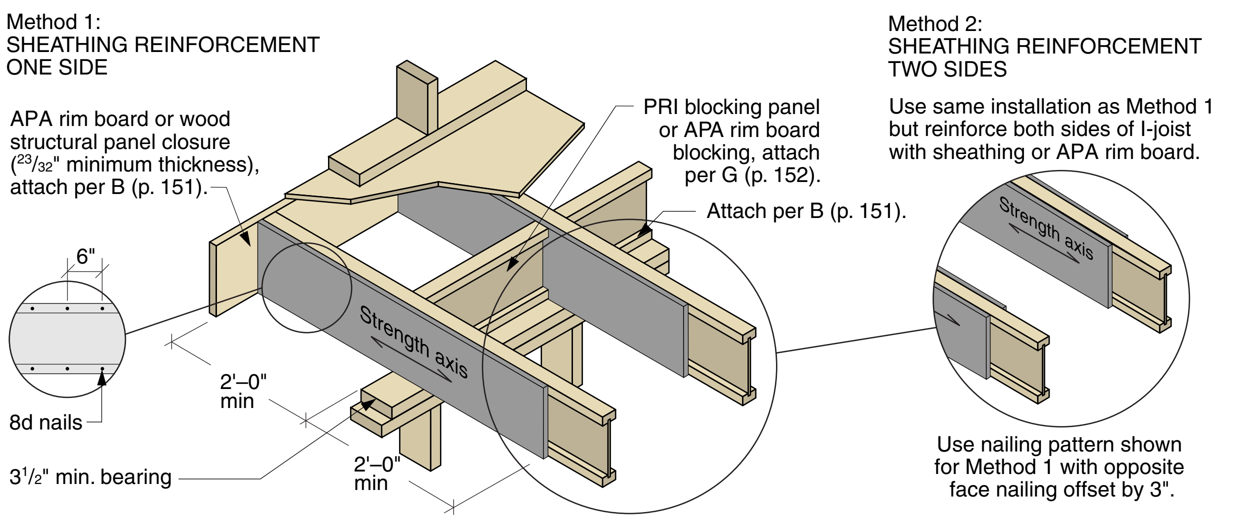




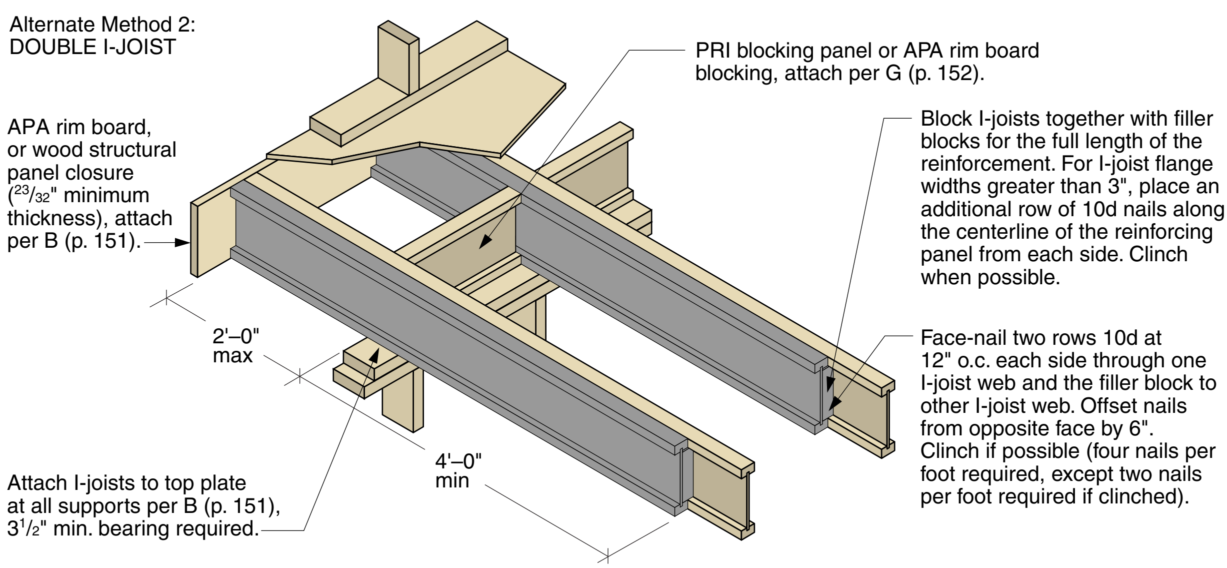
Cantilevers for Building Offsets

I-joists may support a concentrated load applied to the end of the cantilever, such as with a vertical building offset. Whether an I-joist cantilever requires reinforcement should be determined by consulting Table 4 of the APA publication, *Performance Rated I-Joists*. For cantilever-end concentrated load applications that require reinforcing, the cantilever is limited to 2 feet maximum. In addition, blocking is required along the cantilever support and for 4 feet on each side of the cantilever area. Depending on roof loads and layout, three methods of reinforcing are allowed in load bearing cantilever applications: reinforcing sheathing applied to one side of the I-Joist (Method l), reinforcing sheathing applied to both sides of the joist (Method 2), or double I-joists (Alternate Method 2).

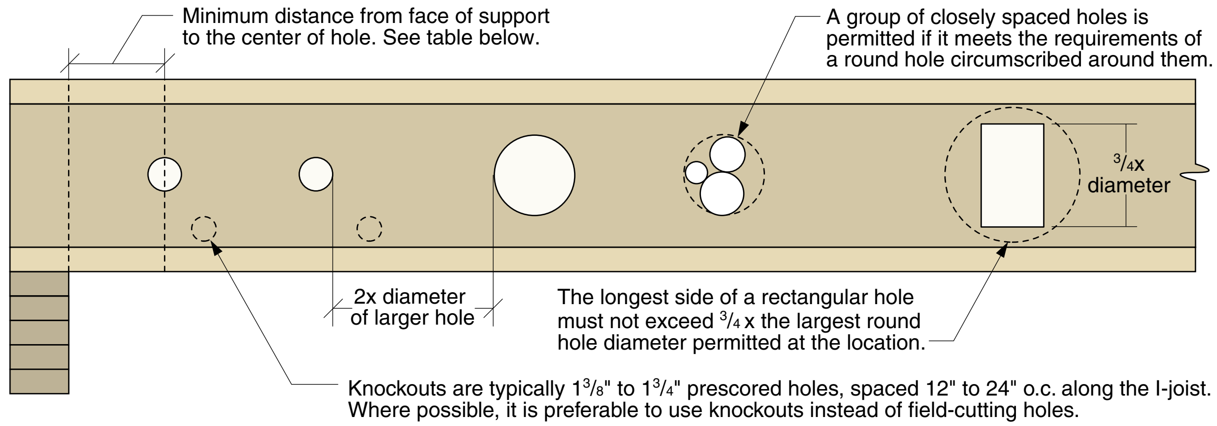
Cantilever Details for Vertical Building Offsets



APA Rated Sheathing 48/24 (minimum thickness 23/32") required on sides of joist. Depth shall match the full height of the joist. Nail with 8d nails at 6" o.c., top and bottom flange. Install with face grain horizontal. Attach I-joist to plate at all supports per B (p. 151).



Allowed Holes in PRI Joists



Minimum Distance from Joist Supports to Center of Hole

Depth, inches	I-Joist Designation	Round Hole Diameter, inches 2	3	4	5	6	7	8	9	10	11	12
	PRI-20	0-06	1-00	2-06	3-06	5-06	–	–	–	–	–	–
	PRI-30	1-00	2-00	3-06	5-00	6-06	–	–	–	–	–	–
9 1/2	PRI-40	0-06	2-00	3-00	4-06	6-00	–	–	–	–	–	–
	PRI-50	1-06	2-06	4-00	5-00	6-06	–	–	–	–	–	–
	PRI-60	2-00	3-00	4-06	6-00	7-06	–	–	–	–	–	–
	PRI-20	0-06	0-06	0-06	0-06	2-00	4-00	6-00	–	–	–	–
	PRI-30	0-06	0-06	0-06	2-00	3-06	5-00	7-00	–	–	–	–
	PRI-40	0-06	0-06	1-06	2-06	4-00	5-06	7-00	–	–	–	–
11 7/8	PRI-50	0-06	0-06	1-00	2-06	4-06	6-00	8-00	–	–	–	–
	PRI-60	1-00	2-00	3-06	4-06	6-00	7-06	9-00	–	–	–	–
	PRI-70	0-06	1-06	2-06	4-00	5-06	7-00	9-00	–	–	–	–
	PRI-80	2-00	3-06	4-06	6-00	7-06	9-00	10-06	–	–	–	–
	PRI-90	0-06	0-06	1-06	3-00	5-00	7-00	9-00	–	–	–	–
	PRI-40	0-06	0-06	0-06	1-00	2-00	3-06	5-00	6-00	8-00	–	–
	PRI-50	0-06	0-06	0-06	0-06	1-00	2-06	4-06	7-00	9-00	–	–
14	PRI-60	0-06	0-06	0-06	2-00	3-06	5-00	6-06	8-06	10-06	–	–
	PRI-70	0-06	0-06	0-06	1-00	2-06	4-06	6-00	8-00	10-06	–	–
	PRI-80	0-06	2-00	3-00	4-06	6-00	7-06	9-00	10-06	12-06	–	–
	PRI-90	0-06	0-06	1-00	2-06	4-00	6-00	7-06	9-06	11-06	–	–
	PRI-40	0-06	0-06	0-06	0-06	0-06	1-06	3-00	4-06	5-06	7-00	9-00
	PRI-50	0-06	0-06	0-06	0-06	0-06	1-06	1-00	2-06	4-06	7-00	10-00
16	PRI-60	0-06	0-06	0-06	0-06	0-06	2-00	3-06	5-06	7-06	9-06	12-00
	PRI-70	0-06	0-06	0-06	0-06	0-06	1-00	3-00	5-00	7-00	9-06	11-06
	PRI-80	0-06	0-06	0-06	2-00	3-06	5-00	6-06	8-06	10-06	12-06	14-06
	PRI-90	0-06	0-06	0-06	1-00	2-06	4-00	5-06	7-06	9-00	11-00	13-06

- Table for I-joist spacing of 24 inches on center or less.
- Hole location distance is measured from the inside edge of supports to the center of the hole.
- Distances are based on uniformly loaded joists that meet the span requirements on the facing page.
- For continuous joists with more than one span, use the longest span to determine hole location in either span.

Residential Floor Spans

The allowable spans in the table below indicate the allowable clear spans for various joist spacings under typical residential uniform floor loads (40 psf live load and 10 psf dead load) for glued-nailed systems. The spans shown are based on repetitive member usage that is typical for all wood products spaced 24 inches on center or less. In addition, floor sheathing must be field glued to the I-joist flanges to achieve the PRI allowable spans. APA PRIs can be used for other applications such as roofs, to support line loads or concentrated loads, etc. when properly engineered using the appropriate design properties.

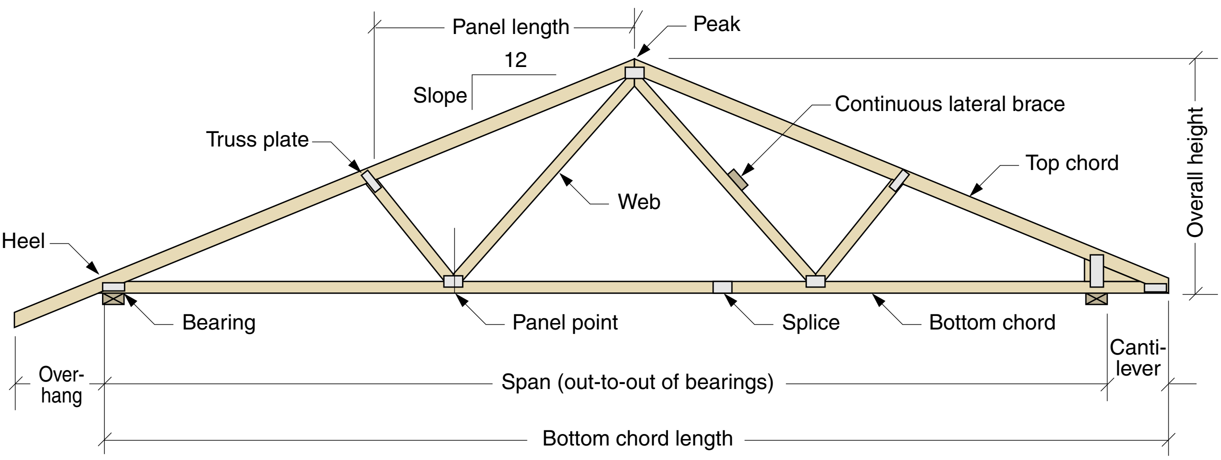
Allowable Spans for APA EWS Performance Rated I-Joists

		Simple Spans				Multiple Spans			
		On-Center Spacing, inches				On-Center Spacing, inches			
Depth, inches	I-Joist Designation	12	16	19.2	24	12	16	19.2	24
	PRI-20	16-07	15-02	14-04	13-05	18-01	16-06	15-07	13-05
	PRI-30	17-01	15-08	14-10	13-10	18-07	17-00	16-01	15-00
9 1/2	PRI-40	18-00	16-05	15-06	14-06	19-07	17-11	16-04	14-07
	PRI-50	17-10	16-04	15-05	14-05	19-05	17-09	16-09	15-07
	PRI-60	18-11	17-04	16-04	15-03	20-08	18-10	17-09	16-06
	PRI-20	19-10	18-02	17-02	16-00	21-08	19-07	16-09	13-05
	PRI-30	20-06	18-09	17-08	16-06	22-04	20-05	18-10	15-00
	PRI-40	21-05	19-07	18-06	16-08	23-05	20-05	18-07	16-07
11 7/8	PRI-50	21-04	19-06	18-05	17-02	23-03	21-02	20-00	16-01
	PRI-60	22-07	20-08	19-06	18-02	24-08	22-06	21-02	19-07
	PRI-70	23-00	21-00	19-10	18-06	25-01	22-10	21-07	18-06
	PRI-80	24-11	22-08	21-04	19-10	27-01	24-08	23-03	21-07
	PRI-90	25-08	23-04	22-00	20-05	27-11	25-05	23-11	22-02
	PRI-40	24-04	22-03	20-06	18-04	25-11	22-05	20-05	18-03
	PRI-50	24-04	22-02	21-0	19-07	26-06	24-02	20-02	16-01
14	PRI-60	25-09	23-06	22-02	20-08	28-00	25-07	24-01	19-09
	PRI-70	26-01	23-10	22-06	20-11	28-05	25-11	23-02	18-06
	PRI-80	28-03	25-09	24-03	22-07	30-10	28-00	26-05	23-11
	PRI-90	29-01	26-05	24-11	23-02	31-08	28-10	27-01	25-02
	PRI-40	26-11	24-03	22-01	19-09	27-11	24-02	22-00	19-08
	PRI-50	27-00	24-08	23-04	20-02	29-06	24-03	20-02	16-01
16	PRI-60	28-06	26-00	24-07	22-10	31-01	28-04	24-09	19-09
	PRI-70	29-00	26-05	24-11	23-01	31-07	27-10	23-02	18-06
	PRI-80	31-04	28-06	26-10	25-00	34-02	31-01	29-03	23-11
	PRI-90	32-02	29-03	27-07	25-07	35-01	31-10	30-00	26-07

- Allowable clear span applicable to residential floor construction with a design dead load of 10 psf and live load of 40 psf. The live load deflection is limited to span/480. The end spans shall be 40% or more of the adjacent span.
- Spans are based on a composite floor with glued-nailed sheathing meeting the requirements for APA rated sheathing or APA rated Sturd-I-Floor® conforming to PRP-108, PS 1, or PS 2 with a minimum thickness of 19/32 inch (40/20 or 20 oc) for a joist spacing of 19.2 inches or less, or 23/32 inch (48/24 or 24 oc) for a joist spacing of 24 inches. Adhesive shall meet APA Specification AFG-01 or ASTM D3498. Spans shall be reduced 1 foot when the floor sheathing is nailed only.
- Minimum bearing length shall be 1 3/4 inches for the end bearings, and 3 1/2 inches for the intermediate bearings.
- Bearing stiffeners are not required when I-joists are used with the spans and spacings given in this table, except as required for hangers.
- This span chart is based on uniform loads.

Wood Trusses

Anatomy of a Wood Truss



With the decreasing availability of large structural lumber, trusses offer cost savings in both roofs and floors. The reason they can do so—in spite of an added cost of fabrication—is that the lengths of lumber subjected to bending stress are broken into smaller sections.

The top left illustration on the facing page shows how a simple triangle formed by two rafters, a ceiling joist, and a vertical tie (a king post truss) divides a building's total clear span into two rafter clear spans, each half as long. The vertical load of the roof is transformed into forces of tension and compression in the directions of the members.

The next illustration shows how, by simple addition of two diagonal members, the queen post truss further divides the rafter clear span.

The facing page shows a small sample (30) of the variety of trusses available from truss manufacturers nation-wide. Designed by computer and manufactured of stress-rated lumber in precision jigs, trusses offer precision, cost-effective solutions to any span problem.

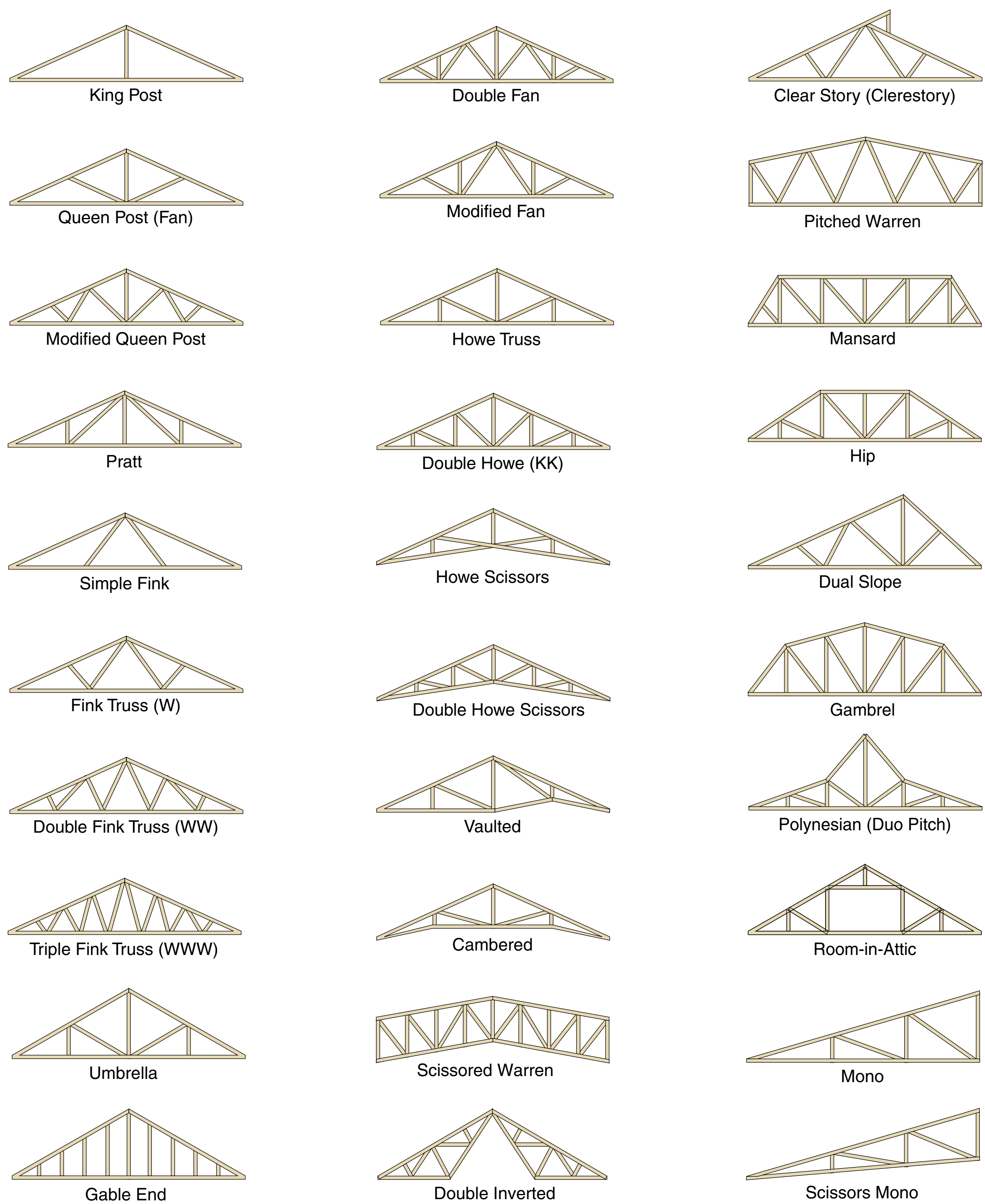
Pages 161–170 contain representative span tables showing clear spans as limited by the species/grades and sizes of the top and bottom chord members. All of the roof-truss tables (pp. 161–169) assume wood moisture content of less than 19% in service, truss spacing of 24” on-center, and roof live and dead loads of 30 psf and 7 psf, respectively.

The floor-truss tables (p. 170) assume moisture content of less than 19% and the spacings, dead loads, and live loads shown. Remember, these tables are for preliminary design guidance only and must be confirmed by the manufacturer.

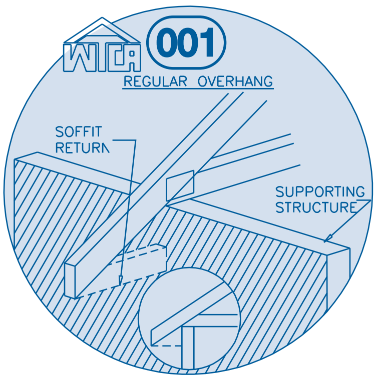
Example: What is the maximum allowable clear span of queen post trusses (p. 161) of #2 southern pine with 24” on-center spacing, roof pitch of 4/12, top-chord (rafter) dead and live loads of 7 psf and 30 psf, and bottom-chord (ceiling joist) dead load of 10 psf, if the top chord is a 2×6 and the bottom chord a 2×4?

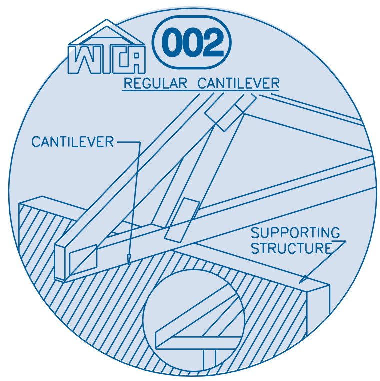
Turn to p. 161. Read horizontally across the row labeled Species Group Southern Pine and Grade #2 to the group of four spans under Pitch of Top Chord 4/12. For a 2×6 top chord the maximum span is 28-2. For a 2×4 bottom chord the maximum span is 18-9. The truss span is thus limited to 18-9 by the 2×4 bottom chord. If we increase the bottom chord to a 2×6 the span will be limited by the bottom chord to 26-3.

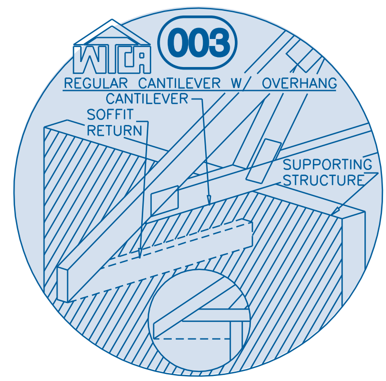
A Variety of Trusses (by No Means Complete)

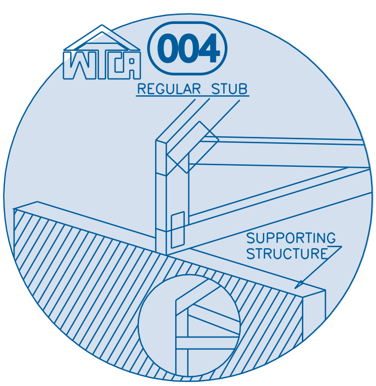


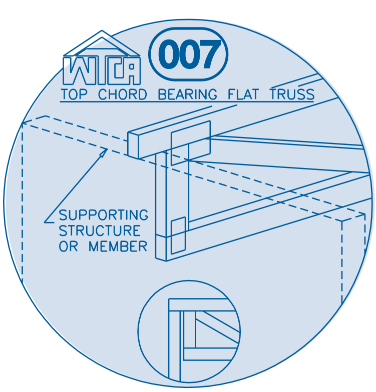
Roof Truss Bearing and Eave Details

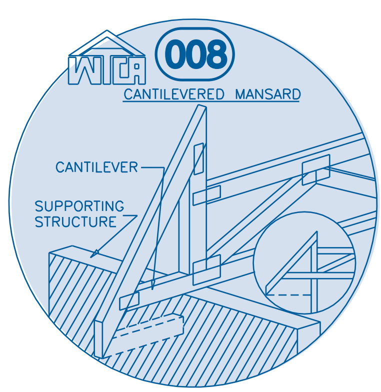




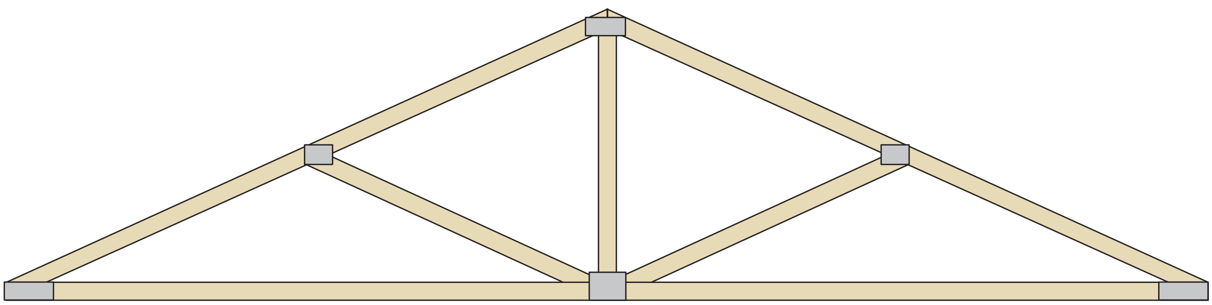








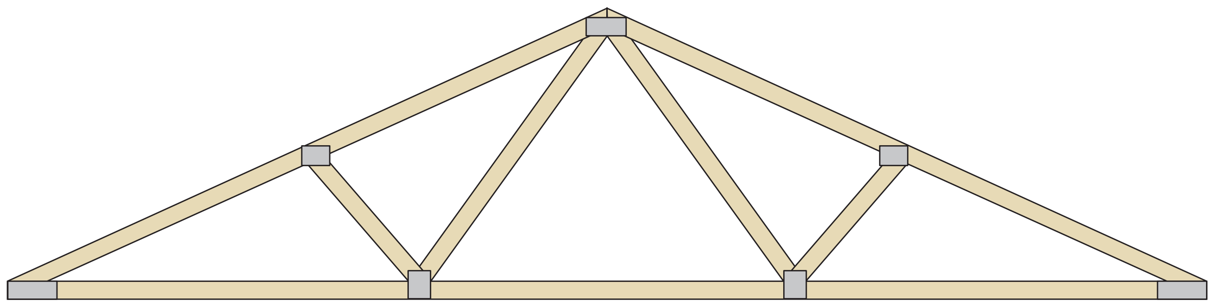
Queen Post Truss



Maximum Allowable (smallest of four figures) Span, feet-inches

		Pitch of Top Chord											
		3/12				4/12				5/12			
		Top Chord		Bottom Chord		Top Chord		Bottom Chord		Top Chord		Bottom Chord	
Species Group	Grade	2×4	2×6	2×4	2×6	2×4	2×6	2×4	2×6	2×4	2×6	2×4	2×6
Southern Pine	#1 Dense	21-6	28-2	21-6	28-2	21-6	28-2	21-6	28-2	21-6	28-2	21-6	28-2
	#1	21-6	28-2	20-8	27-5	21-6	28-2	20-8	27-5	21-6	28-2	20-8	27-5
	#2 Dense	21-6	28-2	20-1	27-3	21-6	28-2	20-1	27-3	21-6	28-2	20-1	27-3
	#2	21-6	28-2	18-9	26-3	21-6	28-2	18-9	26-3	21-6	28-2	18-9	26-3
Douglas Fir-Larch	Sel. Str.	22-4	29-0	22-4	29-0	22-4	29-0	22-4	29-0	22-4	29-0	22-4	29-0
	#1 & Better	22-4	29-0	20-7	28-0	22-4	29-0	20-7	28-0	22-4	29-0	20-7	28-0
	#1	22-4	29-0	19-0	27-0	22-4	29-0	19-0	27-0	22-4	29-0	19-0	27-0
	#2	22-4	29-0	17-3	26-0	22-4	29-0	17-3	26-0	22-4	29-0	17-3	26-0
Spruce Pine-Fir	Sel. Str.	19-9	25-10	19-9	25-10	19-9	25-10	19-9	25-10	19-9	25-10	19-9	25-10
	#1	19-9	25-10	16-10	24-6	19-9	25-10	16-10	24-6	19-9	25-10	16-10	24-6
	#2	19-9	25-10	16-10	24-6	19-9	25-10	16-10	24-6	19-9	25-10	16-10	24-6
Hem-Fir	Sel. Str.	20-8	26-8	20-8	26-8	20-8	26-8	20-8	26-8	20-8	26-8	20-8	26-8
	#1	20-8	26-8	18-1	25-5	20-8	26-8	18-1	25-5	20-8	26-8	18-1	25-5
	#2	20-8	26-8	16-6	23-8	20-8	26-8	16-6	23-8	20-8	26-8	16-6	23-8

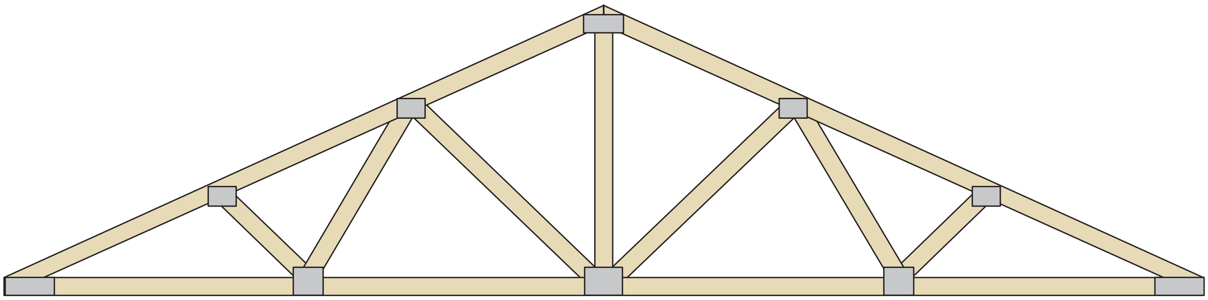
Fink Truss



Maximum Allowable (smallest of four figures) Span, feet-inches

		Pitch of Top Chord											
		3/12				4/12				5/12			
		Top Chord		Bottom Chord		Top Chord		Bottom Chord		Top Chord		Bottom Chord	
Species Group	Grade	2×4	2×6	2×4	2×6	2×4	2×6	2×4	2×6	2×4	2×6	2×4	2×6
Southern Pine	#1 Dense	27-7	40-11	30-10	40-11	30-7	42-0	31-11	42-0	31-11	42-0	31-11	42-0
	#1	26-10	39-11	29-7	40-9	29-9	42-0	30-8	40-9	31-1	42-0	30-8	40-9
	#2 Dense	26-6	39-1	26-6	37-10	29-4	42-0	29-10	40-7	30-7	42-0	29-10	40-7
	#2	25-5	37-5	25-0	35-4	28-2	41-5	27-10	39-1	29-5	42-0	27-10	39-1
Douglas Fir-Larch	Sel. Str.	28-2	41-10	33-2	41-10	31-4	43-2	33-2	43-2	32-8	43-2	33-2	43-2
	#1 & Better	26-8	39-7	30-2	41-9	29-7	43-2	30-6	41-9	30-10	43-2	30-6	41-9
	#1	25-8	38-1	27-5	39-1	28-6	42-2	28-3	40-3	29-8	43-2	28-3	40-3
	#2	24-6	36-4	24-10	35-1	27-3	40-3	25-7	38-8	28-5	41-10	25-7	38-8
Spruce Pine-Fir	Sel. Str.	26-0	38-5	29-0	38-5	29-0	38-5	29-4	38-5	29-4	38-5	29-4	38-5
	#1	23-8	34-11	21-4	29-8	26-5	38-5	24-7	34-5	27-7	38-5	25-0	36-5
	#2	23-8	34-11	21-4	29-8	26-5	38-5	24-7	34-5	27-7	38-5	25-0	36-5
Hem-Fir	Sel. Str.	26-11	39-9	30-9	39-9	30-0	39-9	30-9	39-9	30-0	39-9	30-9	39-9
	#1	24-9	36-7	25-10	36-5	27-6	39-9	26-10	37-11	28-9	39-9	26-10	37-11
	#2	23-8	34-10	23-0	32-5	26-3	38-7	24-5	35-2	27-5	39-9	24-5	35-2

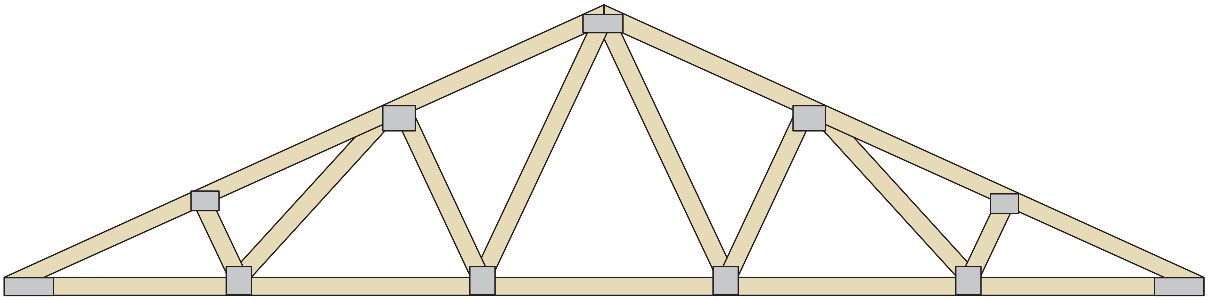
Modified Queen Post Truss



Maximum Allowable (smallest of four figures) Span, feet-inches

		Pitch of Top Chord											
		3/12				4/12				5/12			
		Top Chord		Bottom Chord		Top Chord		Bottom Chord		Top Chord		Bottom Chord	
Species Group	Grade	2×4	2×6	2×4	2×6	2×4	2×6	2×4	2×6	2×4	2×6	2×4	2×6
Southern Pine	#1 Dense	33-2	46-5	33-2	46-5	38-4	54-6	38-8	54-6	41-10	55-10	42-5	55-10
	#1	32-5	46-5	31-9	44-6	37-4	54-6	37-0	52-4	40-9	55-10	40-9	54-2
	#2 Dense	32-1	46-5	27-11	39-7	36-10	54-6	33-0	46-11	40-2	55-10	36-11	52-7
	#2	30-9	45-7	26-4	37-0	35-5	52-5	31-1	43-10	38-8	55-10	34-9	49-1
Douglas Fir-Larch	Sel. Str.	34-0	50-10	40-0	50-10	39-2	57-5	44-0	57-5	42-9	57-5	44-0	57-5
	#1 & Better	32-2	48-1	33-0	46-6	37-1	55-4	37-11	53-10	40-6	57-5	40-6	55-5
	#1	31-1	46-4	29-7	41-10	35-10	53-4	34-4	48-9	39-1	57-5	37-5	53-6
	#2	29-8	44-1	26-8	37-2	34-2	50-9	31-1	43-7	37-5	55-5	33-10	48-5
Spruce Pine-Fir	Sel. Str.	30-11	43-7	30-11	43-7	36-1	51-0	36-3	51-0	38-11	51-0	38-11	51-0
	#1	28-3	41-10	21-11	30-1	32-9	48-6	26-4	36-5	36-0	51-0	29-10	41-5
	#2	28-3	41-10	21-11	30-1	32-9	48-6	26-4	36-5	36-0	51-0	29-10	41-5
Hem-Fir	Sel. Str.	32-5	48-3	37-7	48-3	37-4	52-10	40-10	52-10	40-10	52-10	40-10	52-10
	#1	29-10	44-3	27-7	38-6	34-5	51-0	32-3	45-3	37-8	52-10	35-6	50-4
	#2	28-6	42-3	24-1	33-9	32-10	48-7	28-6	40-1	35-11	52-10	31-11	45-1

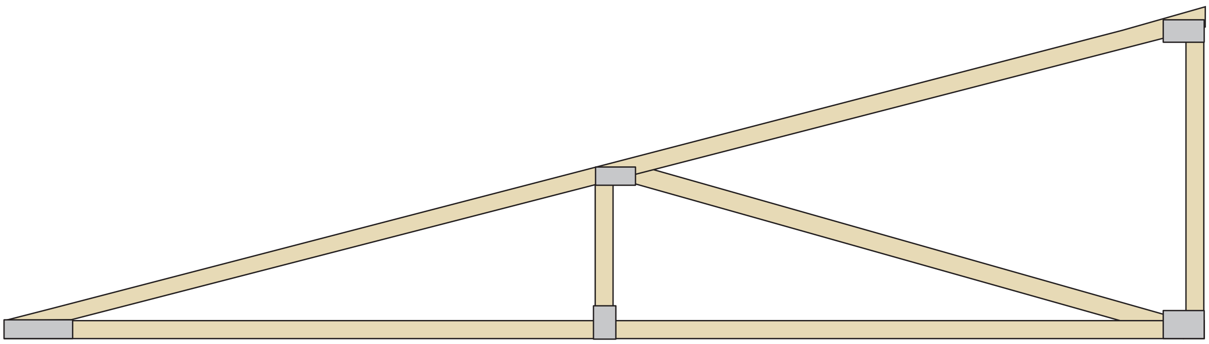
Double Fink Truss



Maximum Allowable (smallest of four figures) Span, feet-inches

		Pitch of Top Chord											
		3/12				4/12				5/12			
		Top Chord		Bottom Chord		Top Chord		Bottom Chord		Top Chord		Bottom Chord	
Species Group	Grade	2×4	2×6	2×4	2×6	2×4	2×6	2×4	2×6	2×4	2×6	2×4	2×6
Southern Pine	#1 Dense	33-3	49-3	35-5	49-3	38-3	57-0	42-4	57-0	41-8	60-0	47-9	60-0
	#1	32-4	48-4	33-11	47-1	37-2	55-7	40-7	56-10	40-7	60-0	45-9	60-0
	#2 Dense	31-11	47-6	29-5	41-7	36-9	54-6	35-9	50-7	40-1	59-4	40-9	57-10
	#2	30-7	45-5	27-9	38-11	35-3	52-3	33-8	47-3	38-6	56-11	38-5	54-0
Douglas Fir-Larch	Sel. Str.	33-11	50-8	43-9	50-8	39-0	58-2	50-11	58-2	42-7	60-0	54-11	60-0
	#1 & Better	32-1	47-11	35-7	49-11	36-11	55-1	42-0	58-2	40-4	60-0	46-11	60-0
	#1	31-0	46-2	31-9	44-7	35-8	53-1	37-9	53-4	39-0	57-11	42-5	60-0
	#2	29-6	43-11	28-4	39-3	34-1	50-7	34-0	47-4	37-3	55-3	38-4	53-8
Spruce Pine-Fir	Sel. Str.	31-1	46-1	32-10	46-1	35-11	53-6	39-6	53-6	39-3	58-4	44-9	58-4
	#1	28-1	41-8	22-10	31-1	32-7	48-4	28-1	38-6	35-10	53-0	32-5	44-8
	#2	28-1	41-8	22-10	31-1	32-7	48-4	28-1	38-6	35-10	53-0	32-5	44-8
Hem-Fir	Sel. Str.	32-3	48-1	40-10	48-1	37-2	55-4	47-11	55-4	40-8	60-0	50-10	60-0
	#1	29-8	44-1	29-4	40-9	34-3	50-10	35-3	49-1	37-6	55-6	39-9	55-9
	#2	28-4	42-1	25-5	35-4	32-9	48-5	30-10	43-0	35-10	52-11	35-2	49-4

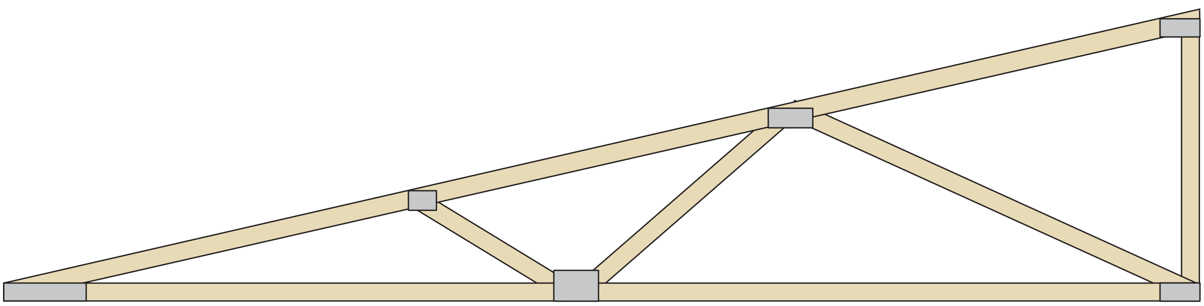
Mono Truss



Maximum Allowable (smallest of four figures) Span, feet-inches

		Pitch of Top Chord											
		3/12				4/12				5/12			
		Top Chord		Bottom Chord		Top Chord		Bottom Chord		Top Chord		Bottom Chord	
Species Group	Grade	2×4	2×6	2×4	2×6	2×4	2×6	2×4	2×6	2×4	2×6	2×4	2×6
Southern Pine	#1 Dense	16-0	23-5	21-6	23-5	16-6	24-1	21-6	24-1	16-10	24-6	21-6	24-6
	#1	15-6	22-11	20-8	23-5	16-0	23-7	20-8	24-1	16-3	23-11	20-8	24-6
	#2 Dense	15-2	22-1	20-1	23-5	15-7	22-8	20-1	24-1	15-10	23-0	20-1	24-6
	#2	14-6	21-0	18-9	23-5	14-11	21-6	18-9	24-1	15-1	21-9	18-9	24-6
Douglas Fir-Larch	Sel. Str.	16-5	24-1	22-4	24-1	17-0	24-9	22-4	24-9	17-4	25-3	22-4	25-3
	#1 & Better	15-3	22-5	20-7	24-1	15-9	23-0	20-7	24-9	16-0	23-4	20-7	25-3
	#1	14-7	21-4	19-0	24-1	15-0	21-10	19-0	24-9	15-2	22-2	19-0	25-3
	#2	13-10	20-3	17-3	24-1	14-2	20-8	17-3	24-9	14-5	20-11	17-3	25-3
Spruce-Pine-Fir	Sel. Str.	15-4	22-4	19-9	22-4	15-10	23-1	19-9	23-1	16-1	23-6	19-9	23-6
	#1	13-8	19-11	16-10	22-4	14-0	20-4	16-10	23-1	14-3	20-8	16-10	23-6
	#2	13-8	19-11	16-10	22-4	14-0	20-4	16-10	23-1	14-3	20-8	16-10	23-6
Hem-Fir	Sel. Str.	15-11	23-3	20-8	23-3	16-6	24-0	20-8	24-0	16-10	24-6	20-8	24-6
	#1	14-2	20-8	18-1	23-3	14-7	21-2	18-1	24-0	14-10	21-6	18-1	24-6
	#2	13-6	19-8	16-6	23-3	13-10	20-1	16-6	23-8	14-1	20-5	16-6	23-8

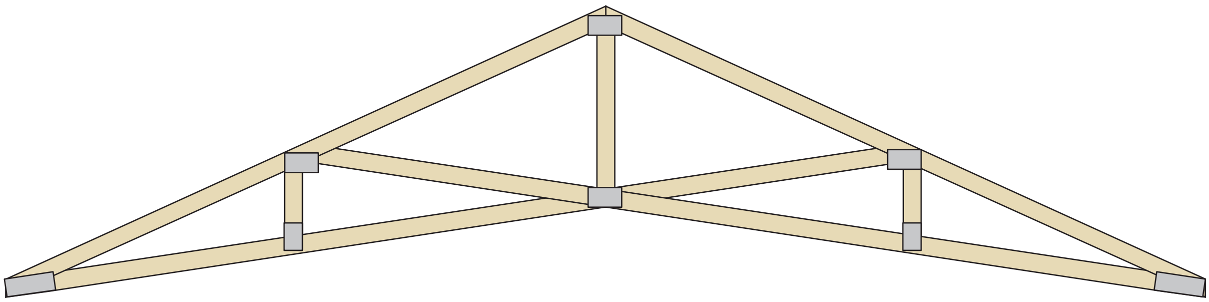
Mono Truss



Maximum Allowable (smallest of four figures) Span, feet-inches

		Pitch of Top Chord											
		3/12				4/12				5/12			
		Top Chord		Bottom Chord		Top Chord		Bottom Chord		Top Chord		Bottom Chord	
Species Group	Grade	2×4	2×6	2×4	2×6	2×4	2×6	2×4	2×6	2×4	2×6	2×4	2×6
Southern Pine	#1 Dense	21-6	28-2	21-6	28-2	21-6	28-2	21-6	28-2	21-6	28-2	21-6	28-2
	#1	21-6	28-2	20-8	27-5	21-6	28-2	20-8	27-5	21-6	28-2	20-8	27-5
	#2 Dense	21-6	28-2	20-1	27-3	21-6	28-2	20-1	27-3	21-6	28-2	20-1	27-3
	#2	21-3	28-2	18-9	26-3	21-6	28-2	18-9	26-3	21-6	28-2	18-9	26-3
Douglas Fir-Larch	Sel. Str.	22-4	29-0	22-4	29-0	22-4	29-0	22-4	29-0	22-4	29-0	22-4	29-0
	#1 & Better	22-4	29-0	20-7	28-0	22-4	29-0	20-7	28-0	22-4	29-0	20-7	28-0
	#1	21-5	29-0	19-0	27-0	22-4	29-0	19-0	27-0	22-4	29-0	19-0	27-0
	#2	20-6	29-0	17-3	26-0	22-4	29-0	17-3	26-0	22-4	29-0	17-3	26-0
Spruce-Pine-Fir	Sel. Str.	19-9	25-10	19-9	25-10	19-9	25-10	19-9	25-10	19-9	25-10	19-9	25-10
	#1	19-9	25-10	16-10	24-6	19-9	25-10	16-10	24-6	19-9	25-10	16-10	24-6
	#2	19-9	25-10	16-10	24-6	19-9	25-10	16-10	24-6	19-9	25-10	16-10	24-6
Hem-Fir	Sel. Str.	20-8	26-8	20-8	26-8	20-8	26-8	20-8	26-8	20-8	26-8	20-8	26-8
	#1	20-8	26-8	18-1	25-5	20-8	26-8	18-1	25-5	20-8	26-8	18-1	25-5
	#2	19-10	22-1	16-6	23-8	20-8	26-8	16-6	23-8	20-8	26-8	16-6	23-8

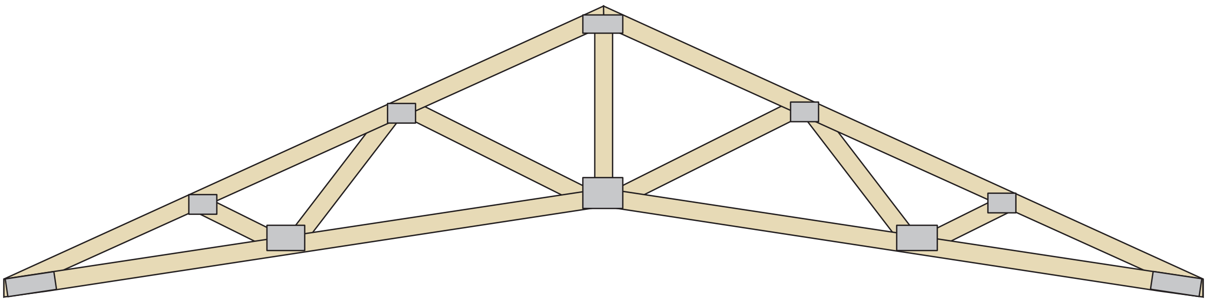
Howe Scissors Truss



Maximum Allowable (smallest of four figures) Span, feet-inches

		Pitch of Top Chord											
		3/12				4/12				5/12			
		Top Chord		Bottom Chord		Top Chord		Bottom Chord		Top Chord		Bottom Chord	
Species Group	Grade	2×4	2×6	2×4	2×6	2×4	2×6	2×4	2×6	2×4	2×6	2×4	2×6
Southern Pine	#1 Dense	20-2	30-0	21-8	30-0	22-5	33-5	26-7	33-5	24-1	35-11	30-8	35-11
	#1	19-7	29-4	20-8	28-7	21-10	32-7	25-5	33-5	23-6	35-0	29-4	35-11
	#2 Dense	19-4	28-10	17-9	25-1	21-6	32-0	22-0	31-2	23-2	34-4	25-7	35-11
	#2	18-6	27-7	16-9	23-6	20-8	30-8	20-9	29-2	22-3	32-11	24-2	34-0
Douglas Fir-Larch	Sel. Str.	20-6	30-8	27-8	30-8	22-10	34-1	33-2	34-1	24-7	36-8	36-6	36-8
	#1 & Better	19-5	29-0	22-1	30-8	21-8	32-4	26-10	34-1	23-4	34-9	30-8	36-8
	#1	18-9	28-0	19-6	27-4	20-11	31-2	23-11	33-8	22-7	33-6	27-5	36-8
	#2	17-10	26-8	17-4	23-11	20-0	29-9	21-4	29-6	21-7	32-0	24-7	34-3
Spruce-Pine-Fir	Sel. Str.	18-9	27-11	19-11	27-11	21-0	31-4	24-7	31-4	22-8	33-9	28-6	33-9
	#1	16-11	25-3	13-7	18-8	19-1	28-4	17-0	23-2	20-8	30-8	19-11	27-5
	#2	16-11	25-3	13-7	18-8	19-1	28-4	17-0	23-2	20-8	30-8	19-11	27-5
Hem-Fir	Sel. Str.	19-6	29-1	25-6	29-1	21-9	32-5	30-10	32-5	23-6	34-11	34-9	34-11
	#1	17-11	26-9	17-11	24-9	20-1	29-10	22-1	30-7	21-8	32-2	25-5	34-11
	#2	17-2	25-6	15-4	21-4	19-2	28-5	19-0	26-5	20-9	30-7	22-1	30-11

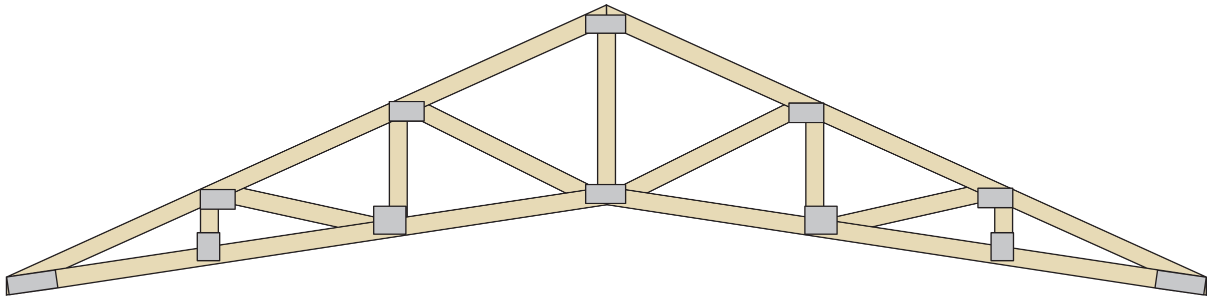
Queen Scissors Truss



Maximum Allowable (smallest of four figures) Span, feet-inches

		Pitch of Top Chord											
		3/12				4/12				5/12			
		Top Chord		Bottom Chord		Top Chord		Bottom Chord		Top Chord		Bottom Chord	
Species Group	Grade	2×4	2×6	2×4	2×6	2×4	2×6	2×4	2×6	2×4	2×6	2×4	2×6
Southern Pine	#1 Dense	20-5	28-5	20-5	28-5	25-2	35-1	25-2	35-1	28-6	40-8	29-1	40-8
	#1	20-5	28-5	19-7	27-1	25-1	35-1	24-1	33-6	27-8	40-8	27-10	38-11
	#2 Dense	20-5	28-5	16-9	23-10	24-10	35-1	20-9	29-5	27-5	40-8	24-3	34-5
	#2	20-5	28-5	15-10	22-4	23-9	35-1	19-7	27-6	26-3	39-1	22-10	32-2
Douglas Fir-Larch	Sel. Str.	22-11	34-5	26-2	34-5	26-4	39-6	31-7	39-6	29-0	43-5	35-10	43-5
	#1 & Better	21-7	32-5	20-10	29-2	24-10	37-3	25-5	35-9	27-5	41-1	29-2	41-1
	#1	20-10	31-4	18-5	25-11	24-1	36-0	22-8	31-10	26-7	39-9	26-1	36-10
	#2	19-9	29-7	16-5	22-9	22-10	34-2	20-2	27-11	25-4	37-9	23-4	32-6
Spruce-Pine-Fir	Sel. Str.	18-10	26-5	18-10	26-5	23-3	32-8	23-3	32-8	26-7	38-1	27-0	38-1
	#1	18-5	26-5	12-11	17-9	21-6	32-1	16-0	21-10	24-0	35-8	18-10	25-10
	#2	18-5	26-5	12-11	17-9	21-6	32-1	16-0	21-10	24-0	35-8	18-10	25-10
Hem-Fir	Sel. Str.	21-7	32-6	24-1	32-6	24-11	37-4	29-3	37-4	27-6	41-2	33-6	41-2
	#1	19-10	29-8	16-11	23-6	22-11	34-3	20-10	28-11	25-5	37-10	24-2	33-8
	#2	19-0	28-5	14-6	20-3	22-0	32-9	17-11	24-11	24-4	36-1	20-11	29-3

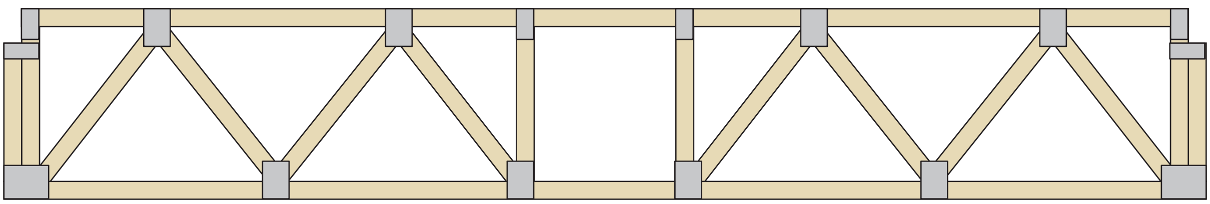
Double Howe Scissors Truss



Maximum Allowable (smallest of four figures) Span, feet-inches

		Pitch of Top Chord											
		3/12				4/12				5/12			
		Top Chord		Bottom Chord		Top Chord		Bottom Chord		Top Chord		Bottom Chord	
Species Group	Grade	2×4	2×6	2×4	2×6	2×4	2×6	2×4	2×6	2×4	2×6	2×4	2×6
Southern Pine	#1 Dense	20-11	29-0	20-11	29-0	25-9	36-6	26-6	36-6	28-4	42-4	31-6	42-4
	#1	20-11	29-0	20-0	27-7	24-11	36-6	25-4	34-9	27-6	41-2	30-1	41-6
	#2 Dense	20-11	29-0	17-0	24-2	24-8	36-6	21-6	30-4	27-2	40-7	25-9	36-3
	#2	20-5	29-0	16-1	22-8	23-7	35-3	20-3	28-5	26-1	38-10	24-3	33-11
Douglas Fir-Larch	Sel. Str.	22-9	34-2	27-5	34-2	26-2	39-3	34-4	39-3	28-10	43-2	40-4	43-2
	#1 & Better	21-5	32-2	21-6	30-0	24-8	37-0	27-2	37-8	27-3	40-10	32-1	43-2
	#1	20-9	31-1	18-11	26-7	23-11	35-9	23-11	33-4	26-5	39-5	28-4	39-9
	#2	19-7	29-5	16-9	23-2	22-8	33-11	21-2	29-0	25-2	37-6	25-2	34-7
Spruce-Pine-Fir	Sel. Str.	19-2	26-11	19-2	26-11	23-10	33-10	24-3	33-10	26-4	39-6	28-11	39-6
	#1	18-3	26-11	13-0	17-11	21-4	31-10	16-4	22-3	23-10	35-5	19-7	26-7
	#2	18-3	26-11	13-0	17-11	21-4	31-10	16-4	22-3	23-10	35-5	19-7	26-7
Hem-Fir	Sel. Str.	21-5	32-3	25-0	32-3	24-9	37-1	31-6	37-1	27-4	40-10	37-2	40-10
	#1	19-8	29-6	17-3	23-11	22-9	34-0	21-10	30-0	25-3	37-7	26-0	35-10
	#2	18-10	28-2	14-8	20-6	21-10	32-6	18-6	25-8	24-2	35-10	22-2	30-8

Floor Truss, 24 inches On-Center



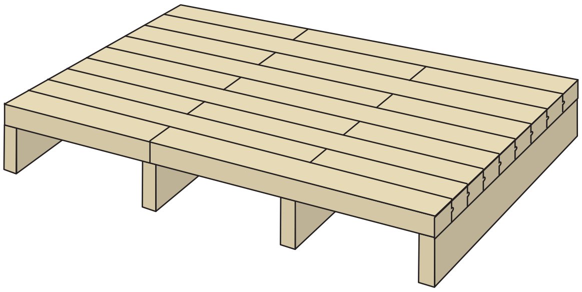
Maximum Allowable Span, feet-inches

Species Group	Grade	16" Deep Top Chord	16" Deep Bottom Chord	20" Deep Top Chord	20" Deep Bottom Chord	24" Deep Top Chord	24" Deep Bottom Chord
Top chord: 40 psf live, 5 psf dead — Bottom chord: 0 psf live, 5 psf dead							
Southern Pine	#1 Dense	20-5	22-4	29-2	25-3	34-0	28-0
	#1	24-9	22-0	28-9	24-6	33-0	27-0
	#2	24-0	19-1	28-3	21-3	31-2	24-0
Douglas Fir-Larch	Sel. Str.	26-8	26-6	31-6	30-0	36-0	33-0
	#1	25-6	21-4	28-8	24-3	31-8	26-6
	#2	23-6	19-6	26-8	22-2	29-6	24-3
Spruce-Pine-Fir	Sel. Str.	24-0	21-3	29-0	24-1	32-0	26-9
	#1	21-0	16-9	24-1	18-9	27-0	20-8
	#2	21-0	16-9	24-1	18-9	27-0	20-8
Hem-Fir	Sel. Str.	25-0	25-0	29-6	28-2	33-8	31-2
	#1	24-3	20-0	27-4	22-7	30-3	25-0
	#2	23-0	18-0	26-0	20-5	28-8	22-8
Top chord: 40 psf live, 10 psf dead — Bottom chord: 0 psf live, 10 psf dead							
Southern Pine	#1 Dense	24-0	19-6	28-0	22-0	30-9	24-4
	#1	23-6	18-9	27-6	20-9	30-0	23-6
	#2	22-4	16-4	25-4	18-4	28-0	20-4
Douglas Fir-Larch	Sel. Str.	26-0	23-0	29-4	26-2	32-4	29-0
	#1	23-0	18-4	25-8	20-6	28-4	23-0
	#2	21-0	16-8	24-0	18-9	26-3	20-9
Spruce-Pine-Fir	Sel. Str.	23-0	18-8	26-0	21-0	29-0	23-4
	#1	19-2	14-3	22-0	16-1	24-1	17-9
	#2	19-2	14-3	22-0	16-1	24-1	17-9
Hem-Fir	Sel. Str.	24-3	22-0	27-4	24-9	30-3	27-4
	#1	21-9	17-0	24-6	19-4	27-0	21-4
	#2	20-7	15-3	23-2	17-3	25-8	19-2

Plank Floors and Roofs

Plank floors and roofs are used in plank-and-beam and post-and-beam constructions. The tables below are for tongue-and-groove planks applied in the alternating two-span style, as shown. Note that two spans are shown in each table:

- limited by fiber stress in tension, F_b
- limited by deflection (modulus of elasticity, E)



Floor: 40 PSF Live Load, Deflection Ratio 1/360, feet-inches

Thickness, inches		Dead Load	F_b, psi				E, 10^6 psi		
Nominal	(Actual)	psf	900	1,200	1,500	1,800	1.0	1.2	1.4
1	(3/4)	5	3-10	4-6	5-0	5-6	2-9	2-11	3-1
2	(1 1/2)	7	7-7	8-9	9-9	10-8	5-6	5-10	6-2
3	(2 1/2)	12	12-0	13-10	15-6	16-11	9-2	9-9	10-3
4	(3 1/2)	15	16-4	18-10	21-1	23-1	12-10	13-8	14-5
6	(5 1/2)	20	24-7	28-5	31-9	34-9	20-4	21-8	22-9

Roof: 20 PSF Live Load, Deflection Ratio 1/180, feet-inches

Thickness, inches		Dead Load	F_b, psi				E, 10^6 psi		
Nominal	(Actual)	psf	900	1,200	1,500	1,800	1.0	1.2	1.4
1	(3/4)	7	5-0	5-9	6-5	7-1	4-4	4-8	4-11
2	(1 1/2)	10	9-6	10-11	12-3	13-5	8-9	9-4	9-9
3	(2 1/2)	15	14-7	16-10	18-10	20-8	14-7	15-6	16-4
4	(3 1/2)	20	19-2	22-2	24-9	27-1	20-5	21-8	22-10
6	(5 1/2)	25	28-5	32-9	36-8	40-2	32-4	34-4	36-2

Roof: 40 PSF Live and Snow Load, Deflection Ratio 1/180, feet-inches

Thickness, inches		Dead Load	F_b, psi				E, 10^6 psi		
Nominal	(Actual)	psf	900	1,200	1,500	1,800	1.0	1.2	1.4
1	(3/4)	7	3-9	4-4	4-10	5-4	3-5	3-8	3-10
2	(1 1/2)	10	7-4	8-5	9-5	10-4	6-11	7-4	7-9
3	(2 1/2)	15	11-8	13-5	15-1	16-6	11-7	12-4	12-11
4	(3 1/2)	20	15-7	18-1	20-2	22-2	16-3	17-3	18-2
6	(5 1/2)	25	23-7	27-3	30-6	33-5	25-8	27-3	28-8

Glulam Beams

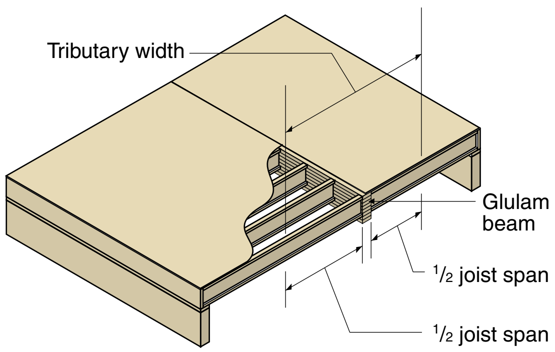
Pound for pound, APA-EWS glulam beams are stronger than steel, and they are attractive enough to leave exposed.

The table below provides glulam floor-beam sizes in I-joist-compatible sizes for the 24F-1.8E stress classification.

The table on the facing page provides the more extensive range of sizes available when I-joist compatibility is not a factor.

Details for incorporating glulam beams into floor framing are shown on pp. 174–175.

Load on a Glulam Beam



24F–1.8E I-Joist-Compatible (IJC) Floor Beams for Simple-Span or Multiple-Span Applications

	Tributary Width, ft						
Span, ft	8	10	12	14	16	18	20
8	3½×9½	3½×9½	3½×9½	3½×9½	3½×9½	3½×11⅞	3½×11⅞
	5½×9½	5½×9½	5½×9½	5½×9½	5½×9½	5½×9½	5½×9½
10	3½×9½	3½×9½	3½×11⅞	3½×11⅞	3½×11⅞	3½×14	3½×14$_2$
	5½×9½	5½×9½	5½×9½	5½×9½	5½×9½	5½×11⅞	5½×11⅞
12	3½×11⅞	3½×11⅞	3½×14	3½×14	3½×14	3½×16	3½×16
	5½×9½	5½×9½	5½×11⅞	5½×11⅞	5½×11⅞	5½×11⅞	5½×14
14	3½×11⅞	3½×14	3½×14	3½×16	3½×16	3½×18	3½×18
	5½×9½	5½×11⅞	5½×11⅞	5½×14	5½×14	5½×14	5½×16
16	3½×14	3½×16	3½×16	3½×18	5½×16	5½×16	5½×18
	5½×11⅞	5½×11⅞	5½×14	5½×14	7×14	7×14	7×16
18	3½×16	3½×18	3½×18	5½×16	5½×18	5½×18	7×18
	5½×11⅞	5½×14	5½×16	7×14	7×16	7×16	—
× × 18	7×18	—					
	5½×14	7×14	7×16	7×16	—	—	—
22	3½×18	5½×18	5½×18	7×18	—	—	—
	5½×16	7×16	7×16	—	—	—	—
24	5½×16	5½×18	7×18$_2$	—	—	—	—
	7×16	7×16	—	—	—	—	—

- Applicable to simple-span or multiple-span applications with a dead load of 10 psf and live load of 40 psf.
- For multiple-span applications, the end spans shall be 40% or more of the adjacent span.
- Service condition = dry.
- Maximum deflection = span/360 under live load.
- F_{bx} = 2,400 psi when tension zone is stressed in tension or 1,600 psi when compression zone is stressed in tension; F_{vx} = 195 psi; $E_x = 1.8 \times 10^6$ psi.
- Beam weight = 36 pcf.
- IJC refers to commonly available residential I-joist depths of 9½, 11⅞, 14, and 16 inches.

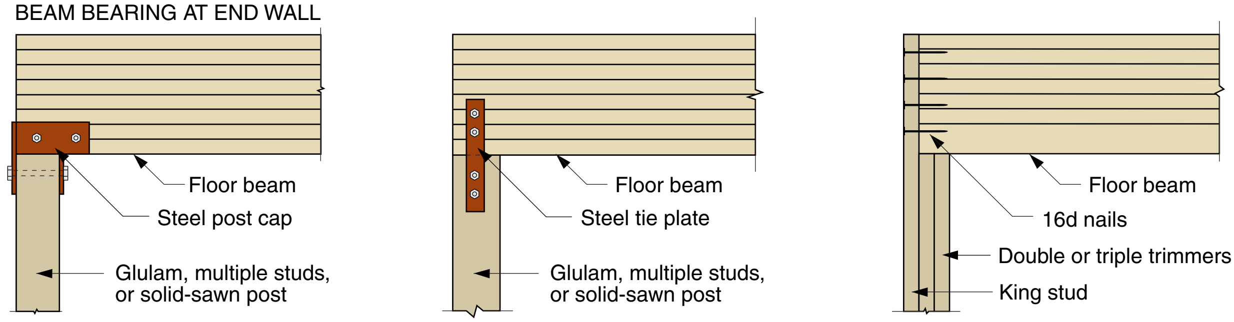
24F–1.8E Floor Beams for Simple-Span or Multiple-Span Applications

Span, ft	Tributary Width, ft						
	8	10	12	14	16	18	20
8	3 1/8×7 1/2	3 1/8×9	3 1/8×9	3 1/8×10 1/2	3 1/8×10 1/2	3 1/8×10 1/2	3 1/8×12
	3 1/2×7 1/2	3 1/2×7 1/2	3 1/2×9	3 1/2×9	3 1/2×10 1/2	3 1/2×10 1/2	3 1/2×10 1/2
	5 1/8×6	5 1/8×7 1/2	5 1/8×7 1/2	5 1/8×7 1/2	5 1/8×9	5 1/8×9	5 1/8× 9
	5 1/2×6	5 1/2×6	6 3/4×6	5 1/2×7 1/2	5 1/2×7 1/2	5 1/2×9	5 1/2×9
10	3 1/8×9	3 1/8×10 1/2	3 1/8×12	3 1/8×12	3 1/8×3 1/2	3 1/8×13 1/2	3 1/8×15
	3 1/2×9	3 1/2×10 1/2	3 1/2×10 1/2	3 1/2×12	3 1/2×12	3 1/2×13 1/2	3 1/2×13 1/2
	5 1/8×7 1/2	5 1/8×9	5 1/8×9	5 1/8×9	5 1/8×10 1/2	5 1/8×10 1/2	5 1/8×12
	5 1/2×7 1/2	5 1/2×7 1/2	5 1/2×9	5 1/2×9	5 1/2×10 1/2	5 1/2×10 1/2	5 1/2×10 1/2
12	3 1/8×10 1/2	3 1/8×12	3 1/8×13 1/2	3 1/8×15	3 1/8×15	3 1/8×16 1/2	3 1/8×18
	3 1/2×10 1/2	3 1/2×12	3 1/2×12	3 1/2×13 1/2	3 1/2×15	3 1/2×15	3 1/2×16 1/2
	5 1/8×9	5 1/8×10 1/2	5 1/8×10 1/2	5 1/8×12	5 1/8×12	5 1/8×13 1/2	5 1/8×13 1/2
	5 1/2×9	5 1/2×9	5 1/2×10 1/2	5 1/2×10 1/2	5 1/2×12	5 1/2×12	5 1/2×13 1/2
14	3 1/8×13 1/2	3 1/8×15	3 1/8×15	3 1/8×16 1/2	3 1/8×18	3 1/8×19 1/2	3 1/8×19 1/2
	3 1/2×12	3 1/2×13 1/2	3 1/2×15	3 1/2×15	3 1/2×16 1/2	3 1/2×18	3 1/2×18
	5 1/8×10 1/2	5 1/8×12	5 1/8×12	5 1/8×13 1/2	5 1/8×13 1/2	5 1/8×15	5 1/8×15
	5 1/2×10 1/2	5 1/2×10 1/2	5 1/2×12	5 1/2×12	5 1/2×13 1/2	5 1/2×15	5 1/2×15
16	3 1/8×15	3 1/8×16 1/2	3 1/8×18	3 1/8×13 1/2	3 1/8×21	3 1/8×21	3 1/8×18
	3 1/2×13 1/2	3 1/2×15	3 1/2×16 1/2	3 1/2×18	3 1/2×19 1/2	3 1/2×19 1/2	3 1/2×21
	5 1/8×12	5 1/8×13 1/2	5 1/8×13 1/2	5 1/8×15	5 1/8×16 1/2	5 1/8×16 1/2	5 1/8×15
	5 1/2×10 1/2	5 1/2×12	5 1/2×13 1/2	5 1/2×15	5 1/2×15	5 1/2×16 1/2	5 1/2×16 1/2
18	3 1/8×16 1/2	3 1/8×18	3 1/8×19 1/2	3 1/8×21	3 1/8×18	3 1/8×19 1/2	3 1/8×19 1/2
	3 1/2×15	3 1/2×16 1/2	3 1/2×18	3 1/2×19 1/2	3 1/2×21	3 1/2×22 1/2	3 1/2×24
	5 1/8×13 1/2	5 1/8×15	5 1/8×16 1/2	5 1/8×16 1/2	5 1/8×15	5 1/8×16 1/2	5 1/8×18
	5 1/2×12	5 1/2×13 1/2	5 1/2×15	5 1/2×16 1/2	5 1/2×18	5 1/2×18	5 1/2×19 1/2
20	3 1/8×18	3 1/8×21	3 1/8×18	3 1/8×19 1/2	3 1/8×19 1/2	3 1/8×21	3 1/8×22 1/2
	3 1/2×16 1/2	3 1/2×19 1/2	3 1/2×21	3 1/2×22 1/2	3 1/2×24	3 1/2×19 1/2	3 1/2×21
	5 1/8×15	5 1/8×16 1/2	5 1/8×15	5 1/8×16 1/2	5 1/8×18	5 1/8×18	5 1/8×19 1/2
	5 1/2×13 1/2	5 1/2×15	5 1/2×16 1/2	5 1/2×18	5 1/2×19 1/2	5 1/2×18	5 1/2×19 1/2
22	3 1/8×19 1/2	3 1/8×18	3 1/8×19 1/2	3 1/8×21	3 1/8×22 1/2	3 1/8×22 1/2	3 1/8×24
	3 1/2×18	3 1/2×21	3 1/2×22 1/2	3 1/2×24	3 1/2×21	3 1/2×22 1/2	3 1/2×24
	5 1/8×6 1/2	5 1/8×15	5 1/8×16 1/2	5 1/8×18	5 1/8×19 1/2	5 1/8×21	5 1/8×21
	5 1/2×15	5 1/2×16 1/2	5 1/2×18	5 1/2×19 1/2	5 1/2×19 1/2	5 1/2×21	5 1/2×21
24	5 1/8×18	5 1/8×19 1/2	5 1/8×21	5 1/8×22 1/2	5 1/8×24	5 1/8×25 1/2	5 1/8×27
	3 1/2×21	3 1/2×22 1/2	3 1/2×24	5 1/2×21	5 1/2×22 1/2	5 1/2×24	5 1/2×25 1/2
	6 3/4×15	6 3/4×16 1/2	6 3/4×18	6 3/4×19 1/2	6 3/4×21	6 3/4×22 1/2	6 3/4×24
	5 1/2×16 1/2	5 1/2×18	5 1/2×19 1/2	6 3/4×19 1/2	6 3/4×21	6 3/4×22 1/2	6 3/4×24

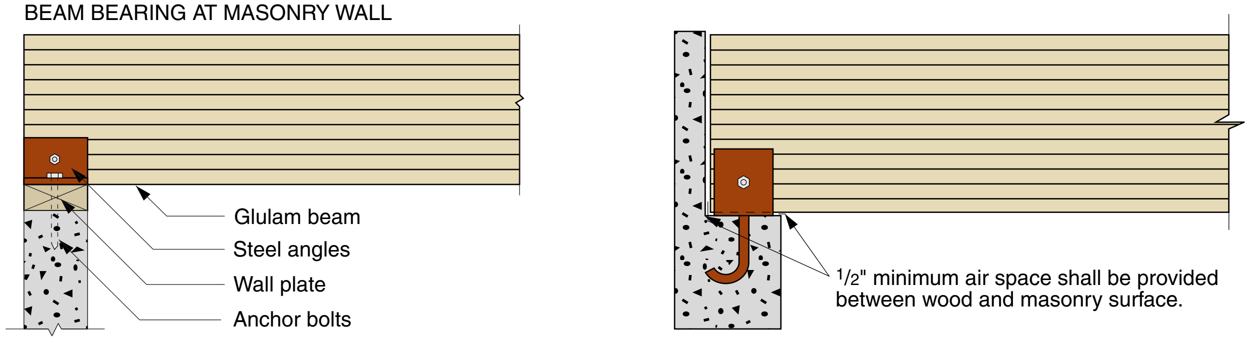
- Applicable to simple-span or multiple-span applications with a dead load of 10 psf and live load of 40 psf.
- For multiple-span applications, the end spans shall be 40% or more of the adjacent span.
- Service condition = dry.
- Maximum deflection = span/360 under live load.
- F_{bx} = 2,400 psi when tension zone is stressed in tension or 1,600 psi when compression zone is stressed in tension; F_{vx} = 215 psi; $E_x = 1.8 \times 10^6$ psi.
- Beam weight = 36 pcf.
- Beam widths of 3 and 5 inches may be substituted for 3 1/8 and 5 1/8 inches, respectively, at the same tabulated depth.

Floor Framing Details

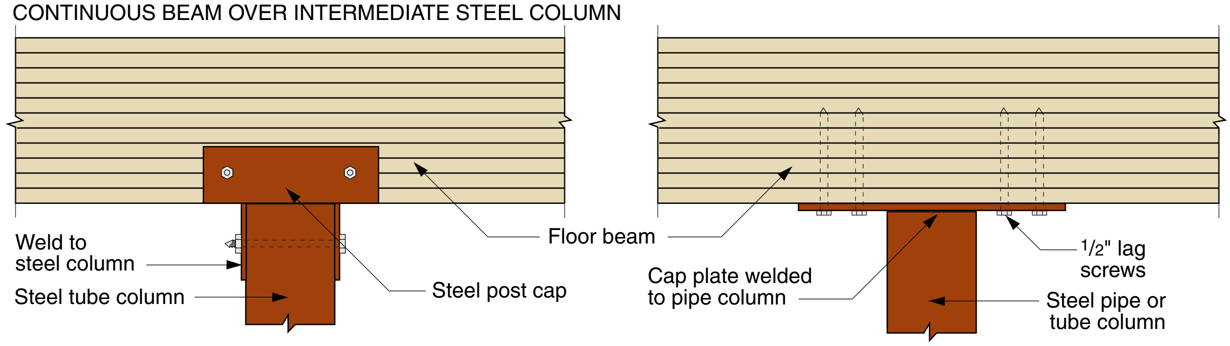
BEAM BEARING AT END WALL



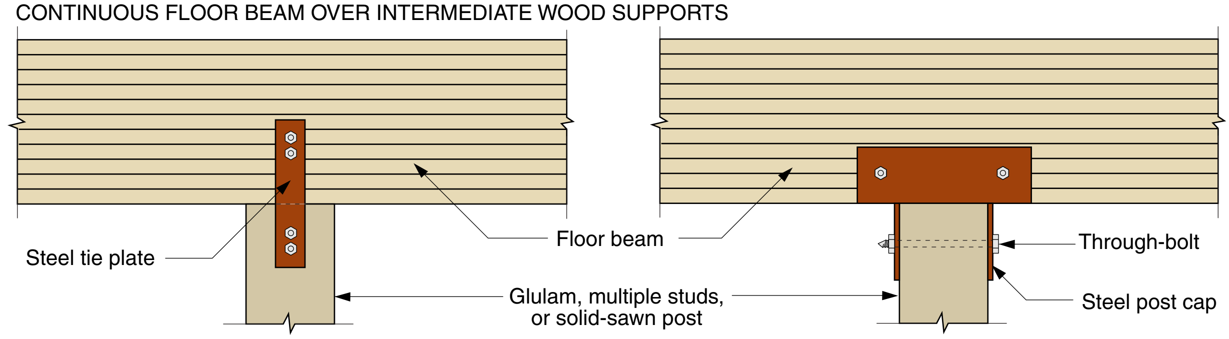
BEAM BEARING AT MASONRY WALL



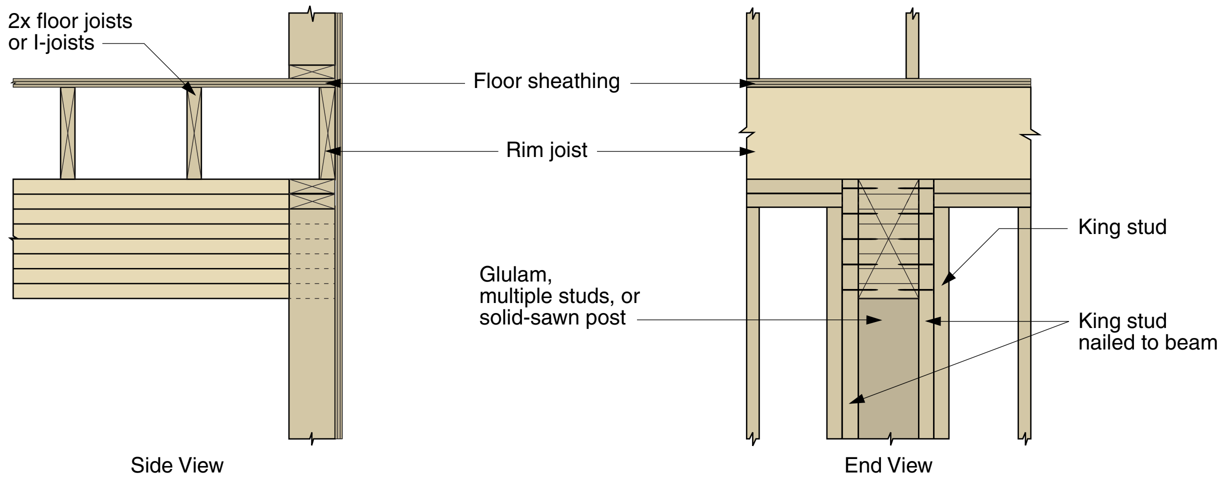
CONTINUOUS BEAM OVER INTERMEDIATE STEEL COLUMN



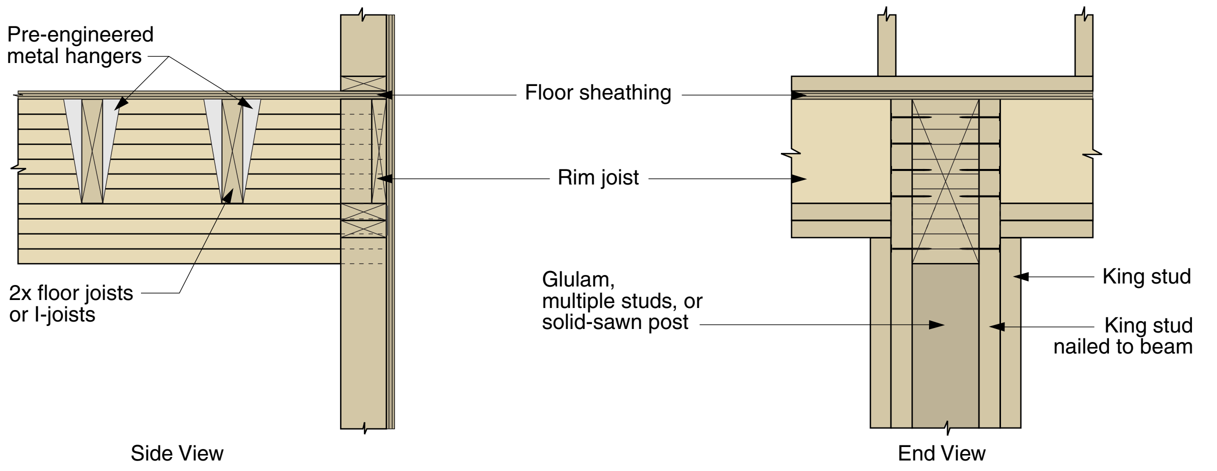
CONTINUOUS FLOOR BEAM OVER INTERMEDIATE WOOD SUPPORTS



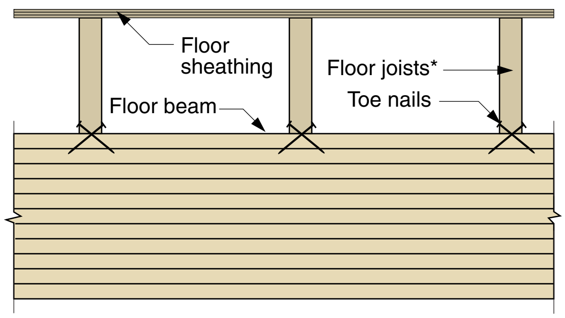
BEAM SUPPORT AT END WALL WITH FLOOR JOIST OVER BEAM



BEAM SUPPORT AT END WALL WITH FLOOR JOISTS FLUSH WITH BEAM

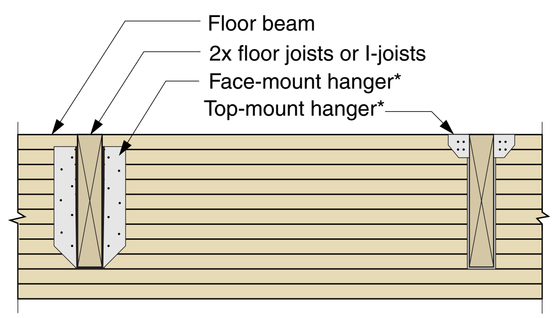


LUMBER JOISTS BEARING ON FLOOR BEAM



*Blocking between joists not shown for clarity

JOISTS MOUNTED FLUSH WITH FLOOR BEAM



*Mixed hanger types are for illustration purpose only.

Panel and Lumber Beams (Box Beams)

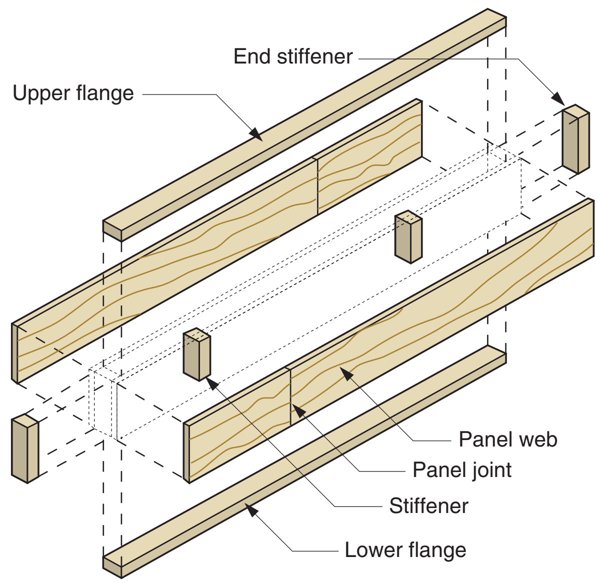
When roof load or span requirements are too great to allow use of commonly available dimension lumber or timbers, panel and lumber beams ("box beams") constructed of 2×4 and 2×6 lumber and APA-trademark structural-use panels can solve the problem. They offer inexpensive alternatives to steel or glued laminated wood beams.

The table shows the allowable loads on beams, in pounds per linear foot, as functions of beam cross section and span.

The lumber is assumed to be No. 1 Douglas-fir or No. 1 southern pine, except No. 2 grades may be substituted if the table loads are reduced by 15%.

The structural panels are assumed to be APA rated sheathing Exposure I, oriented strand board (OSC), composite panels (COM-PLY®), or 4- or 5-ply plywood.

Panel and Lumber Beam Components



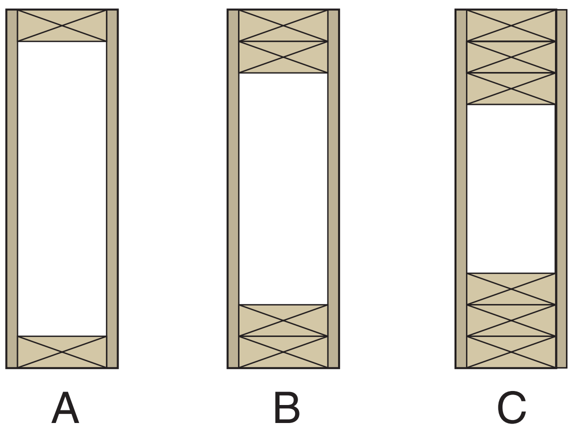
Allowable Loads[1] for Panel and Lumber Beams

Panel	Section	Lb/linear foot 2×4	Lb/linear foot 2×6	Span, feet 10	12	14	16	18	20	22	24
12-INCH-DEEP ROOF BEAM OR HEADER											
15/32" 32/16	A	6	8	278[2]	232[2]	192	147	116	94	78	64
15/32" 32/16	B	9	12	339[2]	283[2]	242[2]	212	176	143	118	91
23/32" 48/24	B	11	14	408[2]	340	291	223	176	143	118	95
23/32" 48/24	C	13	17	–	–	–	234	198	160	133	105
16-INCH-DEEP ROOF BEAM OR HEADER											
15/32" 32/16	A	8	10	393[2]	328[2]	274	210	166	134	111	93
15/32" 32/16	B	10	13	475[2]	396[2]	340[2]	297	264	219	181	152
23/32" 48/24	B	13	16	569[2]	474[2]	406	342	270	219	181	152
23/32" 48/24	C	15	19	–	–	–	–	295	266	219	184
20-INCH-DEEP ROOF BEAM OR HEADER											
15/32" 32/16	A	9	11	515[2]	429[2]	357	273	216	175	144	121
15/32" 32/16	B	12	15	610[2]	509[2]	436[2]	381[2]	339[2]	297	246	207
23/32" 48/24	B	15	18	728[2]	607[2]	520[2]	455[2]	367	297	246	207
23/32" 48/24	C	17	22	–	–	–	–	385[2]	346	312	262
24-INCH-DEEP ROOF BEAM OR HEADER											
15/32" 32/16	A	11	13	643[2]	536[2]	439	336	266	215	178	149
15/32" 32/16	B	13	16	744[2]	620[2]	531[2]	465[2]	413	372	312	262
23/32" 48/24	B	16	20	885[2]	738[2]	632[2]	553	465	377	312	262
23/32" 48/24	C	18	24	–	–	–	–	474[2]	427	388	342

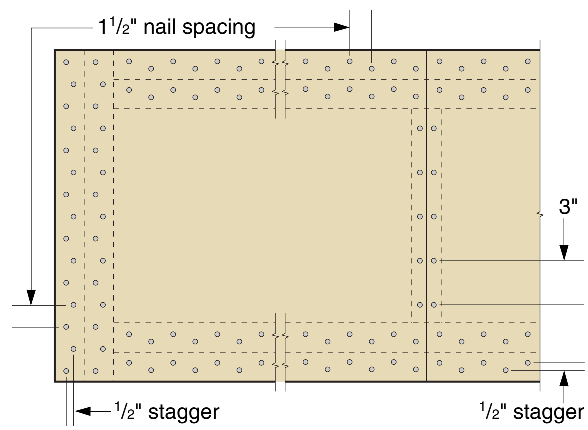
1. Includes 15% snow-loading increase.

2. Lumber may be No. 2 Douglas-fir or No. 2 southern pine without reduction of tabulated capacity.

Cross Sections (see table column 1)



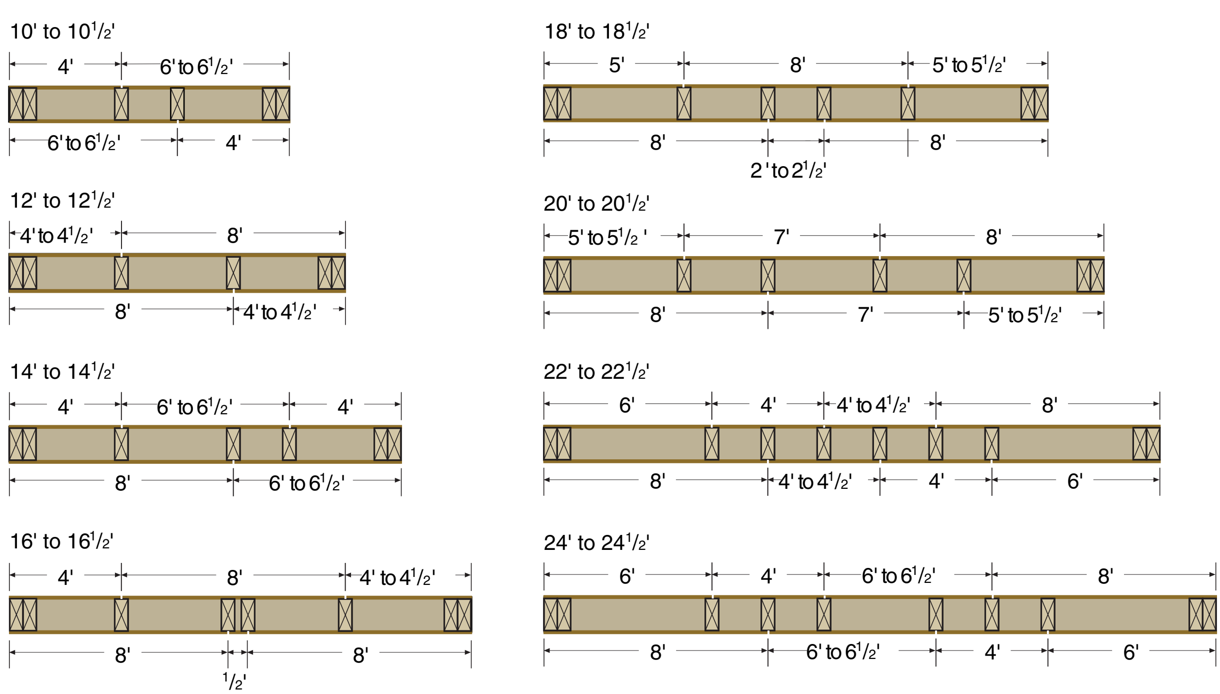
Nailing Pattern



All beams in the load-span tables function with 8d common nails spaced 1 1/2" on center on each side of each flange lamination. The spacing may be doubled to 3" on center in the middle half of the beam. Use corrosion-resistant nails if the beam is exposed to moisture. If staples or nails of other sizes or types are used, the spacing must be adjusted in proportion to the allowable lateral load for the fasteners selected.

Although the nailing shown is structurally adequate, additional stiffness can be developed gluing the panels to the lumber. Any type of wood adhesive will work, but do not reduce the number of nails.

Web Joint Layouts



Steel Beams

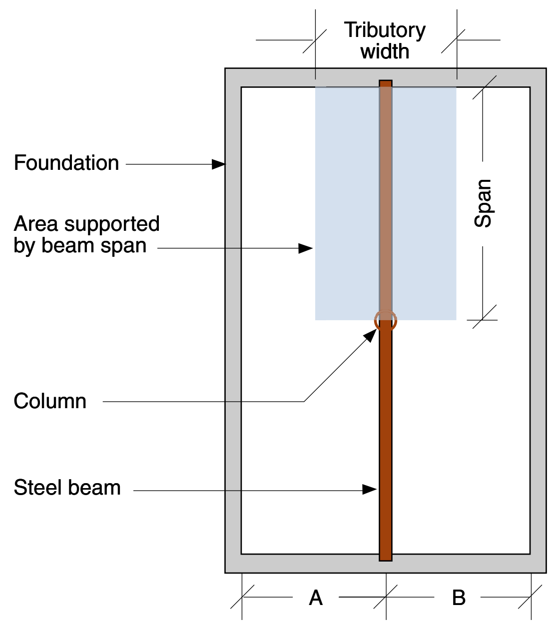
Steel beams often provide the most cost-effective solution when the loads to be carried are large. The tables below and on the facing page show the maximum clear spans (distance between supports) for the most common steel beam: shape W, type A36.

The calculations are based on simple beams, i.e., beams supported only at their ends. The calculations are thus conservative for continuous beams with more than two supports. The beams are assumed to carry the uniformly distributed floor loads shown as the shaded areas in the figure at right, in addition to their own weight and the weights of any interior walls supporting upper level floors.

The beam spans are limited by either: 1) tensile strength (indicated by plain type), or 2) live-load deflection ratio of 1/360.

These tables are intended for planning purposes only. Consult a steel beam supplier or engineer for final specification.

Area Supported by a Simple Beam



Center Beam Supporting a Single Floor: 40 PSI Live, 10 PSF Dead

Maximum Allowable Span (feet-inches)

Beam	Tributary Width Supported by Beam, (A + B)/2									
	6-0	8-0	10-0	12-0	14-0	16-0	18-0	20-0	22-0	24-0
W6×9	14-4	13-0	12-0	11-4	10-10	10-4	9-10	9-4	8-11	8-6
W6×12	15-10	14-4	13-4	12-6	11-11	11-5	10-11	10-7	10-2	9-10
W8×10	17-7	16-0	14-11	14-0	13-2	12-5	11-8	11-1	10-7	10-1
W6×16	17-11	16-2	15-1	14-2	13-6	12-11	12-5	12-0	11-7	11-4
W8×13	19-2	17-5	16-2	15-2	14-5	13-10	13-1	12-5	11-11	11-5
W8×15	20-5	18-7	17-2	16-2	15-5	14-8	14-2	13-7	12-11	12-5
W10×12	21-2	19-4	17-11	16-10	15-7	14-7	13-10	13-1	12-6	11-11
W8×18	22-2	20-2	18-8	17-7	16-10	16-0	15-5	14-11	14-5	14-0
W10×15	23-0	20-11	19-5	18-4	17-5	16-5	15-6	14-8	14-0	13-5
W8×21	23-8	21-7	20-0	18-10	17-11	17-1	16-6	15-11	15-5	15-0
W10×17	24-5	22-2	20-7	19-5	18-5	17-7	16-8	15-11	15-2	14-6
W8×24	24-6	22-2	20-8	19-5	18-6	17-8	17-0	16-5	15-11	15-5
W12×14	25-0	22-10	21-1	19-7	18-2	17-0	16-1	15-4	14-7	13-11
W10×19	25-8	23-5	21-8	20-5	19-5	18-7	17-11	17-1	16-4	15-7
W8×28	25-11	23-6	21-10	20-7	19-6	18-8	18-0	17-4	16-10	16-4
W12×16	26-4	23-11	22-2	20-11	19-5	18-2	17-2	16-4	15-7	14-11
W10×22	27-7	25-0	23-2	21-11	20-10	19-11	19-1	18-6	17-11	17-4
W12×19	28-6	25-11	24-0	22-7	21-6	20-4	19-2	18-2	17-5	16-7
W10×26	29-5	26-10	24-10	23-5	22-2	21-2	20-5	19-8	19-1	18-7

Center Beam Supporting Two Floors: 40+30 PSF Live, 10+10 PSF Dead

Maximum Allowable Span (feet-inches)

	Tributary Width Supported by Beam, (A + B)/2									
Beam	**6-0**	**8-0**	**10-0**	**12-0**	**14-0**	**16-0**	**18-0**	**20-0**	**22-0**	**24-0**
W6×9	11-11	10-7	9-7	8-10	8-2	7-8	7-2	6-11	6-7	6-4
W6×12	13-1	11-11	11-0	10-1	9-5	8-10	8-4	7-11	7-6	7-2
W8×10	14-5	12-7	11-5	10-5	9-8	9-1	8-7	8-2	7-10	7-6
W6×16	14-10	13-6	12-6	11-10	11-0	10-5	9-10	9-4	8-11	8-6
W8×13	15-11	14-2	12-10	11-8	10-11	10-2	9-8	9-2	8-10	8-5
W8×15	16-11	15-5	13-11	12-10	11-11	11-1	10-6	10-0	9-7	9-2
W10×12	16-11	14-11	13-5	12-4	11-5	10-8	10-1	9-7	9-2	8-10
W8×18	18-5	16-10	15-7	14-6	13-6	12-7	11-11	11-5	10-10	10-5
W10×15	19-0	16-8	15-1	13-10	12-10	12-1	11-5	10-10	10-4	9-11
W8×21	19-8	17-11	16-7	15-7	14-8	13-10	13-1	12-5	11-11	11-5
W10×17	20-2	18-1	16-4	15-0	13-11	13-0	12-4	11-8	11-2	10-8
W8×24	20-4	18-6	17-1	16-1	15-4	14-8	14-0	13-4	12-8	12-2
W12×14	19-10	17-5	15-7	14-5	13-5	12-6	11-10	11-4	10-8	10-4
W10×19	21-5	19-5	17-6	16-1	15-0	14-0	13-4	12-7	12-1	11-7
W8×28	21-6	19-6	18-1	17-1	16-2	15-6	14-11	14-4	13-8	13-1
W12×16	21-1	18-7	16-8	15-5	14-4	13-5	12-8	12-0	11-6	11-0
W10×22	22-11	20-10	19-4	17-11	16-7	15-7	14-8	14-0	13-5	12-10
W12×19	23-6	20-8	18-8	17-1	15-11	15-0	14-1	13-5	12-10	12-4
W10×26	24-5	22-2	20-7	19-5	18-2	17-1	16-1	15-4	14-8	14-1

Center Beam Supporting Three Floors: 40+30+30 PSF Live, 10+10+10 PSF Dead

Maximum Allowable Span (feet-inches)

	Tributary Width Supported by Beam, (A + B)/2									
Beam	**6-0**	**8-0**	**10-0**	**12-0**	**14-0**	**16-0**	**18-0**	**20-0**	**22-0**	**24-0**
W6×9	10-0	8-10	7-11	7-4	6-10	6-4	6-0	5-8	5-5	5-2
W6×12	11-5	10-0	9-1	8-4	7-8	7-4	6-11	6-6	6-2	6-0
W8×10	11-10	10-5	9-5	8-7	8-0	7-6	7-1	6-10	6-6	6-0
W6×16	13-2	11-10	10-8	9-10	9-1	8-7	8-1	7-8	7-5	7-1
W8×13	13-4	11-8	10-6	9-8	9-0	8-6	8-0	7-7	7-4	7-0
W8×15	14-6	12-8	11-6	10-7	9-10	9-2	8-8	8-4	7-11	7-7
W10×12	13-11	12-2	11-1	10-2	9-6	8-11	8-5	8-0	7-7	7-0
W8×18	16-5	14-5	13-0	12-0	11-1	10-6	9-11	9-5	9-0	8-7
W10×15	15-7	13-10	12-5	11-5	10-7	10-0	9-5	9-0	8-7	8-2
W8×21	17-6	15-10	14-2	13-1	12-2	11-5	10-10	10-4	9-10	9-5
W10×17	16-11	14-11	13-6	12-5	11-6	10-10	10-2	9-8	9-4	8-11
W8×24	18-0	16-5	15-2	14-0	13-0	12-4	11-7	11-0	10-6	10-1
W12×14	16-2	14-4	12-11	11-11	11-0	10-5	9-8	8-8	8-0	7-4
W10×19	18-2	16-0	14-6	13-4	12-5	11-7	11-0	10-6	10-0	9-7
W8×28	19-1	17-4	16-1	15-1	14-1	13-2	12-6	11-11	11-4	10-11
W12×16	17-5	15-4	13-10	12-8	11-10	11-1	10-6	10-0	9-6	8-10
W10×22	20-2	17-10	16-1	14-10	13-10	12-11	12-2	11-7	11-1	10-2
W12×19	19-5	17-1	15-5	14-2	13-2	12-5	11-8	11-1	10-7	9-11
W10×26	21-8	19-6	17-7	16-2	15-1	14-2	13-5	12-8	12-2	11-8

Timber Framing

History

Also known as post-and-beam, post-and-girt, and post-and-lintel, the timber-framing system was already well developed in Europe before the discovery of America. The main method of fastening the heavy timbers, the mortise-and-tenon joint (see p. 183), was developed sometime between 200 BC and 500 BC, and the self-supporting braced frame was developed around AD 900.

The system is characterized by the use of large, widely spaced load-carrying timbers. Vertical loads are carried by posts at corners and intersections of load-bearing walls. Plates and girts collect distributed roof and floor loads from rafters and joists and transfer them to the posts. Wall studs carry no vertical loads, being used only for attachment of wall sheathing.

Timber framing requires a higher degree of carpentry skill than the so-called stick systems. First, the integrity of the frame depends on the choice and meticulous execution of the wood-peg-fastened joints. Second, the entire frame is precut, each intersecting member being labeled. Finally—usually in a single day—the members are assembled into large wall sections called bents, and then raised with much human power and conviviality. Raising day is the moment of truth for the lead framer.

The timber-frame system evolved more from economic necessity than from aesthetic sensibility. Large timbers were more plentiful, circular-saw and band-saw mills were not available to slice timbers into sticks, and nails were still made by hand, which made them much too costly to use in the quantities needed for stick framing.

Today

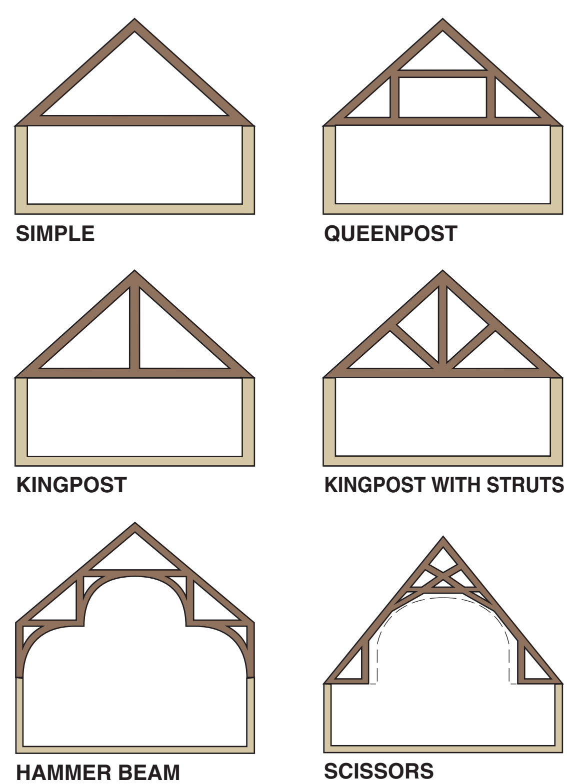
The timber frame enjoys a new popularity today, but not for economic reasons. Even proponents acknowledge that a well-executed timber frame is more expensive than a frame employing wood-saving and labor-saving trusses, metal fasteners, and power nailing. The appeal of the timber frame lies in its material and craftsmanship, as well as in nostalgia.

The timber frame of today remains unchanged. In fact, most framers try simply to emulate the best of the past. What have changed, however, are the insulation and the sheathing systems. Few contractors still practice the classic in-fill system, whereby wall studs are placed between the load-carrying posts to support exterior sheathing and interior finish.

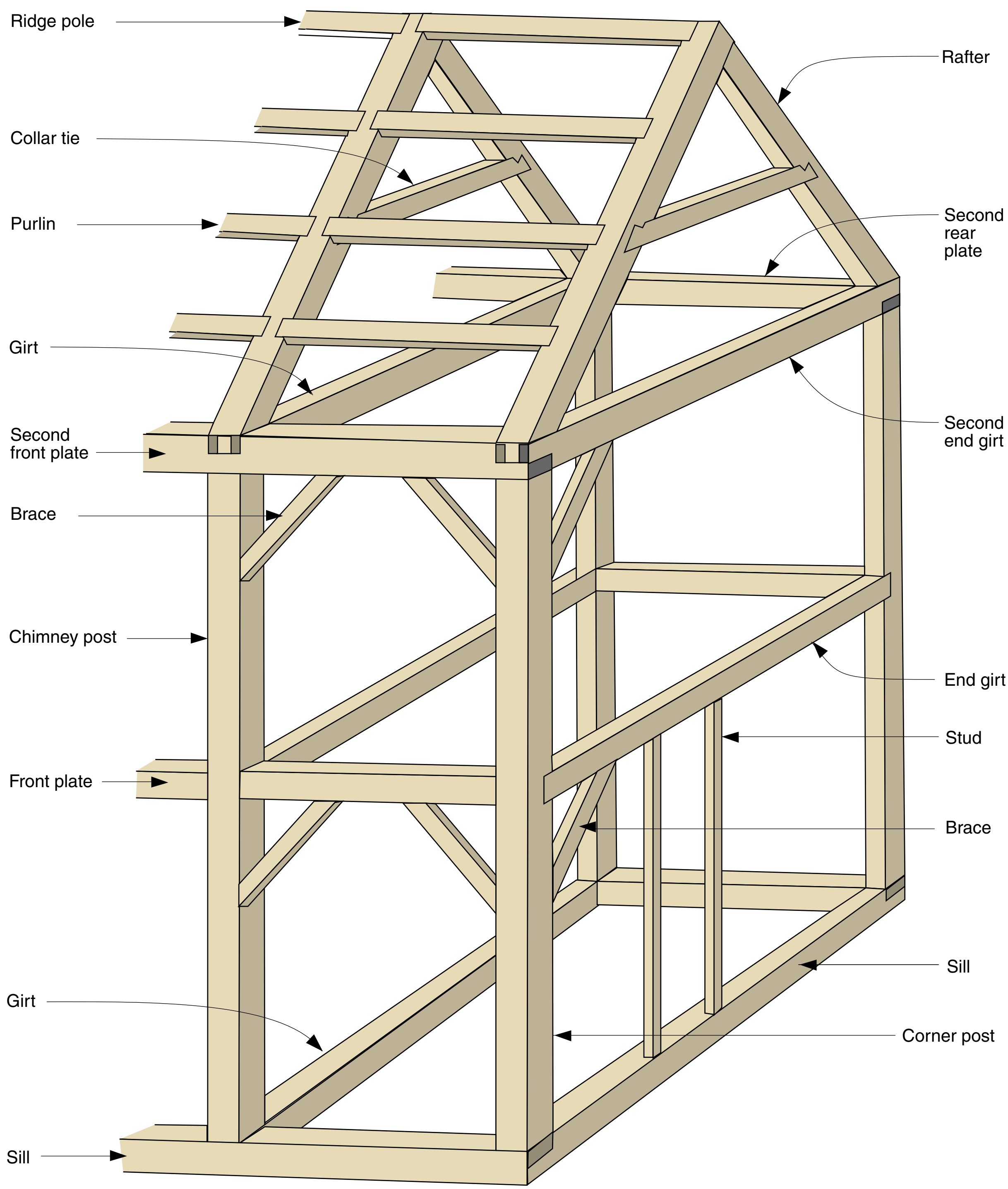
Foam-filled stressed-skin panels dominate the market today. Widely available from dozens of manufacturers, most consist of exterior panels of oriented strand board (OSB) and interior sheets of gypsum drywall, separated by either urethane or expanded polystyrene foam.

Wiring and plumbing were developed after the timber frame. To this day, concealment of pipes and wires requires planning on the part of the designer and preboring of sheathing and roofing panels.

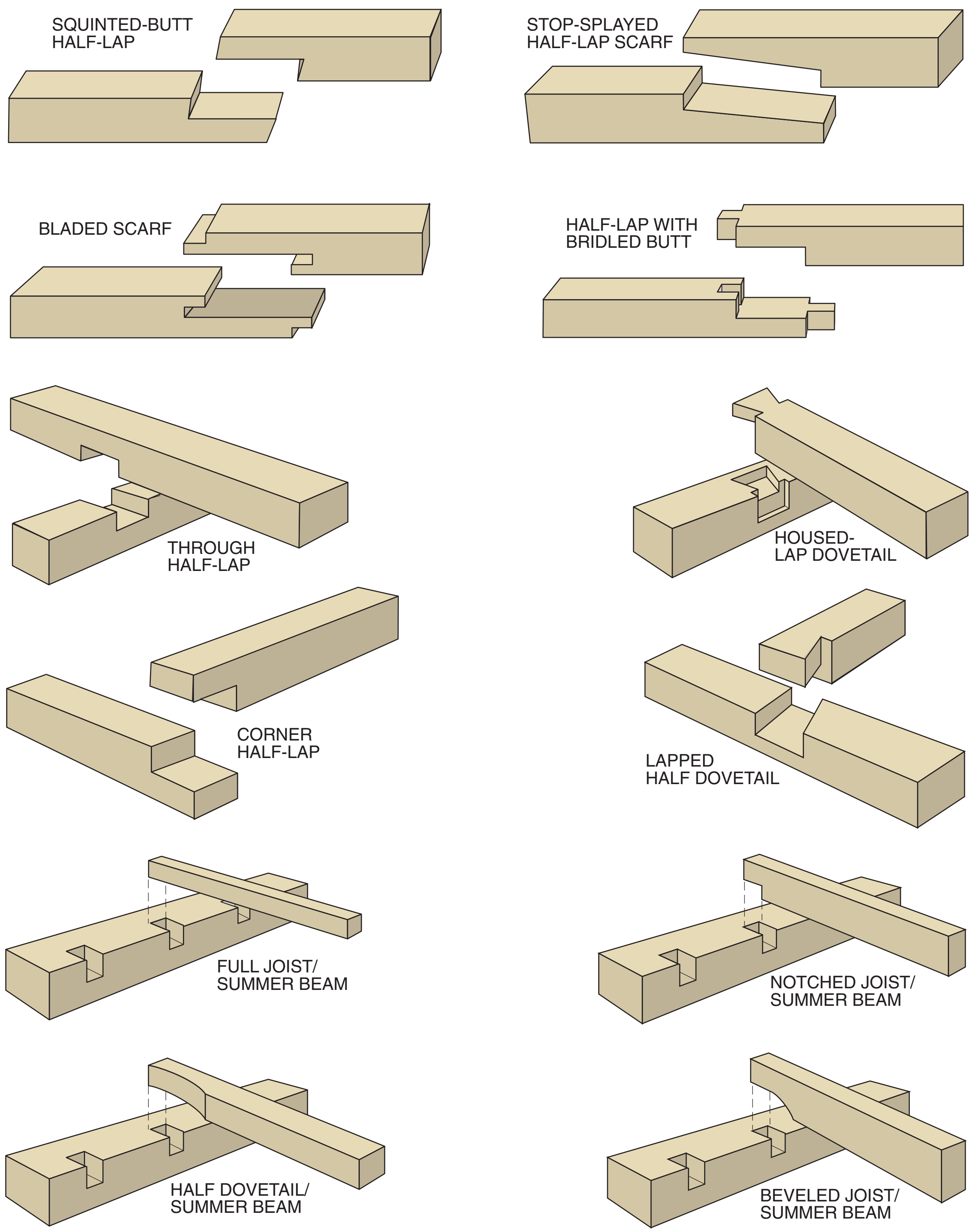
A Variety of Timber-Frame Trusses

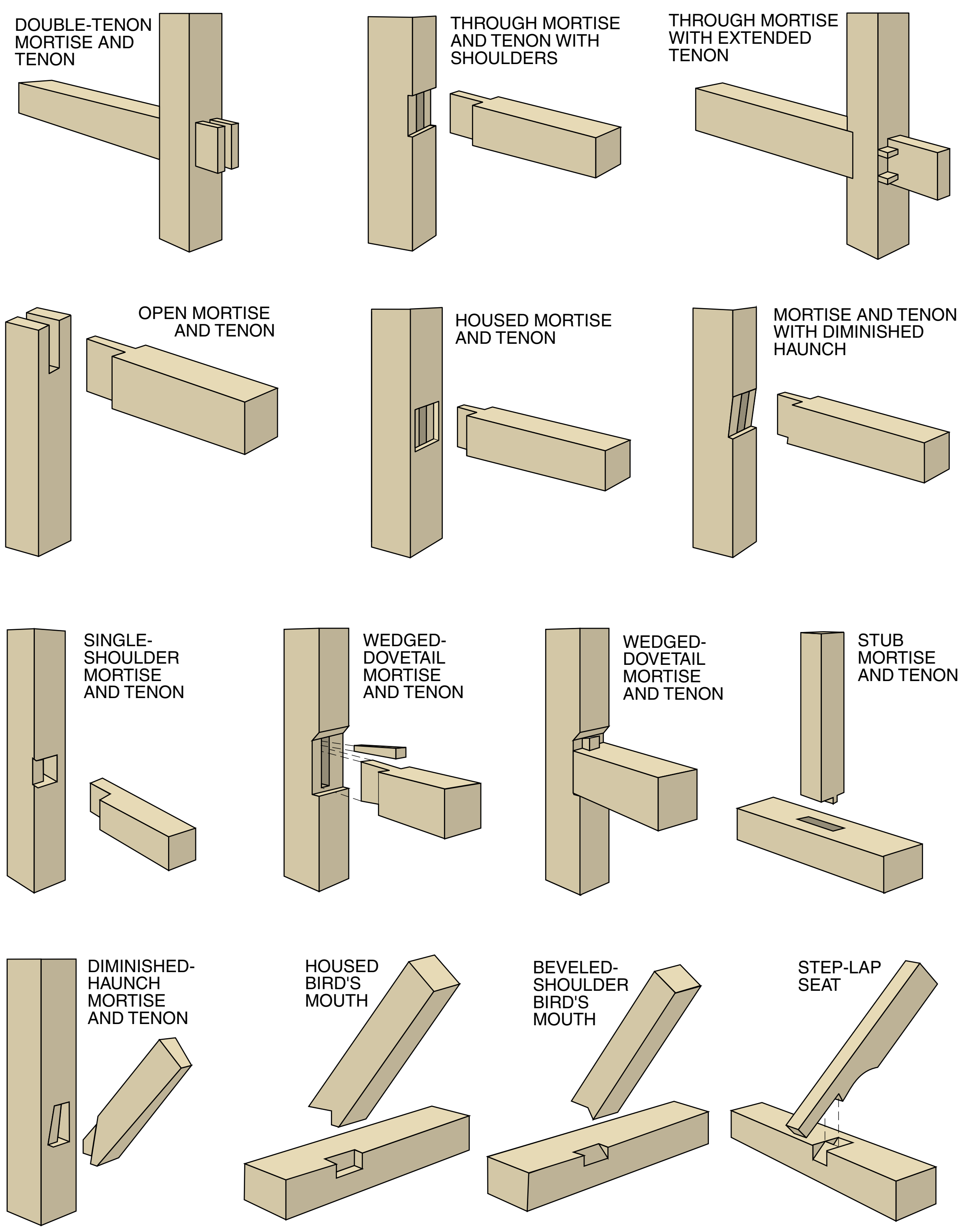


Typical Timber Frame



Timber-Frame Joinery




DOUBLE-TENON MORTISE AND TENON
THROUGH MORTISE AND TENON WITH SHOULDERS
THROUGH MORTISE WITH EXTENDED TENON
OPEN MORTISE AND TENON
HOUSED MORTISE AND TENON
MORTISE AND TENON WITH DIMINISHED HAUNCH
SINGLE-SHOULDER MORTISE AND TENON
WEDGED-DOVETAIL MORTISE AND TENON
WEDGED-DOVETAIL MORTISE AND TENON
STUB MORTISE AND TENON
DIMINISHED-HAUNCH MORTISE AND TENON
HOUSED BIRD'S MOUTH
BEVELED-SHOULDER BIRD'S MOUTH
STEP-LAP SEAT

Balloon Framing

The balloon frame developed in response to at least three innovations in the construction industry:

- Invention of the machine-made nail, which made nailing less expensive than hand-pegged joinery.
- More advanced circular-saw mills, which lowered the cost of standardized sawn lumber.
- Development of a housing industry, which promoted standardization of materials and methods.

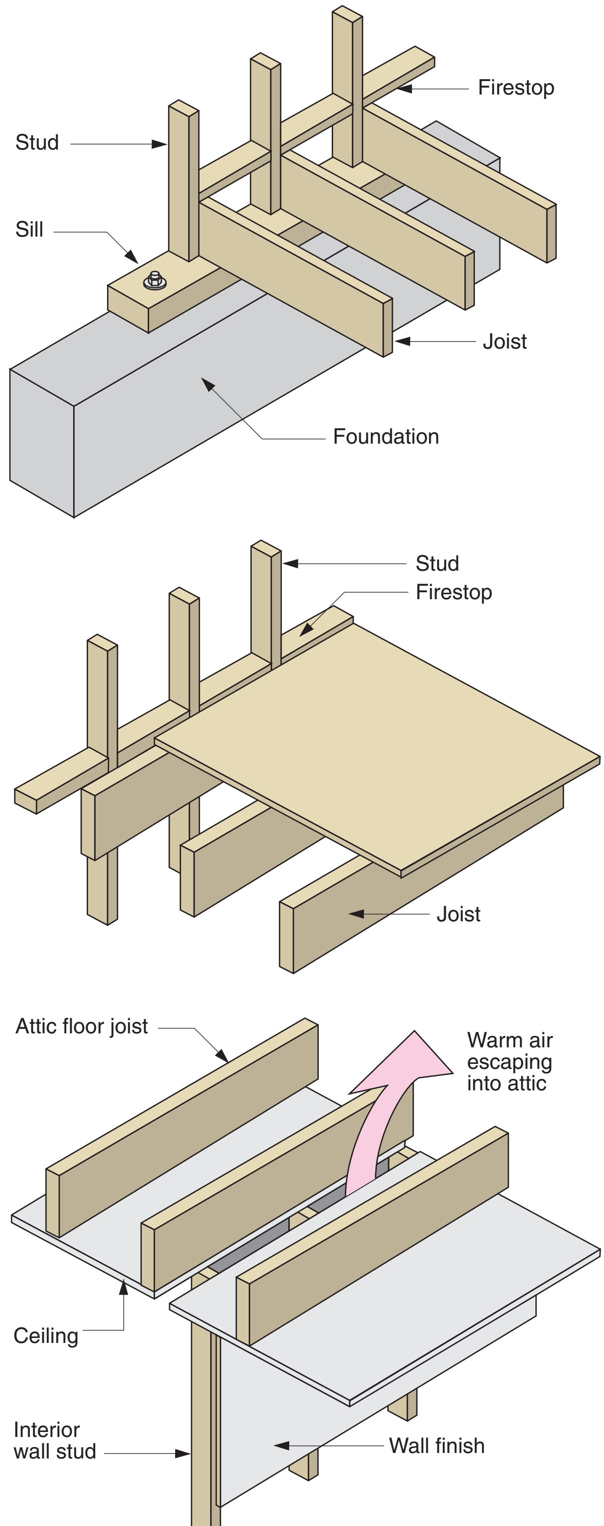
In the balloon frame, there is no requirement for lumber more than 2 inches thick. Plates, sills, and posts are all built up from 2-inch stock. Front and rear girts are replaced by ribbons (or ribbands), 1× 6 or 1×8 boards let into the studs as a support for the joists. Studs now carry most of the vertical load. Bracing is supplied by sheathing panels or by diagonally applied sheathing boards.

The balloon frame gets its name from the fact that the studs run unbroken from sill to top plate, regardless of the number of stories, making the frame like a membrane or balloon. Both the major advantage and disadvantage of the system derive from this fact. In drying, lumber may shrink up to 8 percent in width, but only 0.1 percent in length. Since the overall dimensions of a balloon frame are controlled by length, shrinkage cracks in stucco and plaster finishes are minimized.

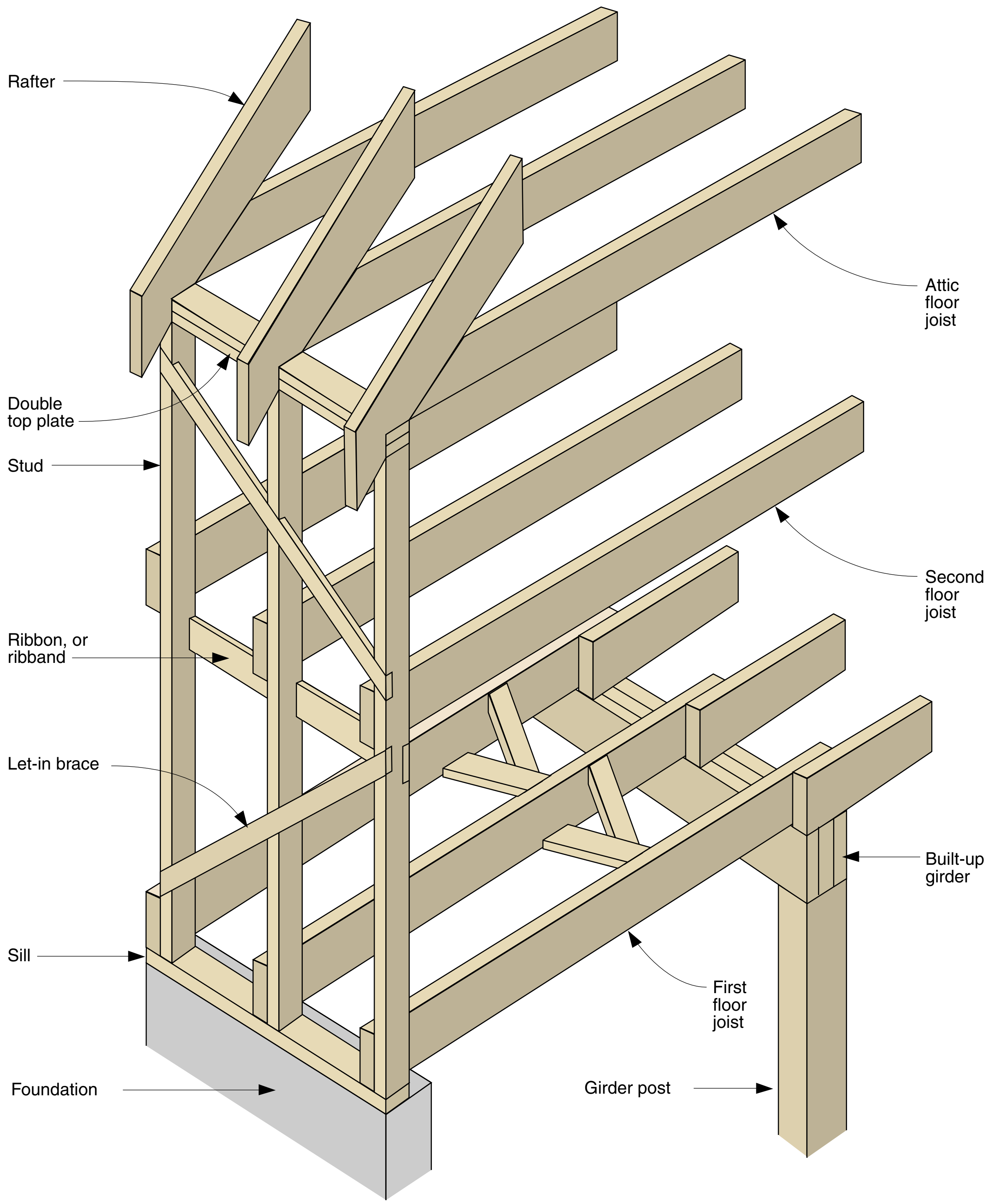
The major disadvantage of the balloon frame is the necessity of fire-stopping the vertical wall cavities, which otherwise would act as flues in rapidly spreading fire from basement to attic. A related disadvantage is the difficulty of insulating the wall cavities, which typically open into the basement at the foundation sill.

Because of the fire danger, and because of the scarcity of long framing members, the balloon frame has been replaced almost entirely by the platform frame, discussed in the next section. Framing details for both systems are similar and are shown in later pages.

Balloon Frame Details



Typical Balloon Frame

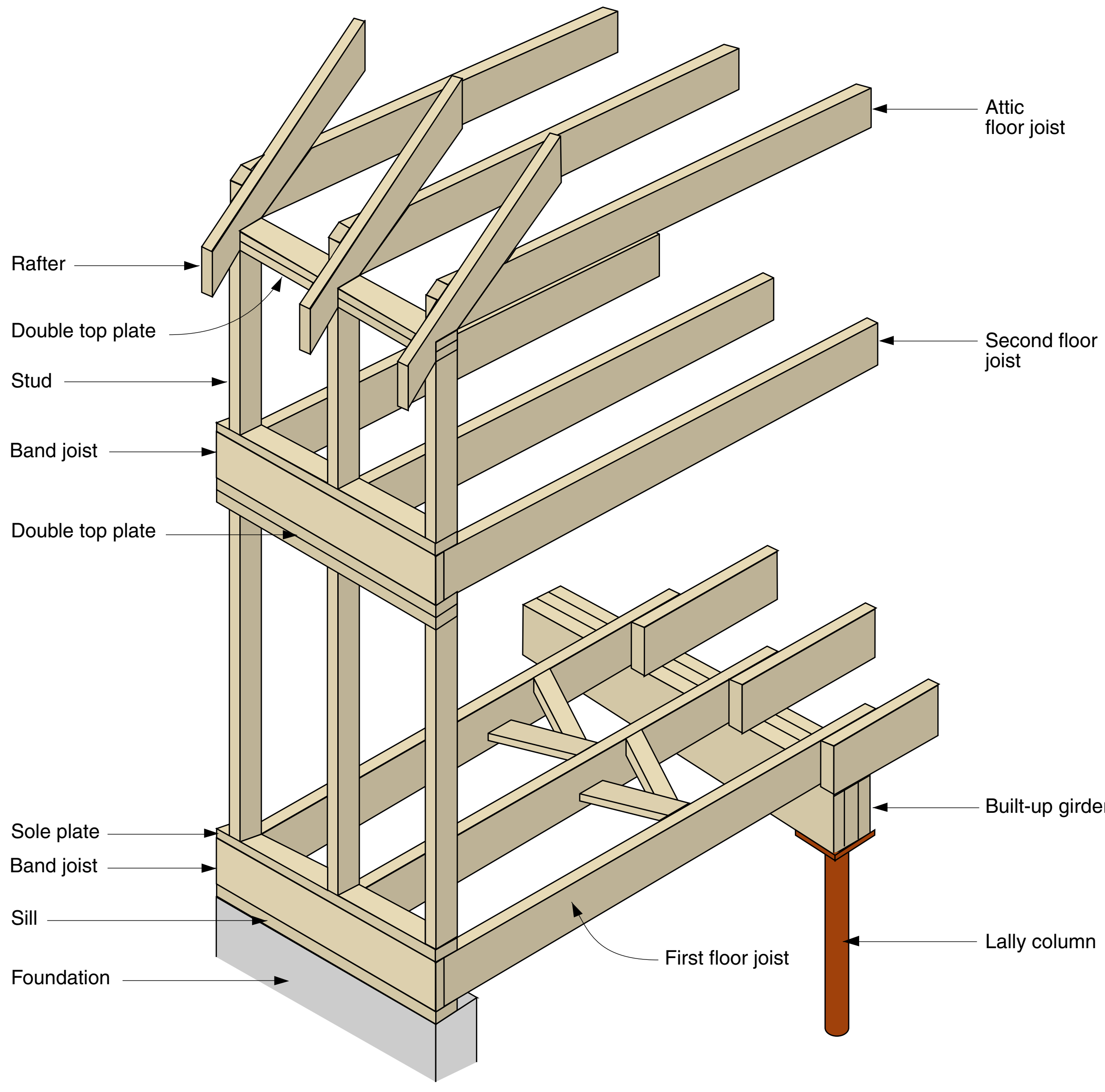


Platform Framing

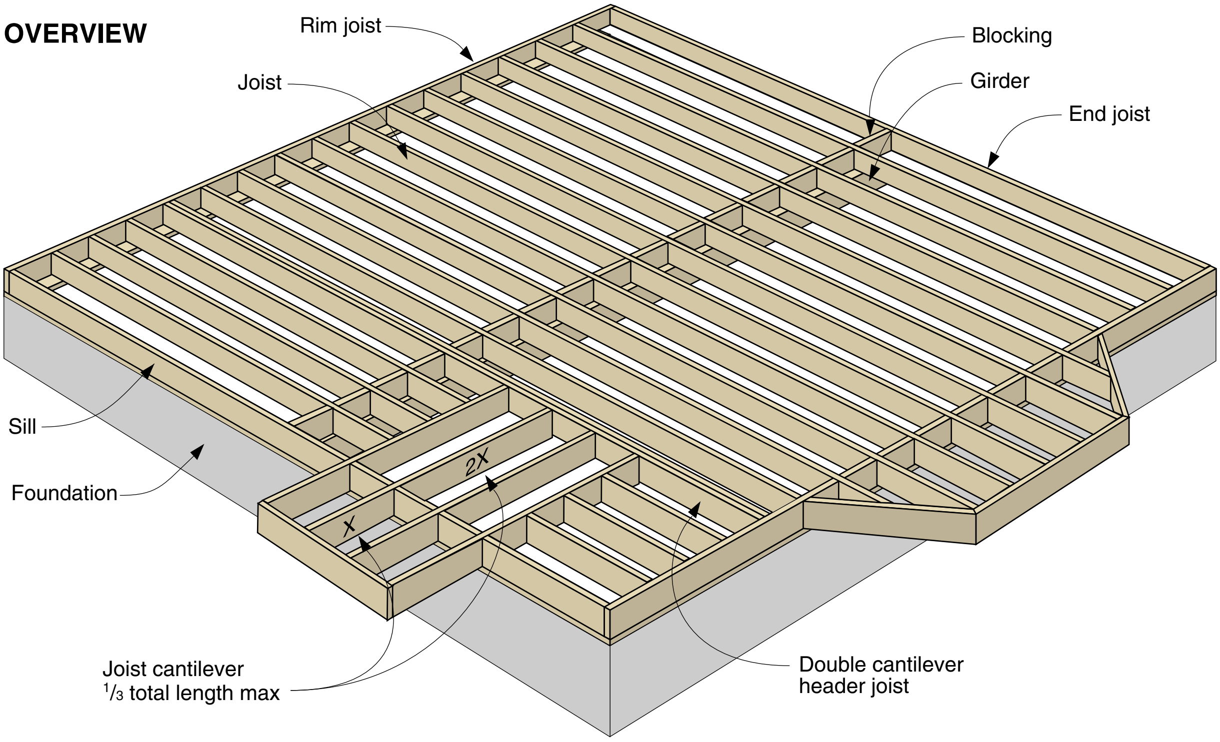
The platform frame solved the fire-stop problem of the balloon frame. Each story of a platform frame is built upon a platform consisting of joists, band joists, and subfloor. After completion of the first-story walls, the second platform is built identical to the first as if the first-story walls were the foundation. Platform framing represented a great step forward in standardization, requiring the lowest levels of carpentry skill and the fewest standard sizes of lumber.

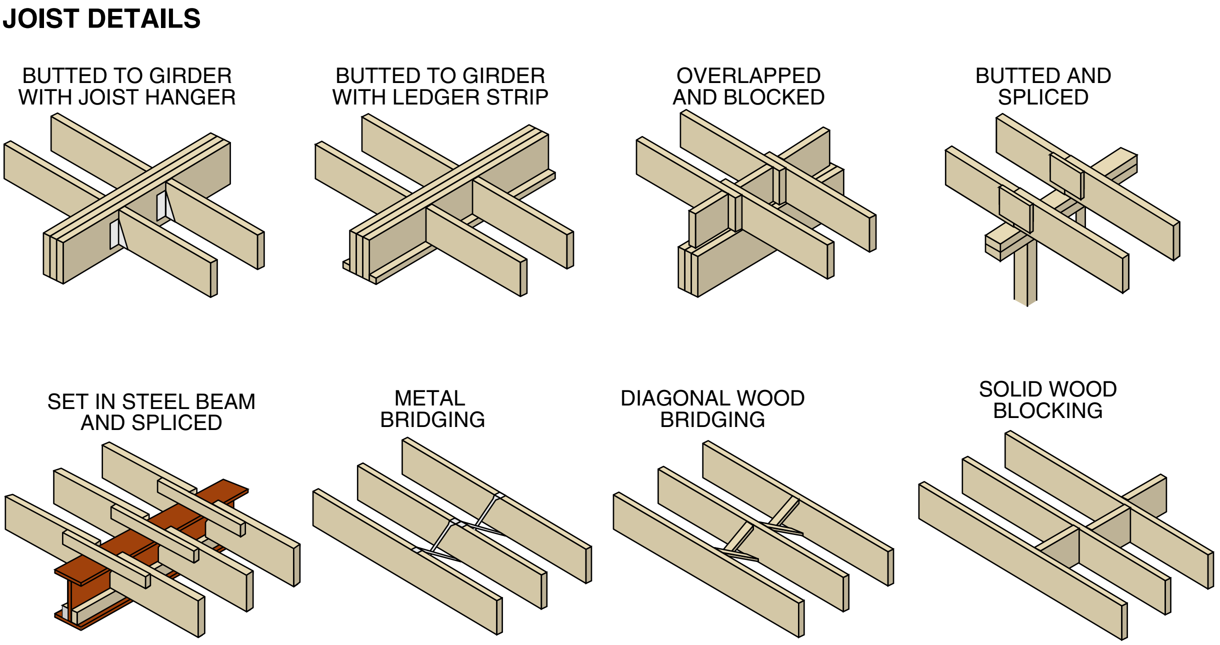
The platform frame also standardized the use of band joists and sole plates. The sole plate and top plate of each wall automatically provide fire-stopping and nailing surfaces for both exterior sheathing and interior drywall. The advent of gypsum drywall and other forms of paneling made frame shrinkage less important. Bracing is provided either by the structurally rated exterior sheathing panels or by diagonally applied sheet metal braces.

Typical Platform Frame

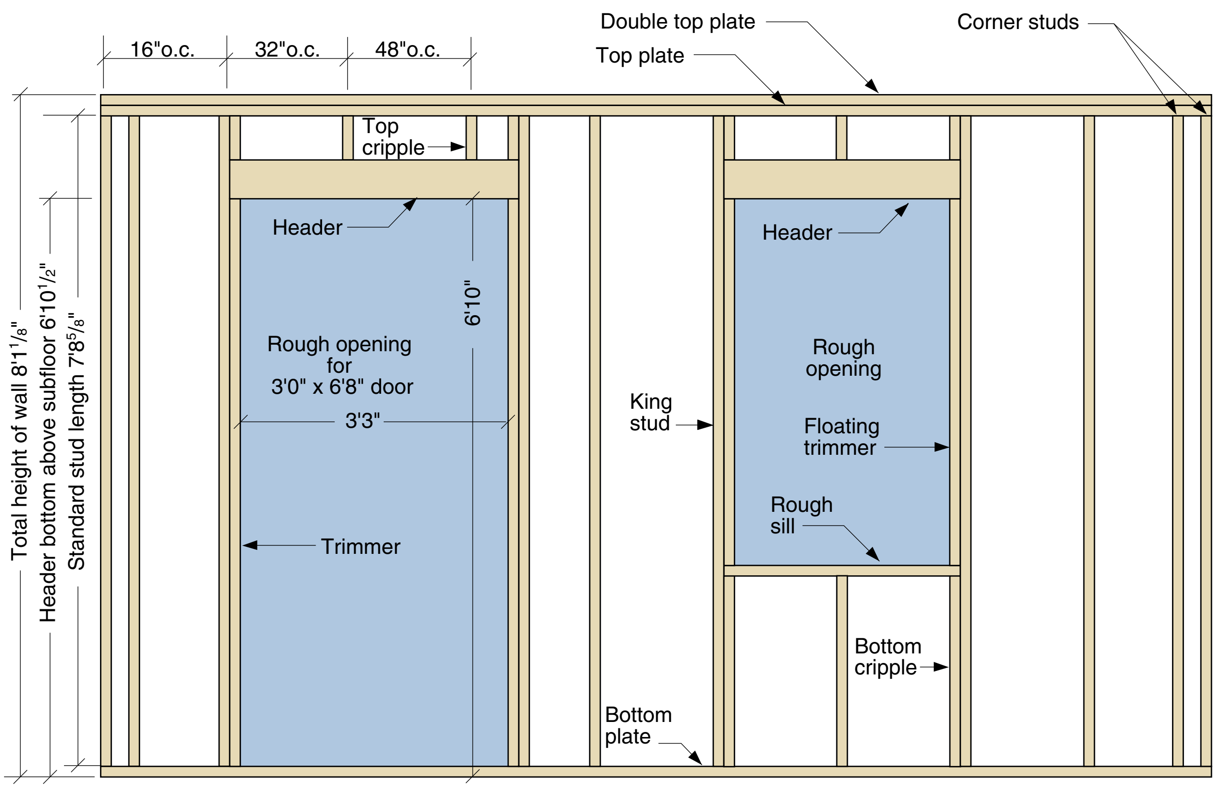


Floor Framing

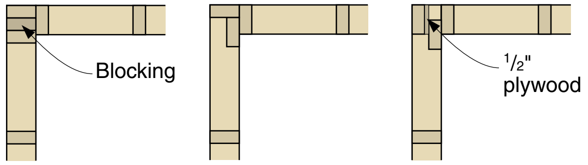




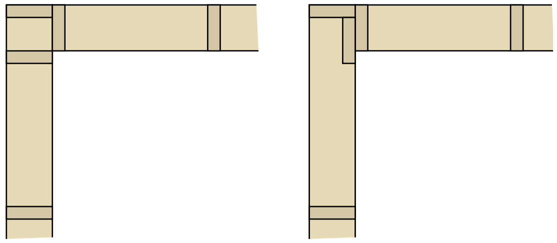
Wall Framing



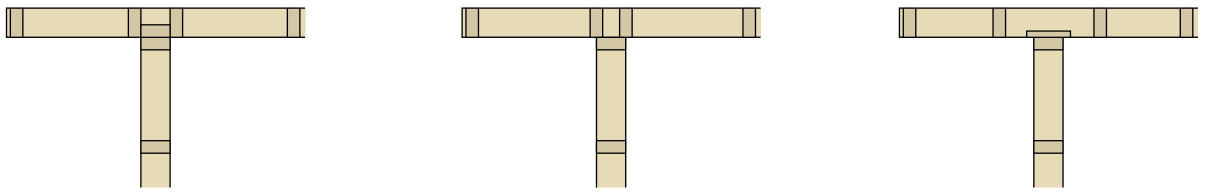
OUTSIDE CORNERS—2X4 WALLS



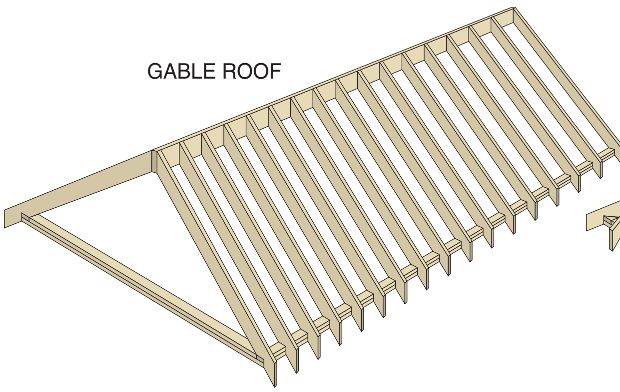
OUTSIDE CORNERS—2X6 WALLS

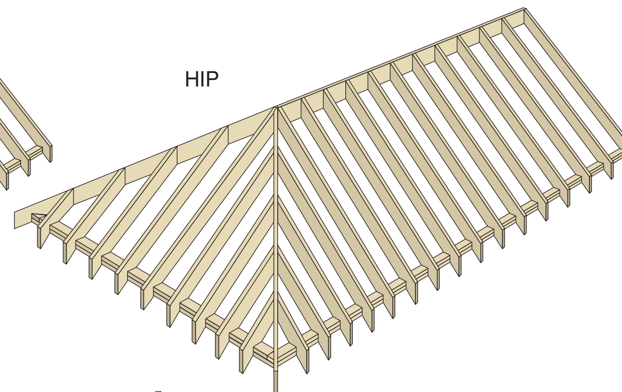


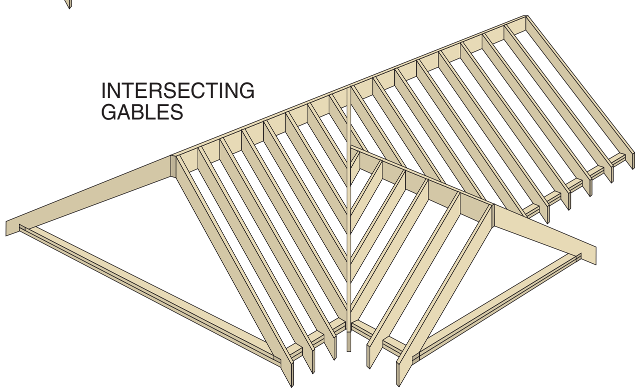
INSIDE CORNERS—2X4 WALLS

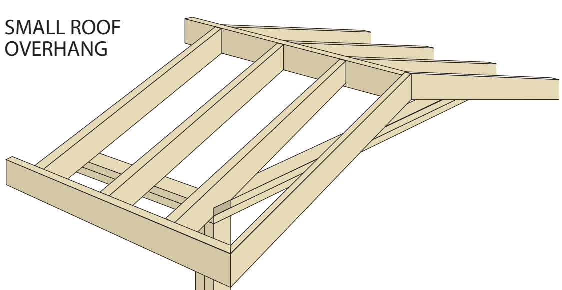


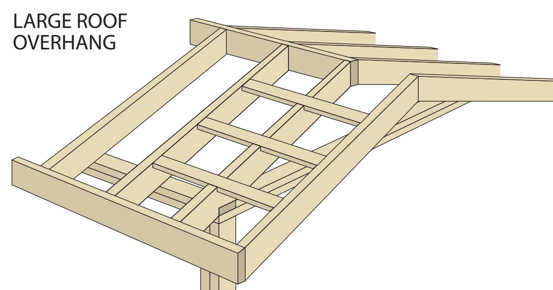
Roof Framing

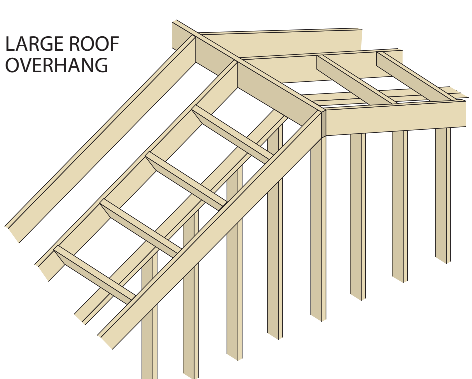


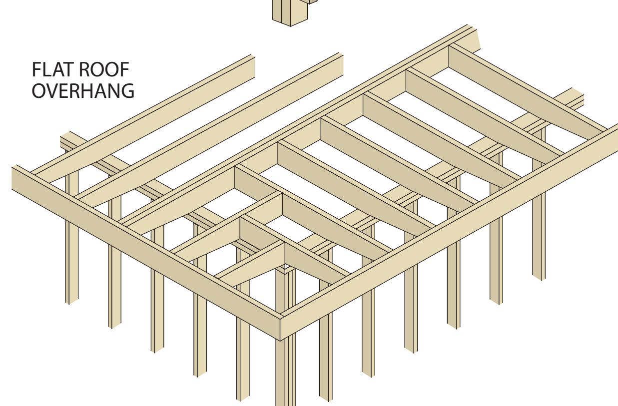




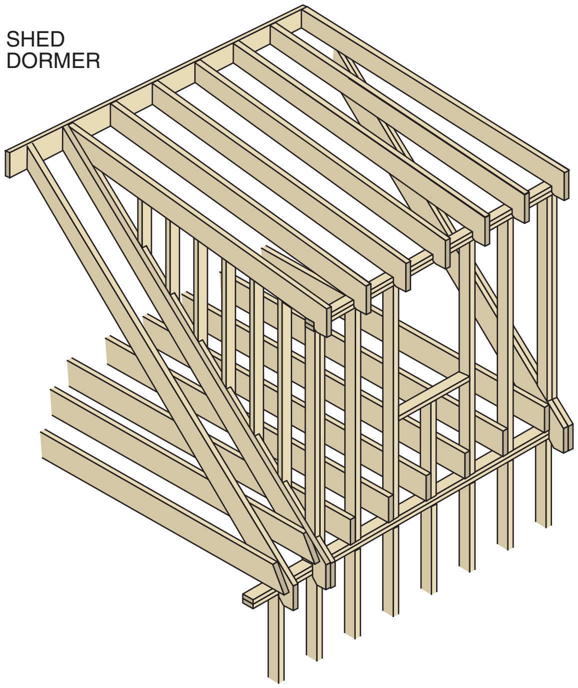


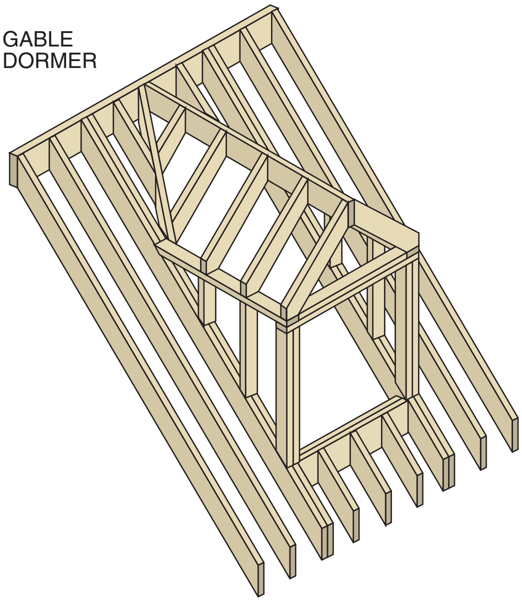


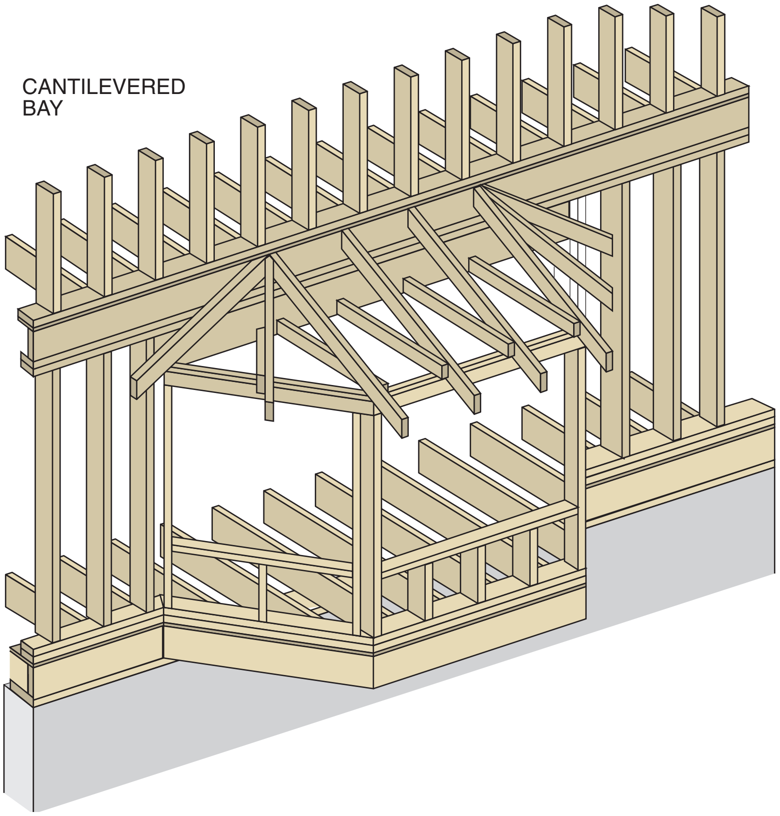




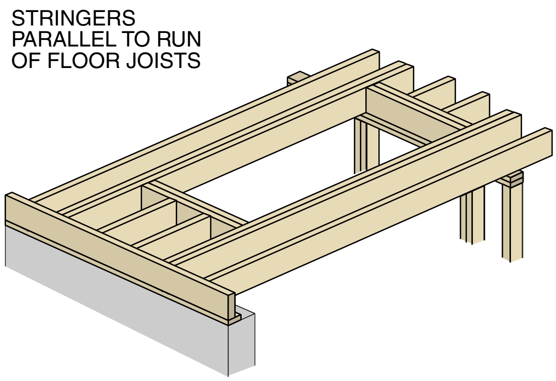
Dormer and Bay Framing

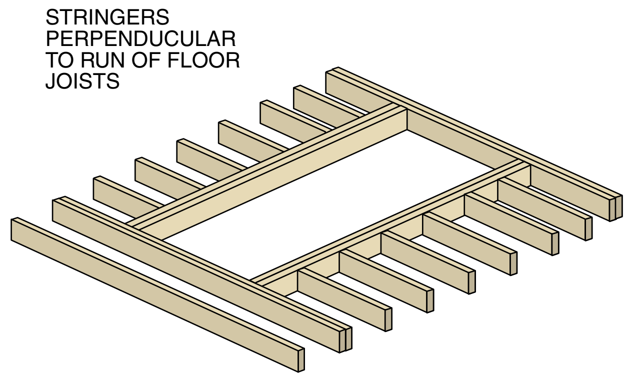


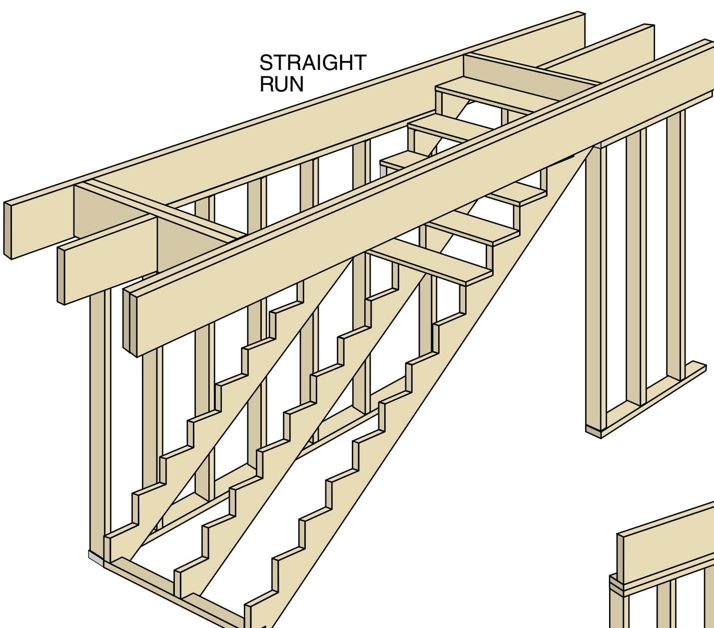


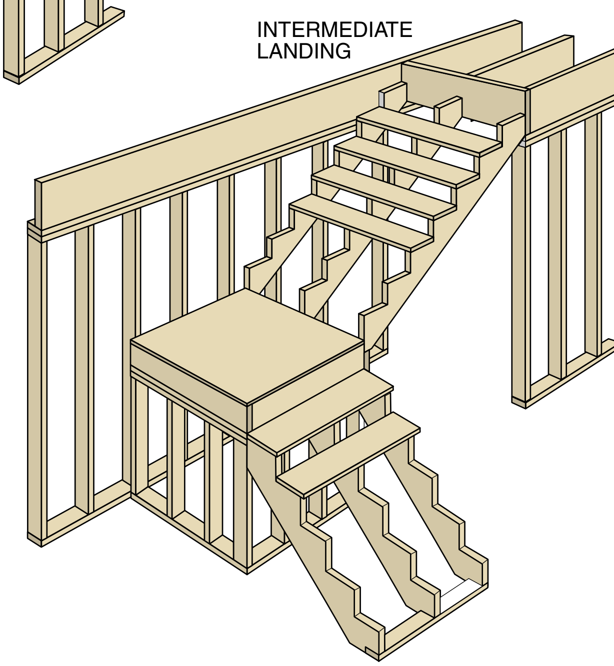


Roof Framing









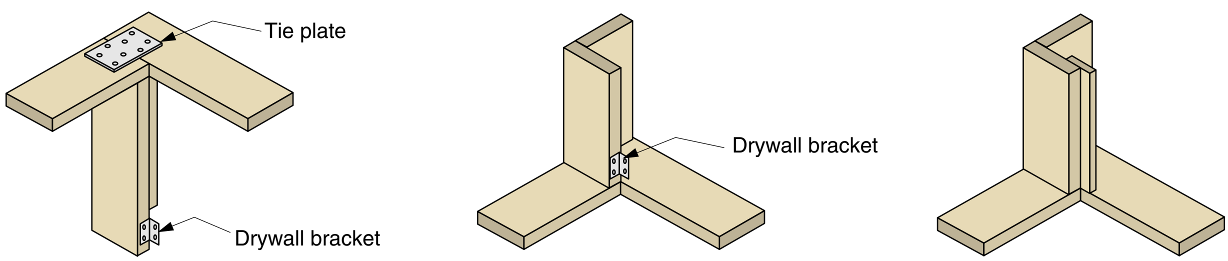
Advanced (OVE) Framing

In an effort to reduce waste in residential building, The National Association of Home Builders (NAHB®) developed what they termed Optimum-Value Engineering (OVE), which reduces the amount of lumber in the frame without sacrificing performance. In fact, because the framing acts as a thermal short circuit (compared to insulation) in the building envelope, OVE saves energy, as well.

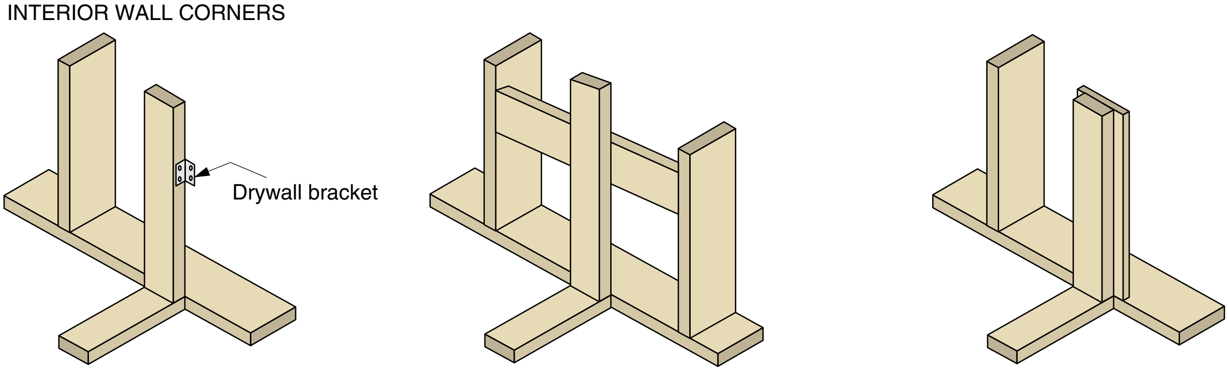
Unfortunately both builders and buyers have been slow to adopt the cost-saving techniques. This is not surprising considering America's apparent faith that bigger is better (bigger portions, bigger vehicles, bigger homes). Attempting to make OVE more compelling, its proponents have begun calling it Advanced Framing. Advanced Framing or OVE, here are its features.

Advanced Framing Details

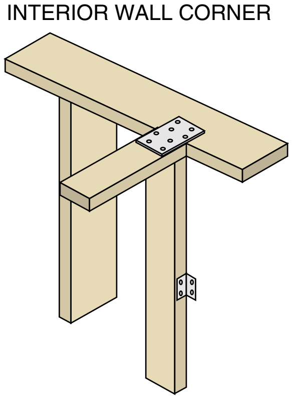
EXTERIOR WALL CORNERS



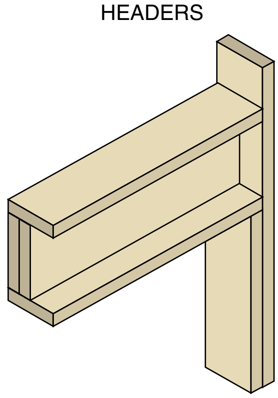
INTERIOR WALL CORNERS



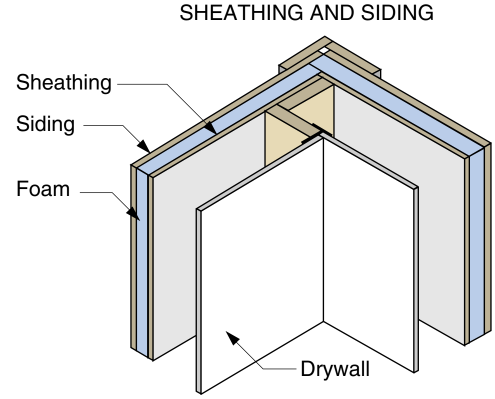
INTERIOR WALL CORNER



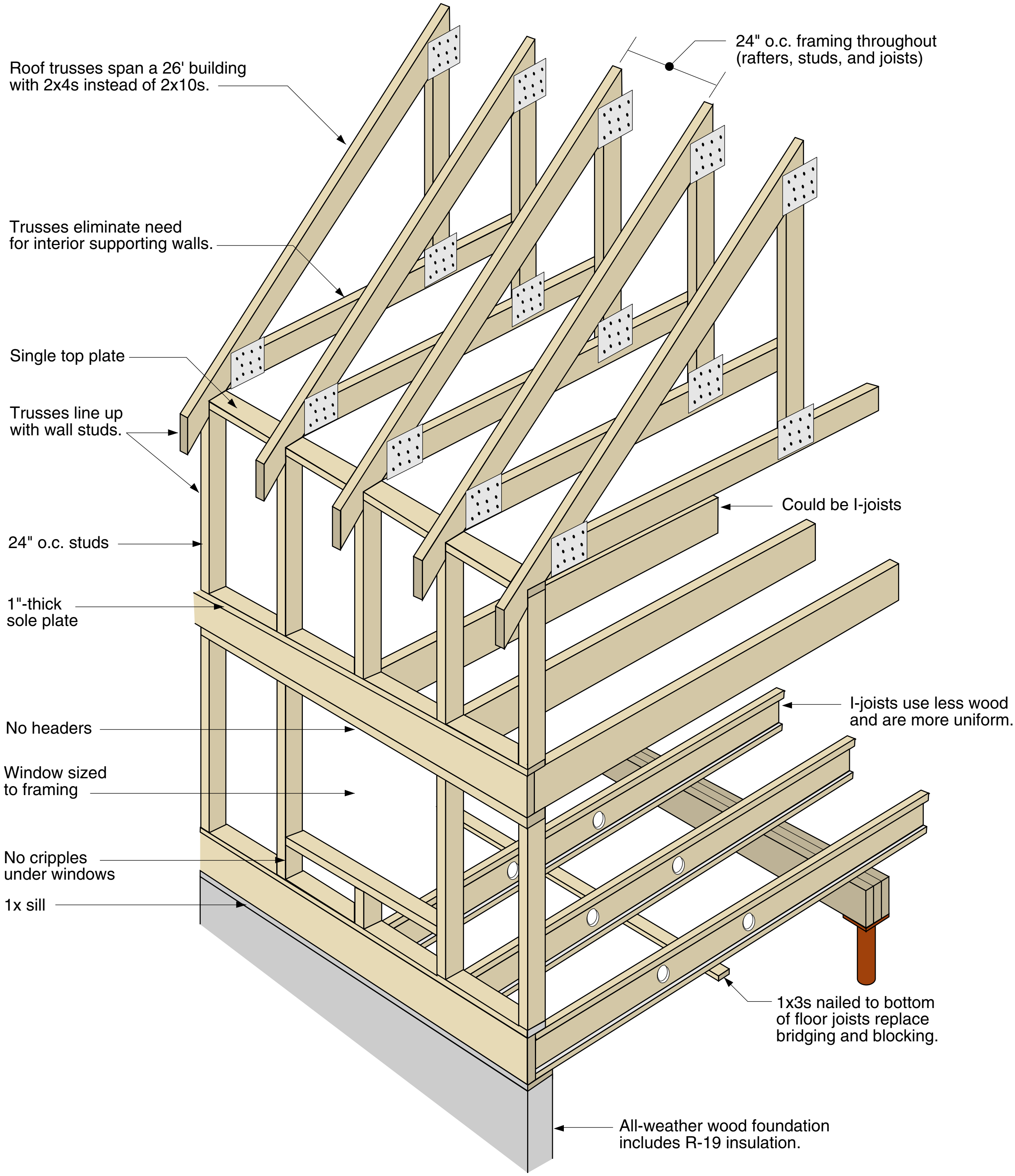
HEADERS



SHEATHING AND SIDING



Typical Advanced Frame



Stair Framing

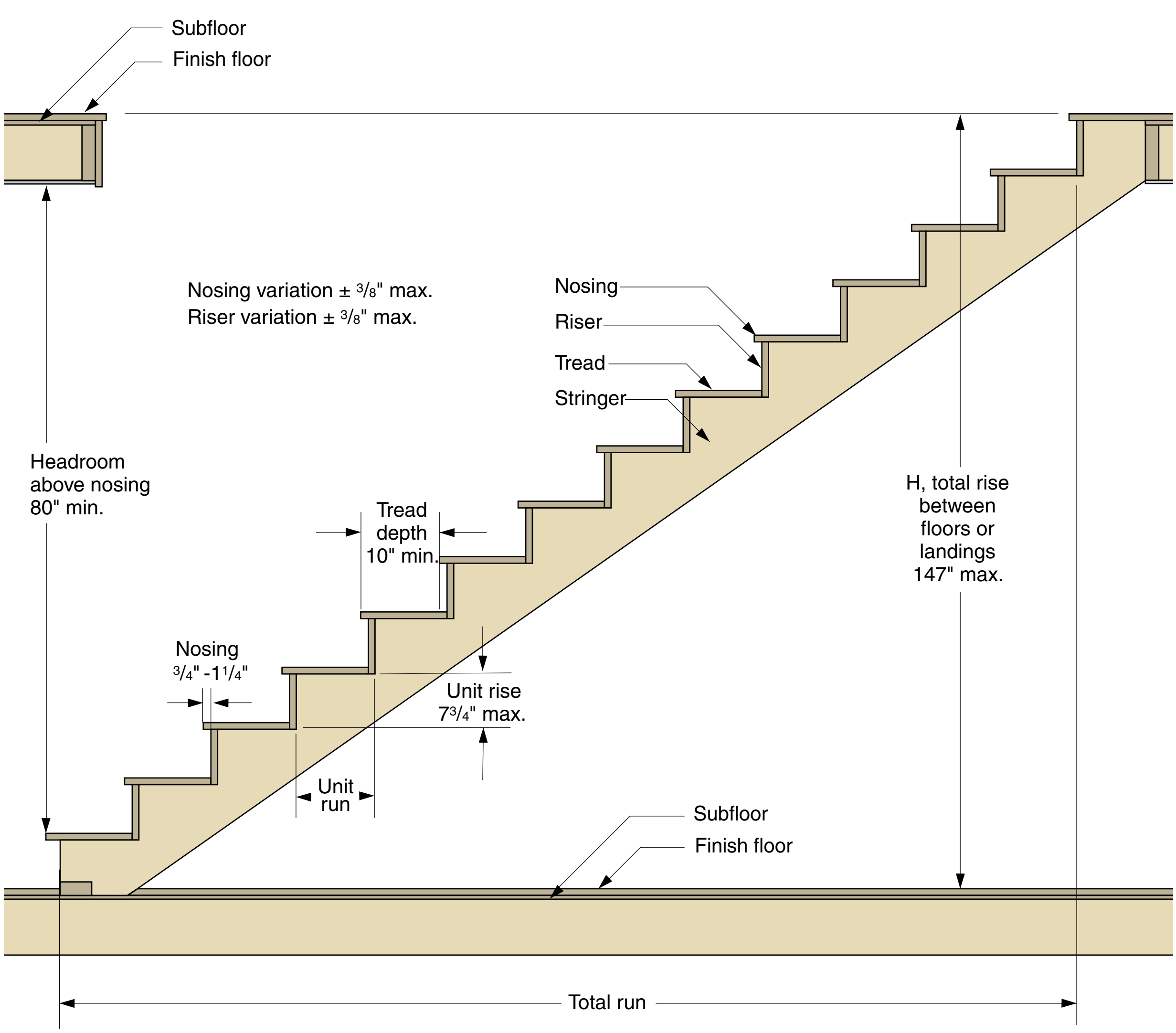
Stairs are the most complicated and difficult element of a building's design. They often serve as a dramatic stage so must be elegant. More important, however, is safety, since tripping and falling down stairs is a leading cause of accidental injury and death.

For this reason, the IRC contains the design requirements covered in pp. 16–21 of Chapter 1.

On the facing page we describe the framing task of laying out the stair stringers so that the finished stairs comply with three critical IRC tread requirements:

- The unit riser must be no more than 7 3/4".
- The tread depth must be at least 10".
- The tread nosing must be from 3/4" to 1 1/4".

Elements and Requirements of Stair Design



Laying Out a Stringer (Example)

Step 1. Measure the total rise, H, between the two finished floors. For example, H = $97^{3}/_{4}$".

Step 2. Determine the unit rise:

Start by dividing H by unit $rise_{max}$, $7^{3}/_{4}$"

$97^{3}/_{4}$" / $7^{3}/_{4}$" = 12.6 risers

Round up to 13 risers and divide H by 13.

Unit rise = $97^{3}/_{4}$" / 13 = 7.52" ($7^{1}/_{2}$")

If superstitious, divide H by 14.

Unit rise = $97^{3}/_{4}$" / 14 = 6.98" (7")

Step 3. Determine the unit run (minimum 10"). Pick a convenient dimension greater than 10". For example, lumberyards sell $11^{1}/_{2}$"-wide treads. With a 1" nosing, the unit run would be $10^{1}/_{2}$".

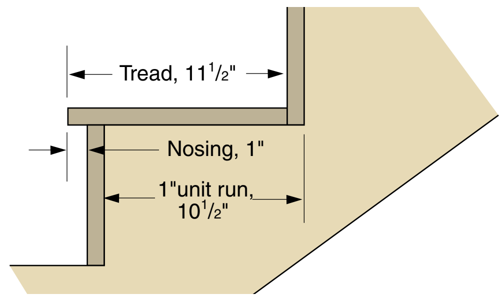
Step 4. Calculate the hypotenuse of the rise/run triangle: hypotenuse = $(\text{unit rise}^2 + \text{unit run}^2)^{1/2}$

$= (7^2 + 10.5^2)^{1/2} = 12.62"$ ($12^{5}/_{8}$")

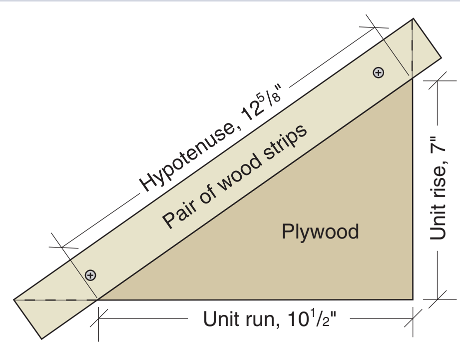
Step 5. Make a rise/run stair jig (see illustration at right).

Step 6. Lay out a stringer. Calculate and, from the right end, mark the 14 multiples of the hypotenuse: 1×$12^{5}/_{8}$", 2 ×$12^{5}/_{8}$", etc. Then slide the stair jig down the stringer drawing the rise and run cut lines.

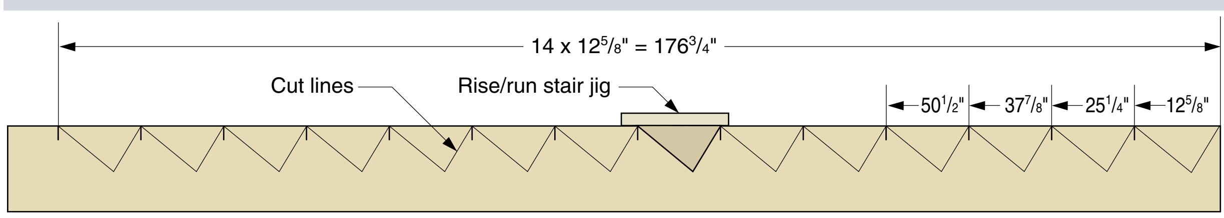
Determining Unit Run (Step 3)



Rise/Run Stair Jig (Step 5)

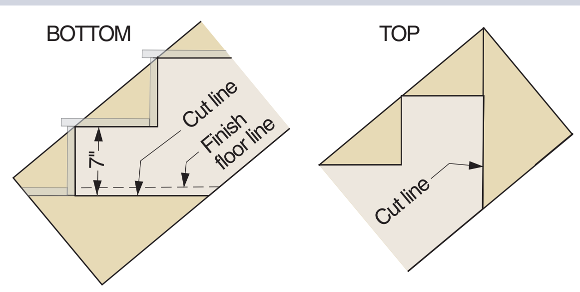


Laying Out a Stringer (Step 6)



Step 7. Mark and cut the top and bottom ends of the stringer as shown. The original stock is the entire width; the finished stringer is shown by the lighter shade.

Finishing the Ends (Step 7)



Meet the Code (IRC)

The following is a partial list of requirements from the *2015 International Residential Code (IRC) for One- and Two-Family Dwellings.* Consult the publication for the full text and additional provisions.

Wood Floor Framing (R502)

- if supported by a wall, decks to be fastened without toenails or nails subject to withdrawal
- joist spans in American Forest & Paper Association℠ (AF&PA) *Span Tables for Joists and Rafters*
- floor cantilever spans not to exceed the nominal depth of the wood floor joist
- joists under parallel bearing partitions to be of adequate size to support load. Double joists, separated for piping or vents, to be solid blocked at ≤4' o.c.
- bearing partitions perpendicular to joists not be offset from supporting girders, walls, or partitions more than joist depth unless joists of sufficient size
- spans of girders fabricated of dimension lumber to be in accordance with AF&PA Span Tables
- ends of joists, beams, and girders to have ≥1 1/2" bearing on wood or metal and ≥3" on masonry or concrete except where supported on a 1×4 ribbon and nailed to the adjacent stud, or by joist hangers
- joists framed from opposite sides over a bearing support to lap ≥3" and be nailed together with ≥3 10d face nails or be spliced for equal strength
- joists butting a wood girder to be supported by framing anchors or ≥2×2 ledger strips
- joists supported at ends by solid blocking, or a header, band, or rim joist, or to an adjoining stud
- joists ≥2×12 nominal supported laterally by solid blocking, diagonal bridging, or a continuous 1×3 strip nailed across bottoms at ≤8' o.c.

Notches in sawn joists, rafters, and beams:

- depth ≤1/6 of member depth, length ≤1/3 of member depth, and not located in middle 1/3 of span
- at the ends, ≤1/4 depth of the member
- tension side of members of ≥4" nominal thickness not to be notched except at ends
- hole diameters ≤D/3 and ≥2" from edges or another hole

Notches in engineered wood products:

- cuts, notches, and holes in trusses, structural composite lumber, structural glue-laminated members, or I-joists are prohibited except where permitted by manufacturer recommendations or professional design

Floor openings:

- floor openings to be framed with header and trimmer joists. When header span ≤4', single header may be same size as floor joist. Single trimmer joists may carry a single header joist located ≤3' of trimmer bearing. When header span >4', trimmers and header to be doubled
- hangers to be used for header to trimmer connection when header span >6'
- tail joists >12' to be supported at header by framing anchors or on ≥2×2 ledger strips

Wood trusses:

- must comply with *National Design Standard for Metal Plate Connected Wood Truss Construction* (ANSI/TPI 1)
- to be braced as shown on truss design drawings
- not to be cut, notched, spliced, or otherwise
- additions of load (e.g., HVAC equipment, water heater, etc.) exceeding design load for the truss not permitted without verification
- truss design drawings to be submitted to building official and provided with delivered trusses

Draftstopping:

- where usable space exists above and below concealed space of a floor/ceiling assembly, draftstops to be installed so area of concealed space ≤1,000 sq ft and divided into equal areas

Wood Wall Framing (R602)

Exterior wall design and construction:

- exterior walls to be in accordance with AF&PA's *National Design Specification (NDS) for Wood Construction*

- exterior walls with foam sheathing to be braced
- structural sheathing fastened directly to framing
- stud walls to have double top plate overlapping at corners and intersections with bearing partitions
- top plate joints offset ≥24"
- single top plate allowed if plate tied at joints, corners, and intersecting walls by a ≥3" × 6" galvanized steel plate nailed by six 8d nails on each side
- where joists, trusses, or rafters are spaced >16" o.c. and bearing studs spaced 24" oc, members to bear within 5" of studs.

Exceptions: 2-2" × 6" top plates, 2-3" × 4" top plates, a third top plate, or solid blocking reinforcing the double top plate

- studs to bear fully on a ≥2" nominal plate

Interior wall design and construction:

- load-bearing walls to be constructed, framed, and fireblocked as specified for exterior walls.
- 2" × 3" @24" o.c. nonbearing walls permitted

Drilling and notching:

- studs in exterior wall or bearing partition may be cut or notched to depth ≤25% of width
- studs in nonbearing partitions may be notched to a depth ≤40% of width
- stud holes ≤60% of width and ≥5/8" from edge
- studs in exterior walls or bearing partitions drilled between 40% and 60% percent to be doubled
- if top plate cut >50% of width, a galvanized metal tie ≥0.054" × 1 1/2" to be fastened both sides with eight 16d nails or equivalent, except if wall covered by wood structural panel sheathing

Fireblocking required in:

- concealed spaces of stud walls and partitions, including furred spaces and parallel rows of studs or staggered studs: vertically at ceiling and floor, and horizontally at intervals not exceeding 10'

Roof Framing (R802)

Design and construction:

- for pitch ≥3/12, rafters fastened to ridge board or gusset plates. Ridge board full depth on cut rafter
- where ceiling joists and rafters not connected at top wall plate, rafter ties required
- where ceiling joists or rafter ties not provided, the ridge to be supported by a wall or girder
- collar ties or ridge straps, spaced ≤4' o.c., to be connected in the upper third of attic space
- ceiling joists to be lapped ≥3" or butted and toe-nailed to a bearing member. Ceiling joists resisting rafter thrust to be fastened to resist such thrust
- ceiling joist and rafter spans as in AF&PA *Span Tables for Joists and Rafters*
- rafter and ceiling joist ends to have ≥1 1/2" bearing on wood or metal and ≥3" on masonry or concrete

Drilling and notching:

- notches in solid lumber joists, rafters, and beams: depth ≤D/6, length ≤D/3, and not in the middle 1/3 of span
- notches at ends of the member ≤D/4
- tension edge if D≥4" not notched except at ends
- hole diameters ≤D/3 and ≥2" from edges or another hole.

Exception: Notch on cantilever permitted if D of remaining portion ≥4" and the length ≤24"

- cuts, notches, and holes in trusses, structural composite lumber, structural glue-laminated members, or I-joists prohibited except where permitted by manufacturer recommendations or professional design
- rafters and ceiling joists >2×10 nominal braced against rotation
- rafters and ceiling joists ≥2×12 supported laterally by solid blocking, diagonal bridging, or a continuous 1×3 strip nailed across bottoms at ≤8' o.c.

Note: The framing of roof openings is the same as floor openings; wood roof trusses are the same as wood floor trusses.

Sheathing

7

If the frame is the building's skeleton, then the sheathing is its skin. Sheathing functions to enclose the building in an airtight barrier, to strengthen its studs, joists, and rafters by tying them together, to brace the building against racking (twisting) under wind and seismic forces, and to provide a base for flooring, siding, and roofing. By far, most sheathing is done with panels manufactured by a member of, and under the inspection of, APA—The Engineered Wood Association. The APA publishes a wide range of builder-oriented literature on its products. Most of the material in this chapter is adapted from its booklet, *Engineered Wood Construction Guide*. The chapter begins by showing and explaining the grade stamps for all of the *APA engineered wood panels*. Next, illustrations and tables show you all you'll ever need to know about *APA subflooring, underlayment, Sturd-I-Floor, glued floor, wall sheathing*, and *roof sheathing*.

Zip System™ sheathing offers an increasingly popular new approach to wall and roof construction adopted by many building contractors, and we illustrate its features.

Finally, we detail the APA Narrow *Wall Bracing* Method to satisfy the bracing requirements of the IRC.

APA Engineered Wood Panels

Panels for construction and industrial applications can be manufactured in a variety of ways: as plywood (cross-laminated wood veneer), as oriented strand board (OSB), or as other wood-based panel products.

Some plywood is manufactured under the provisions of Voluntary Product Standard PS 1-09 for Construction and Industrial Plywood, a detailed manufacturing specification developed cooperatively by the plywood industry and the U.S. Department of Commerce. Other plywood panels, however, as well as composite and OSB panels, are manufactured under the provisions of APA Performance Standard PRP-108, or under Voluntary Product Standard PS 2-04.

These APA performance-rated panels are easy to use and specify because the recommended end use and maximum support spacings are indicated in the APA grade stamp (see illustration at right).

The list at right describes the face (outside) veneer grading system. The panel sides are often of different grade so that less expensive veneers can be used on the side of the panel that will not show.

The tables on the following pages constitute a lumberyard guide to APA sheathing, including veneered and nonveneered panels, and panels intended for exterior and interior conditions.

Bond Classification

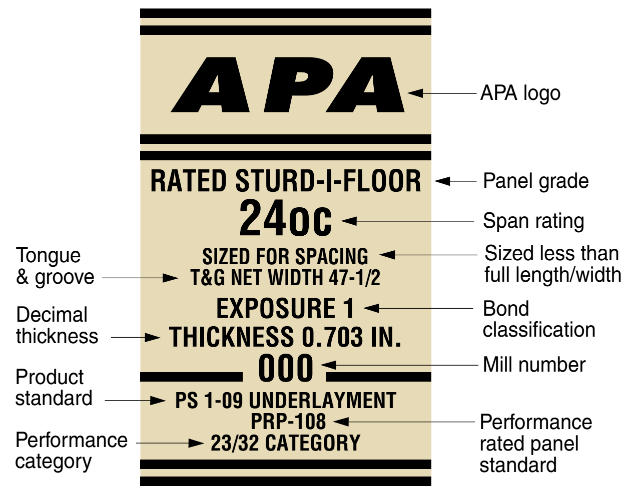
The bond classification relates to moisture resistance of the glue bond, and thus to structural integrity of the panel.

Exterior panels are suitable for repeated wetting and redrying or long-term exposure.

Exposure 1 panels are intended to resist the effects of moisture during construction and for exterior use where not directly exposed to water. Exposure 1 panels are made with the same adhesives used in Exterior panels. However, due to other factors affecting bond performance, only Exterior panels should be used for long-term exposure to weather.

Interior panels are manufactured with interior glue and are intended for interior uses only.

Typical APA Grade Stamp



Plywood Veneer Face Grades

A Smooth, paintable. Not more than 18 neatly made repairs, boat, sled, or router type, and parallel to grain, permitted. Wood or synthetic repairs permitted. May be used for natural finish in less demanding applications.

B Solid surface permits shims, sled or router repairs, tight knots to 1 inch across the grain, and minor splits. Wood or synthetic repairs permitted.

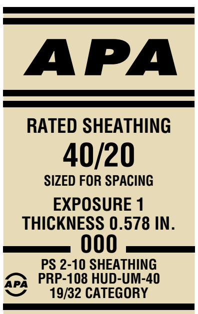
C-Plugged Improved C veneer has splits limited to $1/8$-inch width and knotholes and other open defects limited to $1/4 \times 1/2$ inch. Admits some broken grain. Wood or synthetic repairs permitted.

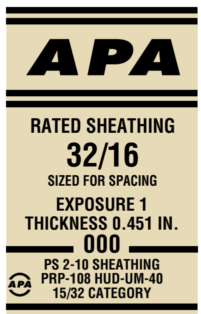
C This veneer has tight knots to $1\frac{1}{2}$ inches. It has knotholes to 1 inch across the grain with some to $1\frac{1}{2}$ inches if the total width of knots and knotholes is within specified limits. Repairs are synthetic or wood. Discoloration and sanding defects that do not impair strength permitted. Limited splits and stitching allowed.

D Knots and knotholes to $2\frac{1}{2}$-inch width across the grain, and $1/2$ inch larger within specified limits, are allowed. Limited splits and stitching permitted. This face grade is limited to Exposure I or Interior panels.

APA Performance-Rated Panels

Typical APA Grade Stamp | **Thicknesses** | **Grade Designation, Description, and Uses**



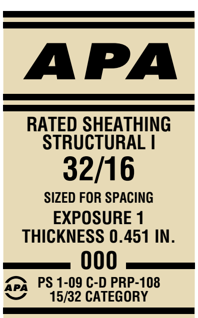


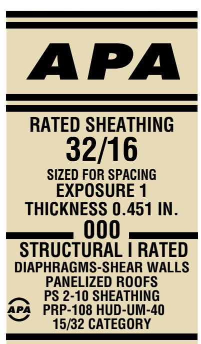
Thicknesses: 3/8, 7/16, 15/32, 1/2, 19/32, 5/8, 23/32, 3/4

APA RATED SHEATHING

Bond Classifications: Exterior, Exposure 1

Specially designed for subflooring and wall and roof sheathing. Also good for a broad range of other construction and industrial applications. Can be manufactured as OSB, plywood, or other wood-based panel.





Thicknesses: 3/8, 7/16, 15/32, 1/2, 19/32, 5/8, 23/32, 3/4

APA STRUCTURAL I RATED SHEATHING

Bond Classifications: Exterior, Exposure 1

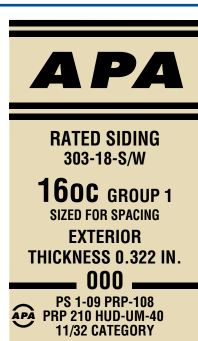
Unsanded grade for use where shear and cross-panel strength properties are of maximum importance, such as panelized roofs and diaphragms. Can be manufactured as OSB, plywood, or other wood-based panel.

Thicknesses: 19/32, 5/8, 23/32, 3/4, 7/8, 1 1/8

APA RATED STURD-I-FLOOR

Bond Classifications: Exterior, Exposure 1

Specially designed as combination subfloor-underlayment. Provides smooth surface for application of carpet and pad and possesses high concentrated and impact load resistance. Can be manufactured as OSB, plywood, or other wood-based panel. Available square edge or tongue-and-groove.



Thicknesses: 11/32, 3/8, 7/16, 15/32, 1/2, 19/32, 5/8

APA RATED SIDING

Bond Classification: Exterior

For exterior siding, fencing, etc. Can be manufactured as plywood, as otherwood-based panel, or as an overlaid OSB. Both panel and lap siding available. Special surface treatment such as V-groove, channel groove, deep groove (such as APA Texture 1-11), brushed, rough sawn, and overlaid (MDO) with smooth- or texture-embossed face. Span rating and face grade classification (for veneer-faced siding) indicated in trademark.

APA Sanded and Touch-Sanded Plywood Panels

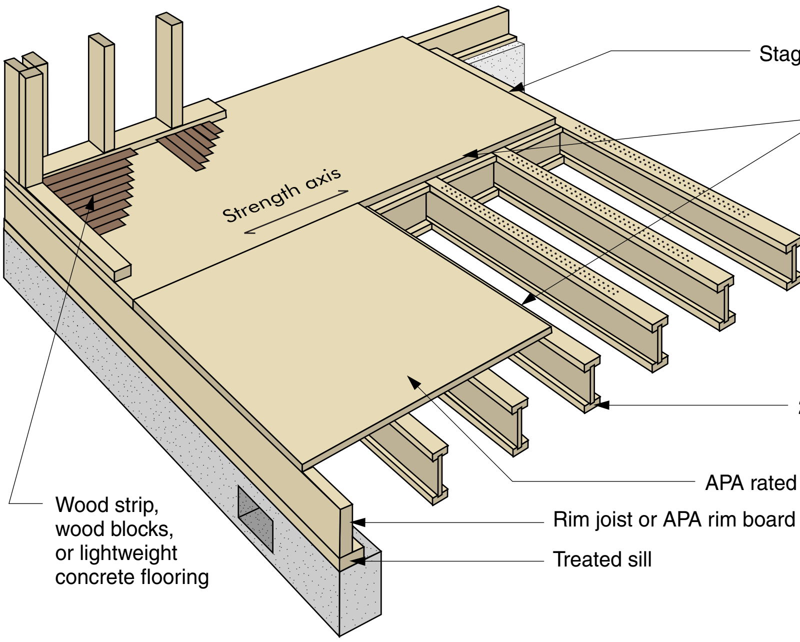
Typical Trademark	Thicknesses	Grade Designation, Description, and Uses
A-A • G-1 • EXT• 0.734 IN. • APA • 000 • PS1-09 • 3/4 CAT	1/4, 11/32 3/8, 15/32 1/2, 19/32 5/8, 23/32 3/4	APA A-A BOND CLASSIFICATIONS: Exposure 1, Exterior Use where appearance of both sides is important for interior applications such as built-ins, cabinets, furniture, partitions; and exterior applications such as fences, signs, boats, shipping containers, tanks, ducts, etc. Smooth surfaces suitable for painting.
A-A • G-1 • EXT• 0.234 IN. • APA • 000 • PS1-09 • 1/4 CAT	1/4, 11/32 3/8, 15/32 1/2, 19/32 5/8, 23/32 3/4	APA A-B BOND CLASSIFICATIONS: Exposure 1, Exterior For use where appearance of one side is less important but where two solid surfaces are necessary.
APA A-C GROUP 1 EXTERIOR THICKNESS 0.703 IN. 000 APA PS 1-09 23/32 CATEGORY	1/4, 11/32 3/8, 15/32 1/2, 19/32 5/8, 23/32 3/4	APA A-C BOND CLASSIFICATION: Exterior For use where appearance of only one side is important in exterior or interior applications, such as soffits, fences, farm buildings, etc.
APA A-D GROUP 1 EXPOSURE 1 THICKNESS 0.328 IN. 000 APA PS 1-09 11/32 CATEGORY	1/4, 11/32 3/8, 15/32 1/2, 19/32 5/8, 23/32 3/4	APA A-D BOND CLASSIFICATION: Exposure 1 For use where appearance of only one side is important in interior applications, such as paneling, built-ins, shelving, partitions, flow racks, etc.
B-B • G-2 • EXT• 0.578 IN. • APA • 000 • PS1-09 • 19/32 CAT	1/4, 11/32 3/8, 15/32 1/2, 19/32 5/8, 23/32 3/4	APA B-B BOND CLASSIFICATIONS: Exposure 1, Exterior Utility panels with two solid sides.
APA B-C GROUP 1 EXTERIOR THICKNESS 0.703 IN. 000 APA PS 1-09 23/32 CATEGORY	1/4, 11/32 3/8, 15/32 1/2, 19/32 5/8, 23/32 3/4	APA B-C BOND CLASSIFICATION: Exterior Utility panel for farm service and work buildings, boxcar and truck linings, containers, tanks, agricultural equipment, as a base for exterior coatings, and other exterior uses or applications subject to high or continuous moisture.

APA Sanded and Touch-Sanded Plywood Panels—*Continued*

Typical Trademark	Thicknesses	Grade Designation, Description, and Uses
APA B-D GROUP 2 EXPOSURE 1 THICKNESS 0.453 IN. 000 PS 1-09 15/32 CATEGORY	1/4, 11/32 3/8, 15/32 1/2, 19/32 5/8, 23/32 3/4	APA B-D BOND CLASSIFICATION: Exposure 1 Utility panel for backing, sides of built-ins, industry shelving, slip sheets, separator boards, bins, and other interior or protected applications.
APA UNDERLAYMENT GROUP 1 EXPOSURE 1 THICKNESS 0.322 IN. 000 PS 1-09 11/32 CATEGORY	1/4, 11/32 3/8, 15/32 1/2, 19/32 5/8, 23/32 3/4	APA UNDERLAYMENT BOND CLASSIFICATION: Exposure 1 For application over structural subfloor. Provides smooth surface for application of carpet and pad and possesses high concentrated and impact load resistance. For areas to be covered with resilient flooring, specify panels with "sanded face."
APA C-C PLUGGED GROUP 2 EXTERIOR THICKNESS 0.451 IN. 000 PS 1-09 15/32 CATEGORY	11/32, 3/8, 15/32, 1/2, 19/32, 5/8, 23/32, 3/4	APA C-C PLUGGED BOND CLASSIFICATION: Exterior For use as an underlayment over structural subfloor, refrigerated or controlled atmosphere storage rooms, open soffits, and other similar applications where continuous or severe moisture may be present. Provides smooth surface for application of carpet and pad and possesses high concentrated and impact load resistance. For areas to be covered with resilient flooring, specify panels with "sanded face."
APA C-D PLUGGED GROUP 2 EXPOSURE 1 THICKNESS 0.451 IN. 000 PS 1-09 15/32 CATEGORY	3/8, 15/32 1/2, 19/32 5/8, 23/32 3/4	APA C-D PLUGGED BOND CLASSIFICATION: Exposure 1 For open soffits, built-ins, cable reels, separator boards, and other interior or protected applications. Not a substitute for underlayment or APA rated Sturd-I-Floor as it lacks their puncture resistance.

APA Subflooring

APA Panel Subflooring Details



Notes:
Provide adequate moisture control and use ground cover vapor retarder in crawl space. Subfloor must be dry before applying subsequent layers.

For buildings with wood- or steel-framed walls, provide 3/4" expansion joints with separate floor framing members and discontinuous wall plates over the joints, at intervals that limit continuous floor areas to 80 feet maximum in length or width, to allow for accumulated expansion during construction in wet weather conditions.

APA Panel Subflooring (APA Rated Sheathing)[1]

Panel Span Rating	Performance Category (in.)	Maximum Span (in.)	Nail Size and Type[4]	Maximum Nail Spacing, (in.)	
				Supported Panel Edges[5]	Intermediate Supports
24/16	7/16	16	6d common	6	12
32/16	15/32, 1/2	16	8d common[2]	6	12
40/20	19/32, 5/8	20[3]	8d common	6	12
48/24	23/32, 3/4	24	8d common	6	12
60/32	7/8	32	8d common	6	12

Source: *Engineered Wood Construction Guide, Form E30W* (Tacoma, Wash.: APA–The Engineered Wood Association, 2016)

1 APA rated Sturd-I-Floor may be substituted when span rating is ≥ tabulated maximum span.

2 6d common nail permitted if panel has a Performance Category of 1/2 or smaller.

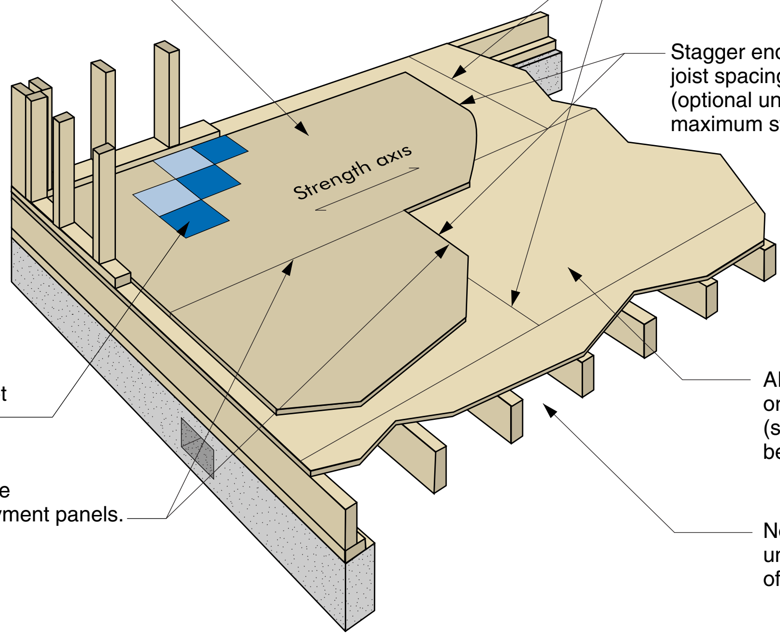
3 Span may be 24" if a minimum of 1 1/2" of lightweight concrete is applied over panels.

4 Other code-approved fasteners may be used.

5 Supported panel joints to lie along the centerline of framing with ≥1 1/2" bearing. Fasteners to be 3/8" from panel edges.

APA Underlayment

APA Plywood Underlayment Details



APA Plywood Underlayment

Plywood Grades[1]	Application	Minimum Thickness (in.)	Fastener Size and Type[2]	Max. Fastener Spacing[4] Panel Edges[3]	Max. Fastener Spacing[4] Intermediate Supports
APA Underlayment APA C-C Plugged Ext	Over smooth subfloor	$^{1}/_{4}$	3d × $1^{1}/_{4}$" ring-shank nails[2]	3"	6 each way
Rated Sturd-I-Floor ($^{19}/_{32}$" or thicker)	Over lumber subfloor or uneven surfaces	$^{11}/_{32}$	min. $12^{1}/_{2}$-ga (0.099") shank dia.	6"	8 each way

Source: *Engineered Wood Construction Guide, Form E30W* (Tacoma, Wash.: APA–The Engineered Wood Association, 2016)

[1] In areas to be finished with resilient floor coverings such as tile or sheet vinyl, or with fully adhered carpet, specify Underlayment, C-C Plugged, or veneer-faced Sturd-I-Floor with "sanded face." Underlayment A-C, Underlayment B-C, Marine Ext, or sanded plywood grades marked "Plugged Crossbands Under Face," "Plugged Crossbands (or Core)," "Plugged Inner Plies," or "Meets Underlayment Requirements" may also be used under resilient floor coverings.

[2] Use 4d × $1^{1}/_{2}$" ring- or screw-shank nails, minimum $12^{1}/_{2}$ gauge (0.099") shank diameter, for underlayment panels with a Performance Category of $^{19}/_{32}$" to $^{3}/_{4}$" thick.

[3] Fasten panels $^{3}/_{8}$" from panel edges.

[4] Fasteners for 5-ply plywood underlayment panels and for panels with a Performance Category greater than $^{1}/_{2}$ may be spaced 6 inches on center at edges and 12" each way intermediate.

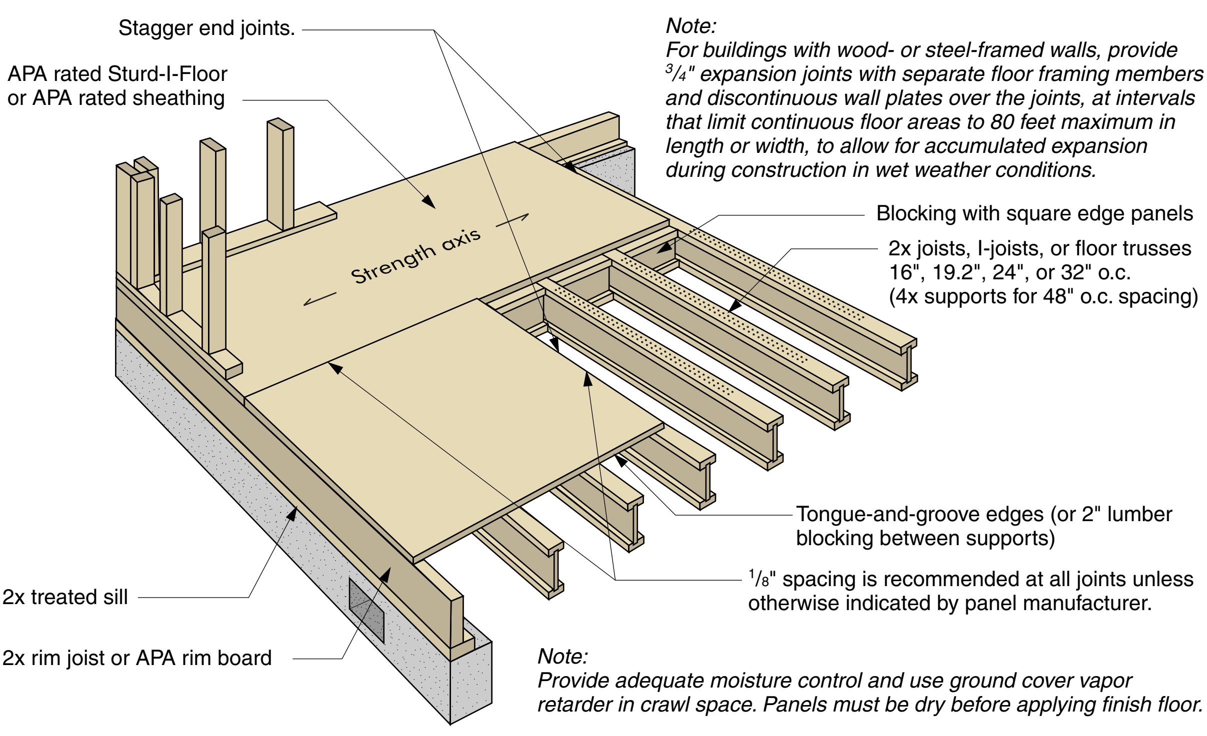
APA Sturd-I-Floor

The APA Rated Sturd-I-Floor is a span-rated APA proprietary product designed specifically for use in single-layer floor construction beneath carpet and pad. The product provides cost-saving and performance benefits of combined subfloor-underlayment construction. It is manufactured in conformance with APA PRP-108 Performance Standards and/or Voluntary Product Standard PS 1 or PS 2. It's easy to use because the maximum recommended spacing of floor joists (span rating) is stamped on each panel. Panels are manufactured with span ratings of 16, 20, 24, 32, and 48 inches. *These assume that use of the panel is continuous over two or more spans with the long dimension or strength axis across supports.*

G1ue-nailing is recommended for Sturd-I-Floor panels, though panels may be nailed only. Recommendations for both methods are given in the top table on the facing page. (See "APA Glued Floor," p. 208, for more detailed gluing recommendations.) Recommended live loads are given in the bottom table on the facing page.

Although Sturd-I-Floor is suitable for direct application of carpet and pad, an additional thin layer of underlayment is recommended under tile, sheet flooring or fully adhered carpet. The added layer restores a smooth surface over panels that may have been scuffed or roughened during construction, or over panels that may not have received a sufficiently sanded surface. When veneer-faced Sturd-I-Floor with "sanded face" is specified, the surface is also suitable for direct application of resilient floor covering. Glued tongue-and-groove edges are recommended under thin floor coverings to ensure snug joints.

APA Rated Sturd-I-Floor Details



APA Rated Sturd-I-Floor[1]

Joist Spacing (in., max.)	Panel Thickness[2] (in.)	Fastening: Glue-Nailed[3] Nail Size and Type	Glue-Nailed Maximum Spacing (in.)[8] Supported Panel Edges[7]	Glue-Nailed Maximum Spacing (in.)[8] Intermediate Supports	Fastening: Nailed-Only Nail Size and Type	Nailed-Only Maximum Spacing (in.)[8] Supported Panel Edges[7]	Nailed-Only Maximum Spacing (in.)[8] Intermediate Supports
16	19/32, 5/8	6d ring- or screw-shank[4]	6[9]	12	6d ring- or screw-shank	6	12
20	19/32, 5/8	6d ring- or screw-shank[4]	6[9]	12	6d ring- or screw-shank	6	12
24	23/32, 3/4	6d ring- or screw-shank[4]	6[9]	12	6d ring- or screw-shank	6	12
	7/8	8d ring- or screw-shank[4]	6	12	8d ring- or screw-shank	6	12
32	7/8	8d ring- or screw-shank[4]	6	12	8d ring- or screw-shank	6	12
48	1 3/32, 1 1/8	8d ring- or screw-shank[5]	6	see ([6])	8d ring- or screw-shank[5]	6	see ([6])

[1] Special conditions may impose heavy traffic and concentrated loads that require construction in excess of the minimums shown.

[2] Panels in a given performance category may be manufactured in more than one span rating. Panels with a span rating greater than the actual joist spacing may be substituted for panels of the same performance category with a span rating matching the actual joist spacing. For example, performance category 19/32 Sturd-I-Floor 20 o.c. may be substituted for performance category 19/32 16 o.c. over joists 16 inches on center.

[3] Use only adhesives conforming to APA Specification AFG-01 or ASTM D3498, applied in accordance with the adhesive manufacturer's recommendations. If OSB panels with sealed surfaces and edges are to be used, use only solvent-based glues; check with panel manufacturer.

[4] 8d common nails may be substituted if ring- or screw-shank nails are not available.

[5] 10d common nails may be substituted with 1 1/8" panels if supports are well seasoned.

[6] Space nails maximum 6" for 48" spans and 12" for 32" spans.

[7] Supported panel joints shall occur approximately along the centerline of framing with a minimum bearing of 1/2". Fasten panels 3/8" from panel edges.

[8] Increased nail schedules may be required where floor is engineered as a diaphragm.

[9] Check with local building official; some local jurisdictions permit nail spacing at 12" o.c.

Recommended Uniform Floor Live Loads for APA Rated Sturd-I-Floor and APA Rated Sheathing with Strength Axis Perpendicular to Supports

Sturd-I-Floor Span Rating	Sheathing Span Rating	Minimum Thickness (in.)	Maximum Span (in.)	Allowable Live Loads, psf[1] — Joist Spacing, in. 12	16	20	24	32	40	48
16 o.c.	24/16, 32/16	7/16 [3]	16	185	100	–	–	–	–	–
20 o.c.	40/20	19/32	19.2	270	150	100	–	–	–	–
24 o.c.	48/24	23/32	24	430	240	160	100	–	–	–
32 o.c.	60/32[2]	7/8	32	–	430	295	185	100	–	–
48 o.c.	–	1 3/32	48	–	–	460	290	160	100	55

[1] 10 psf dead load assumed. Live load deflection limit is 1/360.

[2] Check with suppliers for availability.

[3] 19/32" is minimum performance category of APA rated Sturdi-I-Floor.

APA Glued Floor

The APA glued floor system is based on field-applied construction adhesives that secure wood structural panels to wood joists. The glue bond is so strong that floor and joists behave like integral T-beam units. Floor stiffness is increased appreciably over conventional construction, particularly when tongue-and-groove joints are glued. Gluing also helps eliminate squeaks, floor vibration, bounce, and nail-popping.

Panels recommended for glued floor construction are T&G APA Rated Sturd-I-Floor for single-floor construction, and APA Rated Sheathing for the subfloor when used with a separate underlayment or with structural finish flooring.

Before each panel is placed, a line of glue is applied to the joists with a caulking gun. The panel T&G joint should also be glued. If square-edge panels are used, edges must be supported between joists with 2×4 blocking. Glue panels to blocking to minimize squeaks. Blocking is not required under structural finish flooring or separate underlayment.

Application

1. Snap a chalk line across joists 4' from wall for panel edge alignment and as a glue boundary.

2. Spread glue to lay 1 or 2 panels at a time.

3. Lay first panel tongue side to wall, tap into place with block and sledgehammer, and nail.

4. Apply a 1/4" line of glue to framing members. Apply glue in a serpentine pattern on wide areas.

5. Apply two lines of glue on joists where panel ends butt to ensure proper gluing of each end.

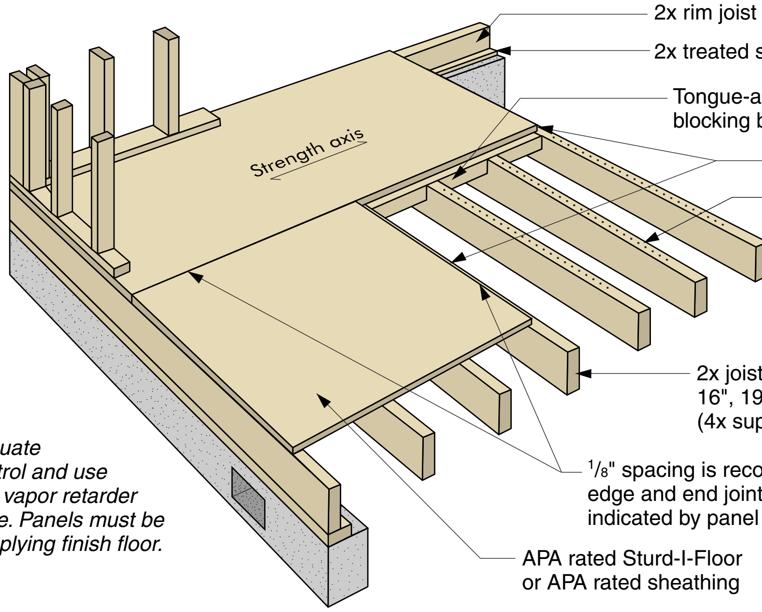
6. After first row is in place, spread glue in groove of 1 or 2 panels at a time before laying next row.

7. Tap second-row panels into place, using a block to protect groove edges.

8. Stagger end joints. A 1/8" space between end joints and edges, including T&G, is recommended.

9. Complete all nailing of each panel before glue sets.

APA Glued Floor Details

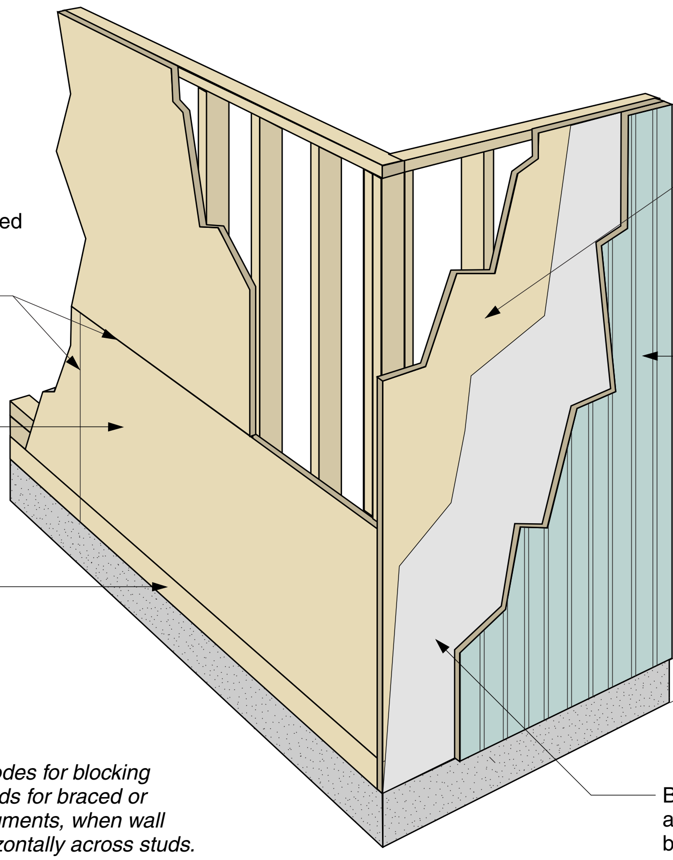


Note 1: Provide adequate moisture control and use ground cover vapor retarder in crawl space. Panels must be dry before applying finish floor.

Note 2: For buildings with wood- or steel-framed walls, provide 3/4" expansion joints with separate floor framing members and discontinuous wall plates over the joints, at intervals that limit continuous floor areas to 80 feet maximum in length or width, to allow for accumulated expansion during construction in wet weather conditions.

APA Wall Sheathing

APA Panel Wall Sheathing Details



(a) Check local building codes for blocking requirements between studs for braced or engineered shear wall segments, when wall sheathing is installed horizontally across studs.

APA Rated Sheathing Applied Direct to Studs[1, 2, 3]

Minimum Nail		Minimum Structural Panel Span Rating	Minimum Panel Performance Category (in.)	Stud Spacing (in. o.c.)	Panel Nail Spacing		Ultimate Design Wind Speed (mph)		
Shank Diameter (in.)	Minimum Penetration (in.)				Edges (in. o.c.)	Field (in. o.c.)	Wind Exposure Category B	C	D
0.113	1.5	24/0, Wall-16, 24	3/8	16	6	12	140	115	110
0.113	1.5	24/16, Wall-24	7/16	16	6	12	140	130	115
0.113	1.5	24/16, Wall-24	7/16	16	6	6	190	160	140
0.131	1.75	24/16, Wall-24	7/16	16	6	12	170	140	135
0.131	1.75	24/16, Wall-24	7/16	16	6	6	190	160	140
0.131	1.75	24/16, Wall-24	7/16	24 or less	6	12	140	115	110

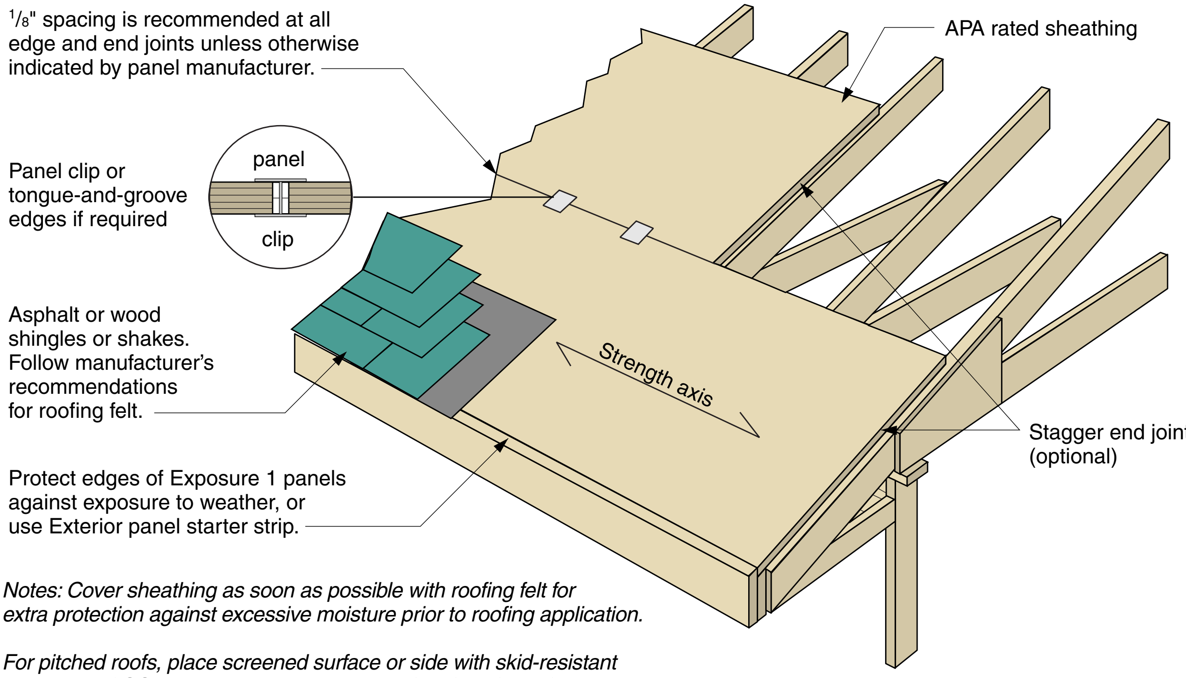
1 Panel strength axis parallel or perpendicular to supports. Three-ply plywood sheathing with studs spaced more than 16 inches on center shall be applied with panel strength axis perpendicular to supports.

2 Effective area, per Chapter 30 of ASCE 7-10 and Section R301.2 of the 2015 IRC, stud specific gravity = 0.42.

3 Supported panel joints shall occur approximately along the center line of framing with a minium bearing of 1/2 inch.

APA Roof Sheathing

APA Panel Roof Sheathing Details



Notes: Cover sheathing as soon as possible with roofing felt for extra protection against excessive moisture prior to roofing application.

For pitched roofs, place screened surface or side with skid-resistant coating up if OSB panels are used. Keep roof surface free of dirt, sawdust, and debris, and wear skid-resistant shoes when installing roof sheathing.

For buildings with conventionally framed roofs (trusses or rafters), limit the length of continuous sections of roof area to 80 feet maximum during construction, to allow for accumulated expansion in wet weather conditions. Omit roof sheathing panels in each course of sheathing between sections, and install "fill in" panels later to complete roof deck installation prior to applying roofing.

Recommended Maximum Spans for APA Panel Roof Decks for Low Slope Roofs[1] (Panel perpendicular to supports and continuous over two or more spans)

Grade	Minimum Nominal Panel Thickness (in.)	Minimum Span Rating	Maximum Span (in.)	Panel Clips per Span[2]
APA rated sheathing	15/32	32/16	24	1
	19/32	40/20	32	1
	23/32	48/24	48	2
	7/8	60/32	60	2
APA rated Sturdi-I-Floor	19/32	20 o.c.	24	1
	23/32	24 o.c.	32	1
	7/8	32 o.c.	48	2

[1] Low-slope roofs are applicable to built-up, single-ply, and modified bitumen roofing systems. For guaranteed or warranted roofs, contact membrane manufacturer for acceptable deck. Low-slope roofs have a slope that is less than 2/12 (2 inches/foot).

[2] Edge support may also be provided by tongue-and-groove edges or solid blocking.

Recommended Uniform Roof Live Loads for APA Rated Sheathing[1] and APA Rated Sturd-I-Floor with Strength Axis Perpendicular to Supports[2]

Panel Span Rating	Minimum Panel Performance Category (in.)	Maximum Span (in.)		Allowable Live Loads, psf[4]							
				Joist Spacing (in.)							
		With Edge Support[3]	Without Edge Support	12	16	20	24	32	40	48	60
APA Rated Sheathing[1]											
12/0	3/8	12	12	30	–	–	–	–	–	–	–
16/0	3/8	16	16	70	30	–	–	–	–	–	–
20/0	3/8	19.2	19.2	120	50	30	–	–	–	–	–
24/0	3/8	24	19.2[5]	190	100	60	30	–	–	–	–
24/16	7/16	24	24	190	100	65	40	–	–	–	–
32/16	15/32	32	28	300	165	110	65	30	–	–	–
40/20	19/32	40	32	–	275	195	120	60	30	–	–
48/24	23/32	48	36	–	–	270	175	95	45	30	–
60/32[6]	7/8	60	40	–	–	–	305	165	100	70	35
60/48[6]	1 1/8	60	48	–	–	–	305	165	100	70	35
APA Rated Sturd-I-Floor[7]											
16 o.c.	19/32	24	24	185	100	65	40	–	–	–	–
20 o.c.	19/32	32	32	270	150	100	60	30	–	–	–
24 o.c.	23/32	48	36	–	240	160	100	50	30	20	–
32 o.c.	7/8	48	40	–	–	295	185	100	55	35	–
48 o.c.	1 3/32	60	48	–	–	–	290	160	100	65	40

[1] Includes APA rated sheathing/Ceiling Deck.

[2] Applies to APA rated sheathing and APA rated Sturd-I-Floor panels 24 inches or wider applied over two or more spans.

[3] Tongue-and-groove edges, panel edge clips (one midway between each support, except two equally spaced between supports 48 inches on center or greater), lumber blocking, or other.

[4] 10 psf dead load assumed.

[5] 19.2 inches for Performance Category 3/8 and 7/16 panels. 24 inches for Performance Category 15/32 and 1/2 panels.

[6] Check with supplier for availability.

[7] Also applies to C-C Plugged grade plywood.

Recommended Minimum Fastening Schedule for APA Panel Roof Sheathing (Increased nails schedules may be required in high wind zones and where roof is engineered as a diaphragm.)

Panel Performance Category[3]	Nail Size	Maximum Nail[1,2] Spacing (in.)	
		Supported Panel Edges[4]	Intermediate
5/16 to 1	8d	6	12[5]
1 1/8	8d or 10d	6	12[5]

[1] Use common smooth or deformed shank nails for panels Performance Category 1 or smaller. For 1 1/8 Performance Category panels, use 8d ring- or screw-shank or 10d common smooth-shank nails.

[2] Other code-approved fasteners may be used.

[3] For stapling asphalt shingles to Performance Category 3/8 inch and thicker panels, use staples with a 15/16-inch minimum crown width and a 1-inch leg length. Space according to shingle manufacturer's recommendations.

[4] Supported panel joints shall occur approximately along the centerline of framing with a minimum bearing of 1/2 inch. Fasteners shall be located 3/8 inch from panel edges.

[5] For spans 48 inches or greater, space nails 6 inches at all supports.

Zip System Sheathing

All-in-one Zip System sheathing panels are engineered to accomplish five tasks in creating energy efficient walls and roofs:

1. Provide a nailable base for siding and trim.

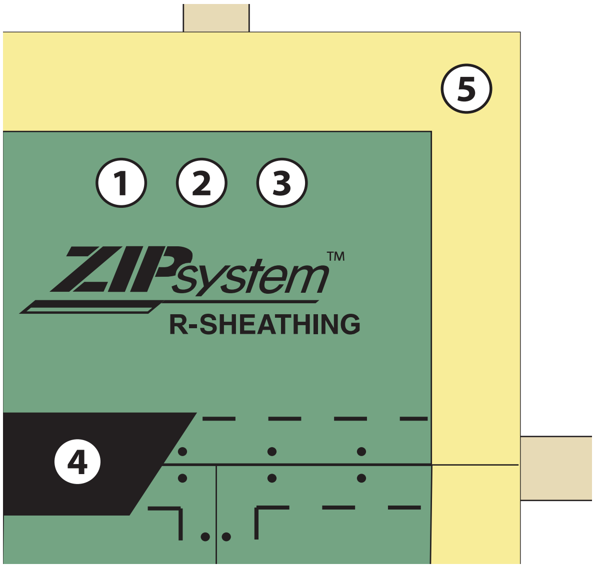
2. Provide shear resistance (bracing) against wind and seismic forces.

3. Provide a water resistive but vapor permeable barrier that resists water intrusion and allows escape of interior water vapor.

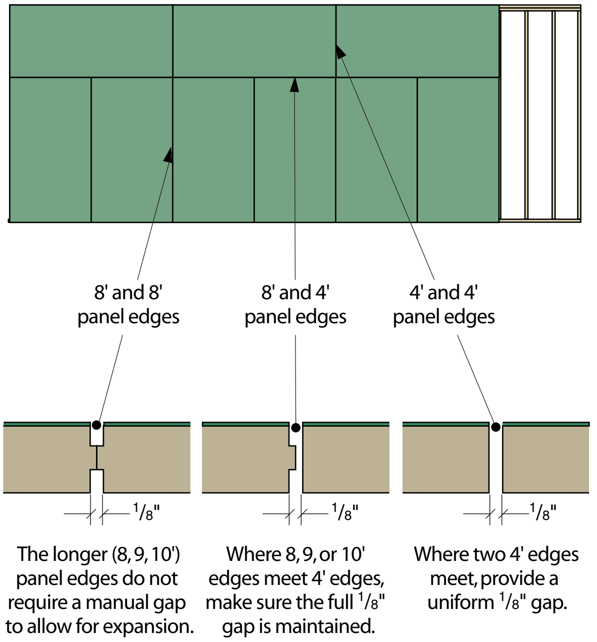
4. Provide a continuous air barrier (using Zip System tape to seal joints between panels) to reduce the energy losses of infiltration.

5. For the R-sheathing product, increase wall or roof R-value by up to 12.0 through the addition of integral foam sheathing.

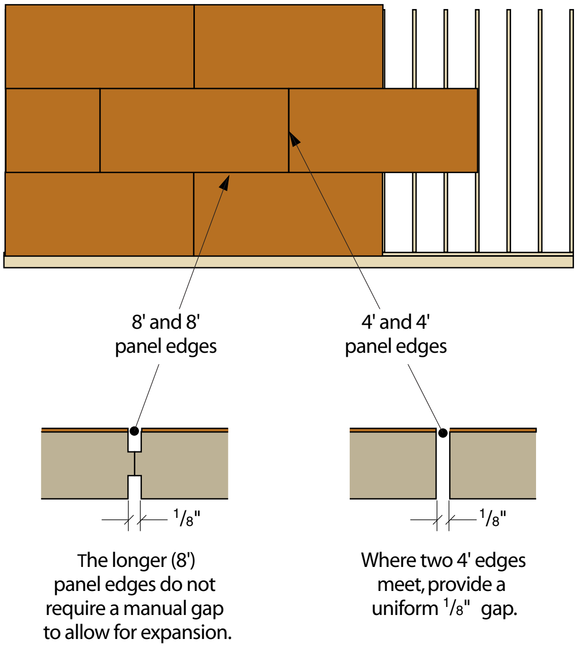
5-in-1 Zip System



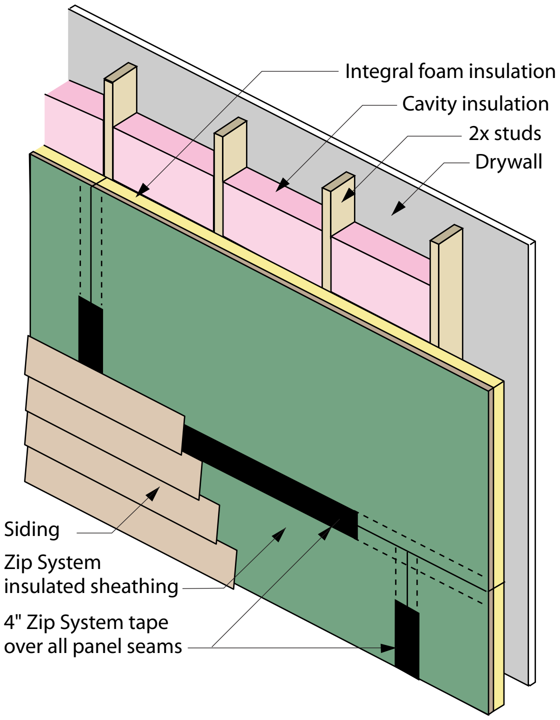
Zip System Wall Sheathing

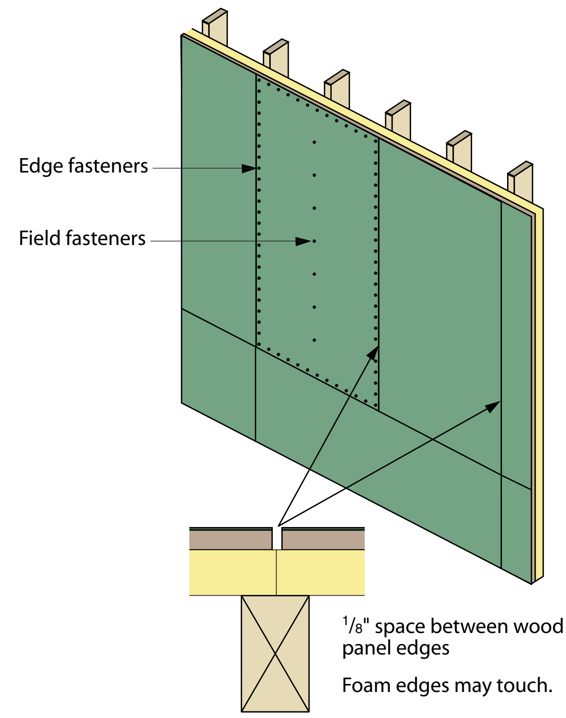


Zip System Roof Sheathing



Zip System R-Sheathing





Fastening and Shear Capacity for Zip System R-sheathing with Douglas Fir-Larch[1] Framing for Wind or Seismic Loading Under the 2012 and 2009 IBC[2,3]

Zip System Type[4]	Nominal Stud Size	Maximum Stud Spacing, in.	Fastener Specification[5]	Edge/Field Spacing, in.	Min. Framing Penetration, in.	Allowable Shear Capacity[6,7]
R-3	2×4	24	0.131″ shank nails	4/12	1.5	245
R-6	2×4	24	0.131″ shank nails	4/12	1.5	NA[8]
R-6	2×4	24	0.131″ shank nails	3/6	1.5	215
R-3	2×4	16	16ga staples, 7/16″ crown, 2″ length	3/6	1.0	210
R-6	2×4	24	15ga staples, 7/16″ crown, 2.5″ length	3/6	1.0	NA[8]

1 For framing of other species, the shear value above must be multiplied by the Specific Gravity Adjustment Factor = [1 - (0.50 - SG)], where SG=Specific Gravity of the framing lumber in accordance with the AF&PA NDS. This adjustment factor must not be greater than 1.

2 Not approved for use as prescriptive wall bracing where the design wind speed is greater than 110 mph or in Seismic Design Categories D or E.

3 Not approved to resist shear in wood-framed shear walls located in Seismic Design Categories D or E.

4 Type R-6 R-sheathing panels have a foam plastic insulation thickness of 1". Type R-3 R-sheathing panels have a foam plastic insulation thickness of 0.5". Type R-12 R-sheathing panels have a foam plastic insulation thickness of 2".

5 Fasteners must be common nails or equivalent, or staples, of a type generally used to attach wood sheathing.

6 The shear walls must have a maximum height-to-width aspect ratio of 2:1.

7 The allowable shear capacity may be increased by 40% for wind in Allowable Stress Design in accordance with Section 2306.3 of the 2012 and 2009 IBC.

8 This panel and fastening configuration is applicable to the prescriptive bracing requirements under the 2009 IRC.

Wall Bracing

The APA Narrow Wall Bracing Method was developed to permit narrow wall segments while satisfying the stringent wall bracing requirements of the IRC.

The method: Sheathe exterior walls with plywood or OSB and install headers extending beyond openings. The lapped-header/sheathing combination forms a semi-moment-resisting frame that provides greater resistance to wind and earthquake. Braced wall segments can be as narrow as 16 inches and hold-downs are not required. See pp. 215–217 for details.

The IRC (Section R602.10.5) allows for wall segments as narrow as 24 inches, but the APA Narrow Wall Bracing Method (Section R602.10.6) adds enough structural support to safely reduce bracing width to 16 inches. As shown below, both methods can be used all around the house at garage, window, and door openings, creating a more pleasing appearance both inside and out. The table below summarizes minimum allowable bracing widths permitted by the IRC.

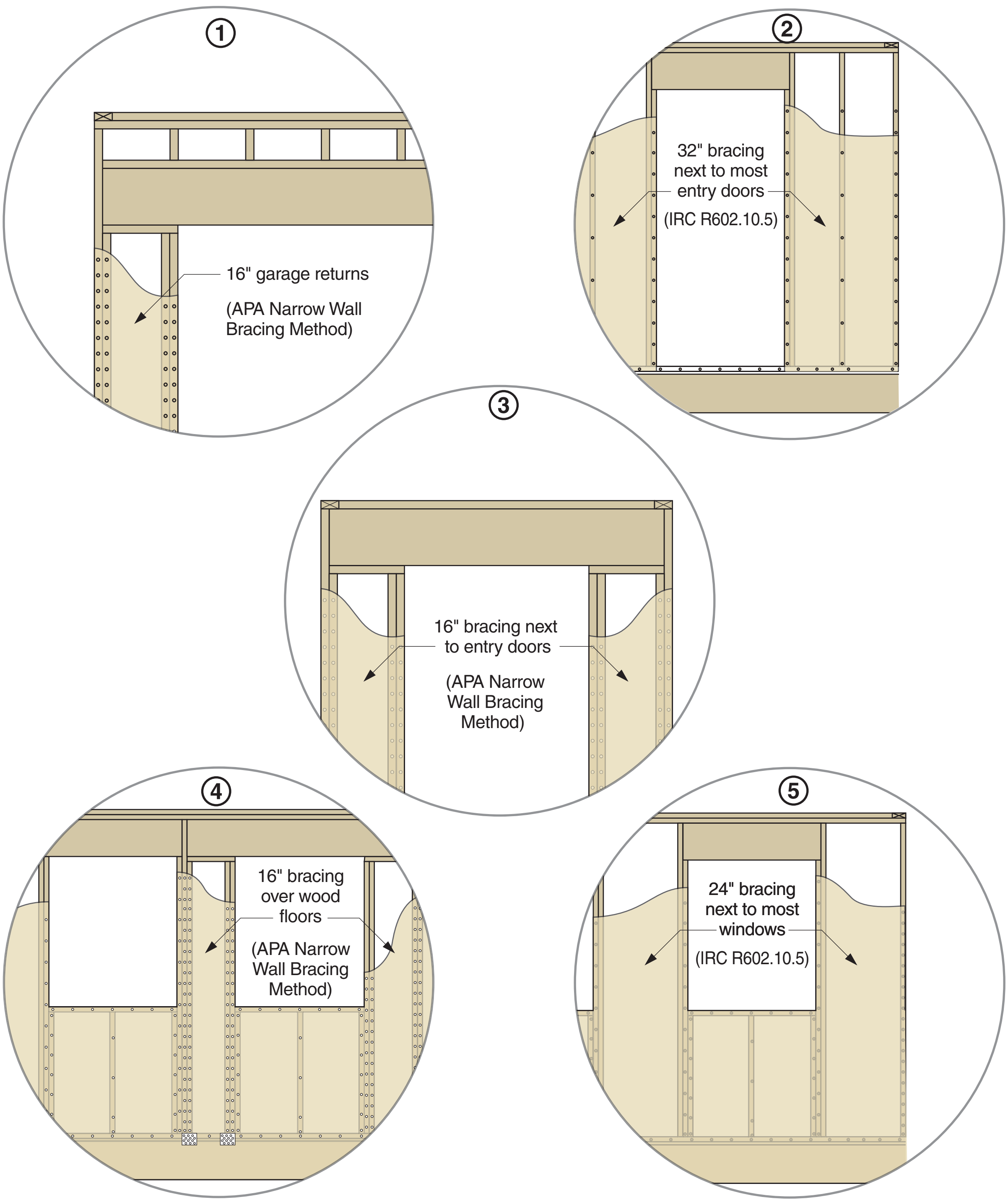
Narrow Bracing Options for a Fully Sheathed Home (see details on facing page)

Allowable Bracing Segment Widths for Fully Sheathed Homes

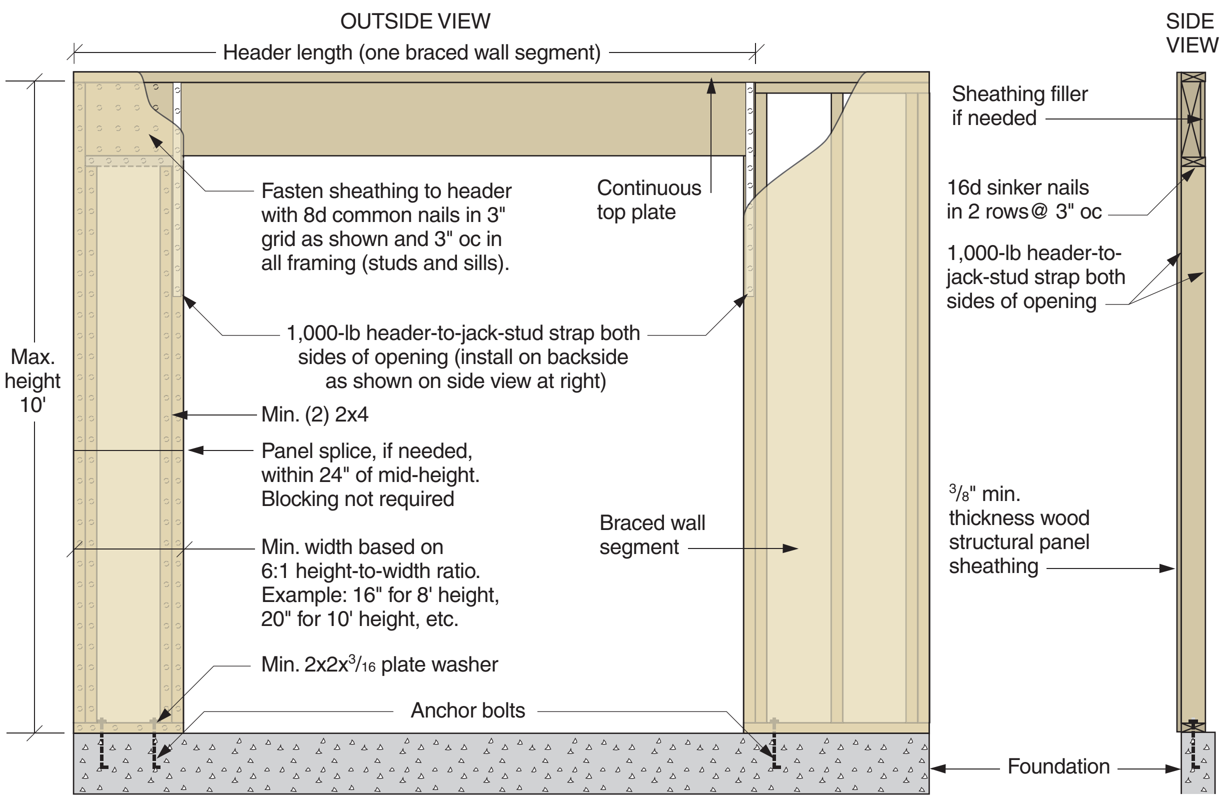
Bracing Construction	Minimum Width of Braced Wall Panel for Wall Height of: 8 feet	9 feet	10 feet	Maximum Opening Height Next to the Braced Wall
IRC R602.10.5 (See Details 2, 5 at right)	32"	36"	40"	85% of wall height
	24"	27"	30"	65% of wall height
APA Narrow Wall[1] Bracing (See Details 1,3,4)	16"	18"	20"	to bottom of header

[1] The minimum width of braced wall segment for the APA Method is based on the height from the top of the header to the bottom of the sill plate. Framing, such as a cripple wall, may be built on top of the header, but it does not affect the height used to determine the minimum braced wall segment width.

Narrow Wall Bracing Details

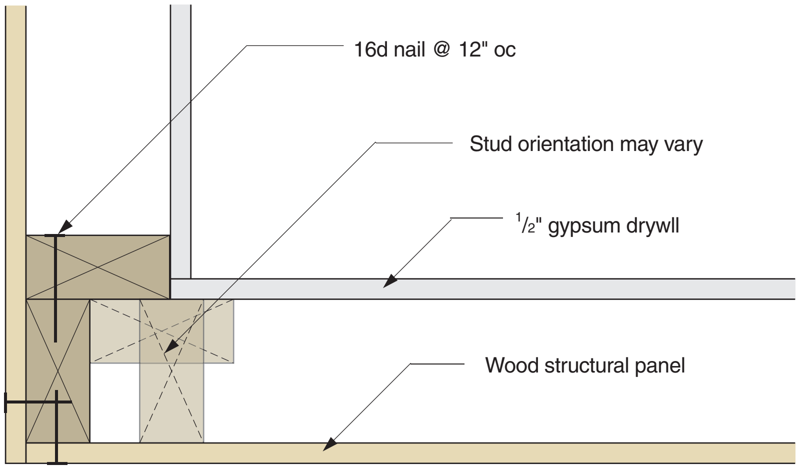


Narrow Wall over Concrete or Masonry Block Foundation

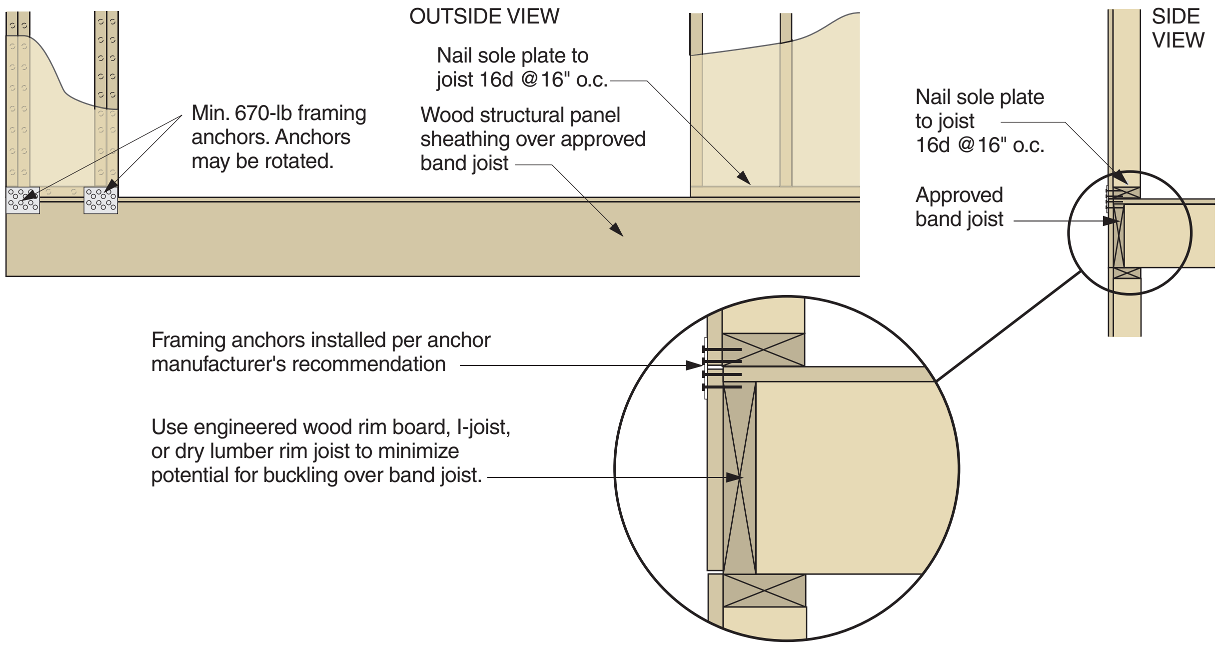


Example of Outside Corner Detail

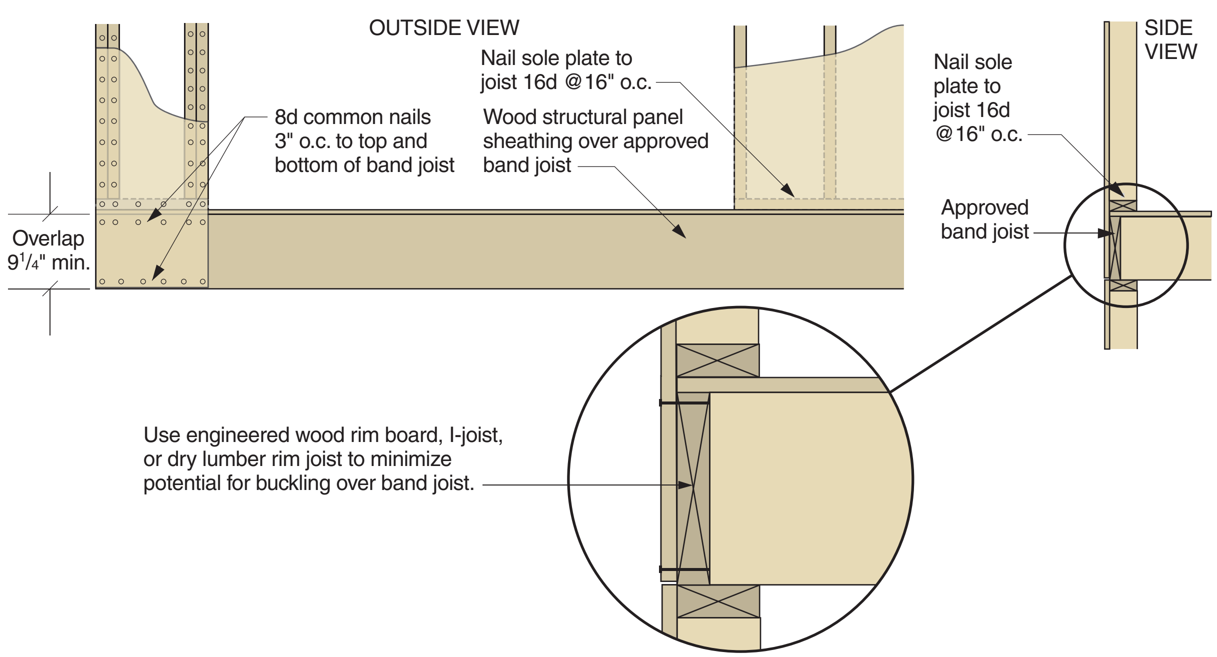
Connect the two walls as shown to provide overturning restraint. The fully sheathed wall line perpendicular to the narrow bracing segment helps reduce the overturning force because the overturning moment acts over a longer distance.



Narrow Wall over Raised Wood Floor or Second Floor—Framing Anchor Option



Narrow Wall over Raised Wood Floor or Second Floor—Panel Overlap Option



8

Siding

The first section identifies the *function of siding* (protection of the walls from moisture) and illustrates the three principles all sidings must follow.

Next, the advantages and disadvantages of all of the common *siding choices* are compared.

The rest of this chapter is filled with illustrations and tables designed to help you successfully install *vinyl siding, fiber-cement lap siding, hardboard lap siding, cedar shingles*, the various *horizontal wood sidings, vertical wood sidings*, combined *plywood siding*, and *stucco*.

Asbestos has been banned from all new construction and poses a dilemma to buyers and owners of homes with existing asbestos siding, so we offer a number of *asbestos siding solutions*.

Finally, we provide you with a checklist of requirements to *meet the code (IRC)*.

The Function of Siding

Aside from decoration and a sometimes dual role as structural sheathing, the function of siding is to keep the structure and interior of a building dry. If the siding is painted, it must be allowed to dry from both sides. Water penetrates siding in one or more of three ways:

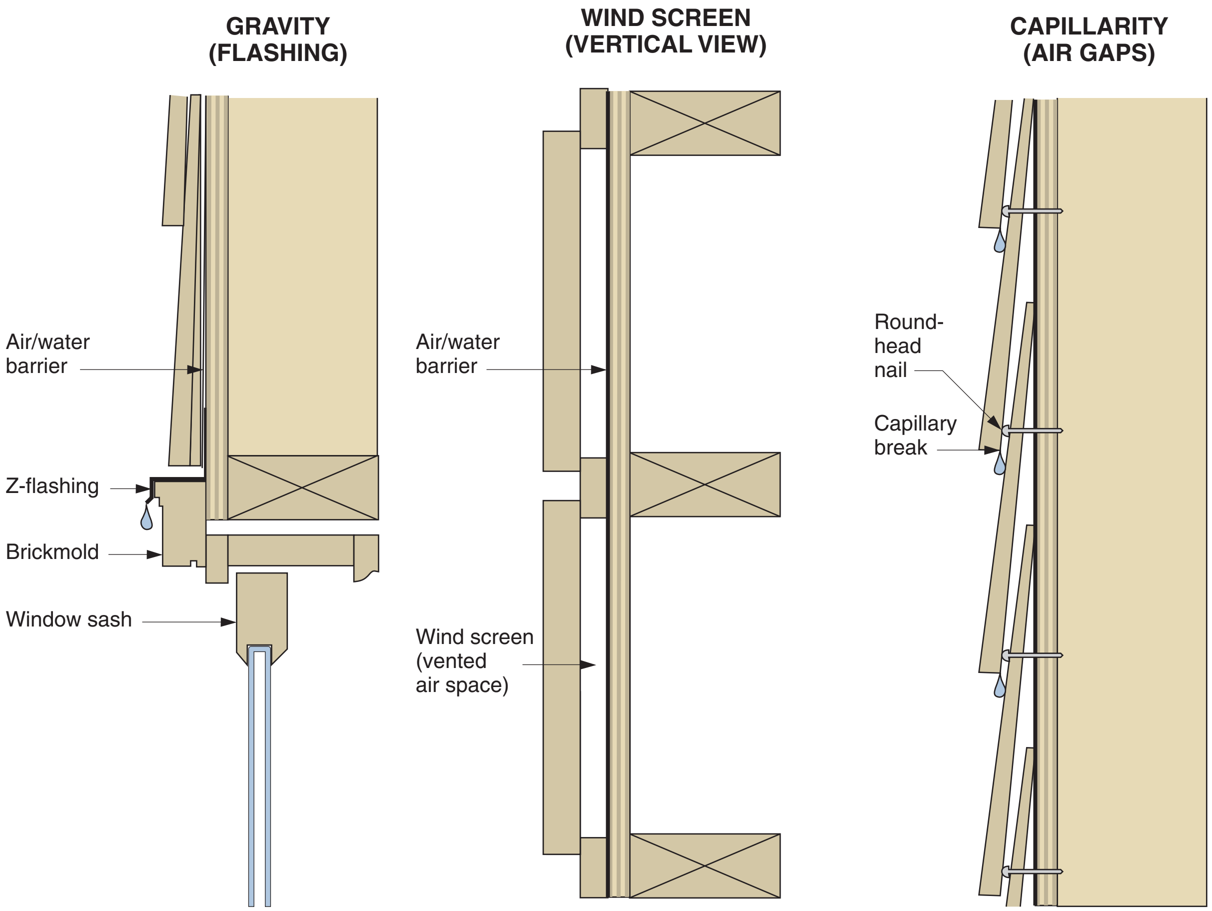
- as bulk water flowing downward under the force of *gravity*
- as rain water driven horizontally by the pressure of *wind*
- as rain water drawn upward by *capillarity* (surface tension acting in small spaces)

The three problems are prevented in three very different ways:

- gravity—by flashing at horizontal junctures of building surfaces and materials
- wind—by venting the back side of siding to equalize air pressures
- capillarity—by eliminating capillary-sized gaps between siding courses, using round head nails or wedges

The illustrations below show examples of each technique. Details specific to each type of siding are presented in the following pages.

Siding Moisture Control



Siding Choices

Things to consider when selecting siding are your home's architectural style, the styles of other homes in the neighborhood, the material and its appropriateness in your climate, and the environmental/energy impact of the material and its manufacture. Other considerations, of course, are the type and amount of care required in its maintenance, its expected lifetime, and initial cost.

In the chart below, *care* includes maintenance of an attractive appearance as well as weathertightness. Vinyl and aluminum are not subject, except for occasional washing, to maintenance, but bright colors may fade over time from exposure to ultraviolet rays.

Life assumes proper maintenance and may vary widely under differing conditions.

Cost is for materials only and does not include the cost of professional installation. In general, labor costs are lowest for vinyl, aluminum, and plywood. Labor can also vary as much as 50% due to popularity of style (and, therefore, competitive pricing) and prevailing wages. For example, stucco would cost far less in the Southwest, where it predominates, than in the Northeast.

Sidings Compared

Material	Care	Life, years	Relative Cost	Advantages	Disadvantages
Aluminum/Steel	None	30	Medium	Ease of installation Low maintenance Fire resistance	Susceptibility to denting Limited colors Difficult repairs
Fiber cement	Paint	30	Medium to high	Dimensionally stable Low maintenance Fire resistance	Hazardous dust when sawn May rattle in high wind
Hardboard	Paint Stain	20	Low	Low cost Fast installation	Susceptibility to moisture Short life Limited availability
Horizontal wood	Paint Stain	50+	Medium to High	Classic appearance Simple repairs Environmentally friendly	High labor cost High maintenance Can rot
Plywood	Paint Stain	20	Low	Low material cost Low labor cost Doubles as sheathing	Appearance Short life
Shingles/Shakes	Stain None	50+	High	Classic appearance Low maintenance Environmentally friendly	Highest labor cost May rattle in high wind
Stucco	Paint None	50+	Low to Medium	Classic in Southwest Low cost where common Fast installation	Professional installation Easily damaged Difficult repairs
Vertical wood	Stain None	50+	Low to Medium	Low material cost Low labor cost Low maintenance	Farmbuilding appearance Uneven weathering
Vinyl	None	30	Low	Fast installation Simple residing option Simple repairs	Fading of bright colors Low impact resistance Environmentally unfriendly

Vinyl Siding

The most important rule for successful installation of vinyl siding is to allow for movement. The thermal expansion coefficient of vinyl (0.000035/°F) is 3× that of aluminum and 10× that of wood. To avoid buckling, all vinyl siding, soffit, and accessories used in exterior applications must be able to move freely as they expand and contract with temperature.

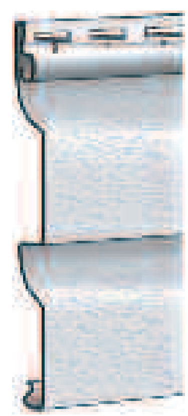
The rules for installation are, therefore:

- Nail in the center of slots.
- Do not nail too tightly.
- Leave at least $^{1}/_{4}$-inch clearance at stops.
- Do not pull horizontal sidings up tight.
- Strap and him all uneven walls.

Parts

5" clapboard

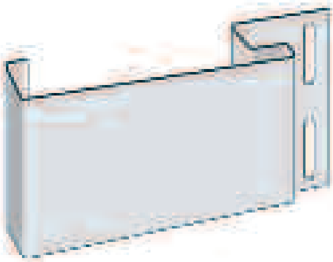
8" clapboard



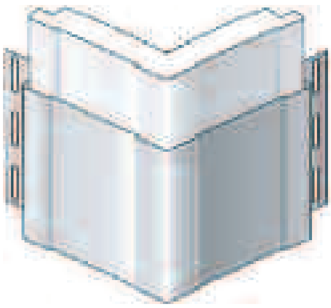
5" Dutch clapboard

Insulated Dutch clapboard

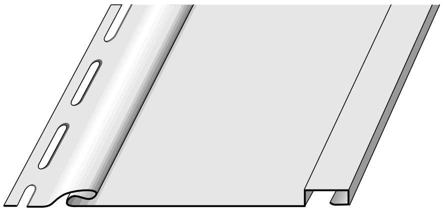
6" Carolina beaded



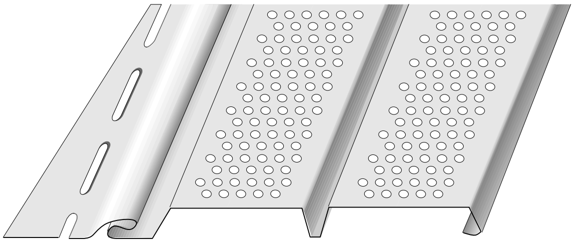
Decorative lineal



Insulated corner

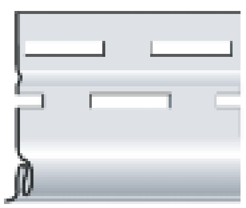


Board and batten

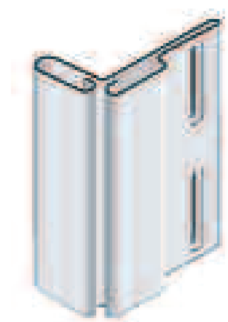


Soffit

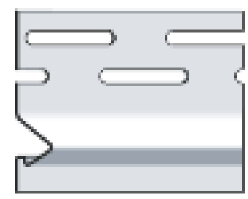
Parts—*Continued*



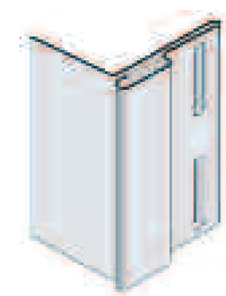
Starter strip



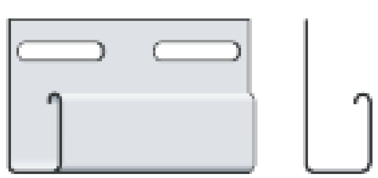
Corner starter strip



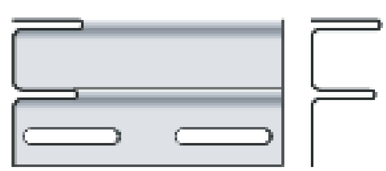
New construction
door & window starter



Remodeling
door & window starter



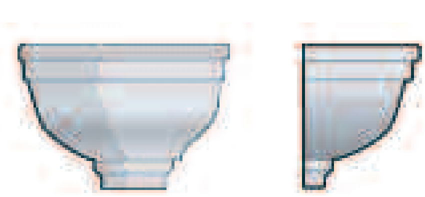
J-Channel



F-Channel

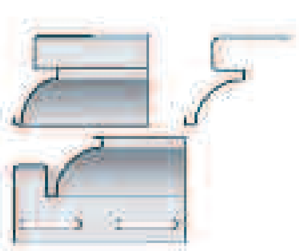
Undersill trim

Crown molding

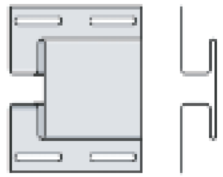


Crown molding cap

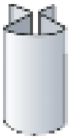
Fascia



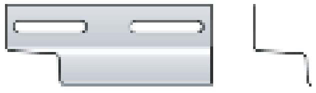
Soffit cove trim



H-bar



Quarter-round insert

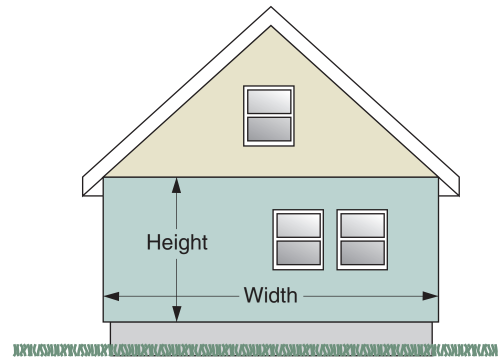


Drip cap

Estimating

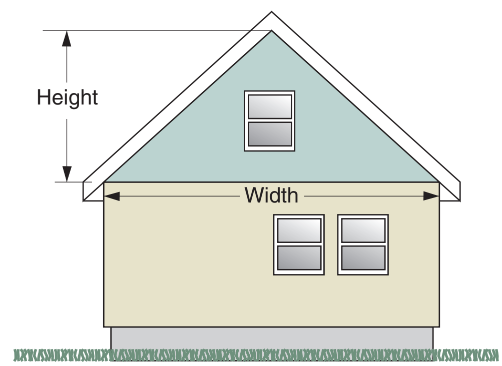
RECTANGULAR WALL

Area = Height x Width = ________



TRIANGULAR GABLE END WALL

$$\text{Area} = \frac{\text{Height} \times \text{Width}}{2} = \_\_\_\_\_\_\_\_$$

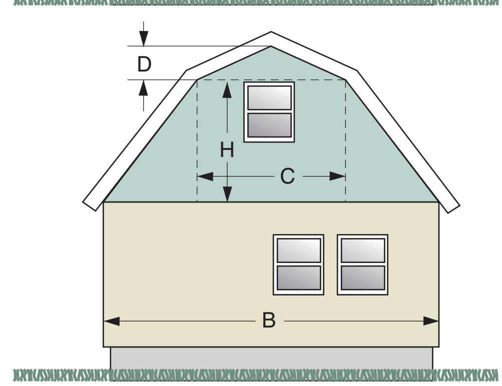


UPPER WALL OF GAMBREL

$$\text{Area} = \frac{(B + C) \times H}{2} = \_\_\_\_\_\_\_\_$$

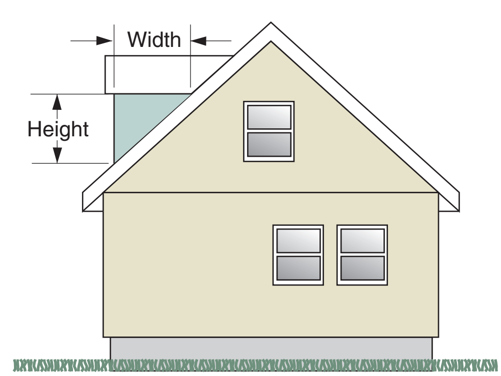
$$+ \frac{C \times D}{2} = \_\_\_\_\_\_\_\_$$

TOTAL = ________



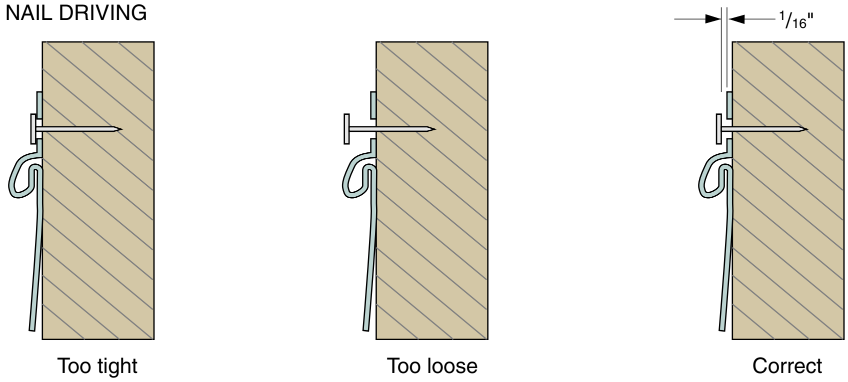
DORMER SIDES (BOTH)

Area = Height x Width = ________

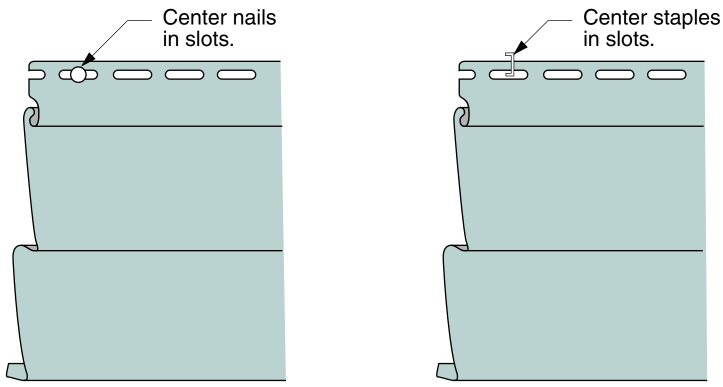


Fastening

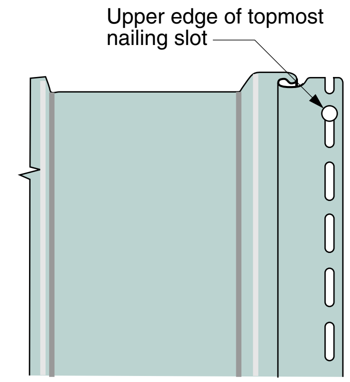
NAIL DRIVING



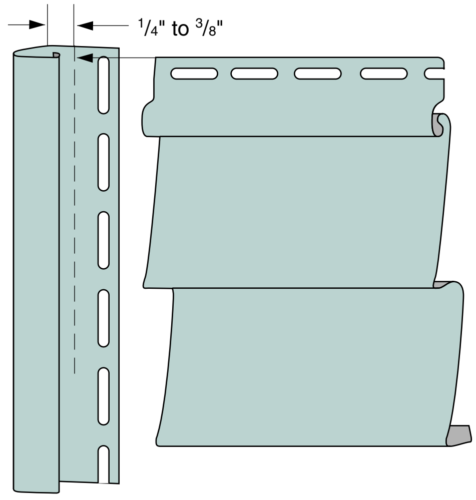
HORIZONTAL LENGTHS



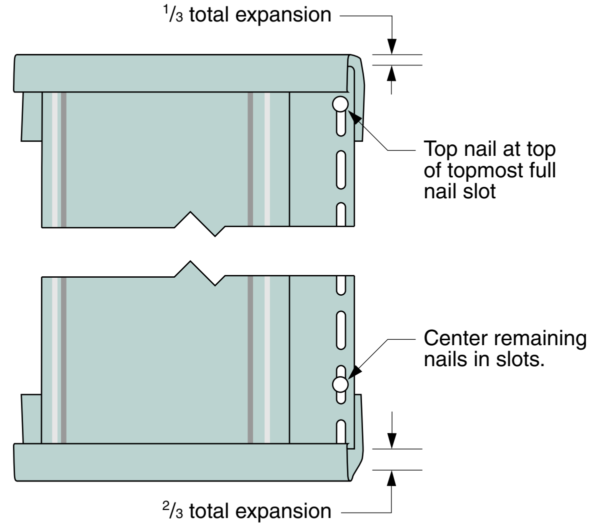
VERTICAL LENGTHS



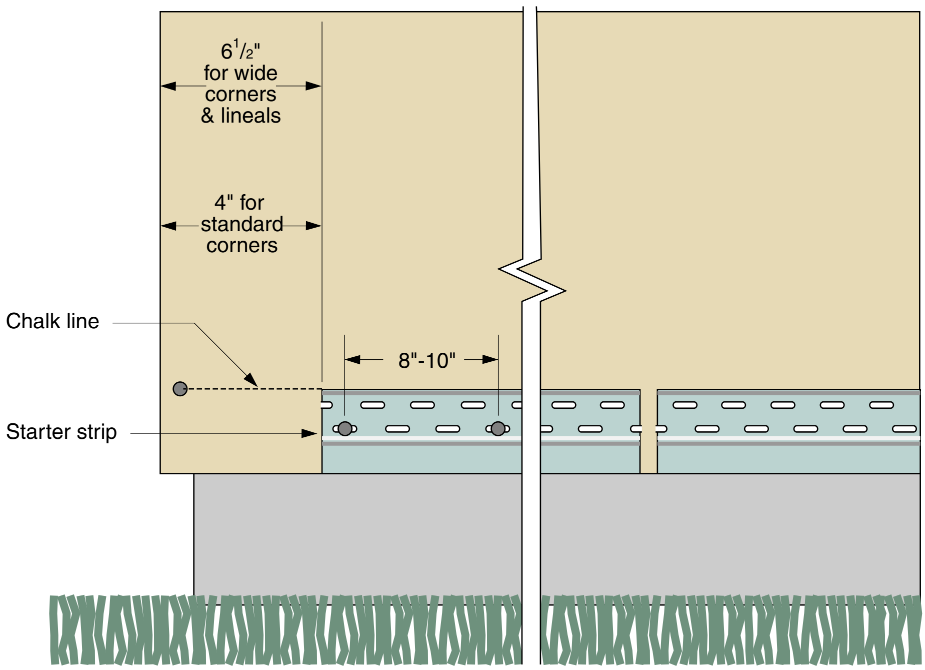
ENDS OF HORIZONTALS

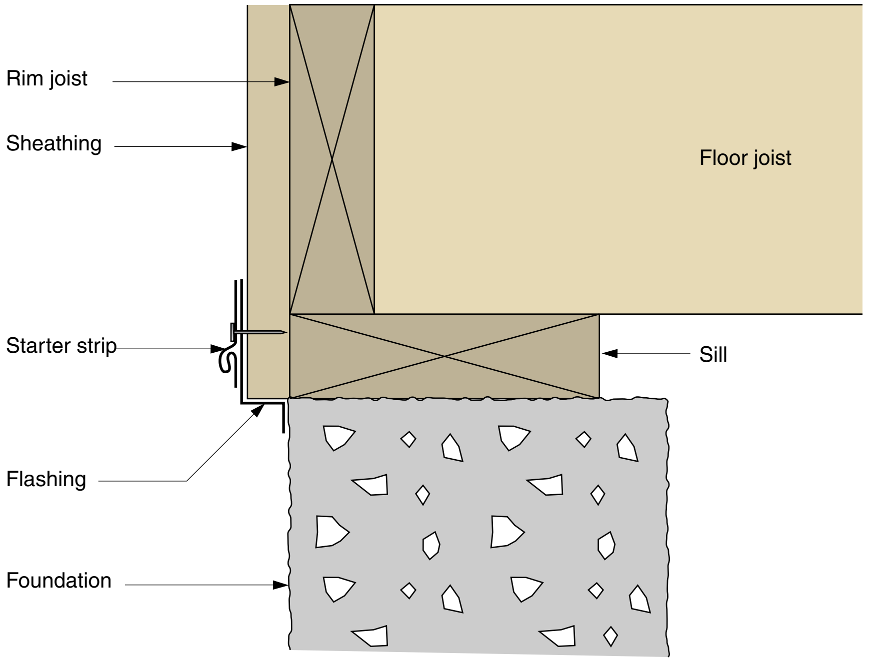


ENDS OF VERTICALS



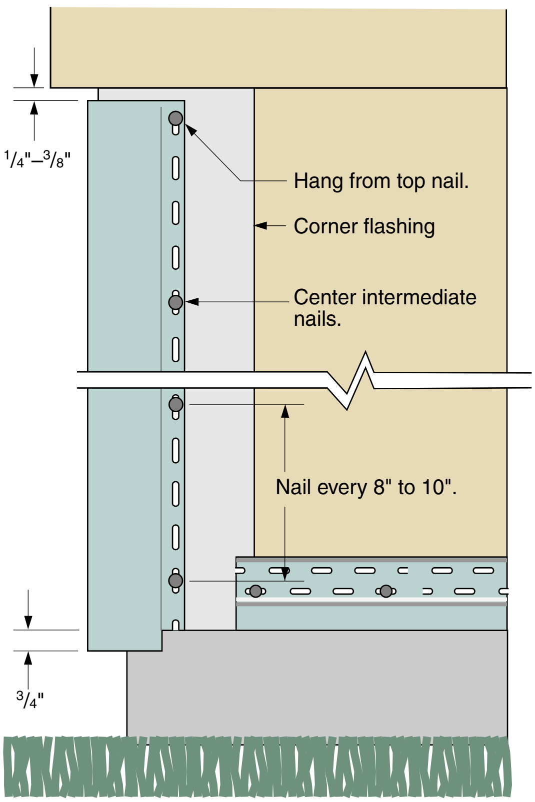
Starting Horizontal Siding



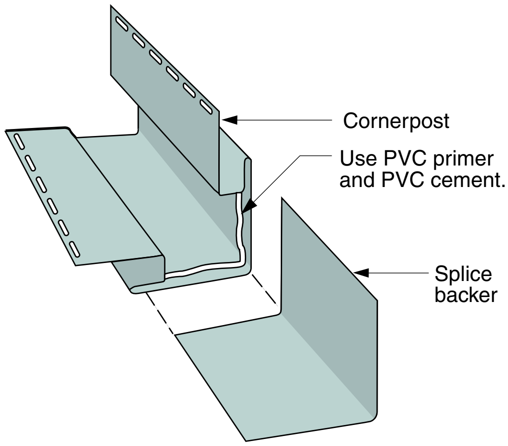


Corners

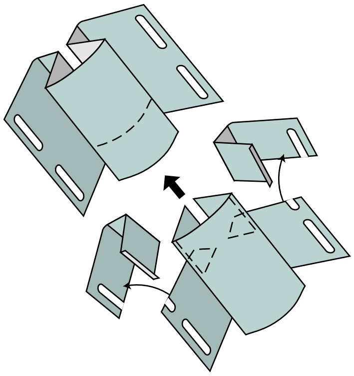
STARTING AT AN OUTSIDE CORNER



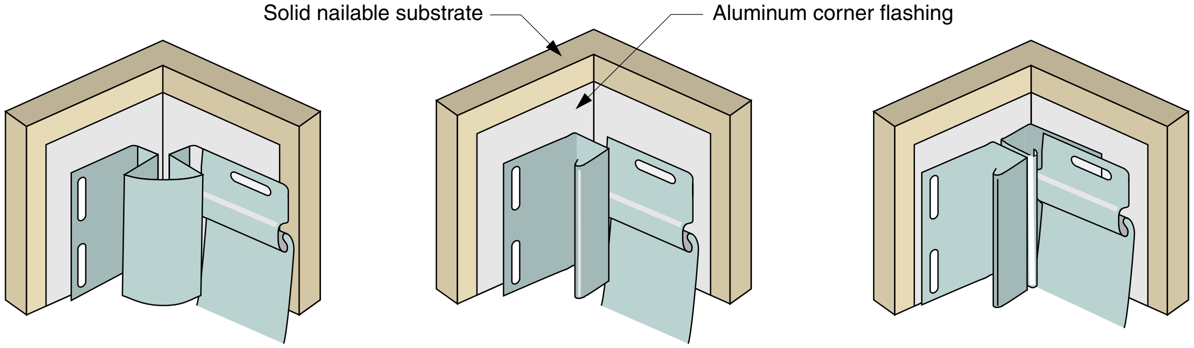
OUTSIDE CORNER SPLICE



INSIDE CORNER SPLICE



INSIDE CORNER OPTIONS



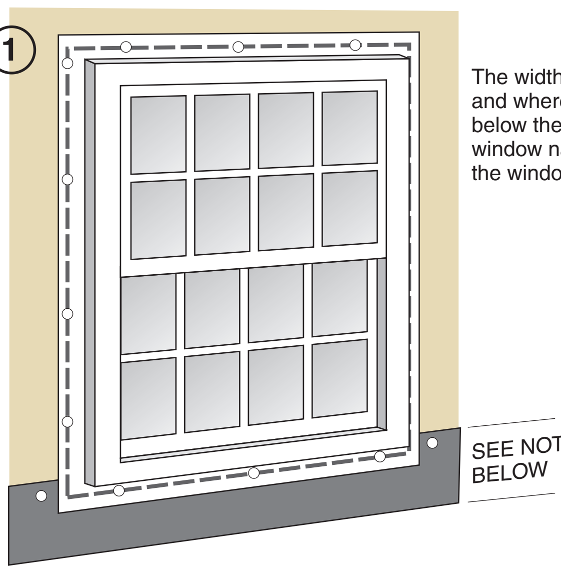
STANDARD 3/4" INSIDE CORNER POST

SINGLE J-CHANNEL

TWO J-CHANNELS

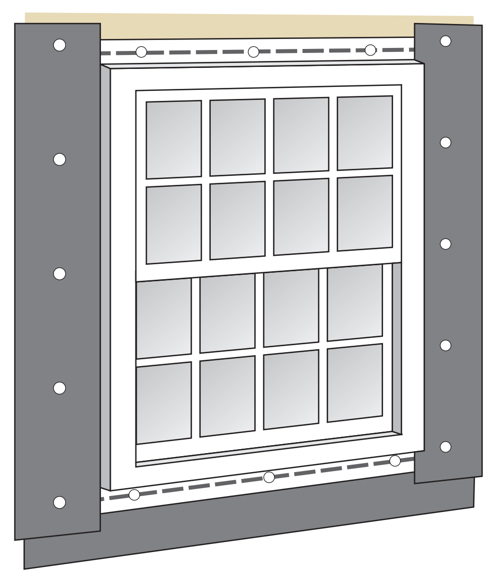
Window and Door Flashing

1



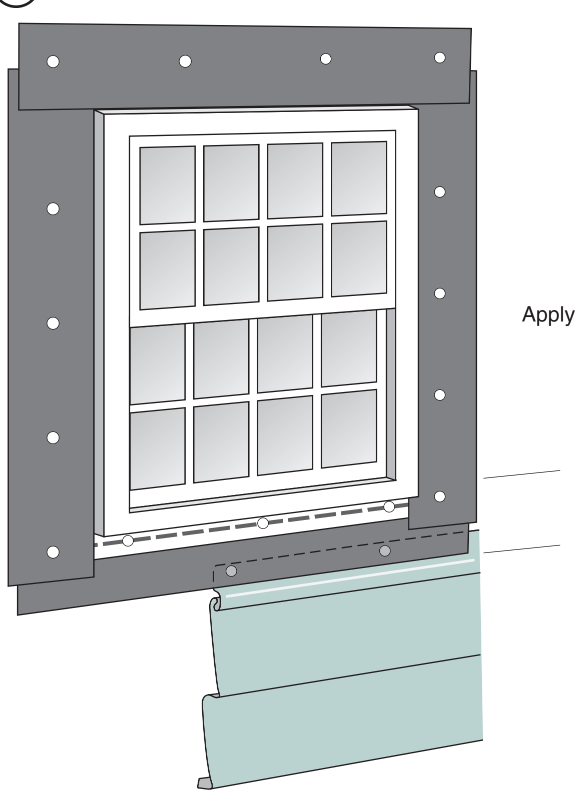
The width of flashings depends on the width of the trim and where the final complete course of siding stops below the window. All flashings should extend past the window nailing flanges. The width of the flashing under the window is sized to allow for the diversion of water.

2



Apply the side flashings by overlapping the bottom flashing.

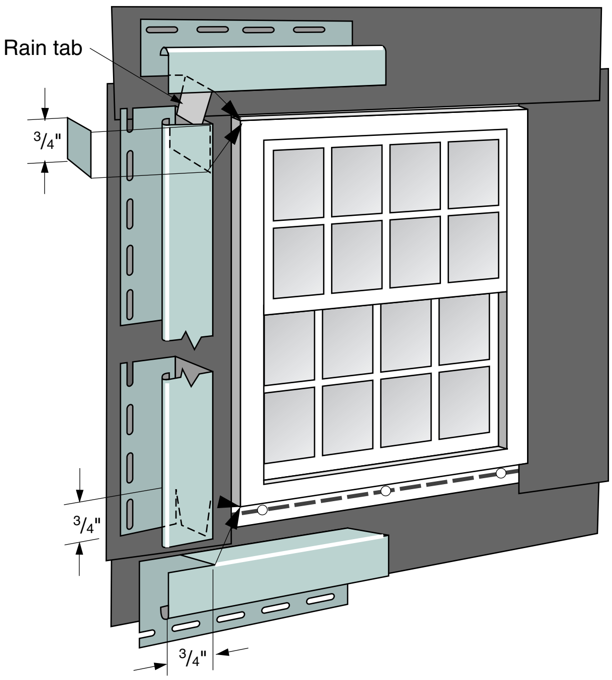
3



Apply the top flashing over the tops of the side flashings.

NOTE: Make sure the width of the bottom flashing is sufficient to overlap the nailing flange of the top course of complete siding panels.

Window and Door Trim



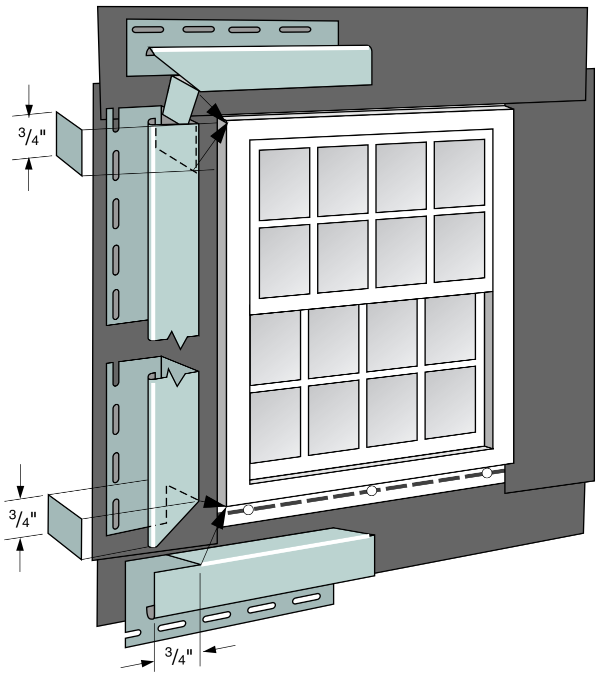
FOR SQUARE CORNERS

Using aviation snips, notch two side pieces of J-channel, as shown, butt against the window casings, and fasten in place.

Cut top and bottom J-channels so that the ends extend beyond the window casings to the outside edges of the side channels.

Place the top J-channel on the casing and fasten in place. Make two cuts in the bottom of the top channel and bend the tab down into the side channel. Repeat on the other side. This forms a water drain.

Make two cuts in the bottoms of the side channels to receive the notched bottom channel. Push the bottom channel up into the side channel slits and butt against the bottom window casing. When snug, fasten in place.



FOR MITERED CORNERS

Square cut the bottom J-channel so that its ends extend beyond the window casings to the outside of the J-channels on either side. Notch the ends for clearance, snug up under the bottom window casing, and fasten in place.

Measure the side J-channels, adding the widths of both top and bottom J-channels. Miter cut the lower ends of both side J-channels at 45 degrees. Notch the channels, position against the side casings and bottom channel, and fasten.

Mark the top J-channel so its ends extend beyond the casings to the outsides of the side J-channels. Miter cut both ends of the the front face, and cut and bend down the water tabs.

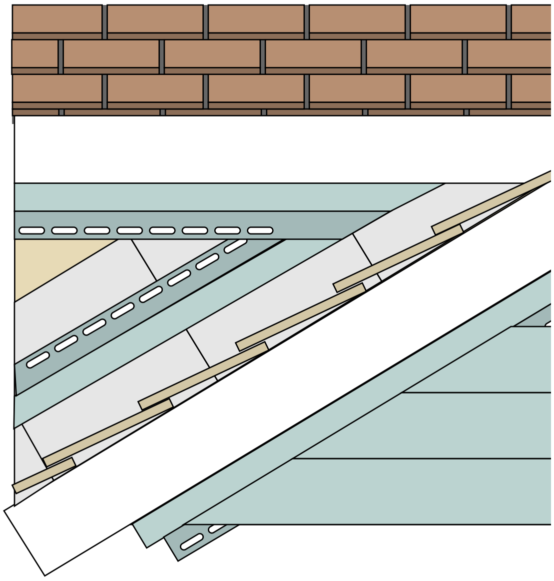
Position the top J-channel against the top of the window casing with the tabs inside the side channels, and fasten.

Gable Ends

ROOF/WALL INTERSECTION

To prevent water infiltration along the intersection of roof and wall, install step flashing before installing J-channel. At points where vinyl siding and accessories will meet at a roof line—such as areas where a gable dormer or a second-story side wall intersect with the roof—it is best to position the J-channel so it is $^{3}/_{4}$" to 1" away from the roof line. Placing the J-channel directly on the roof line would subject it to a buildup of heat, which could result in excessive expansion.

NOTE: If you use more than one length of J-channel to span a wall surface, be sure to overlap J-channels $^{3}/_{4}$". Do not butt J-channel pieces end-to-end.

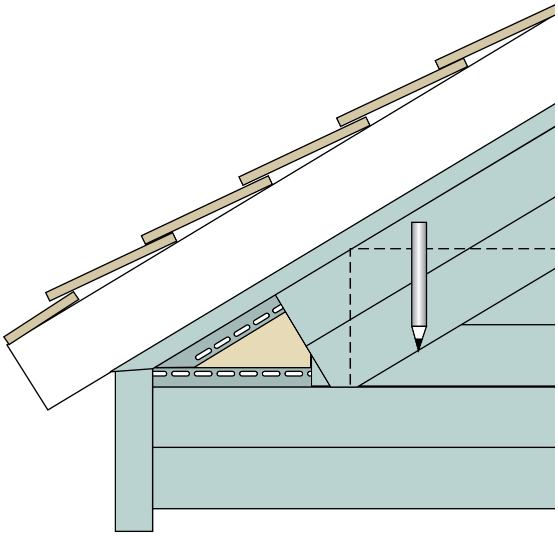


FITTING AT GABLE ENDS

Make a pattern duplicating the slope of the gable. Use this pattern as a cutting guide to panels to fit into the gable ends.

To make the pattern, lock a short piece of siding into the panel gable starter course, as shown in the illustration. Hold a second piece of siding against the J-channel at the slope. Run a pencil along the edge of this piece, transferring the slope angle to the first piece of siding. Cut along the pencil line using a power saw or tin snips. Use the resulting pattern to mark the siding panels before cutting.

NOTE: Double-check the angle of the pattern at every course. If necessary, cut new pattern.

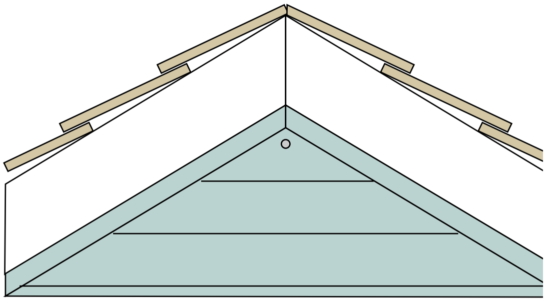


INSTALLING CUT PANELS

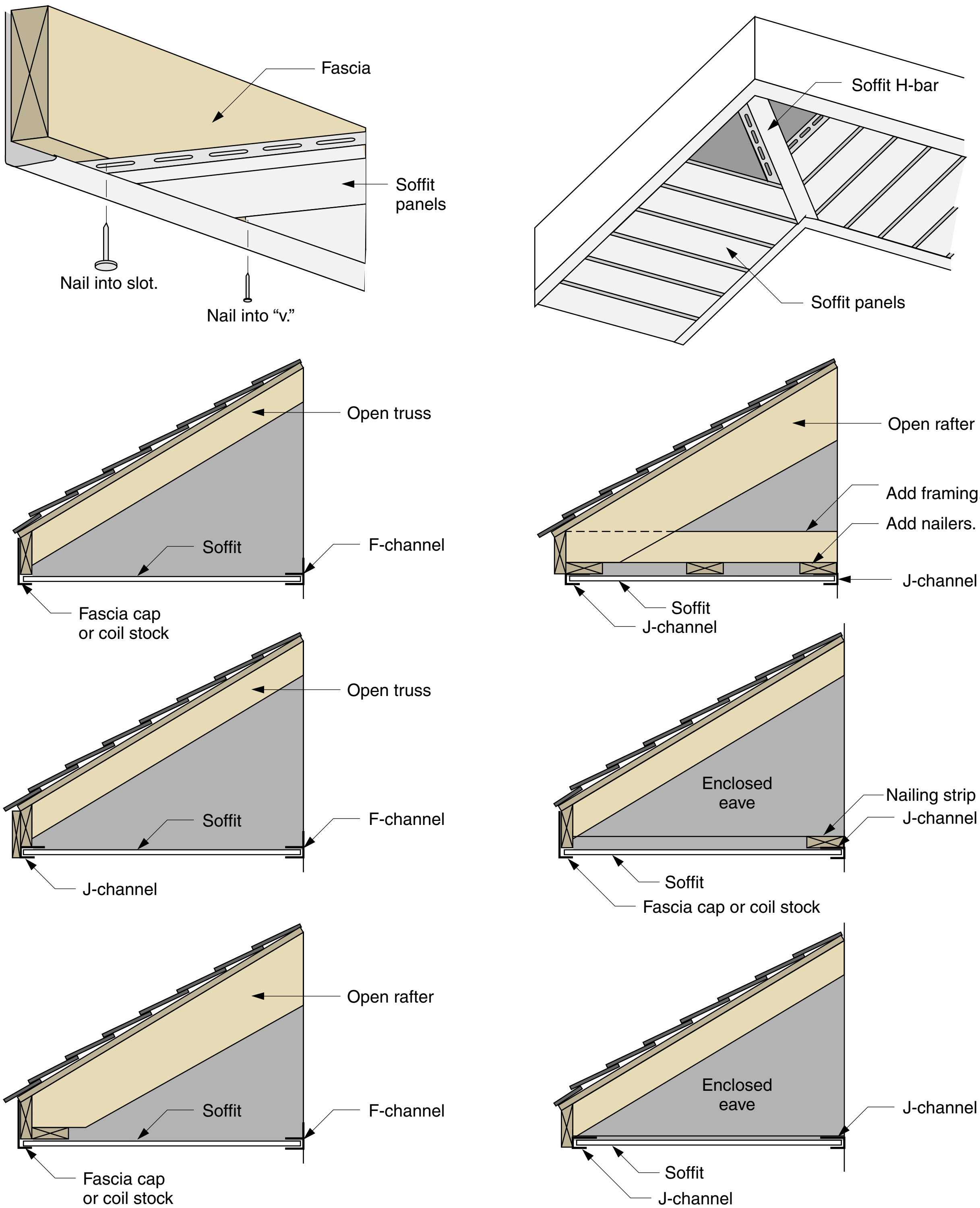
Slip the angled end of the panel into the J-channel along the gable edge, leaving space for expansion. Interlock with the siding panel below.

If necessary to securely fasten the last panel at the peak of the gable, face-nail as shown in the illustration. This is the only place you will face-nail. Use a $1^{1}/_{4}$" to $1^{1}/_{2}$" aluminum nail with painted head that matches the siding.

NOTE: Do not cover louvers in gables.



Soffits


Fascia
Soffit panels
Nail into slot.
Nail into "v."
Soffit H-bar
Soffit panels
Open truss
Soffit
F-channel
Fascia cap or coil stock
Open rafter
Add framing.
Add nailers.
J-channel
Soffit
J-channel
Open truss
Soffit
F-channel
J-channel
Enclosed eave
Nailing strip
J-channel
Soffit
Fascia cap or coil stock
Open rafter
Soffit
F-channel
Fascia cap or coil stock
Enclosed eave
J-channel
Soffit
J-channel

Fiber-Cement Lap Siding

Fiber-cement siding is exactly that—a mixture of wood fiber, sand, and Portland cement. The high percentage of sand and cement make it, essentially, a masonry siding. The wood fibers reduce the weight and reinforce the masonry. It shares characteristics of both wood and masonry.

On the plus side, fiber-cement siding is immune to insect attack, rot, and fire. And because it swells and shrinks with moisture much less than wood, it retains paint well.

On the negative side, fiber cement is more brittle than wood. The 12-foot lengths can snap if supported at the midpoint in the flat position, and striking the edges or corners can chip the material. Also, direct contact between the cementitious siding and aluminum flashing will result in corrosion of the flashing unless the aluminum is anodized.

Lap sidings are typically available in lengths of 12 feet and widths from 5 to 12 inches. Fiber-cement trim is also available, but few builders use it because of its weight and because it's $^5/_8$-inch thickness is insufficient to project beyond the siding.

Cutting fiber-cement siding with power saws produces copious cement dust, so sawing must take place outside. The sand-laden material also dulls saw blades quickly. A better low-cost method is scoring with a special carbide-tipped scoring tool and snapping. A more expensive alternative is using power shears.

The siding can be installed over braced wood or steel studs spaced a maximum of 24" o.c. or directly to minimum $^7/_{16}$"-thick OSB sheathing. It can also be installed over foam insulation up to 1" thick.

See the illustrations on the facing page for fastening and clearance details.

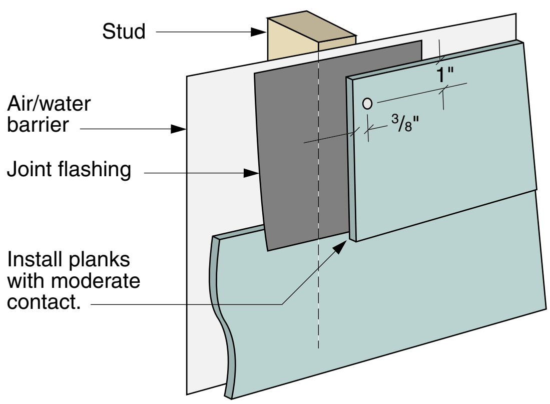
Estimating Number of 12-foot Hardiplanks (assuming zero waste)

	Siding Width/Exposure, inches								
Net Area[1], square feet	$5^1/_4$ 4	$6^1/_4$ 5	$7^1/_4$ 6	$7^1/_2$ $6^1/_4$	8 $6^3/_4$	$8^1/_4$ 7	$9^1/_4$ 8	$9^1/_2$ $8^1/_4$	12 $10^3/_4$
100	25	20	17	16	15	14	13	13	9
200	50	40	33	32	30	29	25	25	19
300	75	60	50	48	44	43	38	38	28
400	100	80	67	64	59	57	50	50	37
500	125	100	83	80	74	71	63	63	47
600	150	120	100	96	89	86	75	75	56
700	175	140	117	112	104	100	88	88	65
800	200	160	133	128	119	114	100	100	74
900	225	180	150	144	133	129	113	113	84
1000	250	200	167	160	148	143	125	125	93
1200	300	240	200	192	178	171	150	150	112
1500	375	300	250	240	222	214	188	188	140
2000	500	400	333	320	296	286	250	250	186
2500	625	500	417	400	370	357	313	313	233
3000	750	600	500	480	444	429	375	375	279
4000	1000	800	667	640	592	572	500	500	372
5000	1250	1000	834	800	740	714	626	626	467

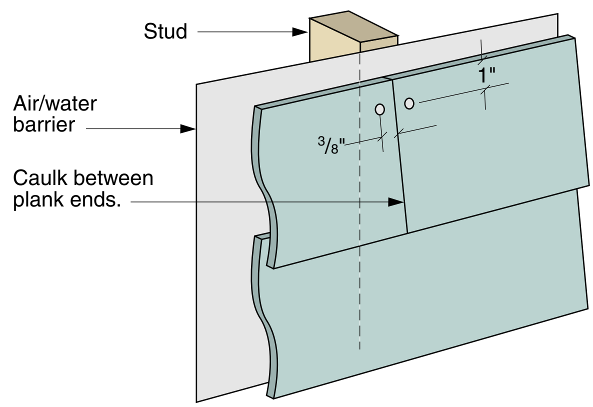
[1] Net Area is wall area, less area of openings.

Fiber-Cement Lap Siding Application Details (Hardiplank)

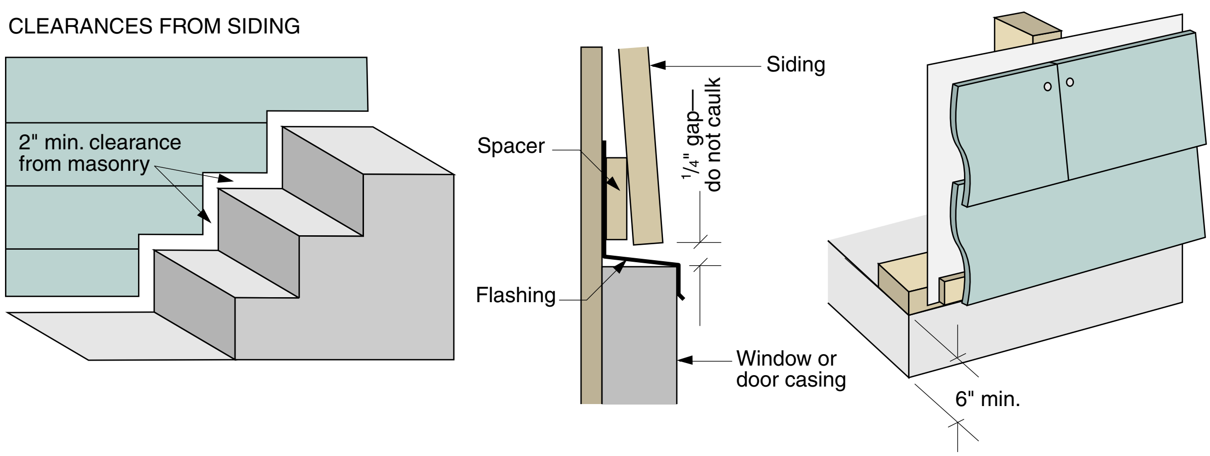
JOINT OPTION 1



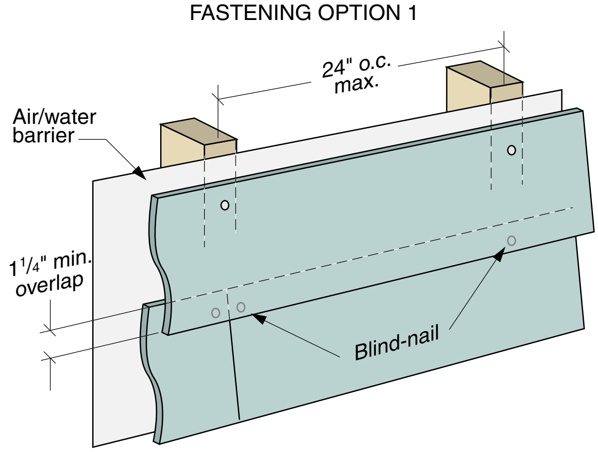
JOINT OPTION 2



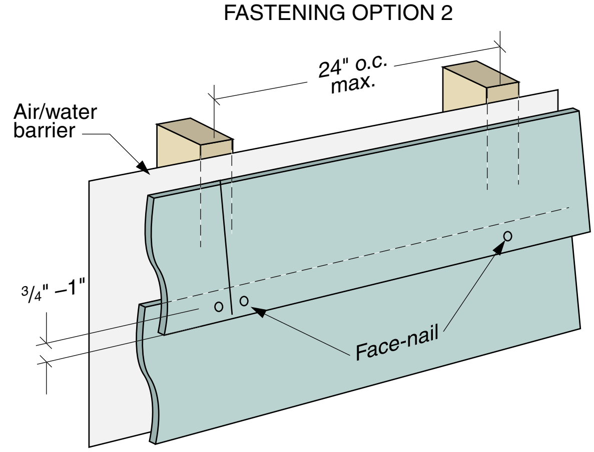
CLEARANCES FROM SIDING



FASTENING OPTION 1



FASTENING OPTION 2



Hardboard Lap Siding

Hardboard lap siding may be cut with either fine-tooth hand or power saws. The cutting action should be into the appearance face of the siding, i.e., face up with hand saws and tablesaws and face down with portable circular saws.

Lap siding may be applied directly to studs or over sheathing. Studs should be spaced 16 inches on-center in both cases. An air-barrier membrane should be used when the siding is applied directly to studs or over board sheathings.

Use only corrosion-resistant nails. Nails should penetrate framing members by $1^1/_2$ inches minimum (8d nails for studs only; 10d nails over sheathing).

Allow at least 6 inches between the siding and the ground or any area where water may collect. A starter strip $1^1/_2$ inches wide and the same thickness as the siding should be installed level with the bottom edge of the sill plate. Nail the starter strip with the recommended siding nails. Cut, fit, and install the first course of siding to extend at least $^1/_4$ inch, but no more than 1 inch, below the starter strip. Nail the bottom edge of the first course of siding 16 inches on-center and through the starter strip at each stud location. Maintain contact at the joints without forcing. Leave a space of $^1/_8$ inch between the siding and window or door frames and corner boards. Caulk this space after the siding is installed.

All joints must fall over studs and be nailed on both top and bottom on each side of the joint. Stagger succeeding joints for best appearance.

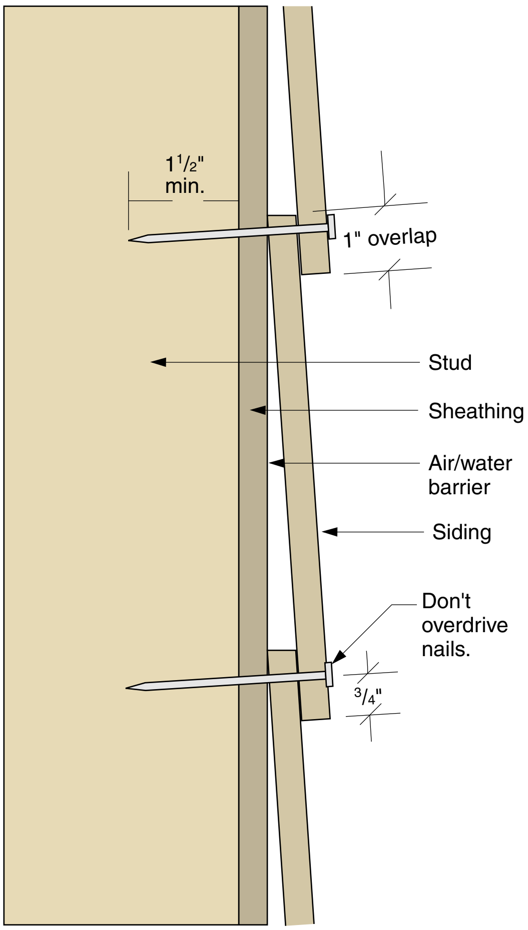
The second and all succeeding courses of siding must overlap the previous course a minimum of 1 inch. Locate nails $^1/_2$ inch from the bottom edge and not more than 16 inches on-center. Nail through both courses and into the framing members.

Install shim strips for continuous horizontal support behind siding wherever it is notched out above or below openings. Use wooden corner boards at least $1^1/_8$ inches thick or formed metal corners (available from distributors) at all inside and outside corners.

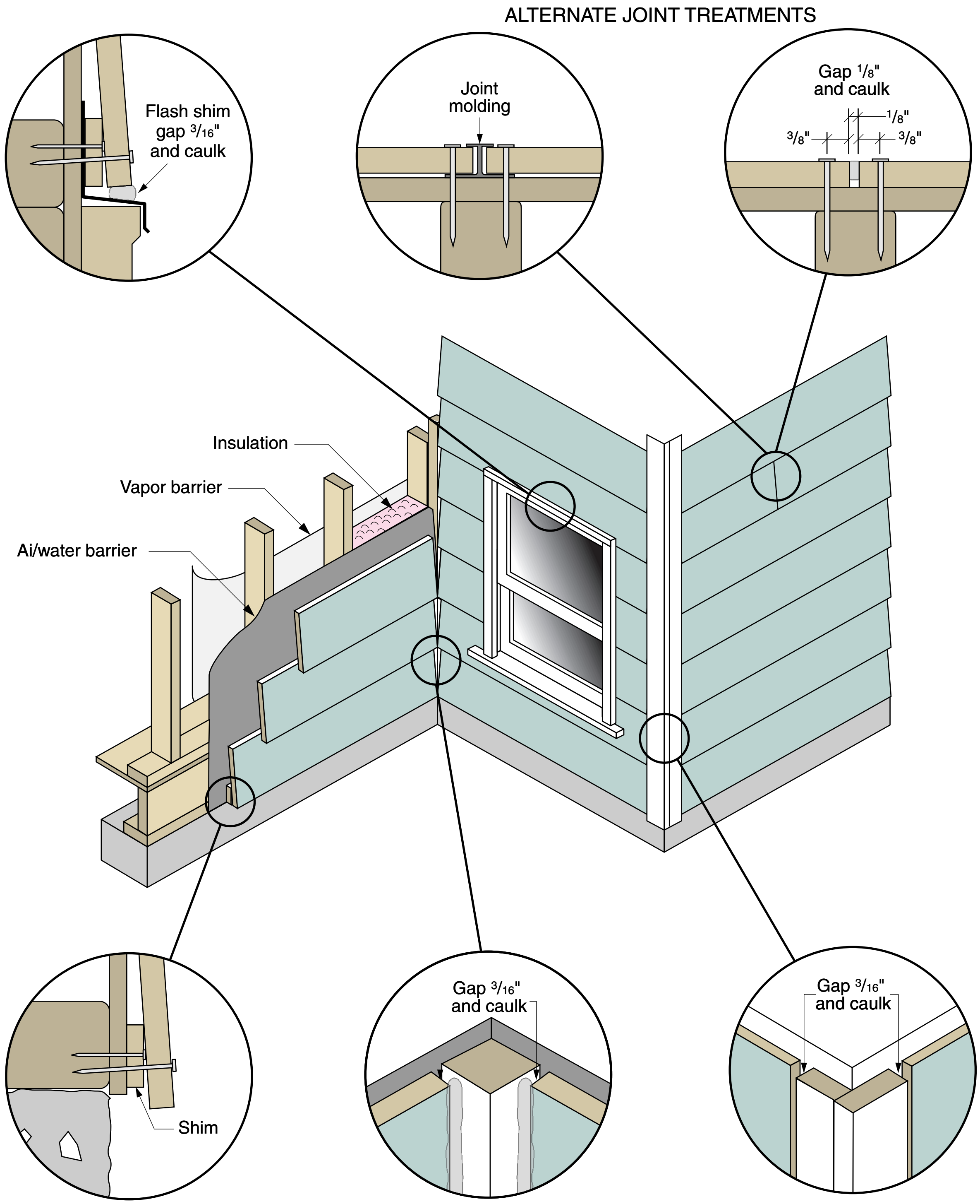
Factory-primed siding should be painted within 60 days after installation. If it is exposed for a longer period, lightly sand the primer, or reprime the siding with a good-quality exterior primer that is compatible with the final finish coat.

Unprimed siding should be finished within 30 days after installation. If the finish will be paint, prime the siding with a good-quality compatible exterior primer.

Nailing Hardboard Lap Siding



Hardboard Lap Siding Application Details



Cedar Shingles

Cedar Shingle Specifications

Grade	Length, inches	Butt, inches	Bundles/ Square	Maximum Exposure[1] and Nails			
				Single Course		Double Course	
RED CEDAR							
No. 1 blue label	16	0.40	4	$7^1/_2$	3d	12	5d
(premium grade, 100% heartwood,	18	0.45	4	$8^1/_2$	3d	14	5d
100% clear, 100% edge grain)	24	0.50	4	$11^1/_2$	4d	16	6d
No. 2 red label	16	0.40	4	$7^1/_2$	3d	12	5d
(good grade, 10” clear on 16” shingle,	18	0.45	4	$8^1/_2$	3d	14	5d
16” clear on 24” shingle)	24	0.50	4	$11^1/_2$	4d	16	6d
No. 3 black label	16	0.40	4	$7^1/_2$	3d	12	5d
(utility grade, 6” clear on 16” shingle,	18	0.45	4	$8^1/_2$	3d	14	5d
10” clear on 24” shingle)	24	0.50	4	$11^1/_2$	4d	16	6d
No. 4 undercoursing	16	0.40	2 or 4	$7^1/_2$	5d	–	–
(for bottom course in	18	0.45	2 or 4	$8^1/_2$	5d	–	–
double-coursed walls)							
No. 1 or 2 rebutted-rejoined	16	0.40	1	$7^1/_2$	3d	12	5d
(machine trimmed, square	18	0.45	1	$8^1/_2$	3d	14	5d
edged, top grade)							
WHITE CEDAR							
Extra (perfectly clear)	16	0.40	4	$7^1/_2$	3d	12	5d
1st clear (7” clear, no sapwood	16	0.40	4	$7^1/_2$	3d	12	5d
2nd clear (sound knots, no sapwood)	16	0.40	4	$7^1/_2$	3d	12	5d
Clear wall (sapwood, curls)	16	0.40	4	$7^1/_2$	3d	12	5d
Utility (undercoursing only)	16	0.40	4	–	3d	–	5d

[1] Exposure given in inches.

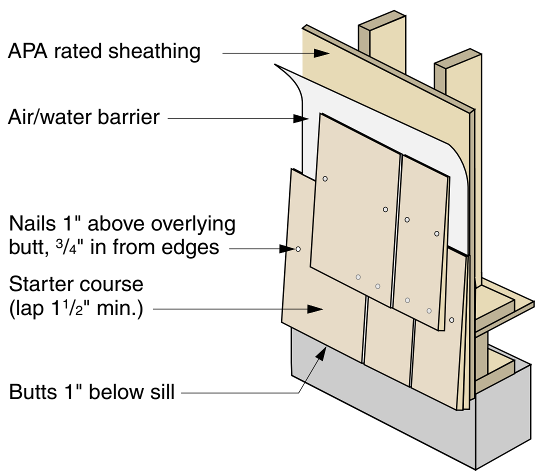
Cedar Shingle Coverage

Length, in	Coverage[1] of One Square at Exposure, inches								
	4	5	6	7	8	9	10	11	12
16	80	100	120	140	160	–	–	–	–
18	72	90	109	127	145	163	–	–	–
24	–	–	80	93	106	120	133	146	160

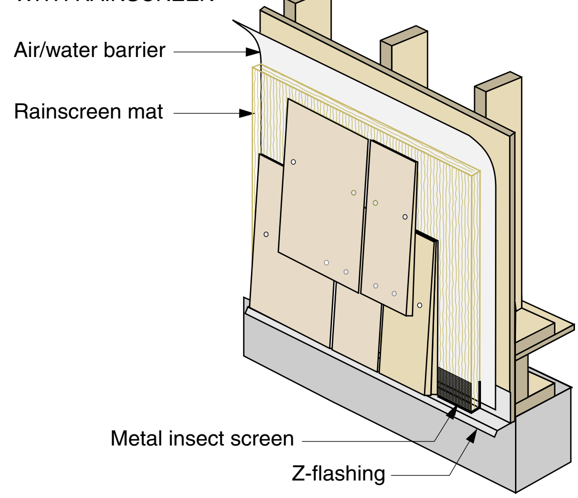
[1] Coverage given in square feet.

Cedar Shingle Siding Application Details

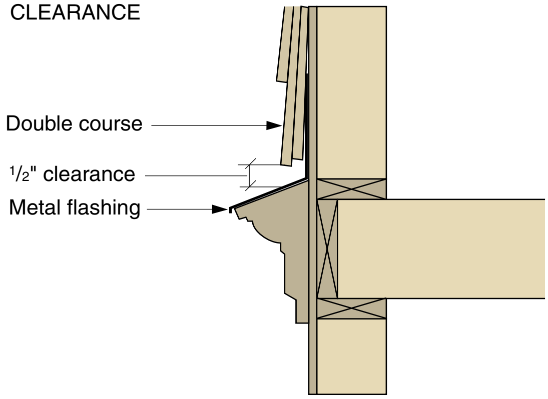
CONVENTIONAL



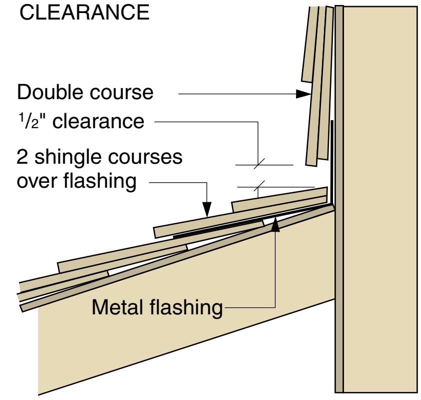
WITH RAINSCREEN



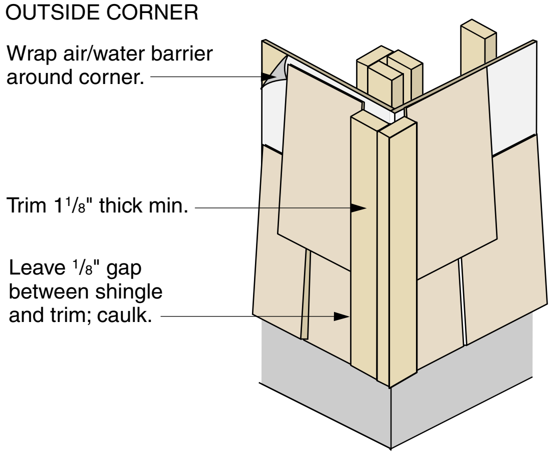
CLEARANCE



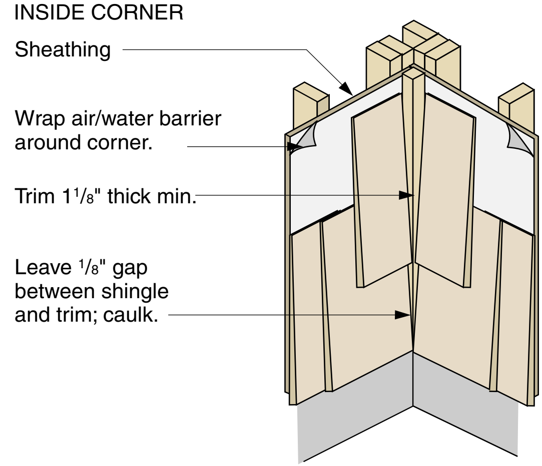
CLEARANCE



OUTSIDE CORNER

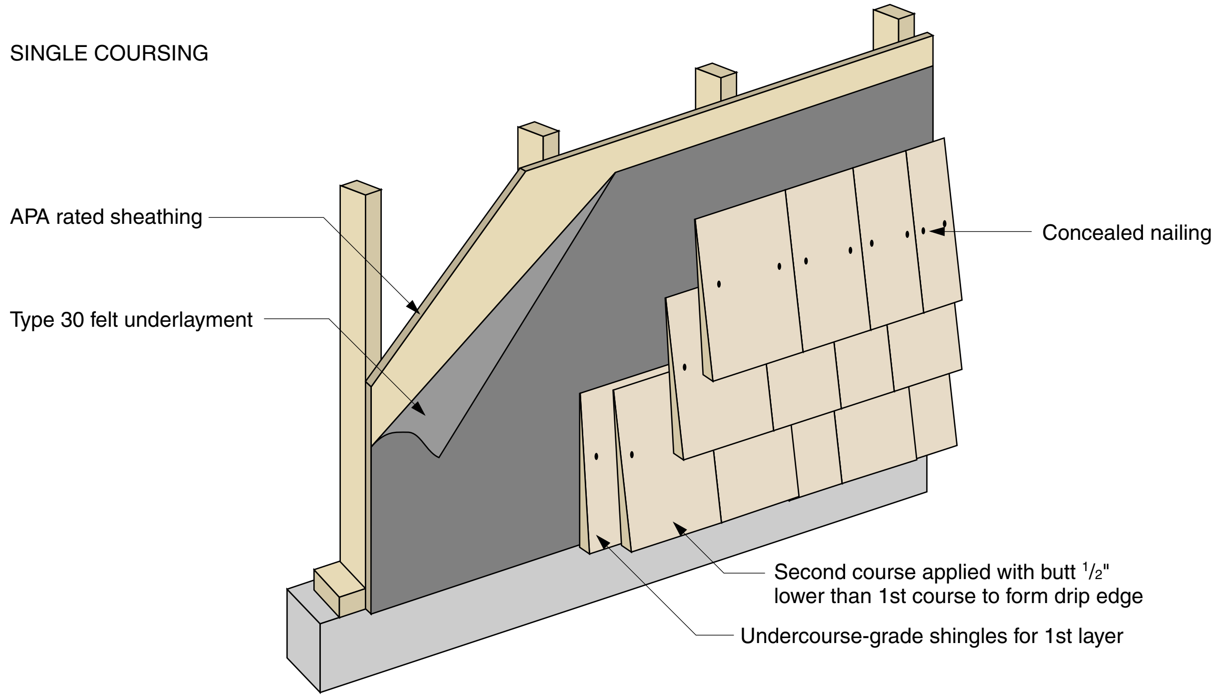


INSIDE CORNER

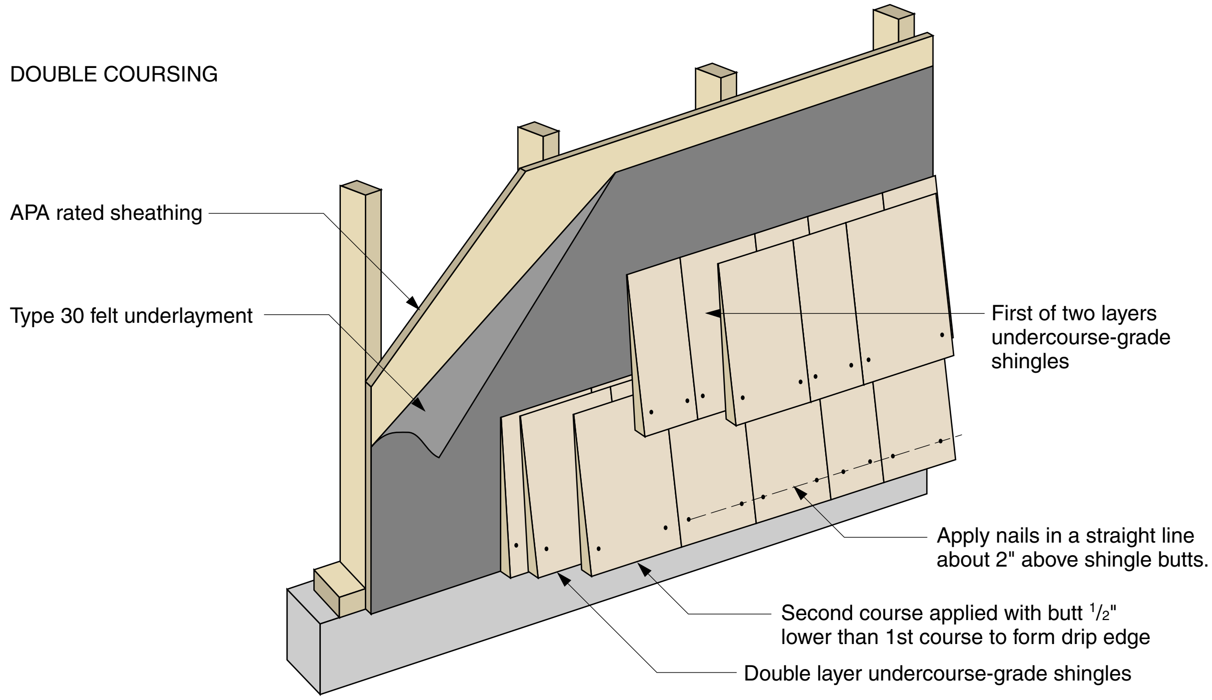


Cedar Shingle Coursing

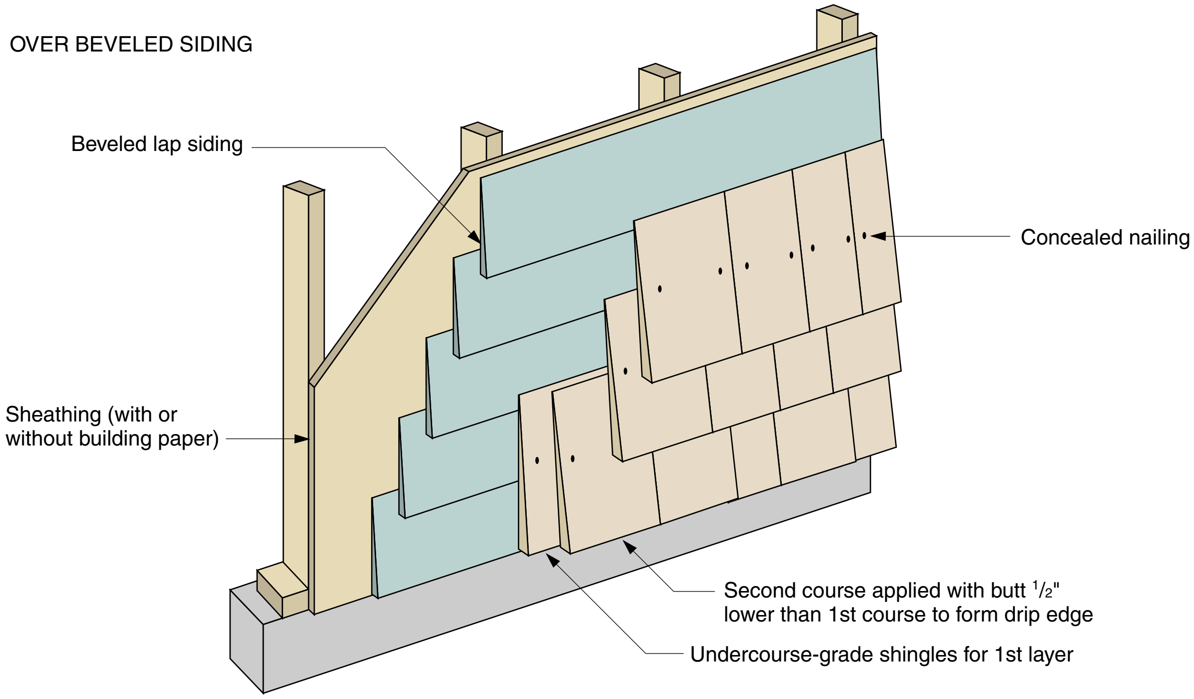
SINGLE COURSING

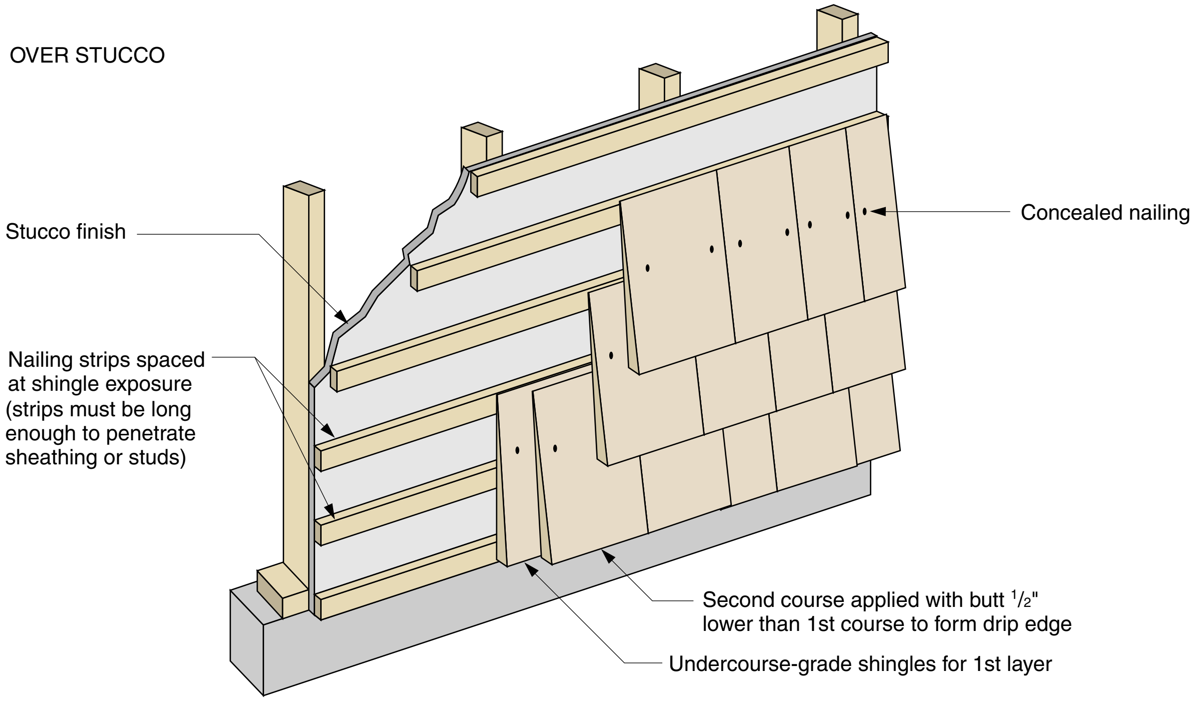


DOUBLE COURSING



Cedar Shingle Siding Over Previous Siding



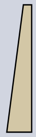
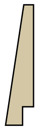
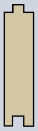
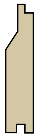
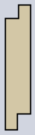
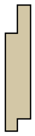
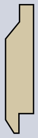
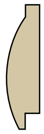


Horizontal Wood Siding

Nails for wood siding should be rust resistant: stainless steel, hot-dipped galvanized, or high-tensile-strength aluminum. Do not use electroplated, galvanized, or bright nails. Recommended penetration into a solid wood base is $1\frac{1}{2}$ inch minimum, or $1\frac{1}{4}$ inch with ring-shank nails.

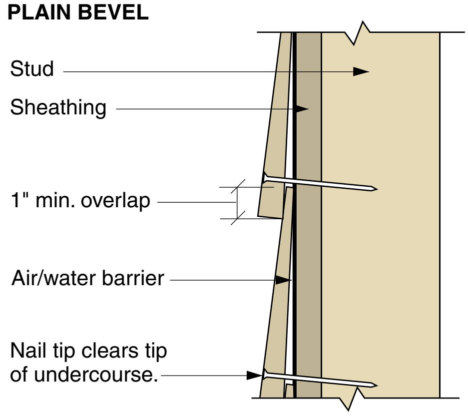
The area factors in the table below simplify estimation of the board footage of siding needed for the various patterns and sizes shown. Simply multiply the length and width of the area to be covered, times the appropriate area factor. Add a 10% allowance for trim and waste to the resulting figure.

Horizontal Wood Siding Patterns

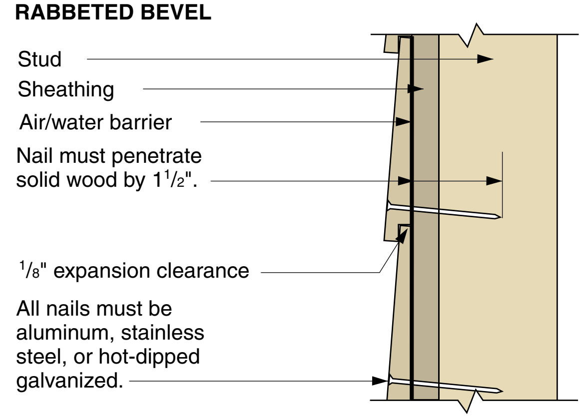
Pattern		Nominal Size, inches	Dressed Size, inches: Total Width	Dressed Size, inches: Face Width	Area Factor
	**Plain bevel (clapboard)**	$\frac{1}{2}\times4$	$3\frac{1}{2}$	$3\frac{1}{2}$	1.60
		$\frac{1}{2}\times6$	$5\frac{1}{2}$	$5\frac{1}{2}$	1.33
		$\frac{3}{4}\times8$	$7\frac{1}{4}$	$7\frac{1}{4}$	1.28
		$\frac{3}{4}\times10$	$9\frac{1}{4}$	$9\frac{1}{4}$	1.21
	**Rabbeted bevel (Dolly Varden)**	$\frac{3}{4}\times6$	$5\frac{1}{2}$	5	1.20
		1×8	$7\frac{1}{4}$	$6\frac{3}{4}$	1.19
		1×10	$9\frac{1}{4}$	$8\frac{3}{4}$	1.18
		1×12	$11\frac{1}{4}$	$10\frac{3}{4}$	1.12
	**Tongue & groove**	1×4	$3\frac{3}{8}$	$3\frac{1}{8}$	1.28
		1×6	$5\frac{3}{8}$	$5\frac{1}{8}$	1.17
		1×8	$7\frac{1}{8}$	$6\frac{7}{8}$	1.16
		1×10	$9\frac{1}{8}$	$8\frac{7}{8}$	1.13
	**Drop (T&G or shiplap)**	1×6	$5\frac{3}{8}$	$5\frac{1}{8}$	1.17
		1×8	$7\frac{1}{8}$	$6\frac{3}{4}$	1.16
		1×10	$9\frac{1}{8}$	$8\frac{3}{4}$	1.13
		1×12	$11\frac{1}{8}$	$10\frac{3}{4}$	1.10
	**Shiplap**	1×6	$5\frac{3}{8}$	5	1.17
		1×8	$7\frac{1}{8}$	$6\frac{3}{4}$	1.16
		1×10	$9\frac{1}{8}$	$8\frac{3}{4}$	1.13
		1×12	$11\frac{1}{8}$	$10\frac{3}{4}$	1.10
	**Channel shiplap**	1×6	$5\frac{3}{8}$	5	1.17
		1×8	$7\frac{1}{8}$	$6\frac{3}{4}$	1.16
		1×10	$9\frac{1}{8}$	$8\frac{3}{4}$	1.13
		1×12	$11\frac{1}{8}$	$10\frac{3}{4}$	1.10
	**V–shiplap**	1×6	$5\frac{3}{8}$	5	1.17
		1×8	$7\frac{1}{8}$	$6\frac{3}{4}$	1.16
		1×10	$9\frac{1}{8}$	$8\frac{3}{4}$	1.13
		1×12	$11\frac{1}{8}$	$10\frac{3}{4}$	1.10
	**Log cabin**	1×6	$5\frac{7}{16}$	$4\frac{15}{16}$	1.22
		1×8	$7\frac{1}{8}$	$6\frac{5}{8}$	1.21
		1×10	$9\frac{1}{8}$	$8\frac{5}{8}$	1.16

Horizontal Wood Siding Application

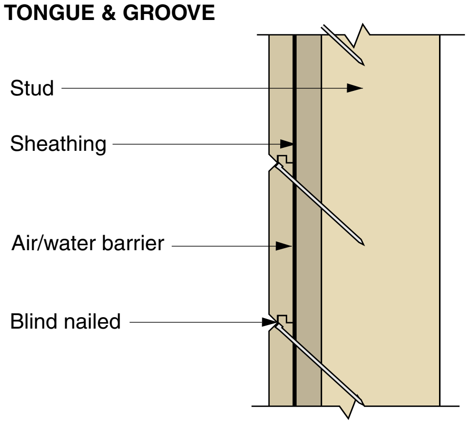
PLAIN BEVEL



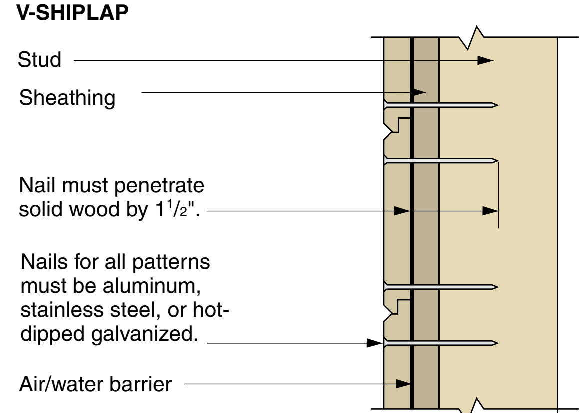
RABBETED BEVEL



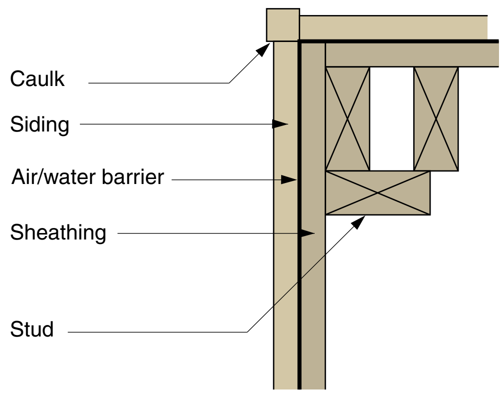
TONGUE & GROOVE



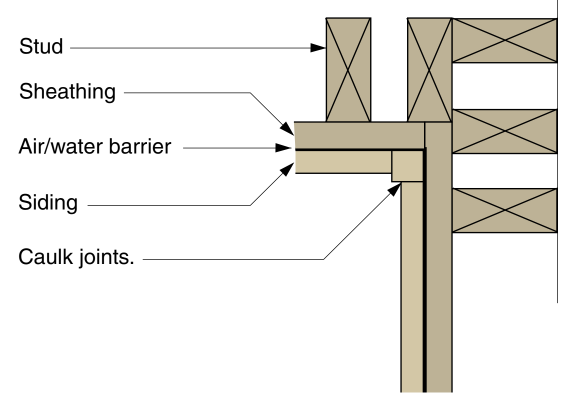
V-SHIPLAP



OUTSIDE CORNER



INSIDE CORNER



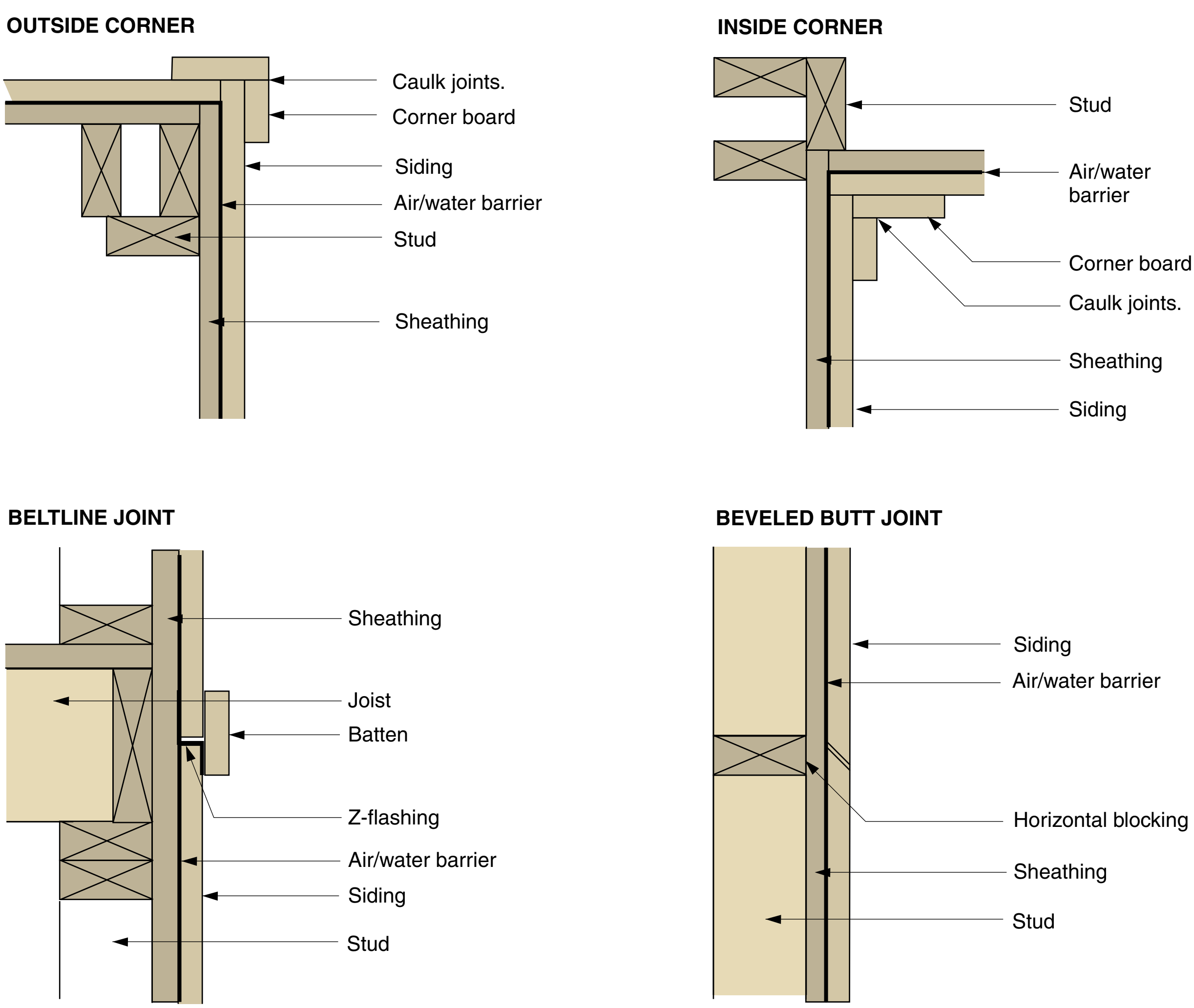
Vertical Wood Siding

Wood changes in width and thickness with changes in moisture content. To minimize problems, install siding after it has dried thoroughly and its moisture content has equilibrated with the air. The recommended procedure is as follows:

- Use as narrow a siding as practical (a rule of thumb is width <8× thickness).
- Select patterns that allow for movement.
- Treat both sides of siding with water repellent before installation.

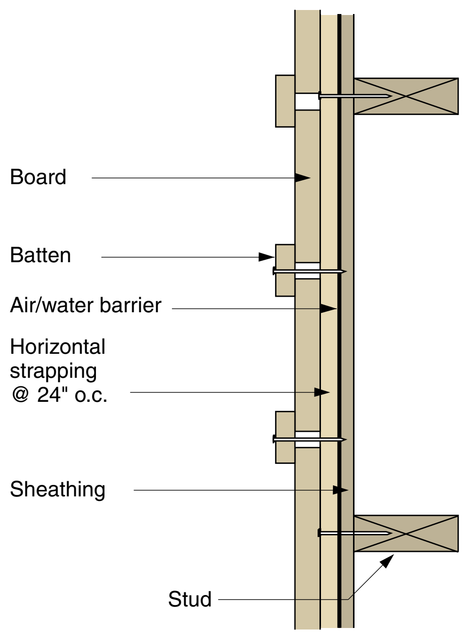
Recommended nailing patterns are shown on the facing page. Nails for applying vertical wood siding should be rust resistant: stainless steel, hot-dipped galvanized, or high tensile-strength aluminum. Do not use electroplated galvanized or unfinished (bright) nails. Recommended penetration into a solid wood base (either studs or wood sheathing) is $1^1/_4$ inches minimum with ring-shank nails. Longer nails are required for installation over other than solid wood sheathing and may require predrilling to avoid splitting the wood.

Joint Treatments in Vertical Wood Sidings

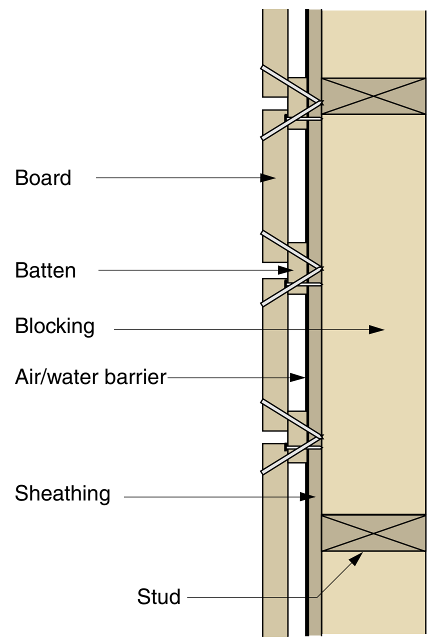


Nailing Patterns in Vertical Wood Sidings

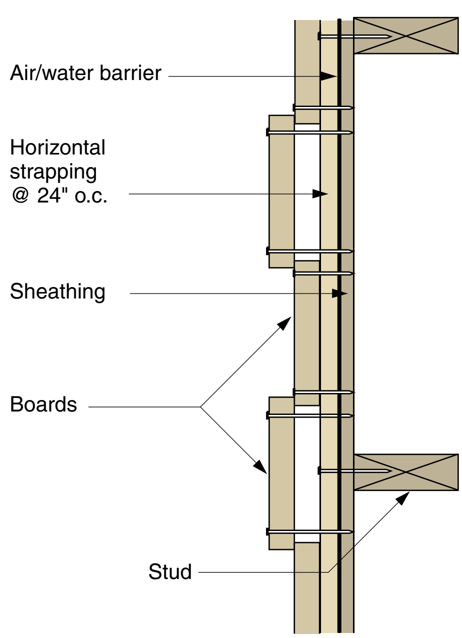
BOARD & BATTEN



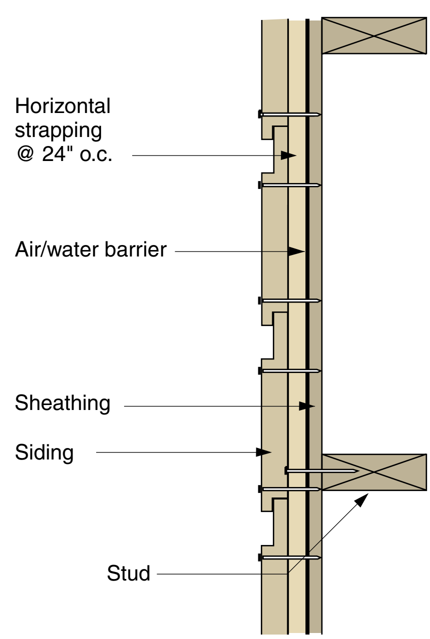
REVERSE BOARD & BATTEN



BOARD & BOARD



CHANNEL SHIP LAP



Plywood Siding

The APA Sturd-I-Wall® system consists of APA rated siding (panel or lap) applied directly to studs or over nonstructural fiberboard, gypsum, or rigid foam insulation sheathing. Nonstructural sheathing is defined as sheathing not recognized by building codes as meeting both bending and racking strength requirements.

A single layer of panel siding, because it is strong and rack resistant, eliminates the cost of installing separate structural sheathing or diagonal wall bracing. Panel sidings are normally installed vertically but may also be placed horizontally (long dimension across supports) if the horizontal joints are blocked. Maximum stud spacings for both applications are given in the table below.

APA Sturd-I-Wall Construction (APA Rated Siding direct to studs and over nonstructural sheathing)

			Max. Stud Spacing (in)			Max. Nail Spacing[e] (in)	
	Siding Description[a]	Nominal Thickness (in.) or Span Rating	Strength Axis Vertical	Strength Axis Horizontal	Nail Size (Use nonstaining box, siding or casing nails)[b,c]	Panel Edges[i]	Intermediate Supports
Panel Siding	APA MDO EXT	$^{11}/_{32}$ & $^{3}/_{8}$	16	24	6d for siding ≥$^{1}/_{2}$" 8d for thicker siding	6[d]	12[f]
		≥$^{15}/_{32}$	24	24			
	APA RATED SIDING EXT	16 o.c. (incl. T1-11)	16	16[g]			
		24 o.c.	24[h]	24[h]			
Lap Siding	APA RATED SIDING-- LAP EXT	16 o.c.	–	16	6d for siding ≥$^{1}/_{2}$"	16 bottom edge	–
		24 o.c.	–	24	8d for thicker siding	24 bottom edge	–

[a] For veneered APA rated siding, including APA 303 siding, recommendations apply to all species groups.

[b] If panel applied over foam insulation sheathing, use next regular nail size. If lap siding installed over rigid foam insulation sheathing up to 1" thick, use 10d (3") nails for $^{3}/_{8}$" or $^{7}/_{16}$" siding, 12d (3$^{1}/_{4}$") nails for $^{15}/_{32}$" or $^{1}/_{2}$" siding, and 16d (3$^{1}/_{2}$") nails for $^{19}/_{32}$" or thicker siding. Use nonstaining box nails for siding installed over foam insulation sheathing.

[c] Hot-dip or hot-tumbled galvanized steel nails are recommended for most siding applications. For best performance, stainless steel nails or aluminum nails should be considered.
Note: Galvanized fasteners may react under wet conditions with the natural extractives of some wood species and may cause staining if left unfinished. Such staining can be minimized if the siding is finished in accordance with APA recommendations, or if the roof overhang protects the siding from direct exposure to moisture and weathering.

[d] For braced wall section with $^{11}/_{32}$" or $^{3}/_{8}$" panel applied horizontally over studs 24" o.c., space nails 3" o.c. along edges.

[e] Recommendations of siding manufacturer may vary.

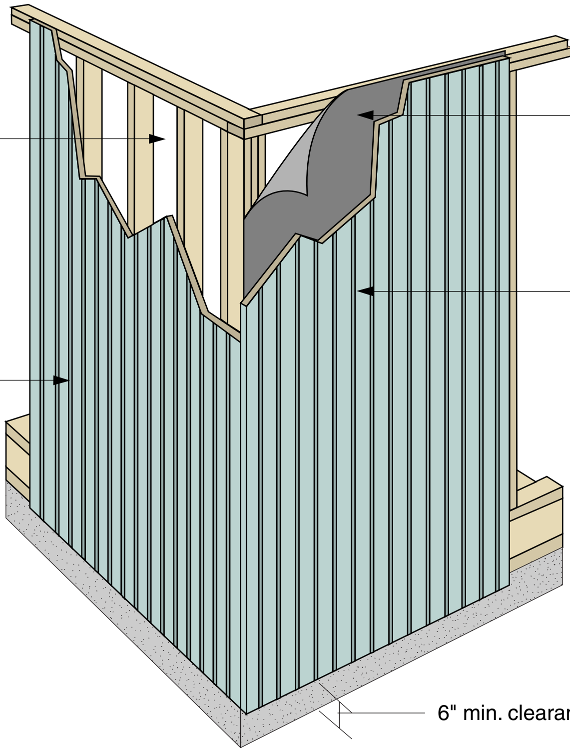
[f] Where basic wind speed exceeds 90 mph (3-second gust), nails attaching siding to intermediate studs within 10% of the width of the narrow side from wall corners shall be spaced 6" o.c.

[g] Stud spacing may be 24" o.c. for veneer-faced siding panels.

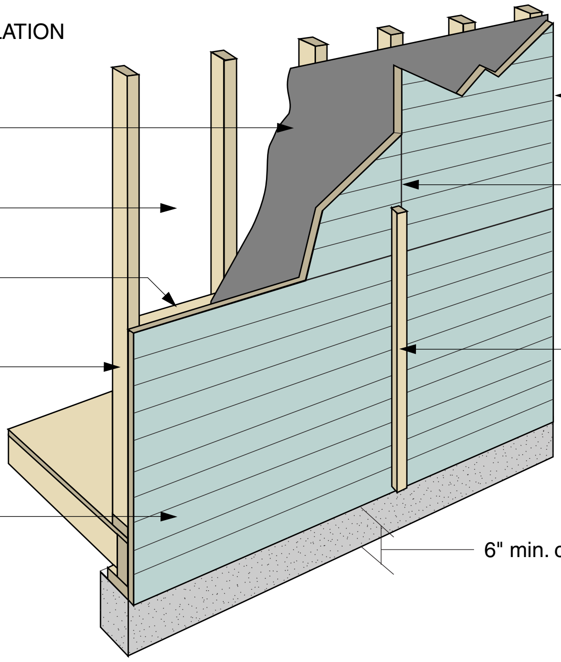
[h] Supported panel joints shall occur approximately along the centerline of framing with a minimum bearing of $^{1}/_{2}$". Fasteners shall be located $^{3}/_{8}$" from panel edges.

APA Sturd-I-Wall Details

VERTICAL PANEL INSTALLATION

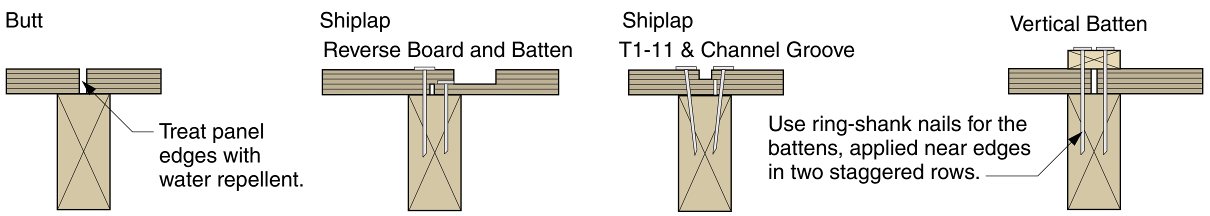


HORIZONTAL PANEL INSTALLATION



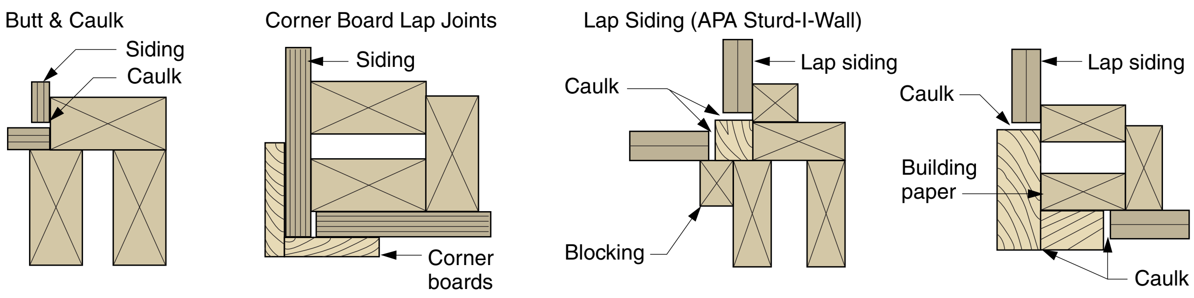
APA Panel Siding Joint Details

VERTICAL WALL JOINTS

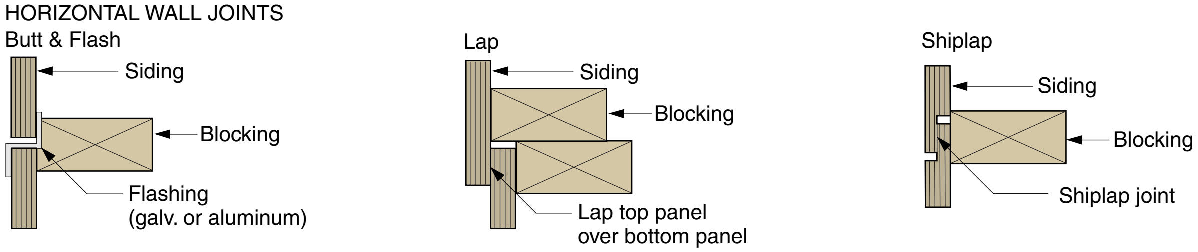


Nailing of both panel edges along shiplap joint is recommended. The "double nailing" is required when wall segment must meet wall bracing or engineered shear wall requirements.

VERTICAL INSIDE & OUTSIDE CORNER JOINTS

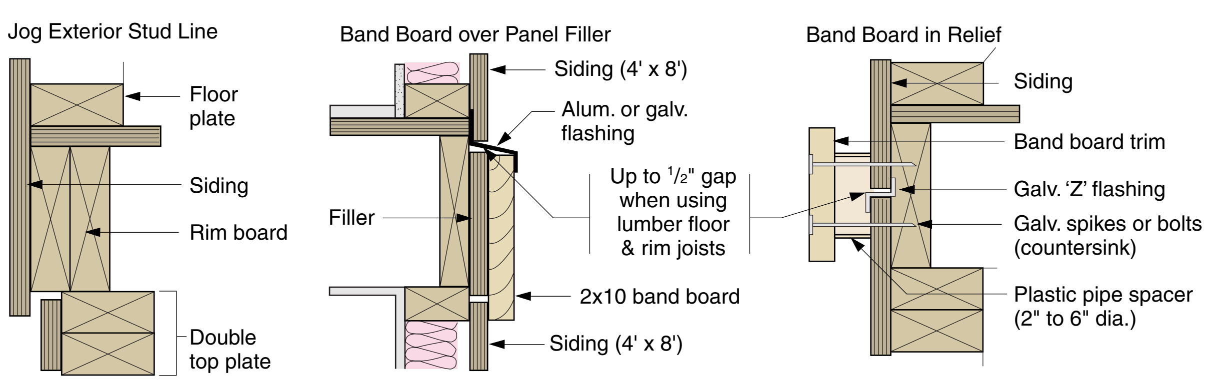


HORIZONTAL WALL JOINTS

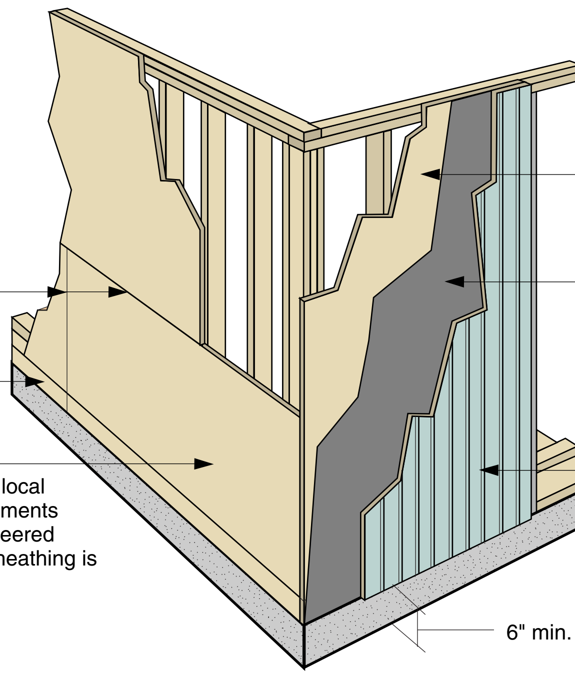


HORIZONTAL BELTLINE JOINTS

For multistory buildings, when conventional lumber floor joists and rim boards are used, make provisions at horizontal joints for shrinkage of framing, especially when applying siding direct to studs.



APA Panel Wall Sheathing



APA Panel Wall Sheathing[a] (APA rated sheathing panels continuous over two or more spans)

Panel Span Rating	Maximum Stud Spacing, in.	Nail Size[b,c]	Maximum Stud Spacing, in.[e] Supported Panel Edges[d]	Maximum Stud Spacing, in.[e] Intermediate Supports
12/0, 16/0, 20/0 or Wall, 16 o.c.	16	6d for panels ≤$1/2$" 8d for thicker panels	6	12
24/0, 24/16, 32/16 or Wall, 24 o.c.	24			

[a] See requirements for nailable panel sheathing when exterior covering is to be nailed to sheathing.

[b] Common, smooth, annular, spiral-thread, or galvanized box.

[c] Other code-approved fasteners may be used.

[d] Fasteners shall be located $3/8$" from panel edges.

[e] Increased nail schedules may be required where wall is engineered as a shear wall.

Stucco

Stucco is a mixture of sand, cement, lime, and water. The most common formula is four parts sand to one part portland cement, with a smaller amount of lime. The amount of water is adjusted for workability. A good starting point for the mix is shown in the table below.

Bases

Stucco can be applied over any suitably rigid base. Cast-in-place concrete and concrete masonry block walls are ideal. Wood-frame walls can be used, provided they are rigidly braced and covered with metal reinforcement. Metal reinforcement comes in several styles: welded wire, woven wire, and expanded metal lath. The latter consists of sheet metal, slit and deformed to provide an open grid that is usually self-furring (held out from the base wall at a constant distance). If the metal reinforcement is not self-furring, it should be attached and held $^1/_4$ inch from the base with special furring nails. The metal reinforcement should be galvanized or otherwise treated to be noncorrosive. The metal reinforcement must be firmly attached and rigid. Joints should overlap a minimum of 1 inch and be made only over a solid backing. For open framing without sheathing, this means at the studs.

Mixes

Achieving the proper mix is the aspect that requires the most experience. (Stucco is not a good candidate for do-it-yourself application.) As in most masonry work, the key is workability. The mix must flow well enough to form a smooth and level coat, but not well enough to sag after application. Also, the amount of sand in the mix influences both strength and susceptibility to later cracking. For convenience, the same mix is used for both the scratch (first) coat and the brown (second) coat, with more sand being added to the brown coat. A factory mix is usually used for the finish coat. The manufacturer's recommendations should be strictly followed.

Control Joints

Control joints allow movement without cracking of the stucco due to thermal expansion and contraction, wetting and drying, and slight movements of the underlying structure. Over concrete masonry, control joints in the stucco are required only over the control joints in the masonry. Over wood walls, control joints should be spaced no more than 18 feet apart, but in no case so as to create unjointed panels of over 150 square feet.

Application

The scratch coat should completely fill the metal reinforcement and be scored or scratched horizontally for good bonding. It should be kept moist for a minimum of 12 hours and allowed to set 48 hours before the next coat. The brown coat (if there is one) should be kept moist for 12 hours and allowed to set for 7 days. The finish coat requires wetting for 12 hours. Painting stucco is not recommended, since complete paint removal would be required before repair or recoating of the stucco.

Typical Stucco Mix

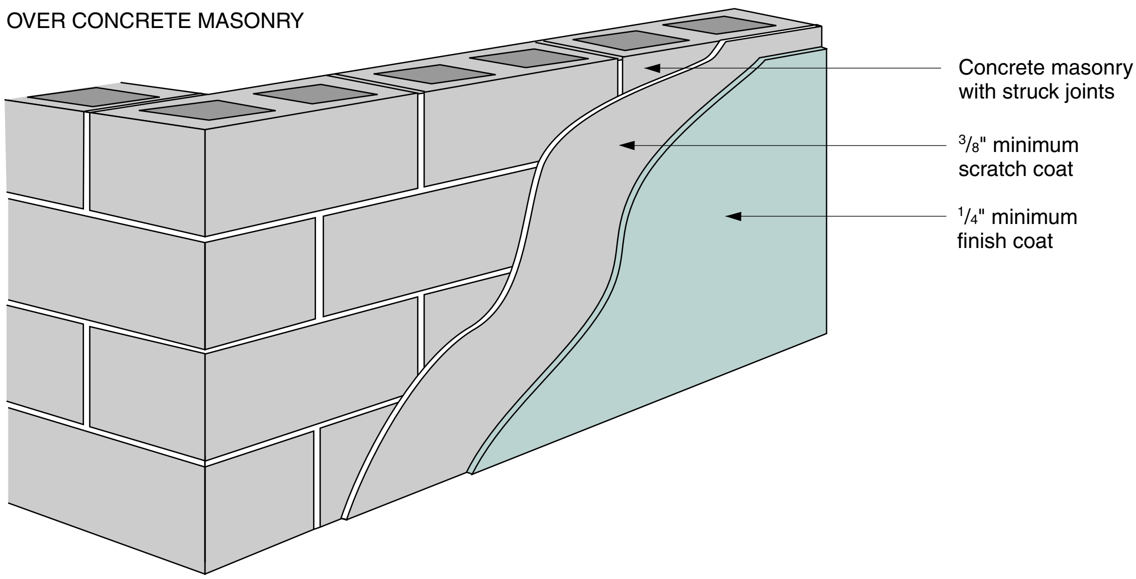
Component	Cubic Feet	Gallons	Pounds
Sharp sand	2	15	200
Portland cement	$^1/_2$	$3^3/_4$	47
Lime	$^1/_3$	$2^1/_2$	12
Water	$^3/_4$	6	48

Optimum Curing Times

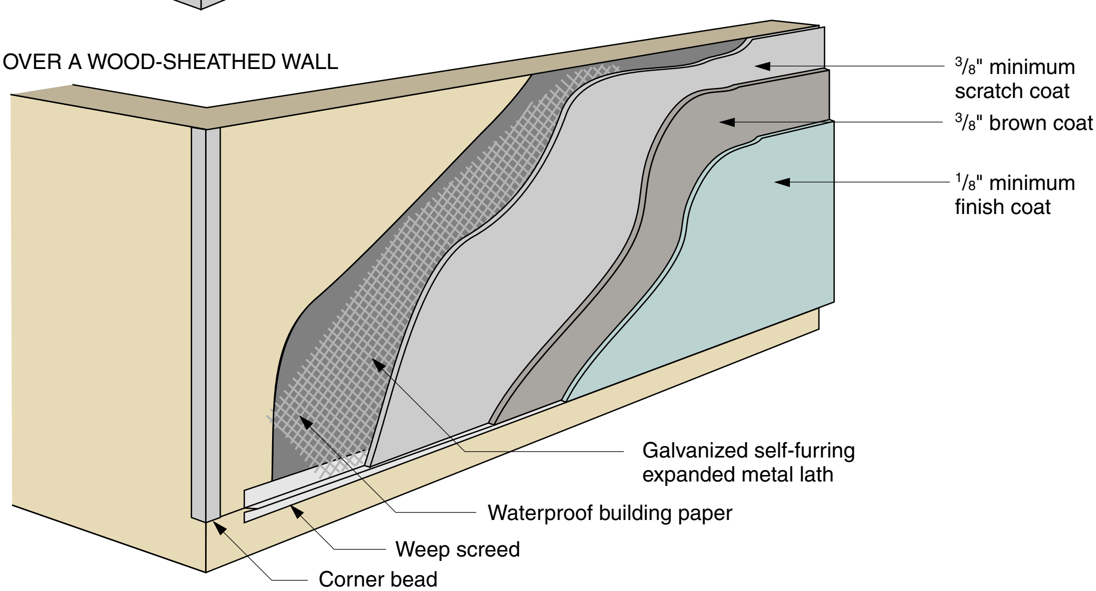
Coat	Keep moist, hours	Total set,days
Scratch	12	2
Brown	12	7
Finish	12	2

Stucco Application

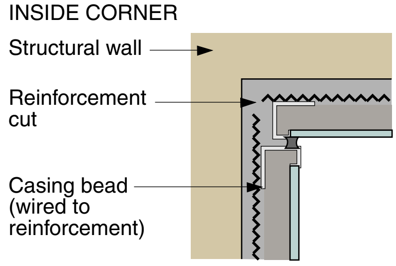
OVER CONCRETE MASONRY



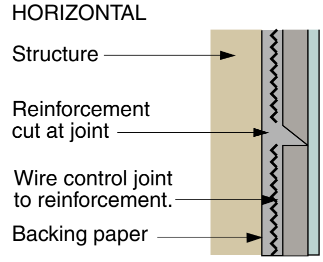
OVER A WOOD-SHEATHED WALL



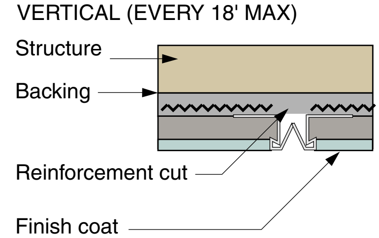
INSIDE CORNER



HORIZONTAL



VERTICAL (EVERY 18' MAX)



Asbestos Siding Solutions

Asbestos is a naturally occurring fibrous mineral that, when mixed with Portland cement, makes a durable, inexpensive, paint-friendly shingle siding. The number of homes still clad in asbestos shingles is testament to their durability. Unfortunately, airborne and inhaled asbestos fibers were found to cause cancer and were banned by the EPA from all building products in 1989. So what should the owner or prospective buyer of an asbestos-sided building do? The paragraphs below describe your options.

Asbestos or Fiber Cement?

First determine whether the siding is really asbestos shingle or a remarkably similar looking fiber-cement shingle. If the siding predates 1980, it probably contains asbestos. If installed after 1989, it doesn't. If there is any question, have a sample tested. Many states offer free tests. If not, asbestos testing labs (search online) charge about $30.

Maintaining, Not Removing

Existing intact asbestos shingles pose no health danger and need not be removed. It is only when shingles are sawn, sanded, or scraped that asbestos fibers become airborne. The least expensive option is maintaining: painting, refastening, and replacing the occasional broken shingle.

Replacing Broken Shingles

Most states allow homeowners living in their own single-family homes to remove or replace asbestos siding following specified removal procedures. Anyone else performing the work must be a licensed asbestos abatement contractor. Removal of asbestos siding from multi-family dwellings and commercial buildings similarly requires a licensed asbestos contractor.

Replacement asbestos shingles are no longer available, but several manufacturers offer a variety of fiber-cement shingles in the most common sizes. The illustration at top on the facing page shows those available from GAF. The illustration at bottom shows the procedure for replacing individual shingles.

Removing and Replacing All

Whether a homeowner or a licensed asbestos abatement contractor, follow the procedure below:

1. Before removing any material, make sure you are wearing a full, disposable, protective suit and hood such as Tyvek. In addition, a respirator (not a paper mask) with HEPA filters and disposable gloves.

2. Create a control zone around the work area with barrier tape. Don't permit unauthorized persons inside the area.

3. Place drop cloths under the work area to collect falling debris. After completion of the job, wet down, roll or fold, and double bag. Dispose of the bagged drop cloth as asbestos waste

4. Keep the siding wet during removal to limit airborne particles and fibers.

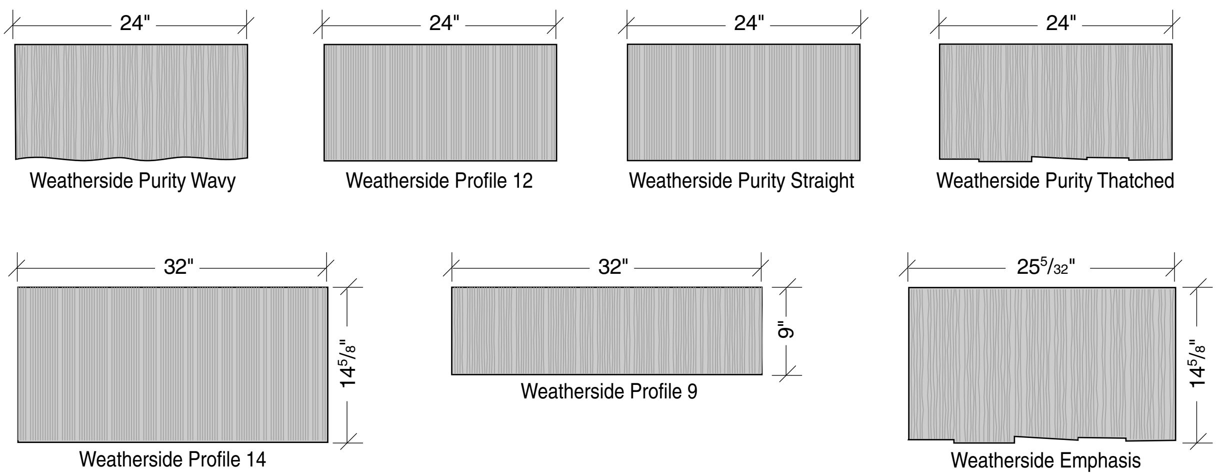
5. Work from top to bottom. As much as possible, remove the shingles whole by pulling the nails straight out with nippers (bottom illustration on the facing page).

6. Bag the debris first in burlap sacks, followed by two plastic bags (6-mil minimum). Alternatively, stack 5 to 10 shingles on 2 layers of 6-mil poly sheeting, fold, then seal with duct tape. Label the bagged or wrapped siding as "asbestos waste."

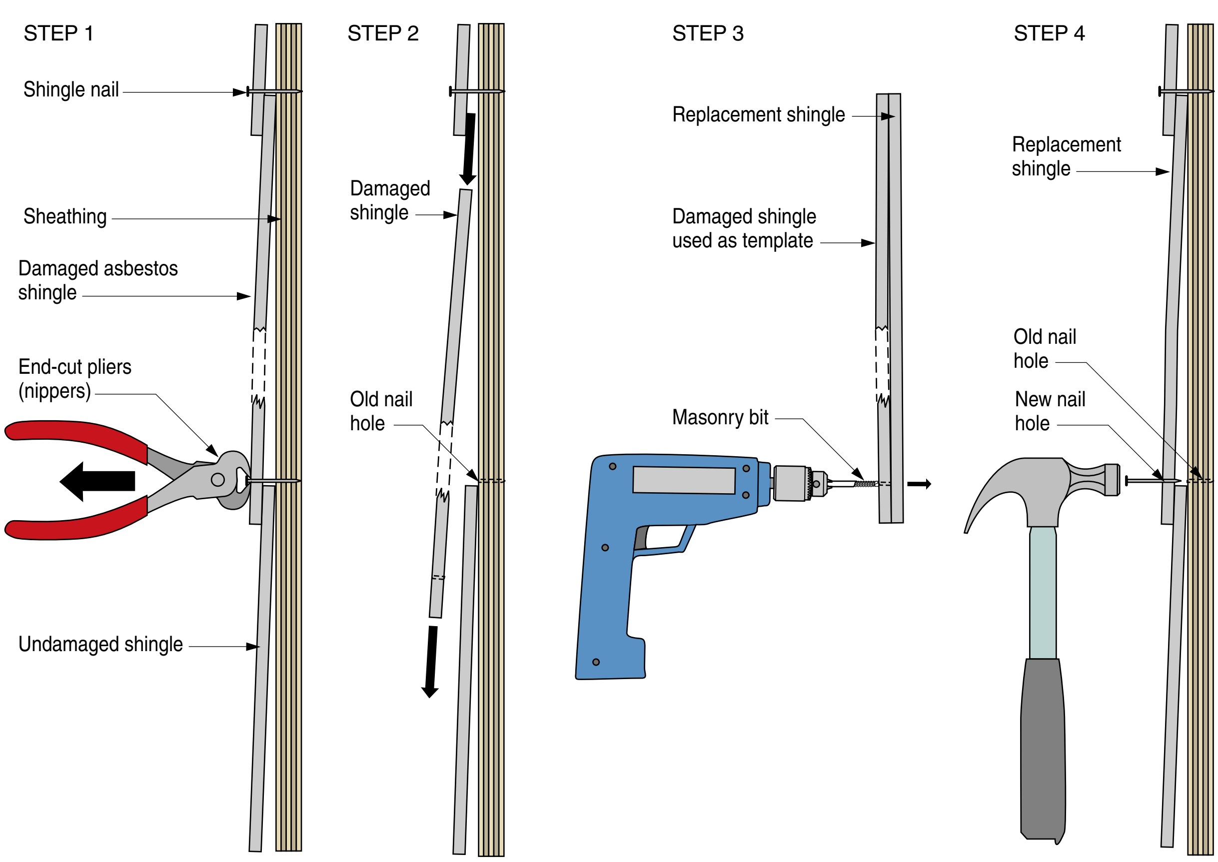
7. Dispose of the sealed debris at a landfill licensed to accept asbestos waste. If none are available to you, call a solid waste disposal company or an asbestos abatement contractor to dispose of your asbestos waste for you.

8. Shower immediately after each work session. Disposable suits and respirator filters should also be disposed as asbestos waste.

GAF Fiber-Cement Replacement Shingles



Replacing a Broken Asbestos Shingle



Meet the Code (IRC)

The following is a partial list of requirements from the *2015 International Residential Code (IRC) for One- and Two-Family Dwellings.* Consult the publication for the full text and additional provisions.

Exterior Covering (R703)

Water-resistive barrier:

- #15 asphalt felt or other approved barrier, free of holes, over studs or sheathing of exterior walls
- applied horizontally and lapped ≥2"
- vertical joints lapped ≥6"
- omission permitted for detached accessory buildings

Panel siding:

- vertical joints to occur over framing members, unless wood or wood structural panel sheathing is used, and be shiplapped or covered with a batten
- horizontal joints lapped ≥1" or shiplapped or be flashed with Z-flashing and occur over solid blocking, wood, or wood structural panel sheathing

Horizontal lap siding:

- lapped ≥1", or ≥1/2" if rabbeted, with ends caulked, covered with batten, or sealed and installed over strip of flashing

Wood shakes and shingles:

- applied either single-course or double-course over nominal 1/2" wood-based sheathing or to furring strips over 1/2" nominal nonwood sheathing
- furring 1×3 or 1×4 fastened to studs with 7d or 8d box nails and spaced at weather exposure
- spacing for expansion between adjacent shingles 1/8"–1/4"; for shakes, 3/8"–1/2"
- offset between joints in courses to be ≥1 1/2"
- weather exposure for shakes and shingles not to exceed that specified in Table R703.6.1
- fastened by two hot-dipped, type 304 or 316 stainless steel, or aluminum nails or staples long enough to penetrate sheathing or furring strips by ≥1/2"
- staples ≥16 gauge with ≥7/16" crown parallel to butt
- fasteners concealed by course above and driven 1" above butt line of next course, 3/4" from edges
- in double-course applications, top shake or shingle face-nailed with 2 casing nails, 2" above butt line
- shingles >8" wide to have 2 additional nails 1" apart near center of the shingle
- bottom courses to be doubled

Exterior plaster:

- lath and lath attachments corrosion-resistant
- expanded metal or woven wire lath attached with 1 1/2"-long, 11-gauge nails with 7/16" head, or 7/8"-long, 16-gauge staples, spaced ≤6"
- ≥3 coats of portland cement plaster over metal or wire lath, and ≥2 coats over masonry, concrete, pressure-preservative treated wood, decay-resistant wood, or gypsum backing
- ≥2 coats if plaster surface covered by veneer or facing material or completely concealed
- for wood-frame construction with slab-on-grade floor slab, plaster to cover, but not extend below, lath, paper, and screed
- ≥0.019" corrosion-resistant or plastic weep screed, with ≥3 1/2" vertical flange at or below sill plate
- screed ≥4" above earth or 2" above paved areas and allow trapped water to drain to exterior
- exterior lath to cover and terminate on attachment flange of weep screed

Table R703.6.1

	Maximum Exposure, inches	
Length, inches	**Single Course**	**Double Course**
Shingles		
16	7	12[1]
18	8	14[2]
24	10 1/2	16
Shakes		
18	8	14
24	10 1/2	18

[1] 10 inches for No. 2 grade

[2] 11 inches for No. 2 grade

Table R703.3(1) Siding Minimum Attachment and Minimum Thickness

Siding Material		Nominal Thickness, inches	Joint Treatment	Support for Siding Material and Fasteners					
				Wood/ Structural Sheathing	Fiberboard Sheathing into Stud	Gypsum Sheathing into Stud	Foam Plastic Sheathing into Stud	Direct to Studs	Fastener Number/ Spacing
Fiber cement	panel	5/16	–	6d common	6d common	6d common	6d common	4d common	6" at edges 12" interior
	lap siding	5/16	–	6d common	6d common	6d common	6d common	6d common	
Hardboard	panel	7/16	–	0.120" nail with 0.225" head	0.120" nail with 0.225" head	0.120" nail with 0.225" head	0.120" nail with 0.225" head	0.120" nail with 0.225" head	6" at edges 12" interior
	lap siding	7/16	–	0.099" nail with 0.240" head	0.099" nail with 0.240" head	0.099" nail with 0.240" head	0.099" nail with 0.240" head	0.099" nail with 0.240" head	Stud spacing 2 per bearing
Horizontal Aluminum	no insulation	0.019	Lap	1 1/2" siding nail	2" siding nail	2" siding nail	1 1/2" siding nail	Not allowed	Stud spacing
		0.024	Lap	1 1/2" siding nail	2" siding nail	2" siding nail	1 1/2" siding nail	Not allowed	
	insulation	0.019	Lap	1 1/2" siding nail	2 1/2" siding nail	2 1/2" siding nail	1 1/2" siding nail	Not allowed	
Steel		29 ga.	Lap	0.113 × 1 3/4 nail or 1 3/4 staple	0.113 × 2 3/4 nail or 2 1/2 staple	0.113 × 2 1/2 nail or 2 1/4 staple	0.113 × 1 3/4 nail or 1 3/4 staple	not allowed	Stud spacing
Particleboard panels		3/8	–	6d box nail	6d box nail	6d box nail	6d box nail	Not allowed	6"edges/12" int
		1/2	–	6d box nail	6d box nail	6d box nail	6d box nail	6d box nail	6"edges/12" int
		5/8	–	6d box nail	8d box nail	8d box nail	6d box nail[y]	6d box nail	6"edges/12" int
Plywood (exterior) panel		3/8–1/2	–	0.099 × 2 nail	0.113 × 2 1/2 nail	0.113 × 2 1/2 nail	0.113 × 2 1/2 nail	0.099 × 2 nail	6"edges/12" int
Vinyl siding		0.035	Lap	0.120/0.313 head or 16-ga. staple	0.120/0.313 head or 16-ga. staple	0.120/0.313 head or 16-ga. staple	0.120/0.313 head	Not allowed	16"o.c. or as mfr. spec.
Wood	rustic, drop	3/8 min	Lap	6d box/siding	6d box/siding	6d box/siding	6d box/siding	8d box/siding	Face nail
	shiplap	19/32 ave	Lap	6d box/siding	6d box/siding	6d box/siding	6d box/siding	8d box/siding	1 nail to 6”
	bevel	7/16	Lap	6d box/siding	6d box/siding	6d box/siding	6d box/siding	8d box/siding	2 nails > 6”
	butt tip	3/16	Lap	6d box/siding	6d box/siding	6d box/siding	6d box/siding	8d box/siding	

9

Roofing

Terms such as *eaves, soffit, fascia,* and *ridge* are referred to throughout this chapter, so before you look up the installation details of your favorite roof, read the first section, *Roofing Terms.*

If you are trying to decide what kind of roofing to install, read the second section, *Roofing Materials.*

The following sections—the real meat of the chapter—describe in words and illustrations how to install ten different types of roofing. They range from *EPDM (rubber membrane)*, suitable for flat roofs, through two versions of roll roofing *(concealed-nail roll roofing* and *double-coverage roofing)*, ubiquitous *asphalt shingles*, classic *cedar shingles* and *cedar shakes*, and regional materials such as *slate* and Spanish *tile*, to preformed *metal panel-* and *standing-seam* roofing.

The best time to install, replace, or repair *gutters* is when you are roofing, so a description of the typical gutter system and all of its parts is included, too.

Finally, as usual, we provide a crib sheet to make sure your roofing will *meet the code (IRC)*.

Roofing Terms

Function of the Roof

The primary function of a roof is to protect the building beneath from moisture damage, whether from rain, snow, or ice. The primary design characteristics controlling success are pitch (angle) and coverage (overlap) of the roofing material.

Pitch and Slope

The pitch of a roof is the vertical rise divided by the total span. The slope of a roof is the vertical rise divided by the horizontal run.

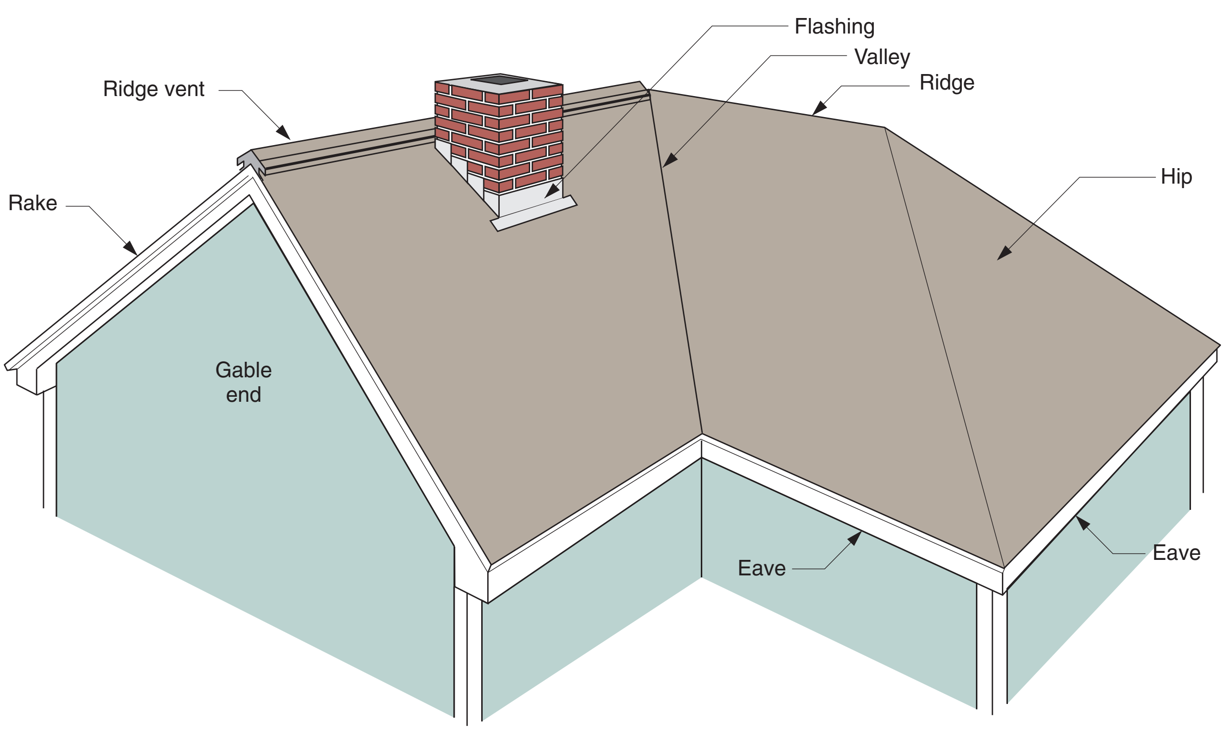
Example: A roof peak is 8 feet above the top plate. The total span (building width) is 24 feet. The pitch is, therefore, 8/12, or 1/3; the slope is 8/12, usually expressed as inches of rise per 12 inches of run, or 8/12.

Exposure and Coverage

Exposure is the down-slope width of roofing material exposed after installation. Coverage is the number of layers of roofing from surface to underlayment.

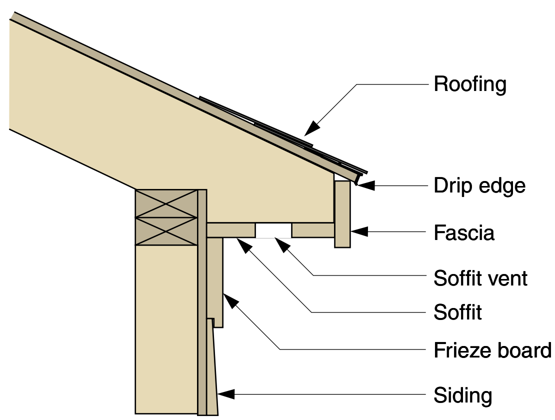
Example: A roof is covered with asphalt shingles measuring 12 inches by 36 inches. The bottom 5 inches of each shingle are exposed. Thus, the exposure is 5 inches, and the coverage is double (coverage varies from double to triple, but the least amount is what counts).

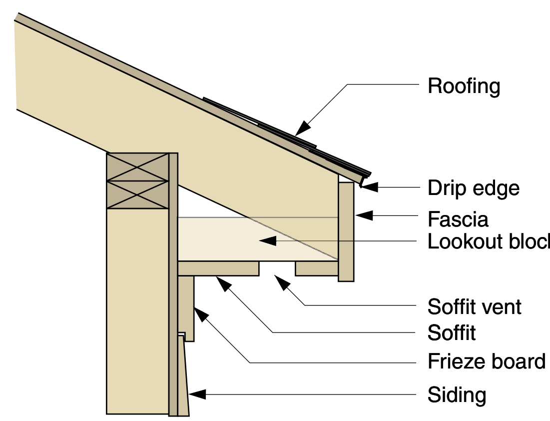
Parts of a Roof

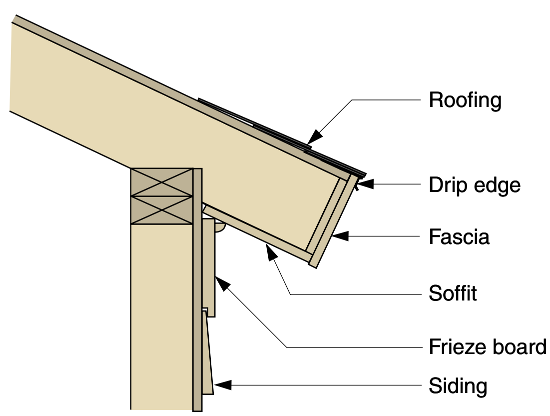


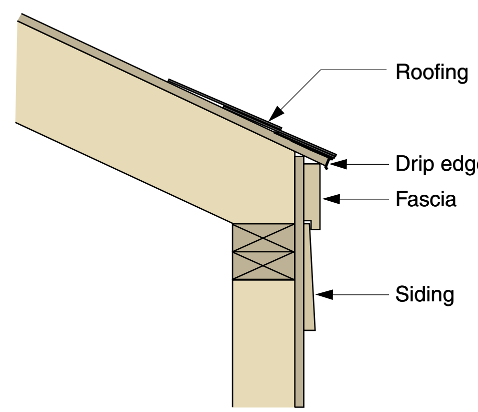
Cornice Terminology

EAVE DETAILS

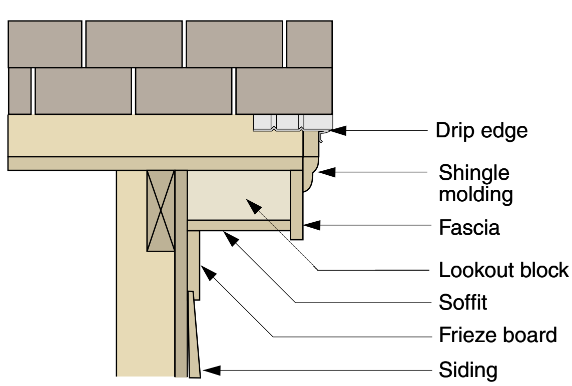


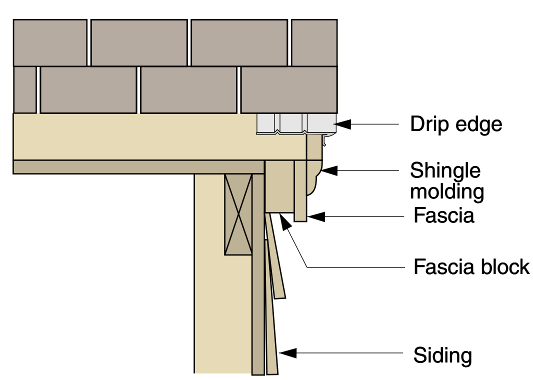






GABLE-END DETAILS



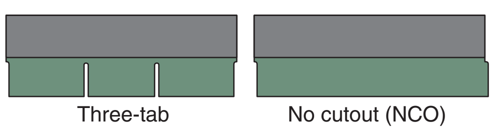
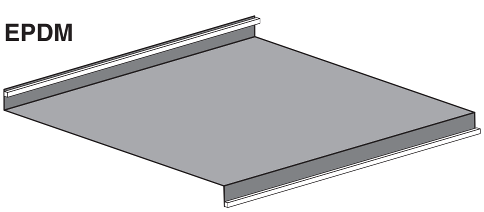
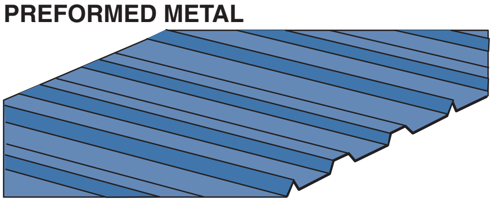
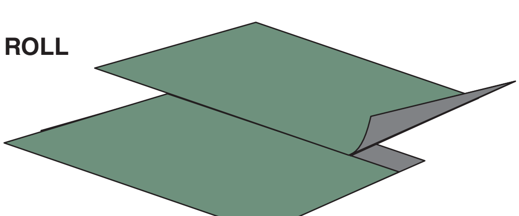


Roofing Materials

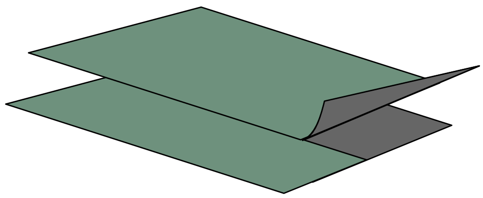
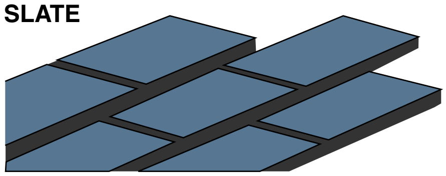
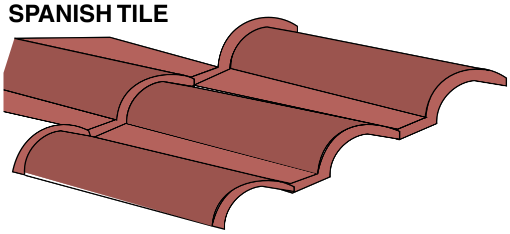
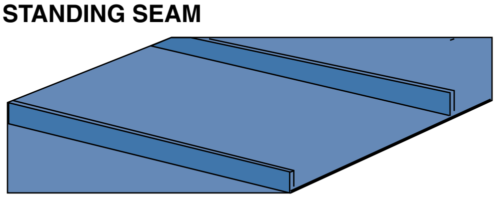
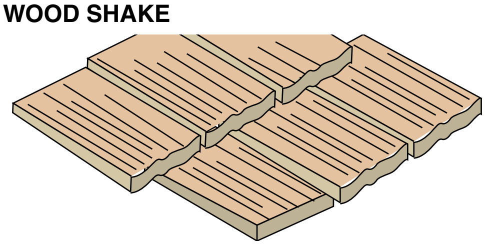
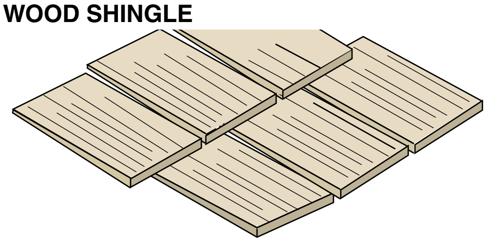
The type of roofing material selected is a function of regional architectural style as well as performance. The most common material by far is the ubiquitous asphalt shingle. However, the mark of a top-quality home in Vermont is the slate roof; in much of ski country, standing seam or preformed metal panel; in the Southwest, Spanish tile.

Be aware of rapid changes in the industry. Preformed metal panels have nearly replaced standing seam, and EPDM (single-ply rubber membrane) is rapidly replacing the old-fashioned built-up roof for flat and low-slope applications.

Roofing Materials Compared

Roofing Type	Minimum Slope	Life, years	Relative Cost	Weight, lb per 100 sq ft
ASPHALT SHINGLE 	4	15–20	Low	200–30
EPDM 	0	20	Medium	30–45
PREFORMED METAL 	3	30–50	Low–Medium	50
ROLL 	2	10	Low	90

Roofing Materials Compared—*Continued*

Roofing Type	Minimum Slope	Life, years	Relative Cost	Weight, lb per 100 sq ft
DOUBLE COVERAGE 	1	15	Low	130
SLATE 	5	100	High	800–1,500
SPANISH TILE 	4	100	Medium	1,000
STANDING SEAM 	3	30–50	Medium	75
WOOD SHAKE 	3	50	High	300
WOOD SHINGLE 	3	25	Medium	150

EPDM (Rubber Membrane)

Flat and low-slope roofs have always been problematical—until the advent of ethylene propylene diene monomer (EPDM) rubber membranes. The material is available in thicknesses of 45 mil (most common), 60 mil, and 90 mil, and in sheets up to 50 feet wide and 100 feet long, making seams unnecessary for most applications.

Adhering Membrane

The membrane may be adhered to any clean, solid, relatively flat surface. Although self-adhesive versions are available, the use of a bonding adhesive similar to contact cement is recommended.

First make sure the substrate is securely fastened. Rigid foam insulation should be fasted 2 feet on-center using screws or ring-shank nails with fender washers. Before application of the adhesive, the surface must be absolutely dry.

Spread the membrane into position over the roof. The membrane should lap intersecting walls by 8 to 12 inches and overhang the roof edges by 3 inches.

Allow 30 minutes for the membrane to lie flat, then fold the membrane back halfway and wipe the surface with the recommended cleaner. Open the adhesive and stir until uniform.

Using a paint roller, apply the adhesive to the deck and to the back of the membrane. Allow adhesive to dry until just tacky. Very carefully, roll the coated membrane back onto the coated deck. Sweep over the membrane with a push broom to fully adhere the membrane.

Repeat the whole process on the remaining half of the membrane.

Intersecting Wall

The membrane should extend 8 to 12 inches up any intersecting wall. Wall siding simply laps over the membrane as if it were roof flashing.

On a masonry (CMU or brick) wall, an aluminum termination bar secures the top edge. First fasten the bar with screws or masonry fasteners. Then trim the membrane flush with the bar, and caulk as shown.

Roof Edges

The membrane laps over the fascia or rake a minimum of 3 inches. Where there is a gutter, lap the membrane over its inside face. The membrane is then fastened to the vertical surface with a termination bar and trimmed even with the bottom of the bar. The top edge of the bar is sealed to the membrane with caulk.

Outside Wall Corners

Cured EPDM membrane has insufficient stretch to make neat outside corners, so patches of easily stretched uncured EPDM are utilized.

First cut the roof membrane where it meets the corner of the wall down to roof level and adhere it to the two walls. This leaves a V-shaped gap in the lapped membrane. Two patches of stretchable uncured EPDM (the second larger than the first) are fully adhered over the gap. The top edges of the patches are secured with termination bar, trimmed flush, and caulked. The remaining exposed edges of the top patch are caulked to the roof membrane.

Roof Penetrations

Prefabricated EPDM boots are available for sealing vent pipes to the roof membrane. Other penetrations may be sealed with patches of uncured EPDM (always doubled) and caulk.

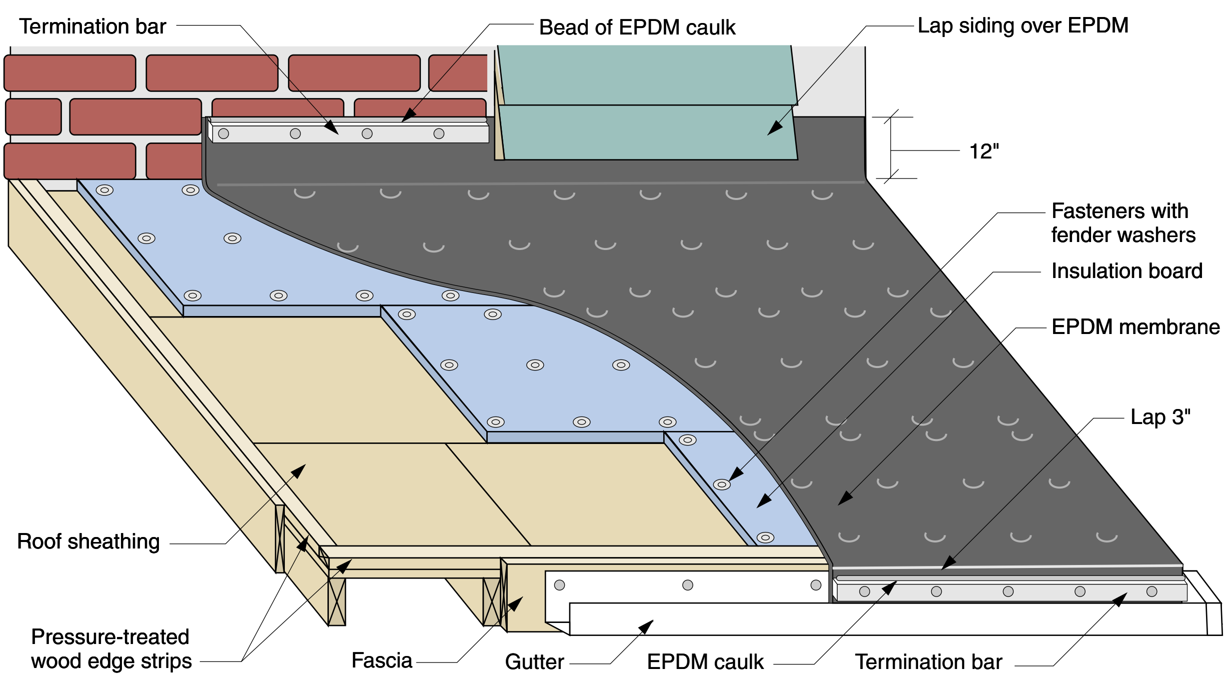
Seams

Sheets of EPDM may be spliced using either a special splicing adhesive or self-adhesive, double-sided seaming tape.

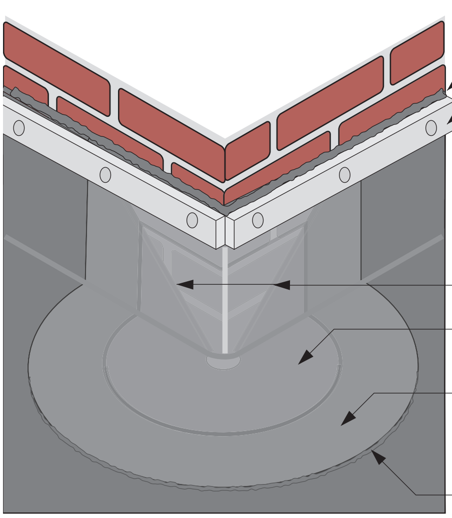
Splicing adhesive is applied to both mating surfaces of a 6-inch overlap and allowed to dry. The seam is then rolled with a hand roller and the exposed edge caulked.

Seaming tape is applied first to one face of the seam with the release paper in place. The membranes are overlapped, and the seam is rolled with the hand roller. Finally, the top piece is adhered as the release paper is slowly removed. The exposed edge is then caulked.

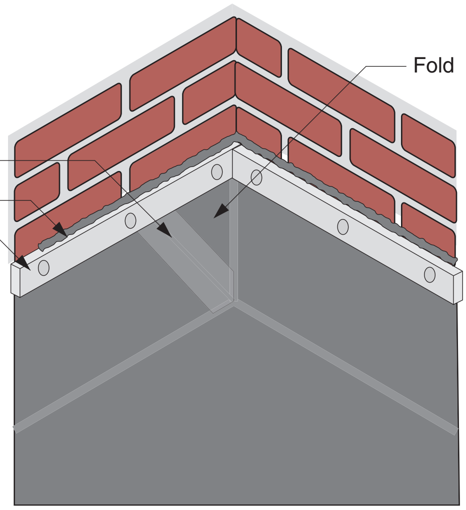
Roof Deck Application



Outside Corner



Inside Corner



Concealed-Nail Roll Roofing

Mineral-surfaced roll roofing is best applied in warm weather. If the temperature is below 45°F, the roofing should first be unrolled and laid flat in a warm space. Extreme care must be used in handling the roofing in cold weather to avoid cracking. In warm weather, unroll the roofing, cut it into 12- to 18-foot lengths, and stack it on the roof for several hours or until the top sheet lies flat. This precaution will reduce the tendency of the roofing to ripple during application as it expands and relaxes from its tightly rolled condition.

Proper sealing of lap joints is critical to avoid leaks on low-slope roofs, so use only the plastic cement recommended by the manufacturer. Warm it if necessary to facilitate even spreading. Also, use only the amount recommended, as excess cement tends to bubble.

The illustration on the facing page shows application parallel to the eaves. Application perpendicular to the eaves is also possible.

Begin by flashing all roof edges as shown. Valleys are flashed with mineral-surfaced roll roofing of the same color. First apply a half strip (18 inches wide), mineral surface down, the full length of the valley, using a minimum number of nails 1 inch from the edges. Next cover that with a full-width sheet, mineral surface up, with minimum nailing 1 inch from the edges.

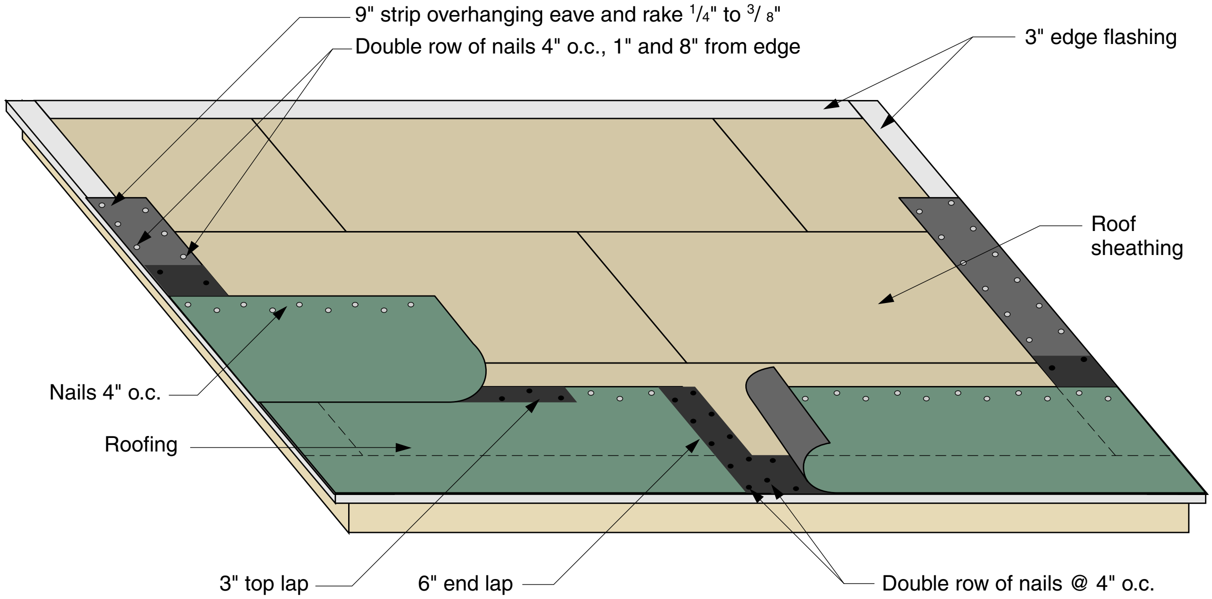
Next apply 9-inch-wide (one-quarter roll width) strips of roofing to eaves and rakes, nailing them 4 inches on-center 1 inch in from each edge. The strip edges should overhang eaves and rakes by approximately 3/8 inch to form a drip edge.

The first full course of roofing is applied with edges even with those of the underlying edge strips. Nail the top edge 4 inches on-center, taking care that the bottom of the succeeding course will completely cover the nails. If more than one length is required, cement and overlap the next length by 6 inches, then fasten it with a double row of nails 4 inches on-center. After the top edge is fully nailed, one person lifts the bottom edge while a second fully coats the eaves and rake edge strips with plastic cement. Thoroughly press the bottom and ends of the sheet into the coated edge strips.

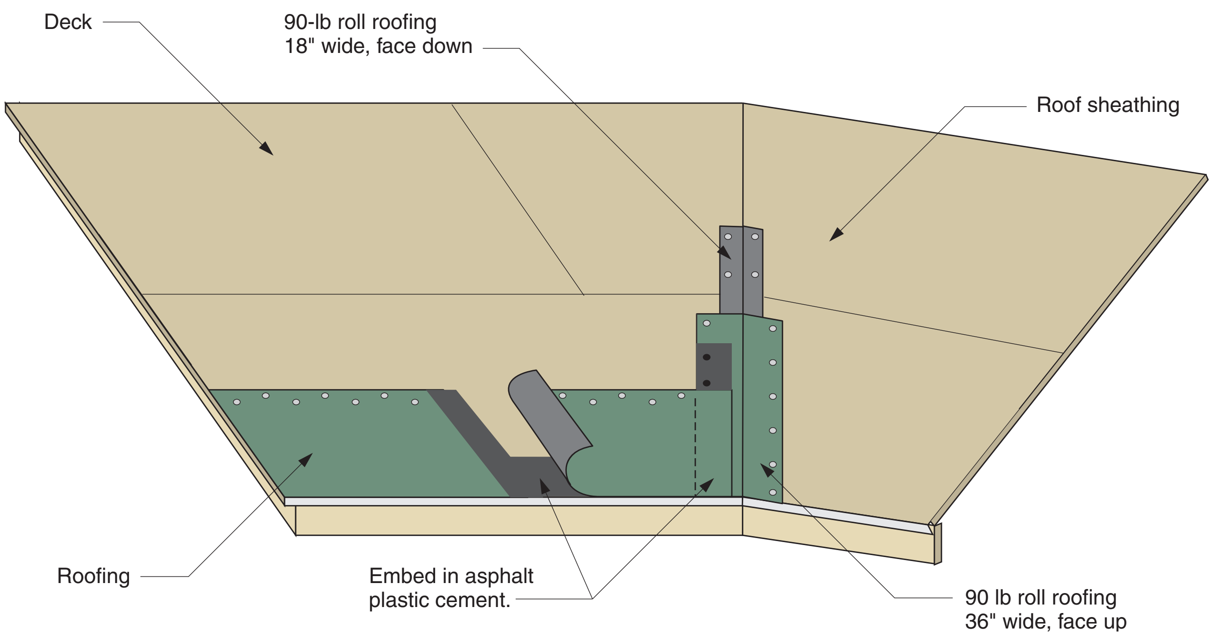
The second and succeeding courses are applied in the same way as the first, except that each course overlaps the preceding by at least 2 inches; 3 inches is better. The sheet is nailed first at the top, allowing for easier correction of ripples, before cementing and nailing of the bottom edge and end laps.

At the valleys and ridges, the sheets are trimmed to butt at the ridge or valley intersections. Chalk lines are snapped 5 1/2 inches to both sides of the intersection, and 2-inch-wide strips of plastic cement are applied. Cut sheets of roofing into 12-inch-wide strips, apply them lengthwise over the intersection, and nail them 3 inches on-center, 3/4 inch from the edges.

Edge Flashing and Covering



Valley Flashing



Double-Coverage Roofing

Double-coverage roofing consists of 17 inches of mineral surfacing, intended for exposure, and 19 inches of selvage (nonmineral-surfaced) to be cemented and lapped. Like the other forms of roll roofing, it is best applied in warm weather in order to avoid cracking and buckling.

In warm weather (over 45°F), unroll the material, cut it into lengths of 12 to 18 feet, and stack it on a flat area of the roof. Allow it to stand until the top sheet lies flat. In cold weather, do the same indoors but be careful not to tear or crack the sheets during transport.

Cementing of the laps is the most critical part of the operation, so use only a plastic cement recommended by the roofing manufacturer, and prewarm the buckets by immersion in warm water if the weather is cold.

The roofing is customarily applied parallel to the eaves, as shown in the illustrations on the facing page. Begin by flashing all roof edges and valleys. Valleys are flashed with mineral-surfaced roll roofing of the same color. First apply a half strip (18 inches wide), mineral surface down, the full length of the valley, using a minimum number of nails 1 inch from the edges. Next cover it with a full-width sheet, mineral surface up, with minimum nailing 1 inch from the edges. The regular courses are then trimmed 3 inches back from the valley intersection, fully cemented to the flashing, and nailed through the selvage portion only.

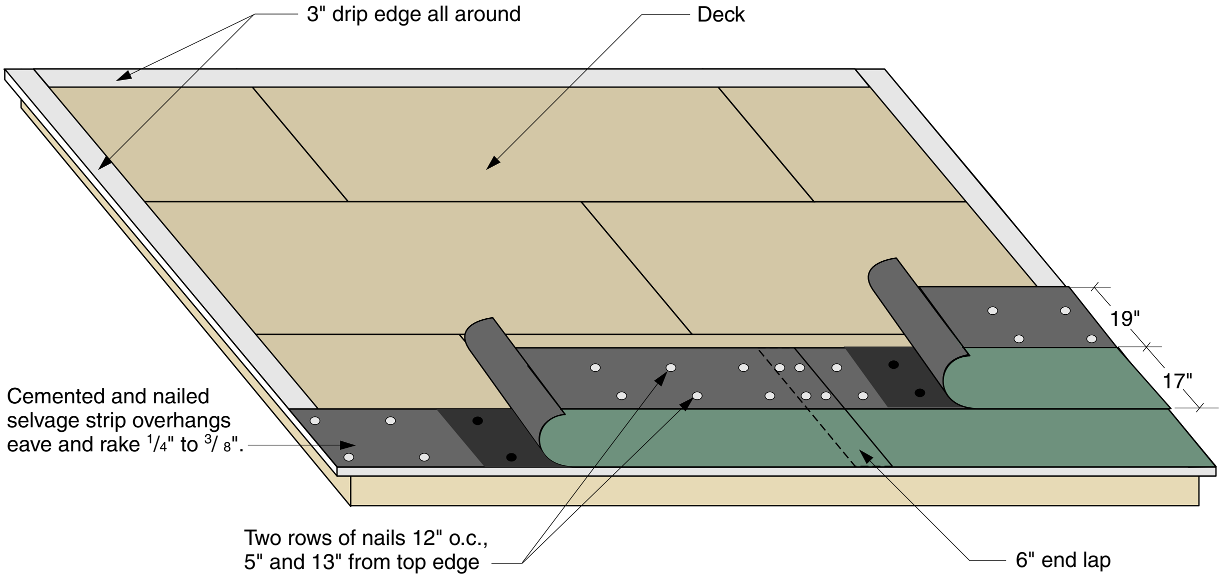
The starter course is formed by splitting a sheet into a 17-inch-wide mineral-surfaced strip and a 19-inch-wide selvage strip. Put the mineral-surfaced strip aside for the final course, and apply the selvage as a starter strip, overhanging both eaves and rakes by $^{3}/_{8}$ inch. Nail the strip 12 inches on-center in two rows: 1 inch above the eaves, and 5 inches from the top. Do not cement the starter strip directly to the deck. Coat the entire exposed surface of the starter strip with plastic cement.

The first regular course is a full-width sheet placed with the bottom edge and ends flush with the edges of the starter strip. Press the mineral-surfaced portion of the sheet into the cement (a roller is handy), and nail the selvage portion to the deck in two rows, 5 inches and 13 inches from the top edge. Succeeding courses are applied in the same fashion, except in this order: Nail top sheet, lift bottom of top sheet and apply cement, and press top sheet into cement.

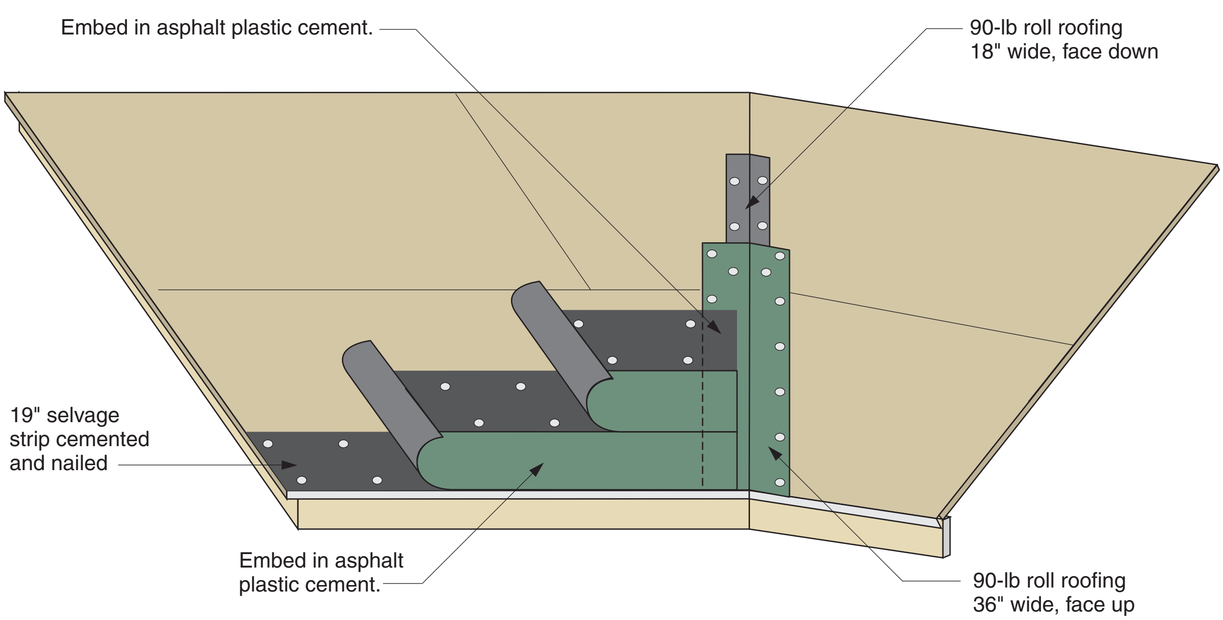
End laps are formed by nailing the surfaced portion of the bottom strip 4 inches on-center and 1 inch from the end, applying a 6-inch-wide band of plastic cement to the entire width and nailing the top strip through the selvage only.

Hips and ridges are finished by covering them with 12-inch-wide strips of roofing. Trim and butt the underlying courses at the intersections. Apply the 12- by 36-inch pieces in exactly the same way as the regular courses, starting with a 12- by 17-inch piece of selvage.

Edge Flashing and Covering



Valley Flashing



Asphalt Shingles

Underlayment and Drip Edges

Begin by installing a drip edge at the eaves. Next apply 15-pound or heavier asphalt-saturated felt underlayment, using a minimum number of nails. Take care to align the felt with the eaves so that the printed lines can serve as guidelines in installing the shingles. Overlap underlayment courses at least 2 inches and end laps 4 inches. Finally, install a drip edge over the underlayment along the rakes.

Eaves Flashing

Where there is any possibility of ice dams, install an eave flashing of mineral-surfaced roll roofing or special plastic or rubber ice-shield membrane from the eaves to a point at least 12 inches inside the wall line.

Valley Flashing

Valleys are flashed with mineral-surfaced roll roofing of the same color. First apply a half strip (18 inches wide), mineral surface down, the full length of the valley, using a minimum number of nails 1 inch from the edges. Next cover with a full-width sheet, mineral surface up, with minimum nailing 1 inch from the edges. Shingle courses will be beveled and trimmed along a line 3 inches from the center of the valley.

Shingle Application

Nails should be galvanized or aluminum, 12 gauge, with min $^3/_8$-inch-dia. heads. The length of the nail should be sufficient to penetrate the deck by $^3/_4$ inch, and the head of the nail should not penetrate the surface of the shingle.

Begin with a starter strip of shingles from which the mineral-surfaced portion has been removed. Remove 3 inches from the end of the first strip so that the cutouts of the first regular course will not fall over a starter joint. Nail the strip 12 inches on-center 3 inches above the eaves, placing the nails to miss the cutouts of the course to follow.

The first course begins with a full-length shingle strip. Install it with the butts of starter and first course aligned. If there is a dormer, snap vertical chalk lines to both sides of the dormer so that vertical alignment of the interrupted courses can be maintained.

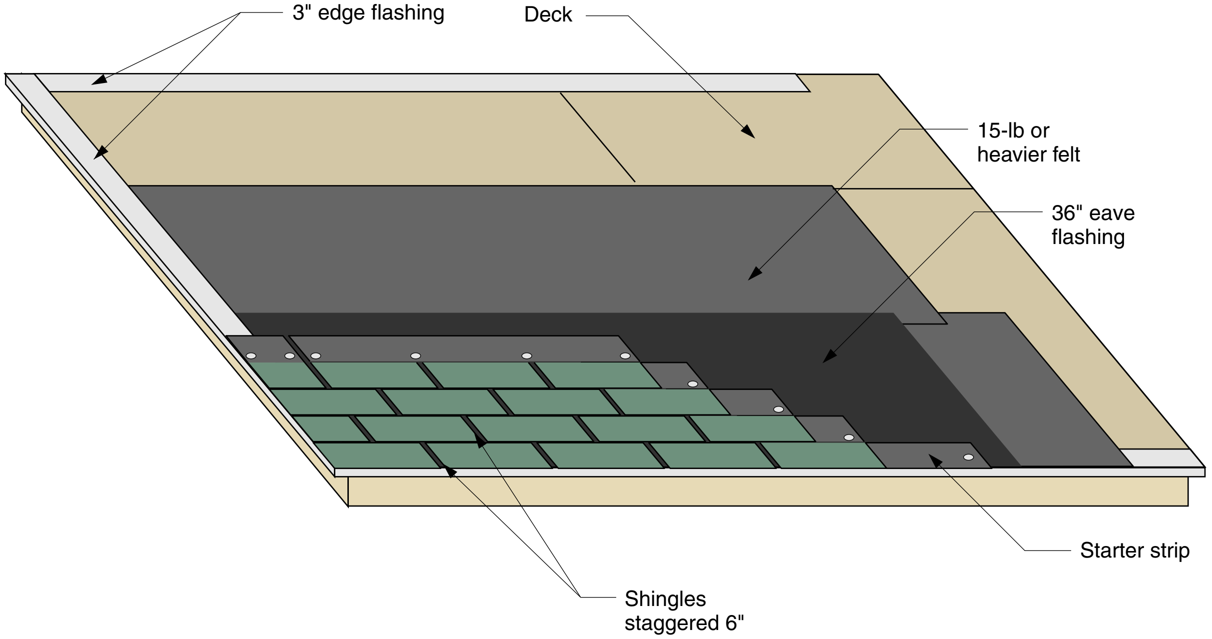
For the most common three-tab shingle, nail it in a line $^5/_8$ inch above the cutouts and 1 inch from each end. With each succeeding course, remove an additional 6-inch width from the first shingle in the row, and line up the butts over the tops of the underlying cutouts. For other types of shingle, follow the manufacturer's directions for nailing.

A less regular effect can be created by removing 4 inches from each succeeding course. The tabs then line up every third course rather than every other course. The disadvantage is the need to measure more often.

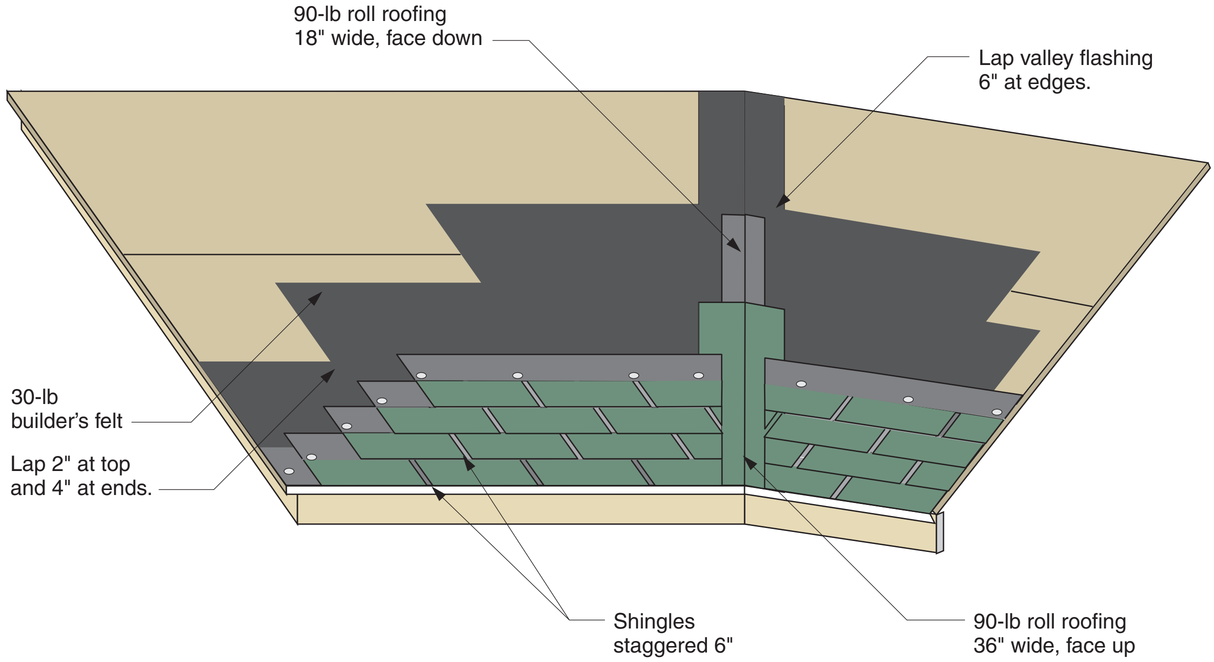
For flashing details at pipes, chimneys, and abutting walls, see the following pages.

For further information about all types of asphalt roofing, see the Asphalt Roofing Manufacturers Association's℠ *Residential Asphalt Roofing Manual.*

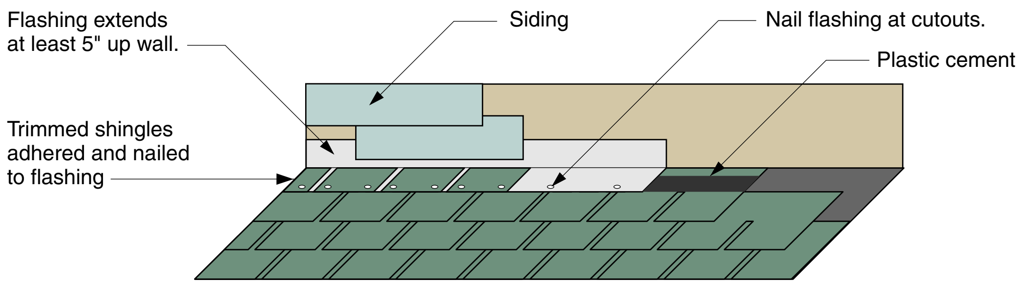
Edge Flashing and Covering



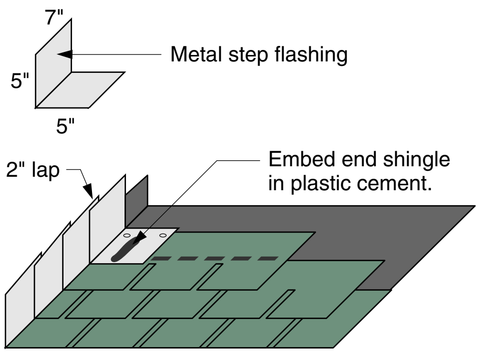
Valley Flashing

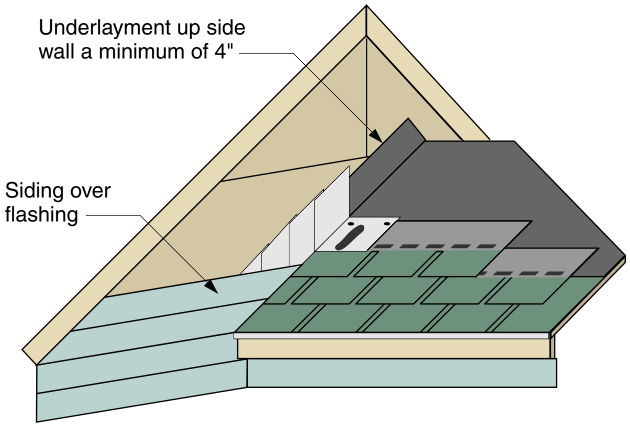


Flashing a Butting Wall

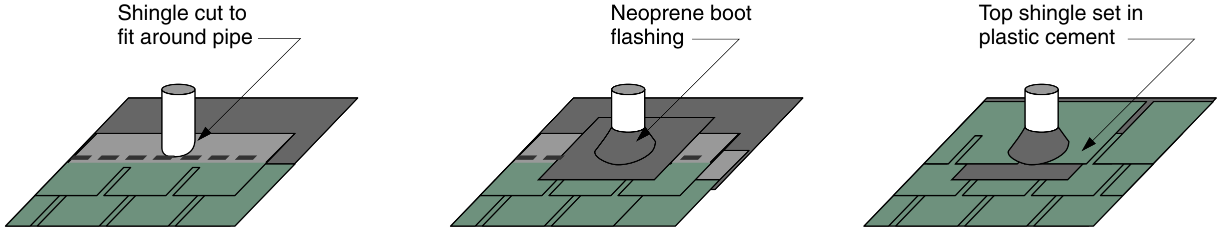


Flashing a Butting Side Wall



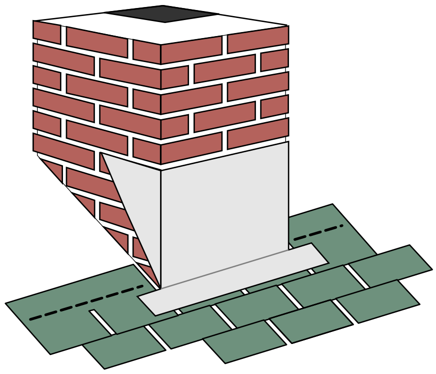


Flashing a Vent Pipe

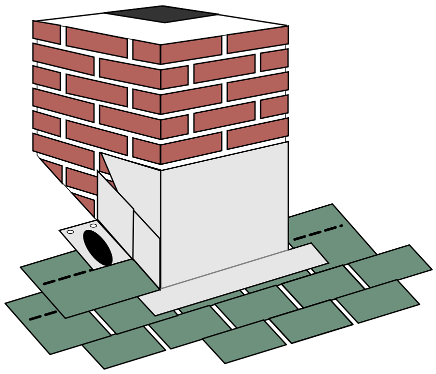


Flashing a Chimney

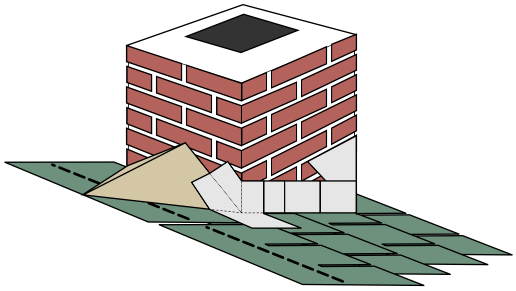
STEP 1
Apply asphalt primer to bricks. Apply metal base flashing to front, overlapping shingles 4".



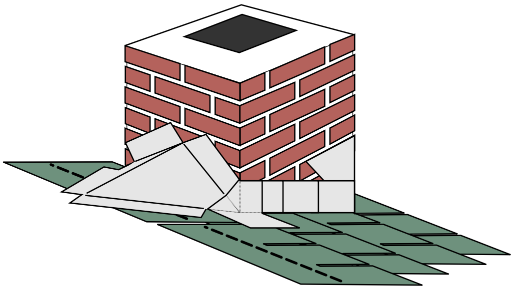
STEP 2
Nail metal step flashing over plastic cement. Embed overlapping shingles in plastic cement.



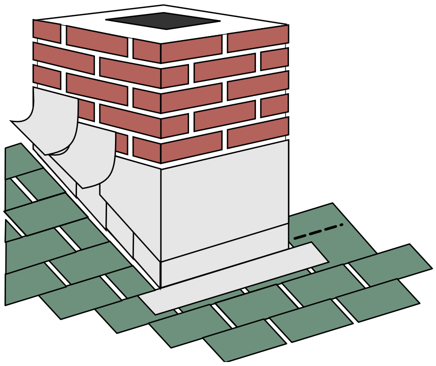
STEP 3
Install wood cricket at rear and shingle to edge. Embed rear corner flashings in cement.



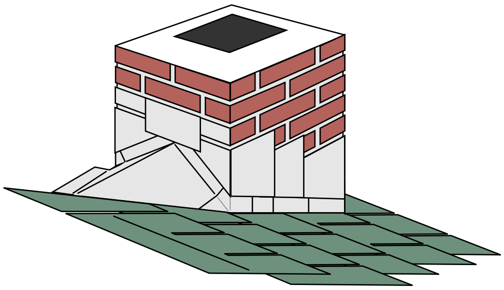
STEP 4
Embed rear base flashing in plastic cement. Nail flashing to deck only.



STEP 5
Set front and side cap flashings $1\,^{1}/_{2}$" into raked joints and refill with mortar.



STEP 6
Install rear corner cap flashings, and install rear cap flashing suitable to the situation.



Cedar Shingles

Being wood, cedar shingles periodically become soaked. For the longest life, wood shingles should be applied over sheathing strips spaced the same as the exposure of the shingles. To allow for swelling, shingles should be spaced at least $^1/_4$ inch apart, regardless of estimated moisture content.

In areas where ice dams occur, the eaves should be flashed with 30-pound asphalt-saturated felt or special ice-shield membrane to at least 24 inches inside the wall line.

The first course should be doubled, with an eaves projection (drip edge) of $1^1/_2$ inches and joints of succeeding courses offset by at least $1^1/_2$ inches. Succeeding courses should be laid with exposure and nailing as shown in the table below.

Red Cedar Shingle Specifications

Shingle Grade	Length, inches	Maximum Exposure @ Roof Slope		Nails for		Description
		<4 in 12	>4 in 12	New Roof	Re-Roof	
No. 1 (blue label)	16	$3^3/_4$	5	3d	5d	Premium grade of shingle for roofs; 100% heartwood, 100% clear, 100% edge grain
	18	$4^1/_4$	$5^1/_2$	3d	5d	
	24	$5^1/_2$	$7^1/_2$	4d	6d	
No. 2 (red label)	16	$3^1/_2$	4	3d	5d	Good grade; flat grain permitted; 10" clear on 16" shingle; 11" clear on 18" shingle; 16" clear on 24" shingle
	18	4	$4^1/_2$	3d	5d	
	24	$5^1/_2$	$6^1/_2$	4d	6d	
No. 3 (black label)	16	3	$3^1/_2$	3d	5d	Utility grade; flat grain permitted; 6" clear on 16" and 18" shingles; 10" clear on 24" shingle
	18	$3^1/_2$	4	3d	5d	
	24	5	$5^1/_2$	4d	6d	

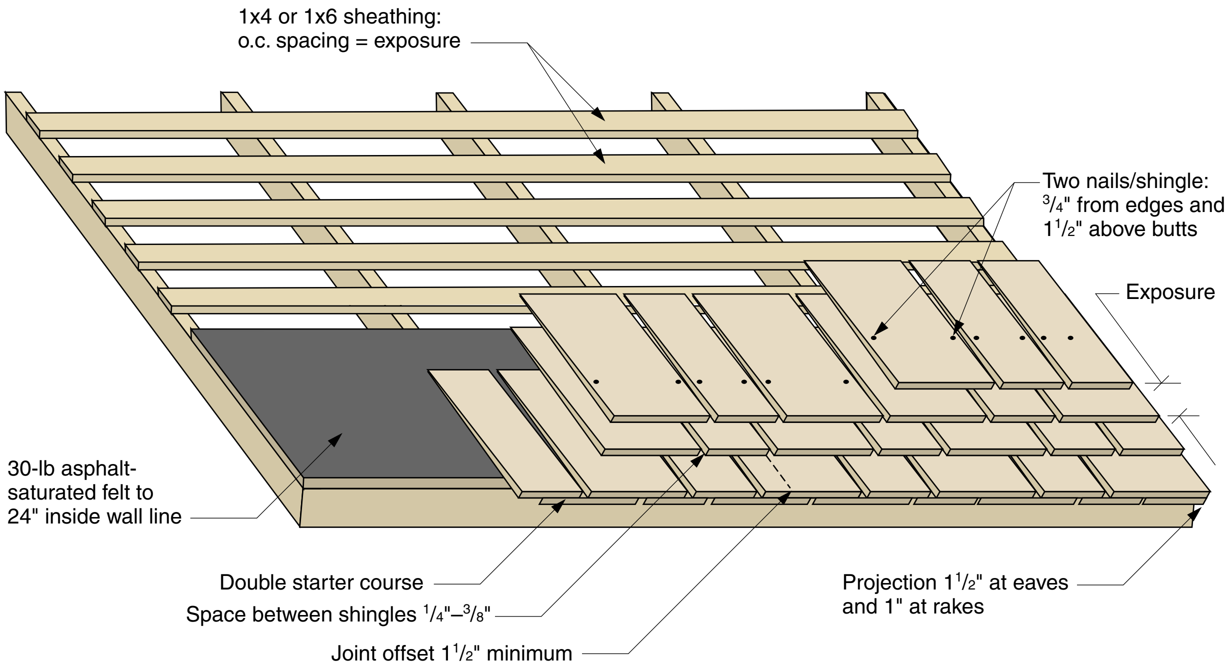
Note: Exposure is given in inches.

Estimating Coverage

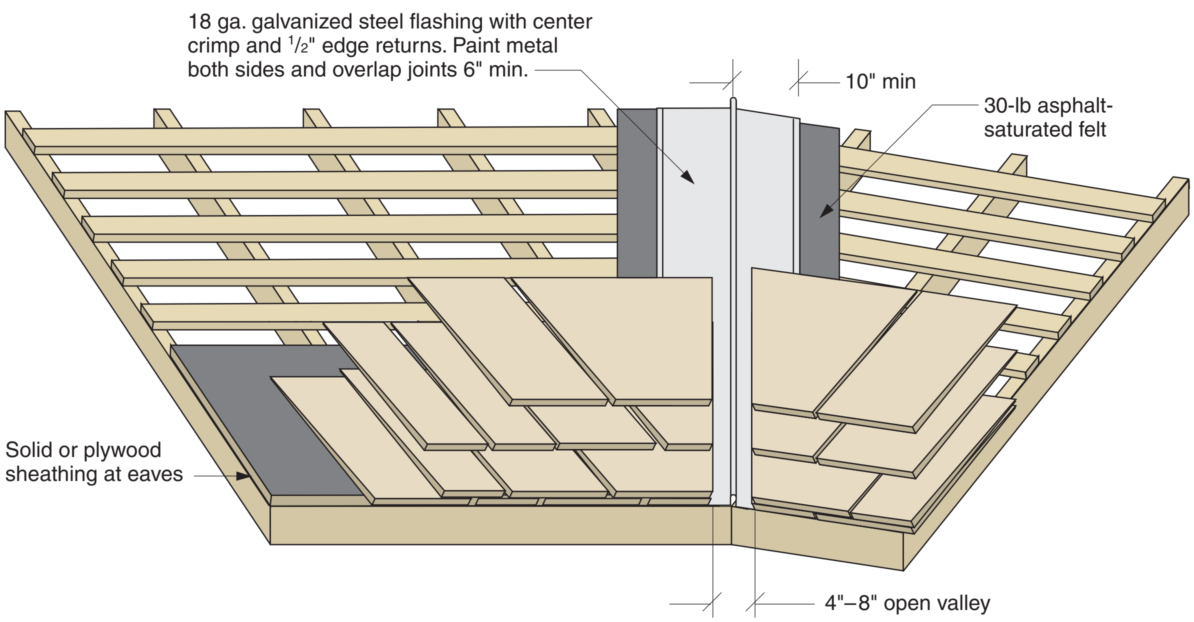
Shingle Length	Square-foot Coverage of 4 Bundles (nominal square) at Weather Exposure of $3^1/_2$"	4"	$4^1/_2$"	5"	$5^1/_2$"	6"	7"	8"	9"	10"
16"	70	80	90	100	110	120	140	160		
18"		72	81	90	100	109	127	145	163	
24"						80	93	106	120	133

Source: *Exterior and Interior Product Glossary* (Bellevue, WA: Red Cedar Shingle & Handsplit Shake Bureau, 1980).

Shingle Application



Open-Valley Flashing



Cedar Shakes

For the longest life, shakes should be applied over sheathing strips spaced the same as the exposure of the shakes. To allow for swelling, shakes should be spaced at least $^1/_2$ inch apart.

In areas where ice dams occur, eaves should be flashed with 30-pound asphalt-saturated felt to 24 inches inside the wall line.

The first course should be doubled, with an eaves projection of 1 inch and joints spaced $1^1/_2$ inches minimum. An 18-inch-wide strip of 30-pound asphalt-saturated felt should be applied over the top of each course, twice the exposure above the butt. Use the exposures and nailing listed in the table below.

Cedar Shake Specification

Shake Grade	Length, inches	Butt inches	Max Exposure @ Roof Slope 4 in 12	Nails for New Roof	Nails for Re-Roof	Description
No. 1 hand split & resawn	18	$^1/_2$–$^3/_4$	$7^1/_2$	6d	7d	First split to uniform thickness with steel froe, then sawn to produce two tapered shakes
	18	$^3/_4$–$1^1/_4$	$7^1/_2$	7d	8d	
	24	$^3/_8$	7	4d	6d	
	24	$^1/_2$–$^3/_4$	7	4d	6d	
	24	$^3/_4$–$1^1/_4$	7	4d	6d	
No. 1 taper split	24	$^1/_2$–$^5/_8$	4	6d	7d	Split with steel froe, then reversed and resplit with taper
No. 1 straight split	18	$^3/_8$	$7^1/_2$	6d	7d	Same thickness throughout; split with steel froe and mallet
	24	$^3/_8$	10	6d	7d	

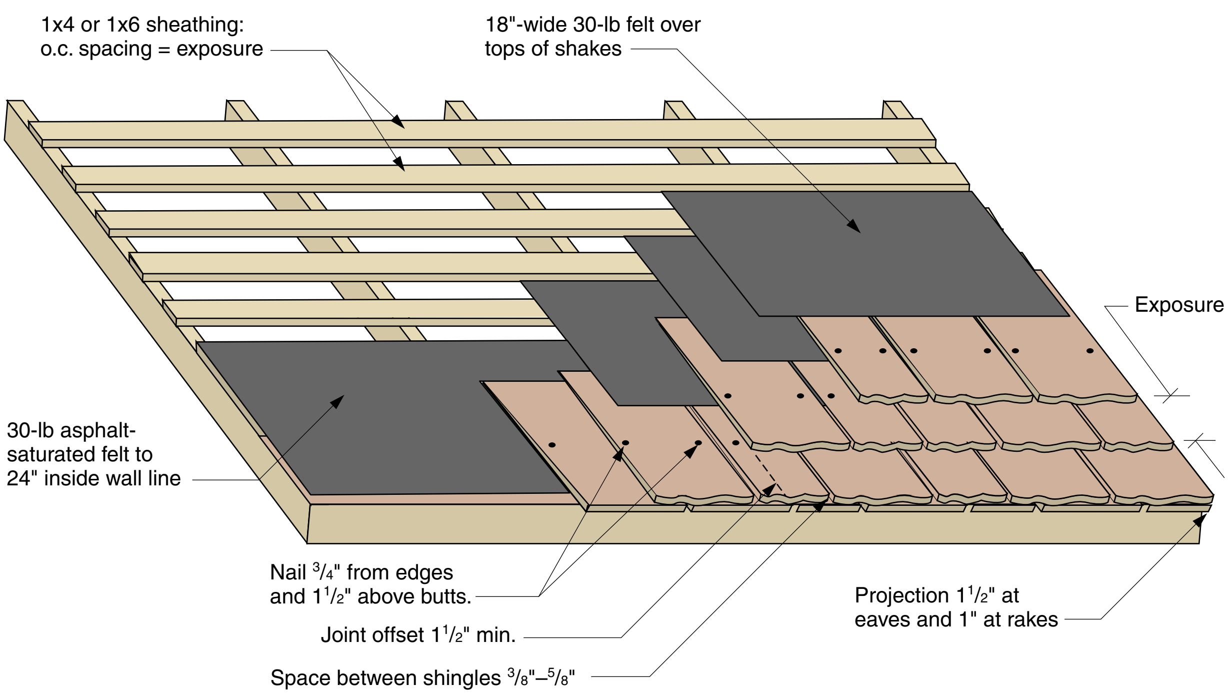
Note: Exposure is given in inches.

Estimating Coverage

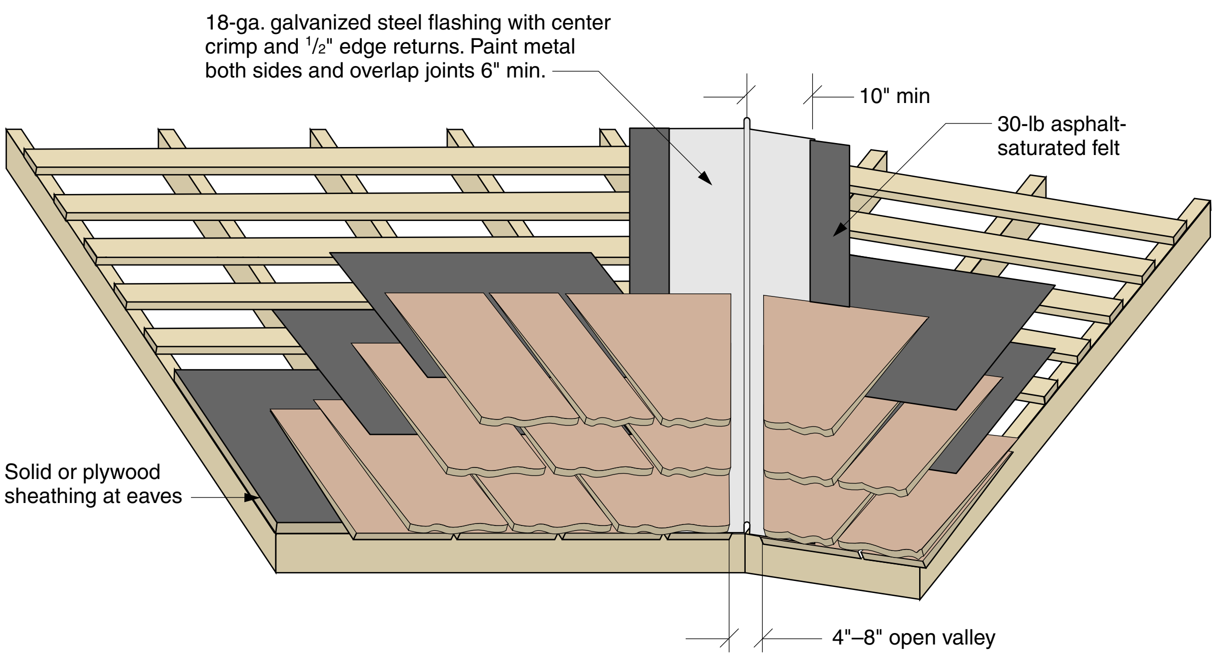
Shingle Length	Square-foot Coverage of 4 Bundles (nominal square) at Weather Exposure of 3$^1/_2$"	4"	4$^1/_2$"	5"	5$^1/_2$"	6"	7"	8"	9"	10"
16"	70	80	90	100	110	120	140	160		
18"		72	81	90	100	109	127	145	163	
24"						80	93	106	120	133

Source: *Exterior and Interior Product Glossary* (Bellevue, WA: Red Cedar Shingle & Handsplit Shake Bureau, 1980).

Shake Application



Open-Valley Flashing



Slate

Standard roofing slate is $^{3}/_{16}$ inch thick. With the customary 3-inch lap, a square (100 square feet of roof covered) weighs up to 750 pounds. Thicker slates weigh proportionally more. Thus, the decision to roof with slate should be made before framing the roof. Slate color is usually designated as falling into one of eight groups: black, blue-black, gray, blue-gray, purple, mottled purple and green, green, and red. Application and flashing of slate is similar to that of asphalt shingles (see the sections on asphalt shingles). The differences are described below.

Size

Slates are cut to uniform size, varying in length or depth (in 2-inch increments) from 10 to 26 inches, and width (in 1- and 2-inch increments) from 6 to 14 inches.

Overlap and Exposure

Standard overlap is 3 inches, with 2 inches for slopes over 12/12 and 4 inches for slopes less than 8/12. Exposure is determined by the slate dimension and overlap using this formula:

$$\text{Exposure} = (\text{slate length} - \text{overlap})/2$$

Example: A 16-inch slate with standard 3-inch overlap would be applied with exposure (16–3)/2, or $6^{1}/_{2}$ inches.

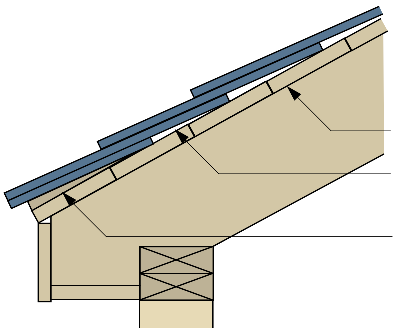
Joint overlap should be 3 inches minimum and (ideally) one-half of a slate.

Nailing

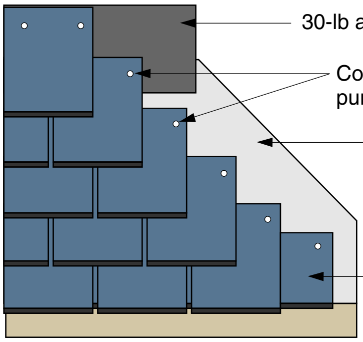
Slates come prepunched with nail holes $^{1}/_{4}$ to $^{1}/_{2}$ inch below the top edge and $1^{1}/_{4}$ to 2 inches from the edges. Special slate punches or a masonry drill must be used to create additional holes in the field. Most slate failures are due to the use of inferior shingle nails. Use only copper slating nails, available from slate distributors. Use 3d nails for slates to 18 inches long, 4d for slates over 18 inches, and 6d nails at hips and ridges. Nail length should be twice the slate thickness plus 1 inch for sheathing penetration. Thus, a standard $^{3}/_{16}$-inch slate calls for nails $1^{3}/_{4}$ inches long.

Slate

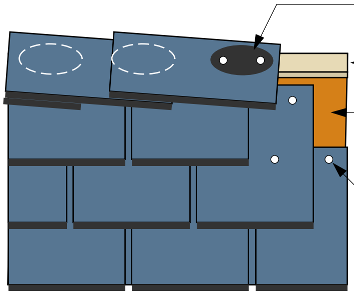
STARTER COURSE



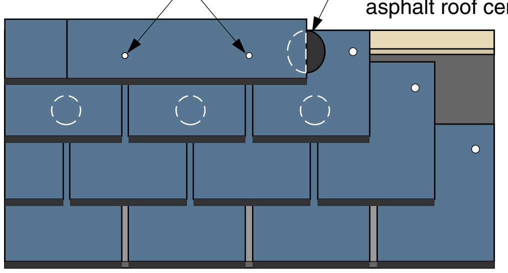
STARTER COURSE



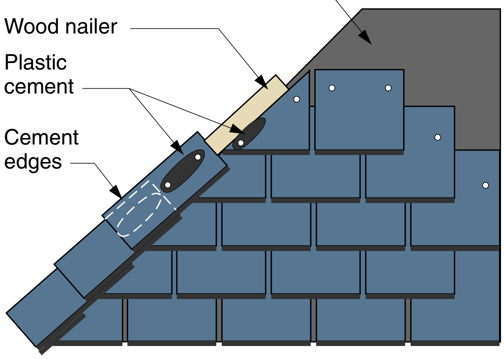
SADDLE RIDGE



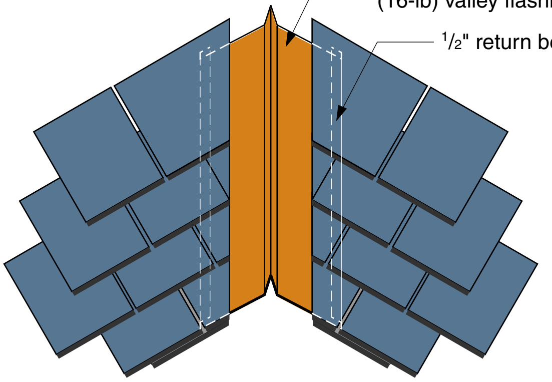
STRIP SADDLE RIDGE



SADDLE HIP



OPEN VALLEY



Tile

Roofing tiles generally are made of fired clay or concrete. Aside from being the most architecturally appropriate in certain regions, they have the advantages of nearly zero maintenance and long life (typically 100 years). Disadvantages include weight (90–110 psf), high installed cost, and minimum roof slope of 4/12.

Clay Tile

Fired at 2,000°F, the surface particles of the tile fuse, or "vitrify," making undamaged tiles virtually waterproof. Tiles to be installed in cold regions, however, should meet the requirements of ASTM C1167 for freeze-thaw regions.

The color of a clay tile is determined by the color of the clay from which it is made. Colors range from browns through orange to red.

Concrete Tile

Extruded under high pressure and cured under controlled conditions, concrete tiles are impervious to both water and freeze damage.

Concrete tiles come in a wider range of colors than clay tiles. "Color-through" tiles result from dyeing the wet concrete. Other tiles have the color applied only to the surface.

Styles

Both clay tiles and concrete tiles—which imitate the original clay versions—come in three categories of height-to-width ratio: high-profile, low-profile, and flat.

High-profile (H/W >1/5) styles include Spanish (or "S"), Mission, Roman, Greek, and Channeled.

Low-profile (H/W ≤1/5) styles include various interlocking designs.

Flat (top-surface relief <$^1/_2$ inch) styles include flat, interlocking flat, simulated shingle, and simulated shake.

Underlayment

Solid sheathing of at least 1-inch (nominal) boards or $^{15}/_{32}$-inch plywood or OSB is recommended under all tile installations.

For slopes ≥4/12, a double layer of 30-pound, or single layer of 40-pound, asphalt-saturated felt is recommended.

For slopes <4/12, a continuous waterproof membrane is recommended.

Fastening

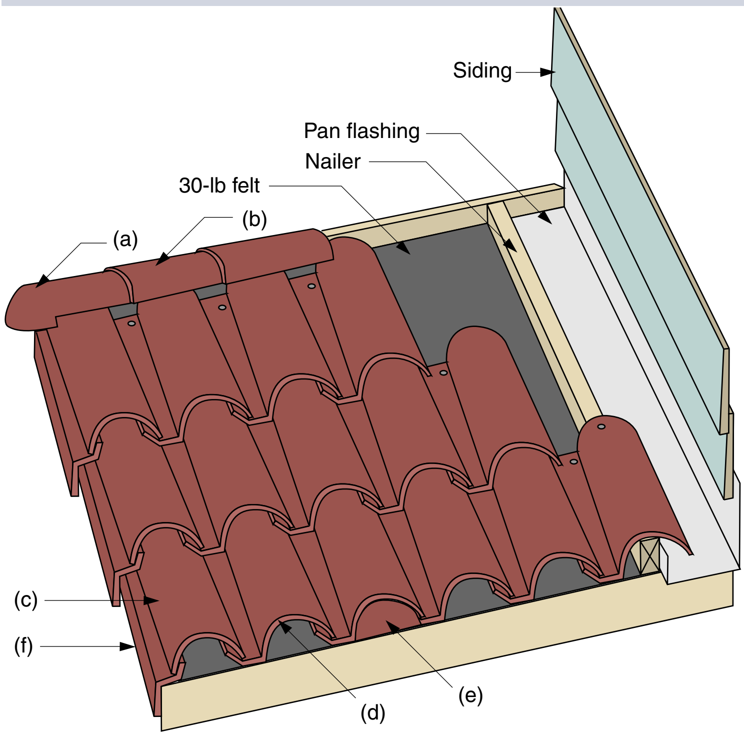
Tiles may be anchored in one of three ways: nailing, wiring, or setting in adhesive.

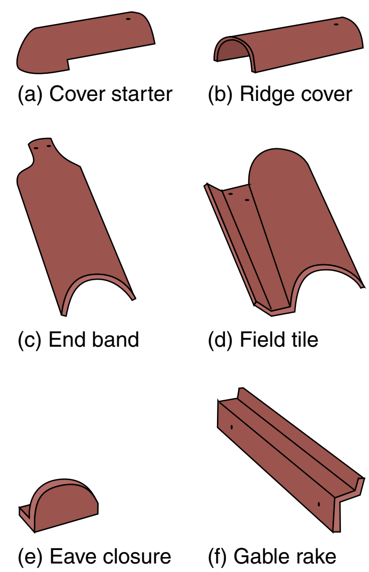
Nailing consists of driving annular-ring or hot-dipped galvanized nails through the tile's nailing hole(s) through the underlayment into the sheathing or into 1× strapping over the underlayment.

Wiring consists of attaching individual tiles with twisted wires to a wound pair of 12-gauge wires running from eave to ridge under each vertical run of tiles. The wound pair provides loops every 6 inches through which the twisted wire is threaded. Wiring is recommended in seismic areas because it decouples the tile mass from the roof structure.

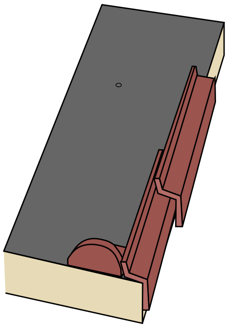
Setting in adhesive rigidly bonds the tile to the substrate and is recommended in areas with high winds. Mortar can be used, but a number of special-purpose adhesives are now available.

Typical Spanish Tile Components

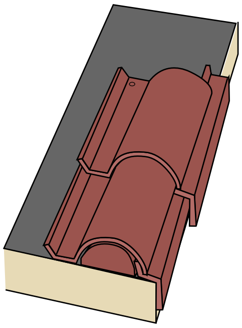




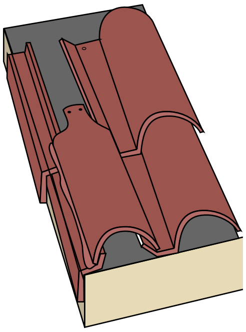
Installation



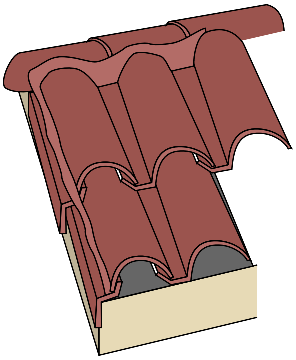
STEP 1
Install right gable-rake tiles, with first tile overhanging eave 2"; install eave closures flush with eave.



STEP 2
Lay first field tile in mastic, covering gable-rake tile nails; space remaining field tiles for roof width.



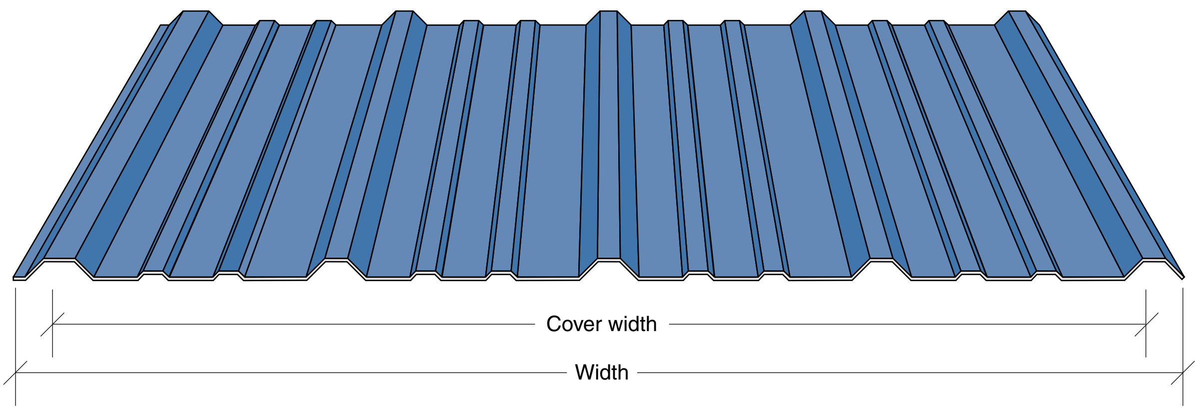
STEP 3
Install left gable-rake tiles; nail a 1x3 on edge as nailer for end-closure tiles; set end tiles in mastic and nail to 1x3.



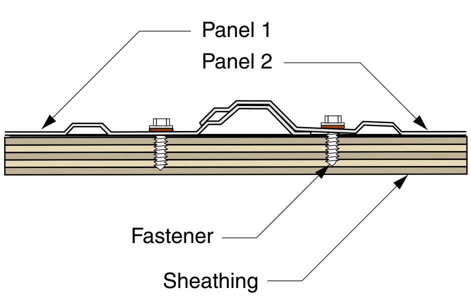
STEP 4
Install a 1x3 ridge nailer; starting and ending with cover starter tiles, lay ridge cover tiles in mastic tinted to match roof.

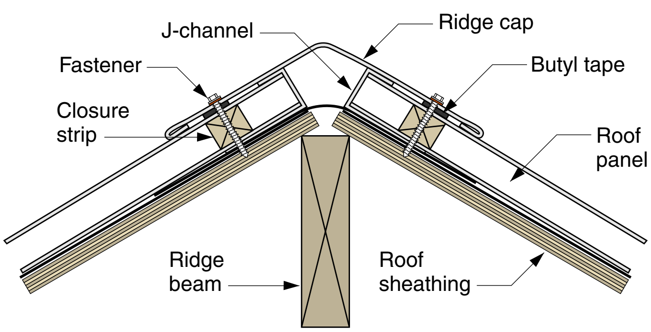
Metal Panel

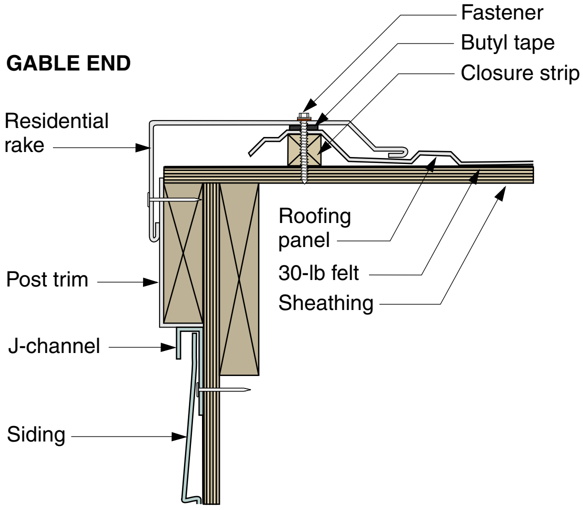
Typical Panels and Dimensions

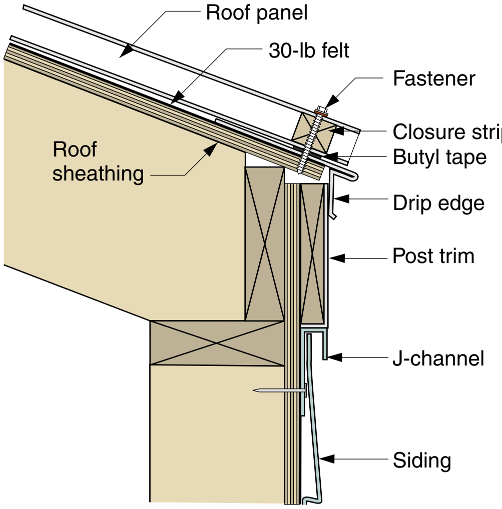


Panel Installation

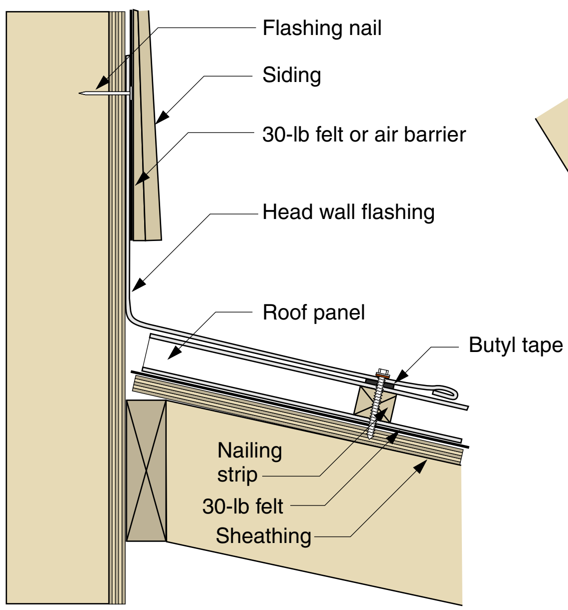


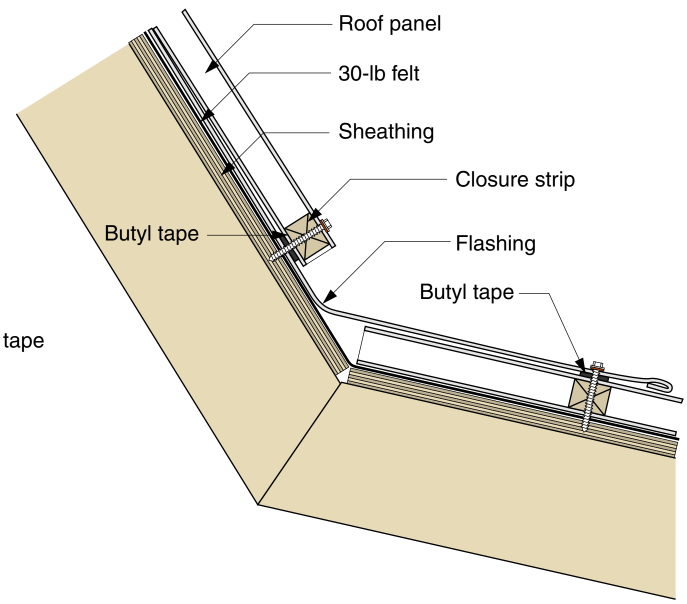




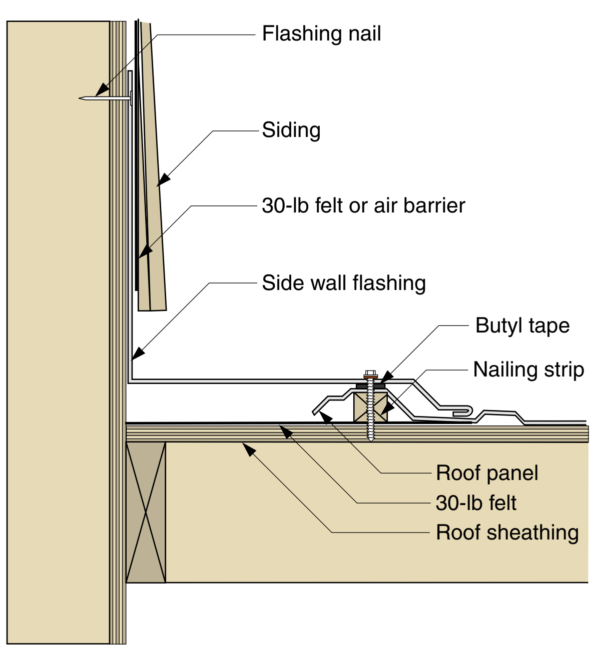


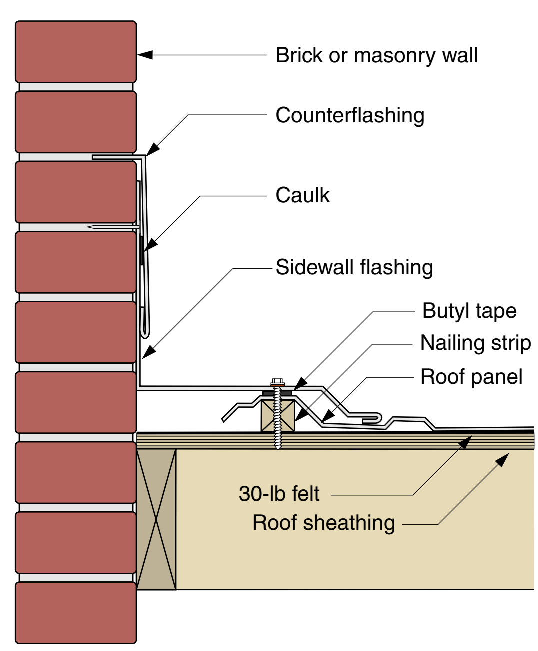
Head Wall and Transition Flashing





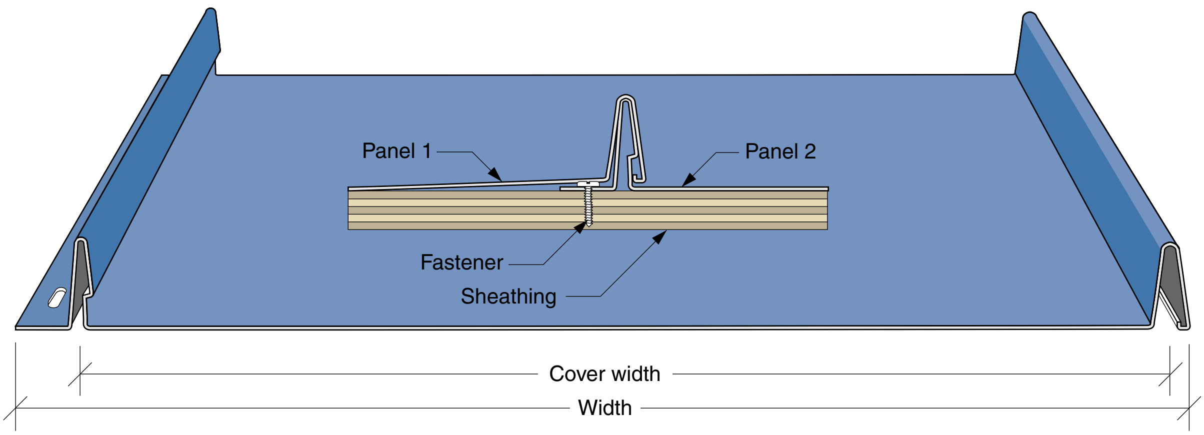
Side Wall Flashing



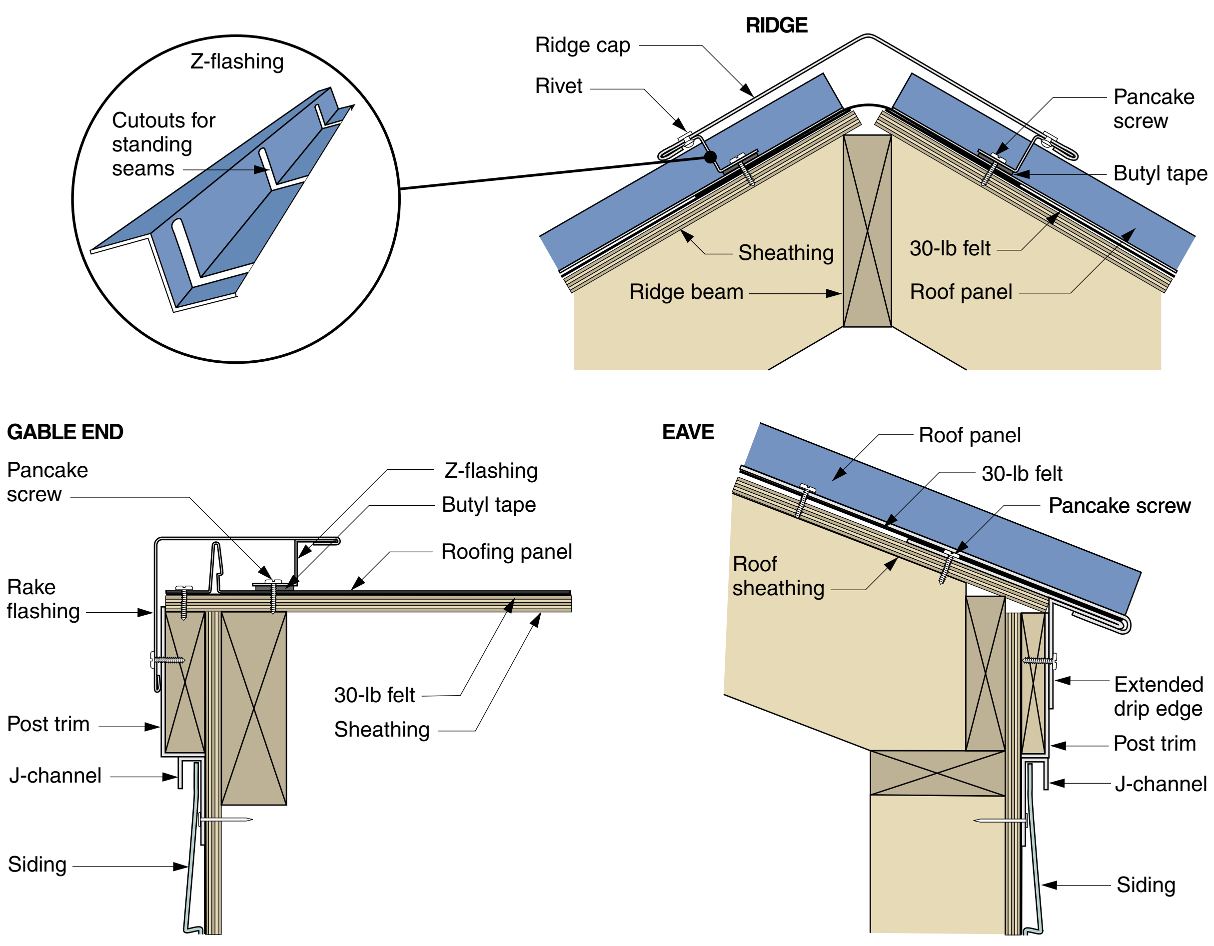


Standing Seam

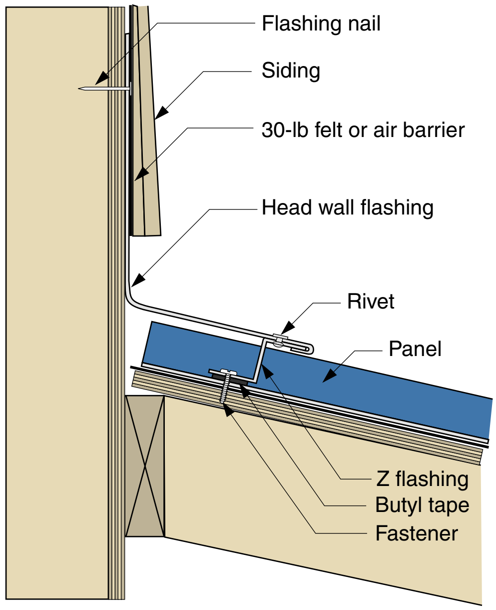
Typical Standing-Seam Panels and Dimensions

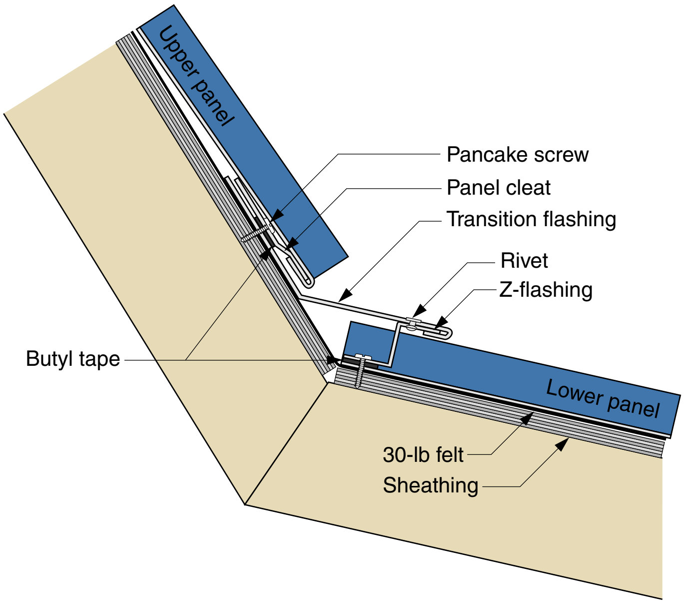


Standing Seam Panel Installation

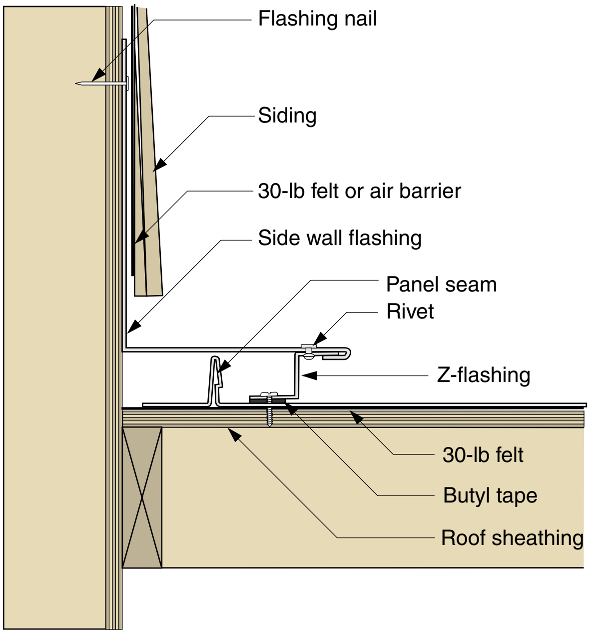


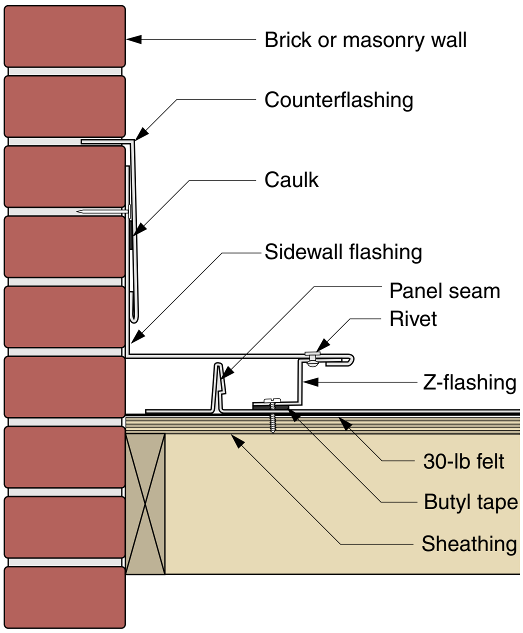
Head Wall and Transition Flashing





Side Wall Flashing





Gutters

Gutters are widely available in plain or painted aluminum or plastic. Less widely distributed are galvanized steel or copper. Gutters and downspouts usually come in 10-foot lengths, although some are available in lengths of 26 and 33 feet as well.

Several different gutter profiles and hanging systems are available. Your home center or hardware store may offer one style in aluminum and another in plastic. Whatever type you choose, your source will be able to provide all of the accessories needed for a complete installation.

Planning

Use the illustration of a typical system on the facing page to determine the number of each accessory needed for your installation. You would be wise to sketch the dimensions of your house, particularly the profile of the critical roof/eaves/fascia area. An experienced clerk can then verify the pieces needed. Before installation, as a final check, layout all pieces on the ground in their final relative positions.

Installation

Use a line level (level on a string) to mark the fascia with the proper slope. The slope should be 1 inch per 16 feet minimum, from one corner to another on a short building, or from center to both ends on a longer building. If the building is extremely long, intermediate low points and downspouts may be required.

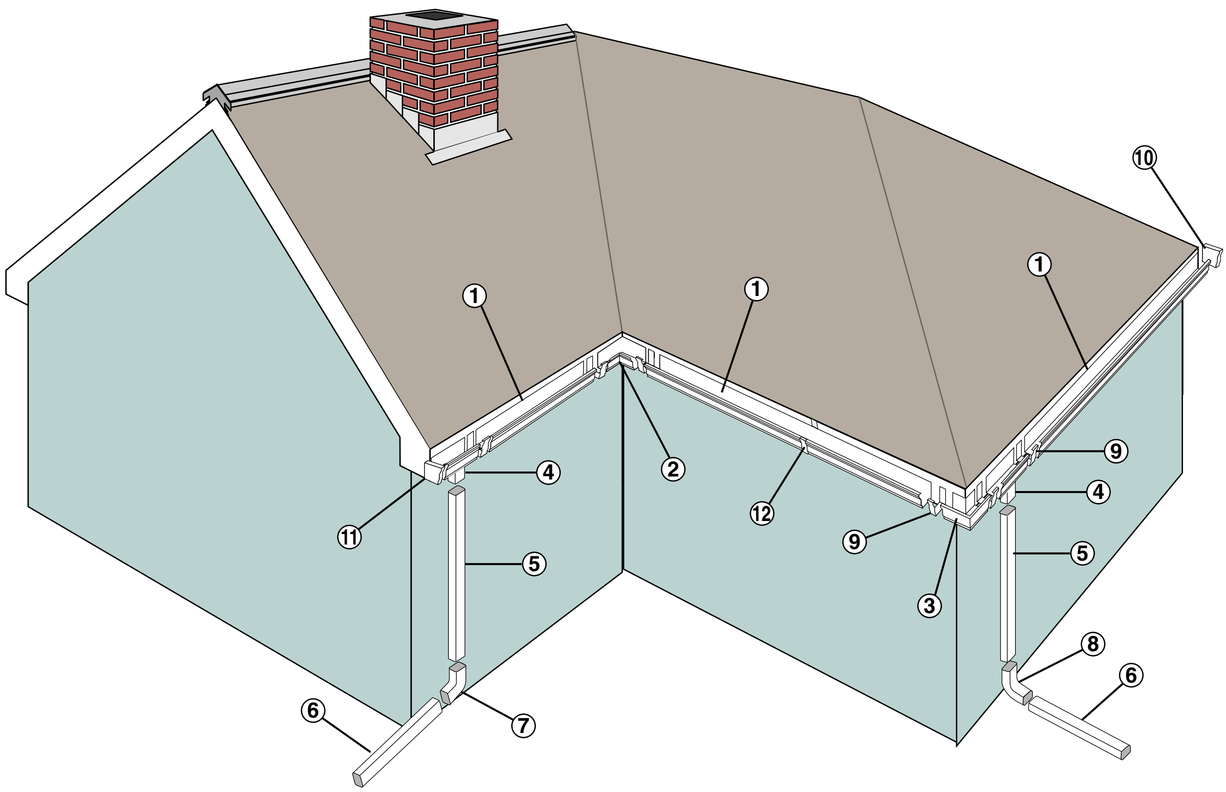
Begin installation at a building corner. Attach end cap, downspout, or corner miter as required before attaching the first length of gutter. If a support molding is planned, install it before the gutter to facilitate handling of the gutter.

Attach the gutter to the fascia with hangers every $2^1/_2$ feet on-center. The three most common types of hanger are shown at bottom on the facing page. Connect sections of gutter with slip joints as you go. PVC slip joints may be glued as you go. Others are caulked after the complete installation with gutter mastic or silicone sealant.

If the downspout discharges into an underground drainage system, install strainers over the inlet of each gutter outlet to prevent clogging of the underground system. If the downspout discharges aboveground, install an elbow and a leader (horizontal section of downspout) leading at least 5 feet away and down-slope from the building foundation.

Finally, if there are trees near your house, install a strainer cap over the gutter outlet to prevent clogging by leaves. Most gutter problems can be avoided by periodic removal of debris. Many gutter failures are due to the freezing of backed-up water, which destroys the mastic seal. Also, the weight of ice can prove more than the gutter hangers can bear.

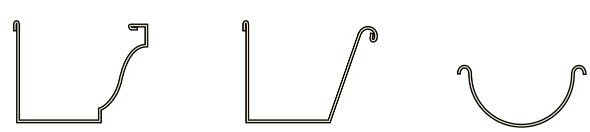
Parts of a Gutter System



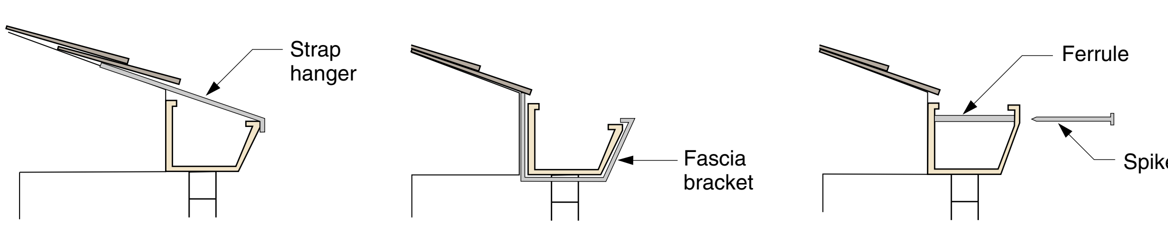
PARTS

1. Gutter
2. Inside corner
3. Outside corner
4. Outlet
5. Downspout
6. Leader
7. Style B elbow
8. Style A elbow
9. Slip connector
10. Right end cap
11. Left end cap
12. Hanger

GUTTER STYLES



HANGER STYLES



Meet the Code (IRC)

The following is a partial list of requirements from the *2015 International Residential Code (IRC) for One- and Two-Family Dwellings.* Consult the publication for the full text and additional provisions.

Roof Drainage (R801.3)

To discharge >5' from foundation or into drain pipe where expansive or collapsible soils exist

Roof Ventilation (R806)

- enclosed attics and rafter spaces to have cross ventilation for each separate space by vents with corrosion-resistant 1/16" to 1/4" wire mesh
- total net free vent area of ≥1/150 of vented space, except 1/300 if 40% to 50% of vent area ≤3' below the high point of the space
- 1/300 OK with 1-perm vapor barrier on the warm-in-winter side of ceiling in Climate Zones 6, 7, and 8
- ≥1" space between insulation and sheathing at vent for free air flow
- unvented attics permitted if:
  1. no interior vapor retarders installed on the ceiling side (attic floor) of the attic or enclosed roof
  2. air-impermeable insulation applied directly to top or bottom of roof deck

Weather Protection (R903)

- flashings required at wall/roof intersections, at changes in slope or direction, and around roof openings
- metal flashings to be corrosion resistant and ≥No. 26 galvanized sheet
- crickets or saddles required on ridge side of chimneys and penetrations >30" wide
- drains to be installed at each low point of the roof
- where roof drains required, same-size overflow drains to be installed with inlet line 2" above low point of roof, or overflow scuppers 3× the size of roof drains and with opening height ≥4" to be installed in adjacent parapet walls with inlet flow 2" above low point of roof
- overflow drains not connected to roof drain lines

Roof Coverings (R905)

Asphalt shingles:

- to be fastened to solidly sheathed decks
- to be used only on roof slopes ≥2:12
- dbl underlayment required on slopes 2:12 to 4:12
- self-seal or interlocking strips required
- fasteners to be galvanized, stainless, aluminum, or copper, ≥12-ga. shank and ≥3/8" head, of length to penetrate roofing and ≥3/4" into sheathing
- in ice dam areas, an ice barrier of ≥2 layers of underlayment cemented together or of a self-adhering polymer modified bitumen sheet, from roof edge to ≥24" inside exterior wall line
- base and cap flashing of ≥0.019" corrosion-resistant metal or ≥0.77 psf mineral surface roll roofing
- valley flashings permitted:
  1. corrosion-resistant metal ≥24" for open valley
  2. two plies roll roofing, with bottom layer 18" and top layer ≥36" wide for open valley
  3. one-ply smooth roll roofing ≥ 36" wide or as described in 1 and 2 above for closed valley
  4. alternate materials permitted: 0.0216" cold-rolled copper, 0.0216" lead-coated copper, 0.0162" high-yield copper, 0.0162" lead-coated high-yield copper, 0.024" aluminum, 0.0179" galvanized steel, 28-ga. stainless, 0.027" zinc alloy, painted tern
- cricket or saddle required on high side of any chimney or ≥30" wide penetration
- vertical sidewall flashing to be of step-flashing

Clay and concrete tile:

- to be applied over solidly sheathed decks or spaced structural sheathing boards
- to be used only on roof slopes ≥2.5:12
- dbl underlayment required on slopes 2.5:12 to 4:12
- fasteners to be corrosion resistant, ≥11-ga. shank and ≥5/16" head, of length to penetrate ≥3/4" into deck
- attaching wire to be ≥0.083"
- perimeter fastening areas to include three tile courses and be ≥36" wide from either side of hips or ridges and edges of eaves and gable rakes
- perimeter tiles fastened with ≥1 fastener per tile

- tiles with installed weight <9 psf require ≥1 fastener per tile regardless of roof slope
- tiles in snow areas to be fastened with ≥2 per tile
- tiles on solid sheathing require 1 fastener per tile
- tiles on spaced sheathing or solid sheathing with battens require no fasteners
- tiles on spaced sheathing with no battens require 1 fastener per tile, except at odd rows if slope <5:12
- flashing and counterflashing to be ≥No. 26 galvanized sheet gauge corrosion-resistant metal
- valley flashing to extend ≥11" from centerline and have a splash diverter rib ≥1" high at flow line
- valley flashings for roof slopes of ≥3:12 to have 36"-wide Type I underlayment the full length of valley
- where the average daily temperature in January is ≤25°F and slope <7:12, metal valley flashing underlayment to be solid-cemented to the roofing underlayment or be self-adhering polymer modified bitumen sheet

Mineral-surfaced roll roofing:
- to be applied to a solid deck
- not to be installed on roof slopes of <1:12
- in ice dam areas, an ice barrier of ≥2 layers of underlayment cemented together or of a self-adhering polymer modified bitumen sheet, from roof edge to ≥24" inside exterior wall line

Slate and slate-type shingles:
- to be applied to a solid deck
- to be installed on roof slopes of ≥4:12
- in ice dam areas, an ice barrier of ≥2 layers of underlayment cemented together or of a self-adhering polymer modified bitumen sheet, from roof edge to ≥24" inside exterior wall line
- headlap: 4" at <8:12, 3" at 8-20:12, 2" at ≥20:12
- secured to roof with two fasteners per slate
- flashing and counterflashing of sheet metal
- valley flashing ≥15" wide
- flashing to be an uncoated thickness of ≥0.0179" zinc-coated G90

Wood shingles:
- to be applied to solid deck or 1×4 nominal spaced sheathing spaced at weather exposure
- to be installed on roof slopes of ≥3:12
- solid sheathing required where the average daily temperature in January is ≤25°F
- solid sheathing under an ice barrier
- in ice dam areas, an ice barrier of ≥2 layers of underlayment cemented together or of a self-adhering polymer modified bitumen sheet, from roof edge to ≥24" inside exterior wall line
- laid with a side lap ≥1 $^1/_2$" between joints in courses
- no 2 joints in any 3 adjacent courses in alignment
- spacing between shingles to be $^1/_4$" to $^3/_8$"
- fasteners to be stainless or galvanized and penetrate the sheathing ≥$^3/_4$"
- to be attached with two fasteners per shingle, positioned per the manufacturer's instructions
- valley flashing ≥No. 26 gauge corrosion-resistant sheet metal and extend 10" from the centerline for slopes <12:12, and 7" from the centerline for slopes ≥12:12

Wood shakes (same as wood shingles except):
- where 1×4 spaced sheathing installed 10" o.c., additional 1×4 boards to be installed between
- spacing between shakes to be $^3/_8$" to $^5/_8$"
- to be attached with two fasteners per shingle, positioned per the manufacturer's instructions
- fasteners ≤1" from edges and ≤2" above bottom
- to be interlaid with 18" strips of ≥No. 30 felt, the lower edge of each above the butt of the shake it covers a distance equal to twice the weather exposure

Metal roof panels:
- to be applied to solid or spaced sheathing, except where designed to be applied only to spaced supports
- min. slope for lapped, nonsoldered-seam metal roofs 3:12, except $^1/_2$:12 with applied lap sealant
- min. slope for standing-seam roofs $^1/_4$:12
- to be corrosion resistant
- in absence of manufacturer's instructions, fasteners to be galvanized or stainless (300 series for copper roofs)

0 1 2 3 4 5

Windows and Doors

10

Can you imagine your house without windows? Windows perform more functions than any other component of a house. The more you know about windows, the more they can do for you.

About Windows spells out all of the things windows can do and the types of windows you can buy from a window dealer or home center. Whether you are building a new house or replacing an existing window, you need to know about *window installation*.

With rising energy prices, *window energy performance* is more important than ever. We show you how windows gain and lose energy and how to *match windows to climate*.

Skylights are not as familiar as windows, but they can light a space twice as efficiently as a window in a wall, so we include a section on a typical skylight product line.

If you are installing a whole wall of windows (for a spectacular view or for a sunspace, for example), you should be interested in *site-built windows*—patio door glazings that can cut your window costs by half.

The second half of this chapter is *about doors:* their functions, how they are constructed, and how they are installed.

Door installation is an exacting task, so we show the details of both interior and exterior, prehung, and slab-type doors.

There is even a section on doors to the basement. Whether you are building new or converting your basement to a more accessible space, you can find the size of steel *bulkhead door* that will fit your house.

Finally, we provide you with a checklist to make sure your windows and doors *meet the code (IRC).*

About Windows

Window Types

The illustration below shows eight generic types of residential windows available from dozens of manufacturers.

Double-hung windows contain two sashes, both of which slide up and down. A variation is the single-hung window, in which the top sash is generally fixed.

Casement windows hinge to one side, which is specified when a unit is ordered. They are very effective at capturing breezes, provided they open toward the prevailing breeze.

Fixed windows are often used in conjunction with operable windows of other styles. Inexpensive "window walls" can be constructed of patio doors and site-built fixed windows utilizing patio door glazing units of the same size.

Awning windows are used for ventilation at low levels, such as in a sunspace, or as high windows in bathrooms and kitchens.

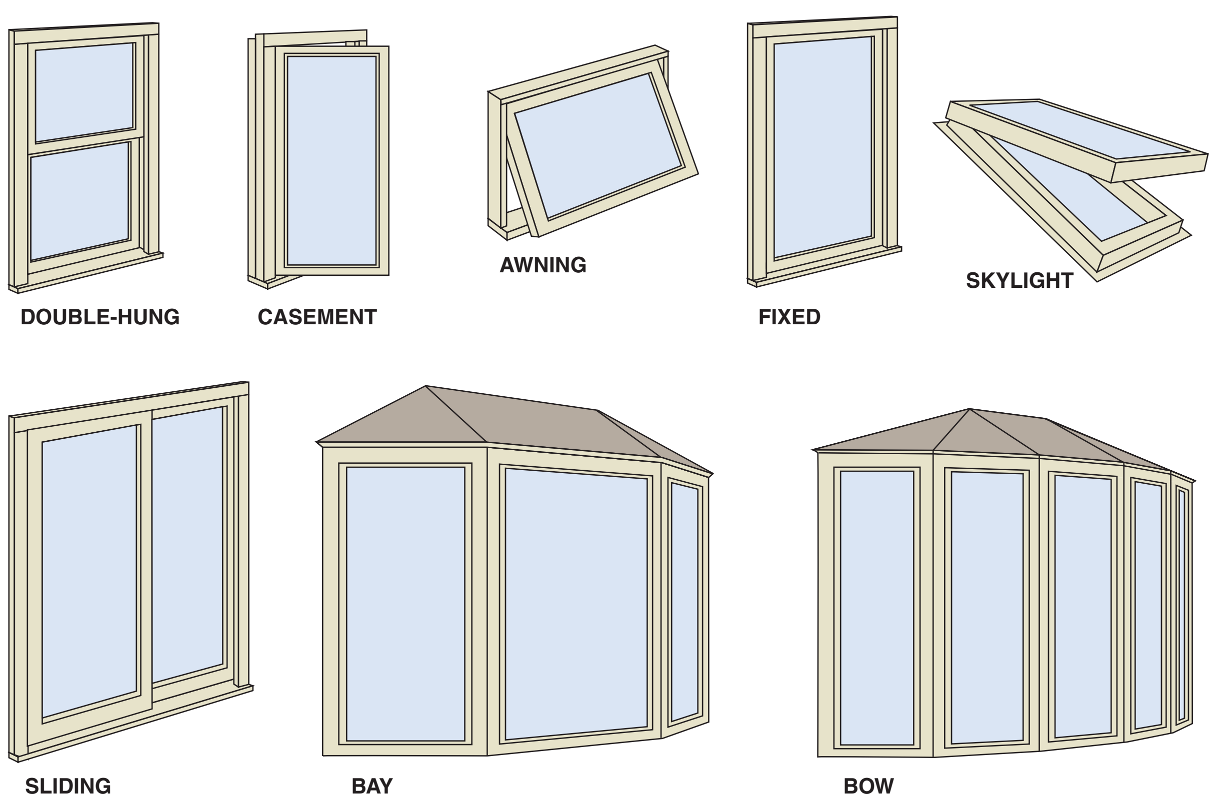
Sliding windows are an inexpensive alternative for high windows in bathrooms and kitchens.

Skylights, also known as roof windows, are extremely effective summer exhaust ventilators. They are also more effective in admitting natural daylight than are vertical windows of the same size.

Bay windows add space to rooms (often with window seats) in addition to adding an architectural design feature to an elevation. They most often are assembled from a center fixed unit and two double-hung or casement flankers.

Bow windows are more elegant expressions of the bay. They are often assembled from fixed and casement units of the same unit dimensions.

Common Window Types



Anatomy and Measurements

Window manufacturers provide four sets of dimensions (width × height).

Architects require unit size to produce building elevations, glass size for solar gain, and egress opening for the building code. Builders require rough opening, framing sill height, and location on the plan to the center of the unit.

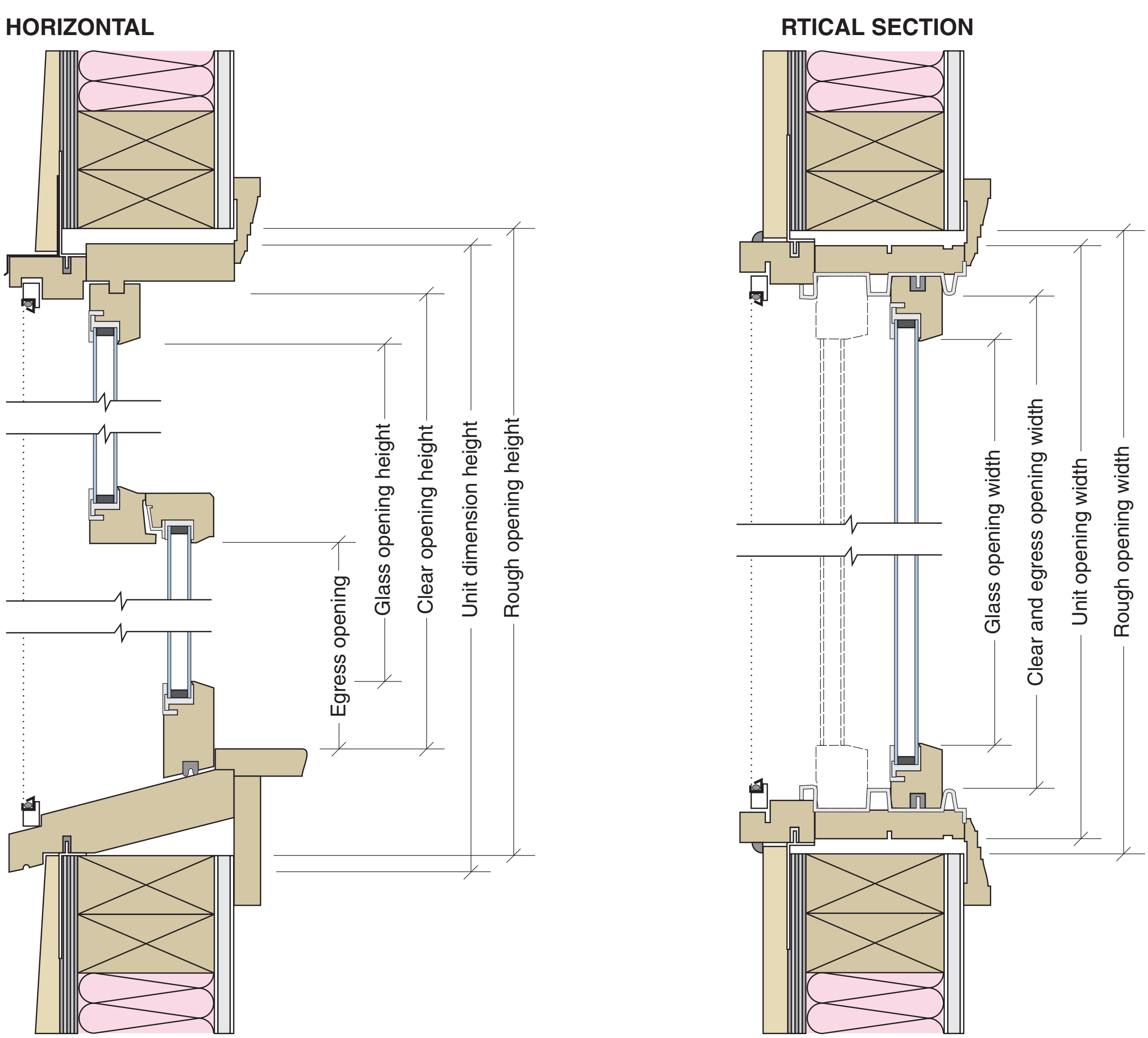
Rough opening is the width and height of the framing opening—generally from 3/8 to 1/2 inch greater than jamb width and height.

Unit size is the overall size of the window unit, including casing if provided. With a casing, unit dimension will be larger than the rough, or framing, opening. With a nailing flange instead of casing, the unit dimension will be the dimensions of the jambs, or less than the rough opening.

Egress opening is the actual width and height, without removing a sash, of the opening a person might pass through in case of fire.

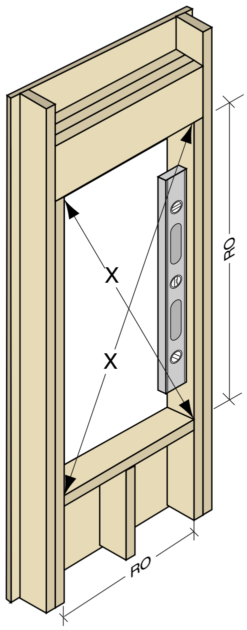
Glass size is the width and height of the clear portion of glass through which sunlight can pass.

Dimensions of a Typical Double-Hung Window

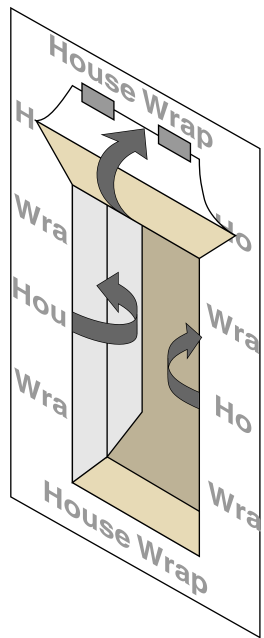


Window Installation

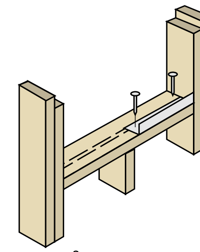
Modern Double-Hung Window Installation



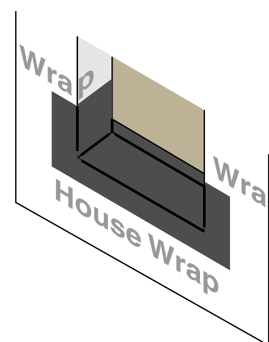
1. Check opening width and height of RO. Diagonals must be within $^1/_8$".



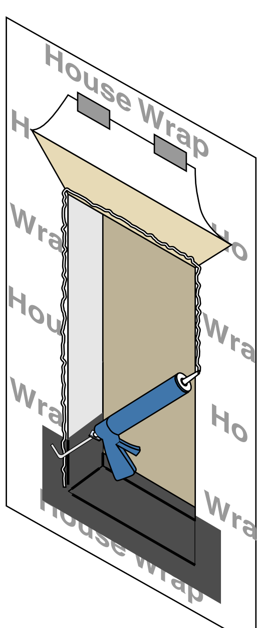
2. Slit house wrap down middle, fold, and staple flaps back. Cut top flap as shown and tape up.



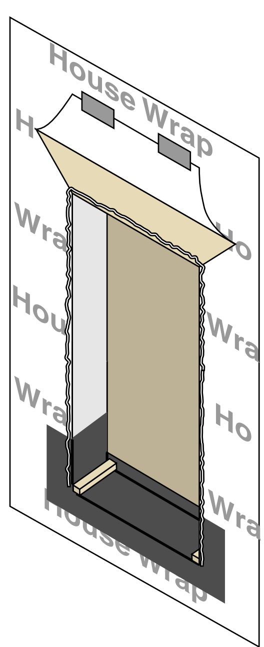
3. Install $^3/_4$" back dam.



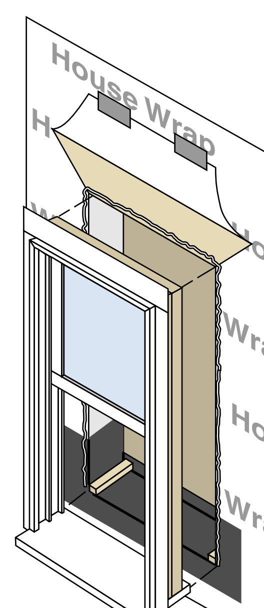
4. Install flexible flashing.



5. Apply a bead of sealant to sides and top (not bottom).

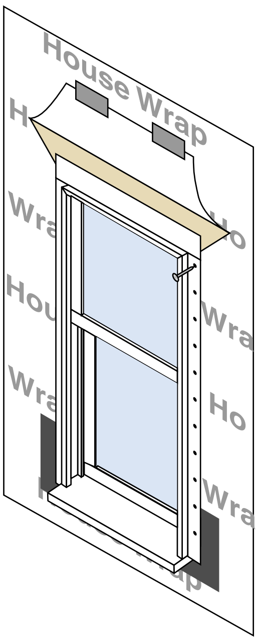


6. Place bottom shims in corners.

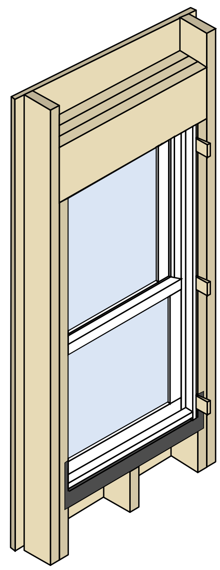


7. Place window in opening; press against sealant.

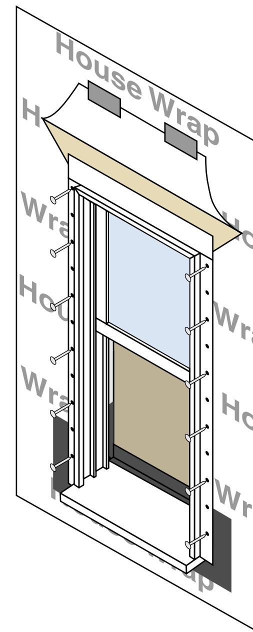
Modern Double-Hung Window Installation—*Continued*



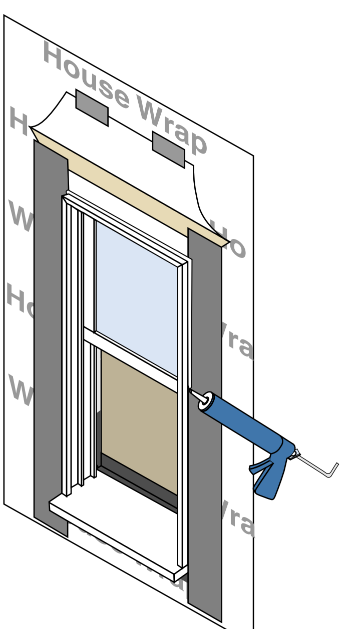
8. Lock the sashes with the sash lock, then fasten a top corner of the nailing flange.



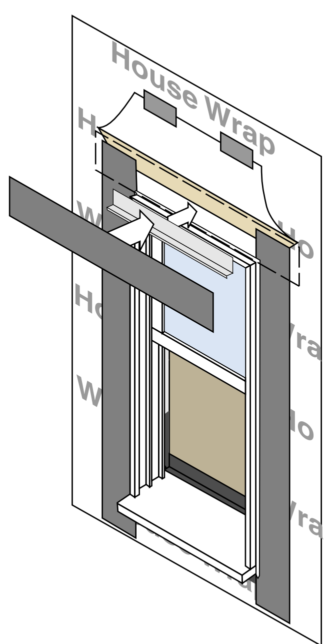
9. Using shims at both sides and the bottom, adjust until diagonals are equal.



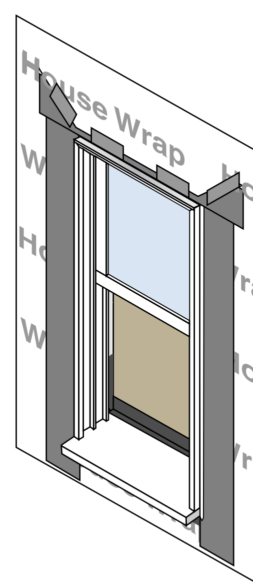
10. Fasten the nailing flange all around 6" o.c.



11. Apply flashing strips to both sides, then caulk around sides and top.



12. Install the top drip cap; cover with a top strip of flashing.



13. Fold house wrap down and tape to top flashing. After siding, caulk siding/window-frame joint.

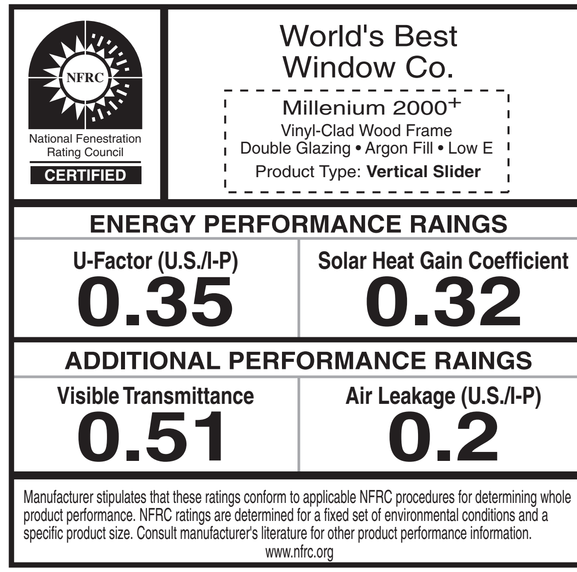
Window Energy Performance

Window Performance Labels

The National Fenestration Research Council (NFRC) is a non-profit public/private collaboration of manufacturers, builders, designers, specifiers, code officials, consumers, utilities, and regulators that has established a national energy performance rating system for fenestration products. The NFRC system rates a fenestration product's U-factor, solar heat gain coefficient, visible light transmittance, and air leakage, which can be used to determine whether a product meets an energy code.

NFRC labels can be found on all ENERGY STAR® window, door, and skylight products, but ENERGY STAR bases its qualification only on U-factor and SHGC ratings.

Typical Window Performance Label



Performance Factors

Windows, doors, and skylights gain and lose heat in the following ways:

- conduction through the glazing and frame
- adiation from outside (typically from the sun) and from inside from room-temperature objects, such as people, furniture, and interior walls
- air leakage

These properties are measured and rated in the following energy performance characteristics:

U-factor The rate at which the unit conducts non-solar heat flow, expressed in Btu/hr-ft^2-°F. For windows, skylights, and glass doors, a U-factor may refer to just the glazing alone, but NFRC U-factor ratings represent the entire window performance, including frame and spacer material. The lower the U-factor, the more energy-efficient the window, door, or skylight.

Solar heat gain coefficient (SHGC) The fraction of solar radiation admitted through the unit—either directly and/or absorbed—and subsequently released as heat inside a home. The lower the SHGC, the less solar heat it transmits and the greater its shading ability. Units with high SHGC ratings are more efficient at collecting solar heat gain during the winter. Units with low SHGC ratings are more effective at reducing cooling loads during the summer by blocking heat gained from the sun. The target SHGC should therefore be determined by factors including climate, orientation, and external shading.

Visible transmittance (VT) The fraction of the visible spectrum of sunlight (380 to 720 nanometers), weighted by the sensitivity of the human eye, transmitted through a unit's glazing. Units with higher VT transmit more visible light. The target VT should be determined by daylighting and interior glare requirements.

Air leakage The rate of air infiltration around or through a unit subjected to a specific pressure difference, in units of cubic feet per minute per square foot of frame area (cfm/ft^2).

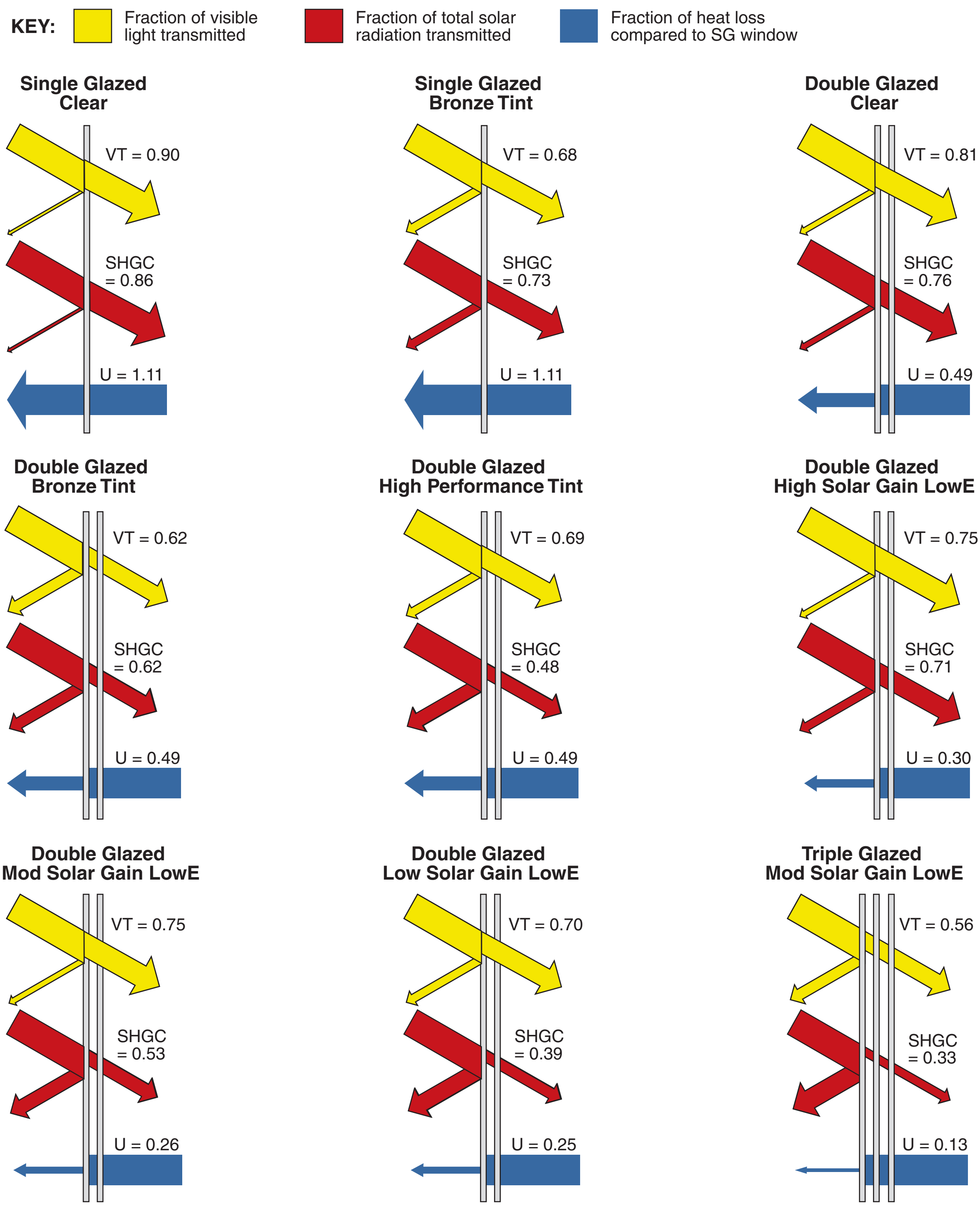
Light-to-solar gain (LSG) The ratio of VT to SHGC measures the efficiency of a glazing in transmitting daylight while blocking heat gains. This energy performance rating isn't always provided.

Typical Performance Factors for Window Types

Type of Window	Type of Glazing: SG Clear	DG Clear	DG with Bronze/Gray Tint	DG with Hi Solar Gain Low-E, Argon	DG with Mod Solar Gain Low-E, Argon	DG with Low Solar Gain Low-E, Argon	TG with Mod Solar Gain Low-E, Argon
U-FACTOR							
Alum w/thermal break	1.00	0.63	0.63	0.50	0.48	0.47	—
Aluminum	1.16	0.76	0.76	0.61	0.60	0.59	—
Fiberglass	—	0.44	0.44	0.29	0.27	0.26	0.18
Hybrid/Composite	0.84	0.49	0.49	0.37	0.35	0.34	—
Insulated Vinyl	—	0.44	0.44	0.29	0.27	0.26	0.18
Vinyl	0.84	0.49	0.49	0.37	0.35	0.34	—
Wood	0.84	0.49	0.49	0.37	0.35	0.34	—
Wood Clad	0.84	0.49	0.49	0.37	0.35	0.34	0.29
SHGC							
Alum w/thermal break	0.70	0.62	0.52	0.58	0.48	0.33	—
Aluminum	0.76	0.68	0.76	0.64	0.53	0.37	—
Fiberglass	—	0.60	0.49	0.56	0.46	0.31	0.40
Hybrid/Composite	0.64	0.56	0.47	0.53	0.44	0.30	—
Insulated Vinyl	—	0.60	0.49	0.56	0.46	0.31	0.40
Vinyl	0.64	0.56	0.47	0.53	0.44	0.30	—
Wood	0.64	0.56	0.47	0.53	0.44	0.30	—
Wood Clad	0.64	0.56	0.47	0.53	0.44	0.30	0.38
VT							
Alum w/thermal break	0.70	0.63	0.48	0.62	0.65	0.59	—
Aluminum	0.75	0.68	0.51	0.62	0.65	0.59	—
Fiberglass	—	0.63	0.48	0.58	0.60	0.55	0.50
Hybrid/Composite	0.65	0.59	0.44	0.54	0.56	0.52	—
Insulated Vinyl	—	0.63	0.48	0.58	0.60	0.55	0.50
Vinyl	0.65	0.59	0.44	0.54	0.56	0.51	—
Wood	0.65	0.59	0.44	0.54	0.56	0.51	—
Wood Clad	0.65	0.59	0.44	0.54	0.56	0.51	0.47

Data from the Efficient Windows Collaborative, *www.efficientwindows.org*

Solar/Thermal Properties of Glazings



Matching Windows to Climate

Different climates (heating, cooling, and mixed) call for different window types. The Efficient Windows Collaborative website—*http://www.efficientwindows.org/*—contains window selection guidance for both new and existing buildings.

Of greatest value is the site's interactive Window Selection Tool. The tool allows you to select:

- one of 219 US and Canadian cities
- new or existing construction
- windows or skylights
- type of glass (including all types)
- window frame (metal or non-metal, with or without thermal breaks)

Using current energy prices, the Selection Tool calculates the estimated annual heating and cooling bills for each window type, assuming either a typical new house (2,250 sq. ft.) or a typical existing house (2,150 sq. ft.), 15% window-to-floor areas equally distributed on all four sides, and typical shading (interior shades, overhangs, trees, and neighboring buildings). The U-factor and SHGC for each window type are for the entire window including the frame.

For the purpose of this handbook, we present the results obtained by running the Selection Tool for 40 cities (see table at right) and eight window types (see the **bold** window numbers in the table on p. 296).

To select windows for a project, find the city in the table at right whose cooling degree hours (CDH) and heating degree days (HDD) most closely match those for your project's location. Then find the bar graph results for that city on pp. 297–303. The heights of the bar graphs show the annual heating bills (red bars) and annual cooling bills (blue bars) for each of the eight bold-numbered window types listed in the table on p. 296. Compare the total heating plus cooling bills of the different window types to find the most efficient type for your climate.

For an even more comprehensive comparison, go to the website and run your own analysis.

Window Cities and Climate

State, City	DMT	CDH	HDD
Alabama, Birmingham	21	21,000	2,900
Alaska, Fairbanks	-47	0	14,000
Arizona, Phoenix	34	55,000	1,400
Arkansas, Little Rock	20	23,800	3,200
California, Los Angeles	43	10,600	1,200
Colorado, Denver	1	5,900	6,000
Connecticut, Hartford	7	4,800	6,200
Delaware, Wilmington	14	8,200	5,000
DC, Washington	17	12,400	4,200
Florida, Miami	47	39,000	200
Georgia, Atlanta	22	16,800	3,000
Idaho, Boise	10	8,000	5,800
Illinois, Chicago	0	9,700	6,200
Indiana, Indianapolis	2	9,100	5,700
Iowa, Des Moines	-5	10,500	6,600
Kentucky, Louisville	10	13,300	4,500
Maine, Portland	-1	1,100	7,500
Maryland, Baltimore	13	9,500	4,700
Massachusetts, Boston	9	5,400	5,600
Michigan, Detroit	6	4,900	6,600
Minnesota, Duluth	-16	800	9,900
Mississippi, Jackson	25	25,200	2,400
Missouri, St Louis	6	17,800	4,900
Montana, Great Falls	-15	3,600	7,800
Nevada, Las Vegas	28	43,000	2,500
New Hampshire, Concord	-3	2,000	7,400
New Mexico, Albuquerque	16	11,000	4,400
New York, New York	15	9,500	4,900
North Dakota, Bismarck	-19	4,600	9,100
Oklahoma, Tulsa	13	26,500	3,700
Pennsylvania, Pittsburgh	5	5,000	6,000
Rhode Island, Providence	9	3,600	5,900
Tennessee, Nashville	14	18,500	3,800
Texas, Houston	33	30,500	1,500
Utah, Salt Lake City	8	9,900	5,800
Vermont, Burlington	-7	2,600	8,000
Virginia, Richmond	17	12,300	4,000
Washington, Seattle	26	1,000	5,100
West Virginia, Charleston	11	8,800	4,700
Wisconsin, Madison	-7	3,300	7,600

Window Types

Window #	Glazings	Tint	Coating	Ar/Kr Gas?	Frame	U-value	SHGC	VT
1	Single	Clear	None	No	Metal	>=1.00	>=.60	>=.60
2	Single	Tinted	None	No	Metal	>=1.00	>=.60	>=.60
3	Double	Clear	None	No	Metal	.71–.99	>=.60	>=.60
4	Double	Tinted	None	No	Metal	.71–.99	.41–.60	.51–.60
5	Double	Hi-Perf. Tint	None	No	Metal	.71–.99	.41–.60	.51–.60
6	Double	Clear	HSG Low-E	Yes	Metal	.56–.70	>=0.60	>=0.60
7	Double	Clear	MSG Low-E	Yes	Metal	.56–.70	.26–.40	.51–.60
8	Double	Clear	LSG Low-E	Yes	Metal	.56–.70	<=.25	.51–.60
9	Double	Clear	None	No	Metal/TB	.56–.70	>.60	>.60
10	Double	Tinted	None	No	Metal/TB	.56–.70	.41–.60	.41–.50
11	Double	Hi-Perf. Tint	None	No	Metal/TB	.56–.70	.41–.60	.51–.60
12	Double	Clear	HSG Low-E	Yes	Metal/TB	.41–.50	.41–.60	.51–.60
13	Double	Clear	MSG Low-E	Yes	Metal/TB	.41–.55	.26–.40	.51–.60
14	Double	Clear	LSG Low-E	Yes	Metal/TB	.41–.55	<=.25	.51–.60
15	Single	Clear	None	No	Non-metal	.71–.99	>=.61	>=.60
16	Single	Tinted	None	No	Non-metal	.71–.99	.41–.60	.41–.50
17	Double	Clear	None	No	Non-metal	.41–.55	.41–.60	.51–.60
18	Double	Tinted	None	No	Non-metal	.41–.55	.41–.60	<=.40
19	Double	Hi-Perf. Tint	None	No	Non-metal	.41–.50	.26–.40	.41–.50
20	Double	Clear	HSG Low-E	Yes	Non-metal	.31–.40	.41–.60	.51–.60
21	Double	Clear	MSG Low-E	Yes	Non-metal	.31–.40	.26–.40	.51–.60
22	Double	Clear	LSG Low-E	Yes	Non-metal	.31–.40	<=.25	.41–.50
23	Triple	Clear	MSG Low-E	Yes	Non-metal	.21–.25	.26–.40	.41–.50
24	Triple	Clear	LSG Low-E	Yes	Non-metal	.21–.25	<=.25	<=.40
25	Double	Clear	HSG Low-E	Yes	Non-metal, TI	.26–.30	.41–.60	.51–.60
26	Double	Clear	MSG Low-E	Yes	Non-metal, TI	.26–.30	.26–.40	.51–.60
27	Double	Clear	LSG Low-E	Yes	Non-metal, TI	.26–.30	<=.25	.41–.50
28	Triple	Clear	MSG Low-E	Yes	Non-metal, TI	<=.20	.26–.40	.41–.50
29	Triple	Clear	LSG Low-E	Yes	Non-metal, TI	<=.20	<=.25	<=.40

KEY:

HSG = High Solar Gain

MSG = Medium Solar Gain

LSG = Low Solar Gain

TB = Thermal Break

TI = Thermally Improved

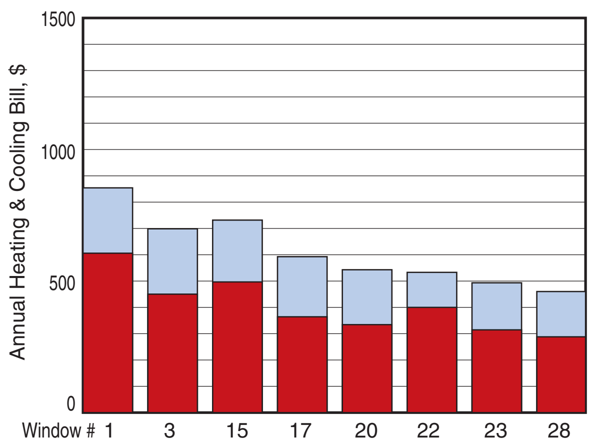
The following seven pages show the results of running the Efficient Windows Collaborative Window Selection Tool for 40 US cities. The bar heights indicate the annual heating (red) and cooling (blue) bills for typical new 2,250-sq.ft. homes where all of the windows are of one of eight types. The numbered window types are those shown in **bold** numbers in the table on the facing page.

The heating and cooling dollar figures reflect the fuel prices current at the time of the analysis, 2013. The true value of the analysis lies in the relative costs rather than the absolute costs, however. For more up-to-date results, go to the website: *www.efficientwindows.org/.*

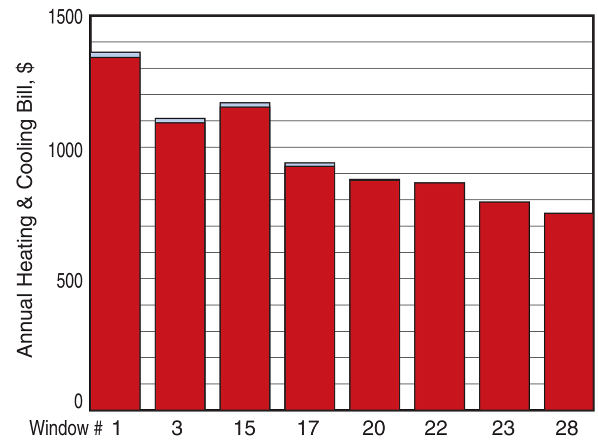
Example: Your site has a climate similar to that of Hartford, CT. According to the bar graph for Hartford, most of the annual heating plus cooling bill is due to heating. Your question is how much you might save by installing triple-glazed with non-metallic frame, moderate-solar-gain low-E windows (window type 28) versus double-glazed with non-metallic frame, high-solar-gain low-E windows (window type 20)?

The total heating and cooling bills for windows #28 and #20 are $720 and $850 respectively, so the savings would be $130 per year. Assuming low inflation, the 30-year saving would total approximately $3,900.

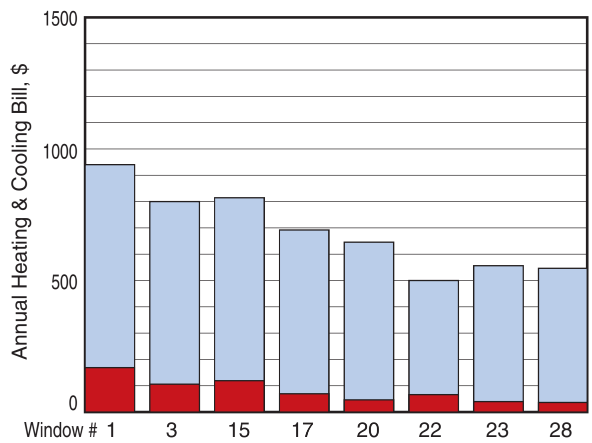
Birmingham, Alabama



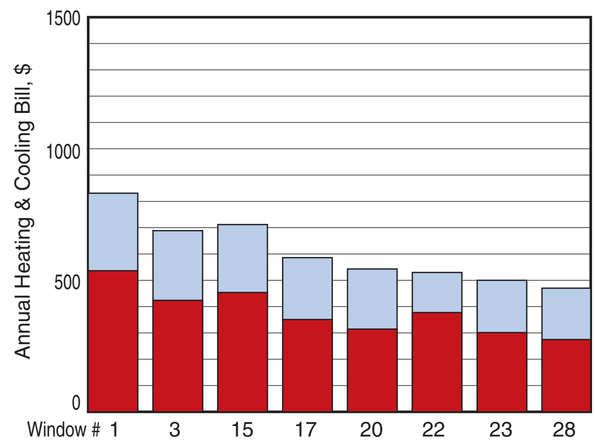
Fairbanks, Alaska



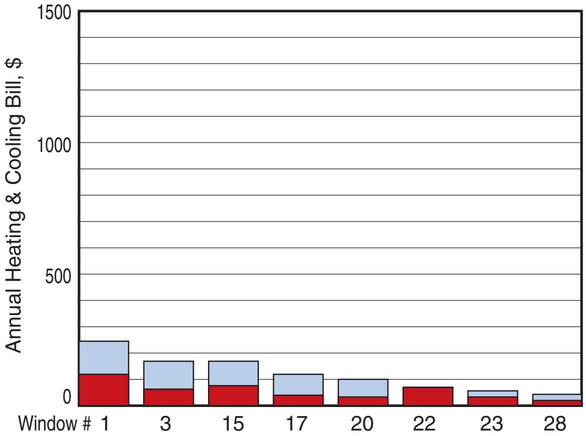
Phoenix, Arizona



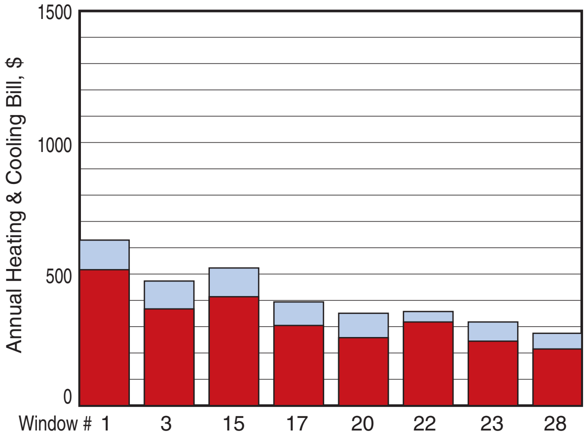
Little Rock, Arkansas



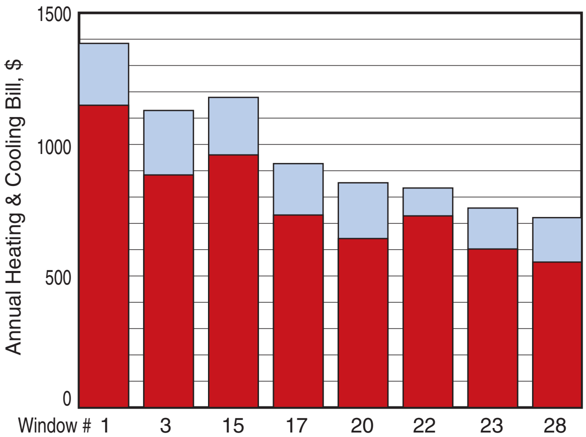
Los Angeles, California



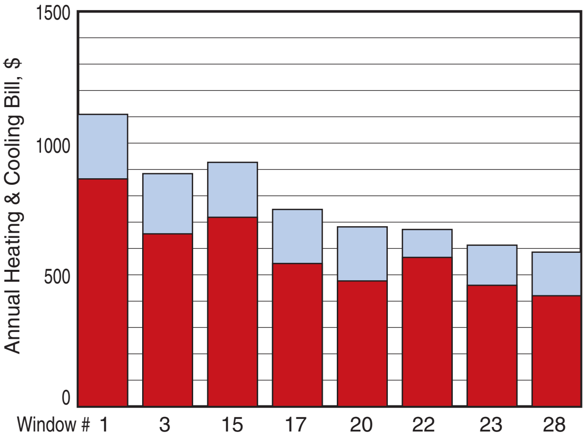
Denver, Colorado



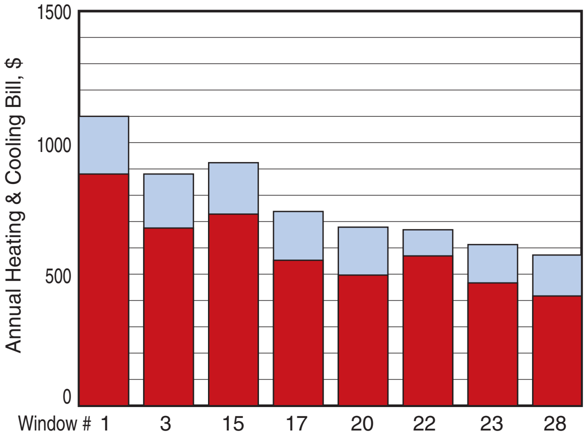
Hartford, Connecticut



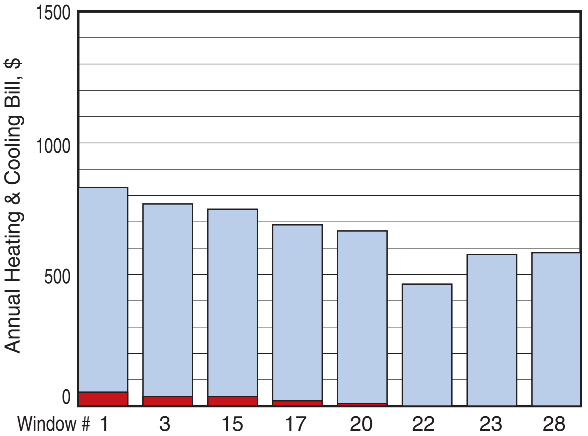
Wilmington, Delaware



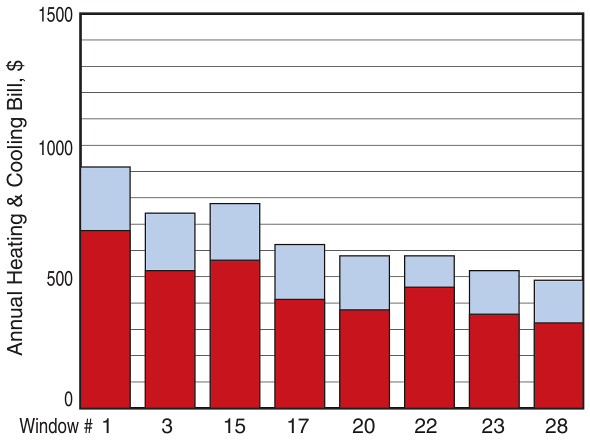
Washington, DC



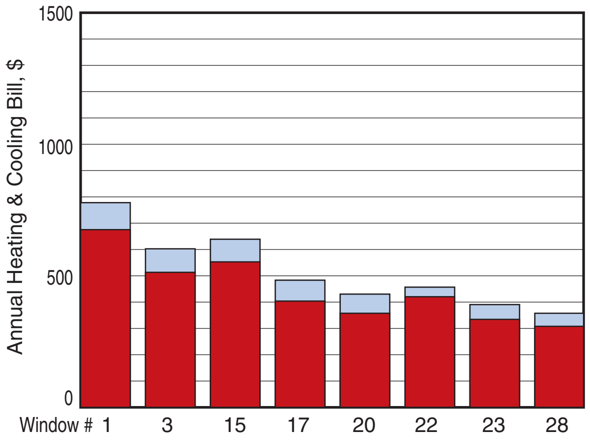
Miami, Florida



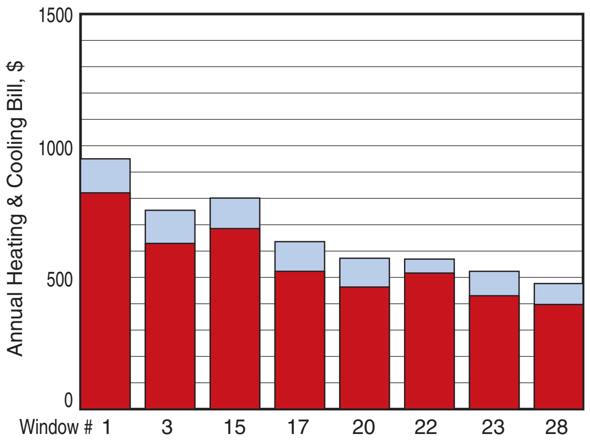
Atlanta, Georgia



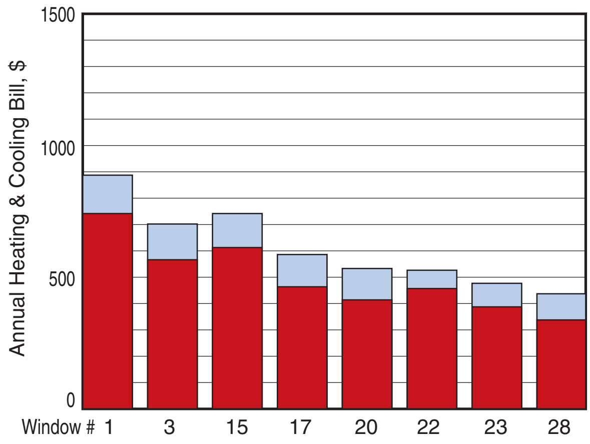
Boise, Idaho



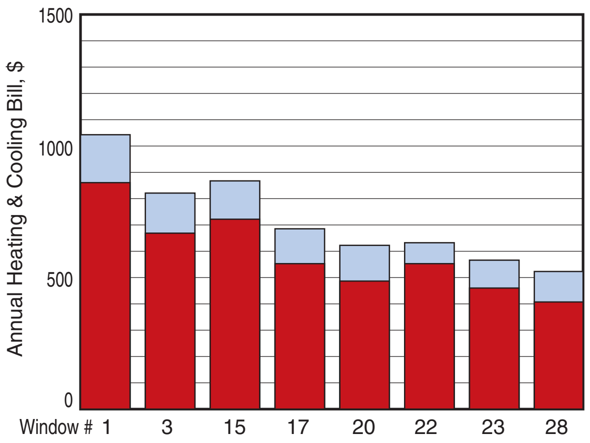
Chicago, Illinois



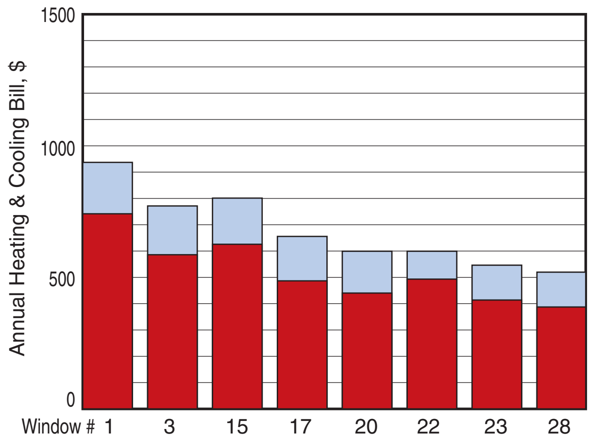
Indianapolis, Indiana



Des Moines, Iowa



Louisville, Kentucky



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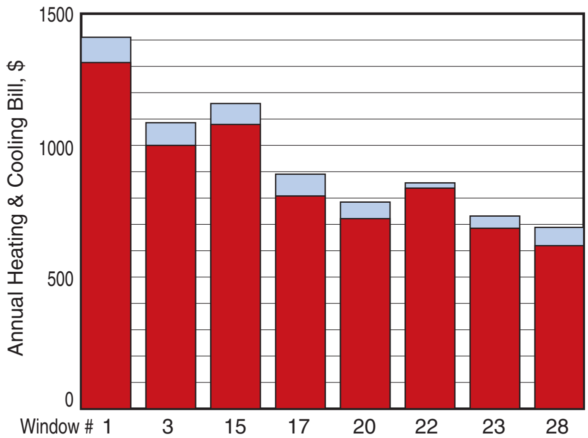

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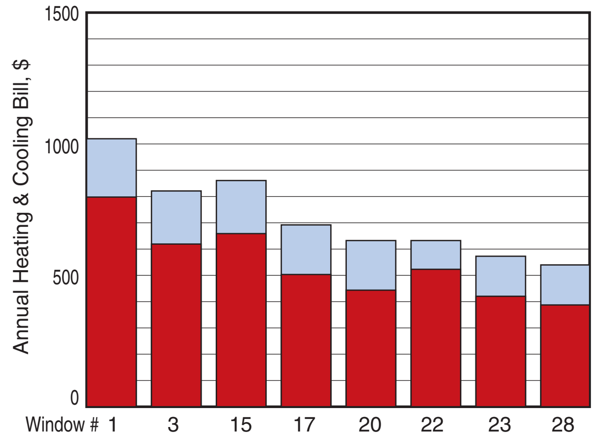
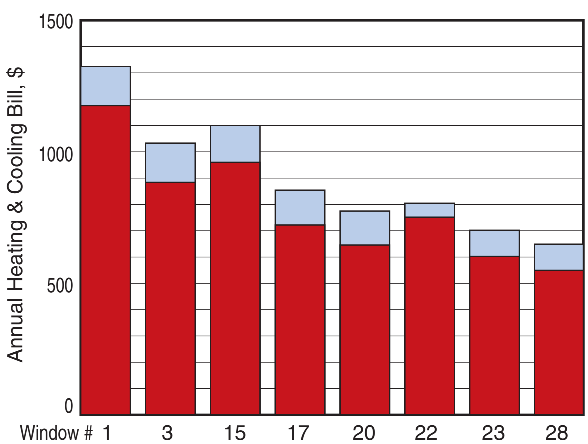


Boston, Massachusetts



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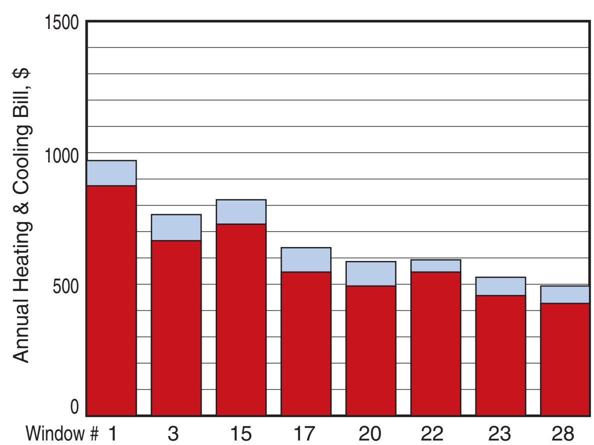

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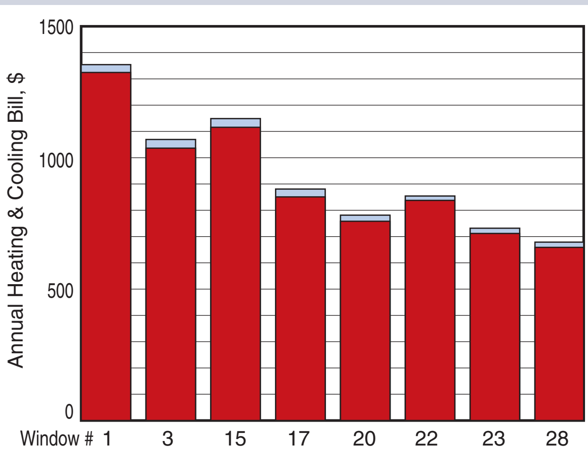

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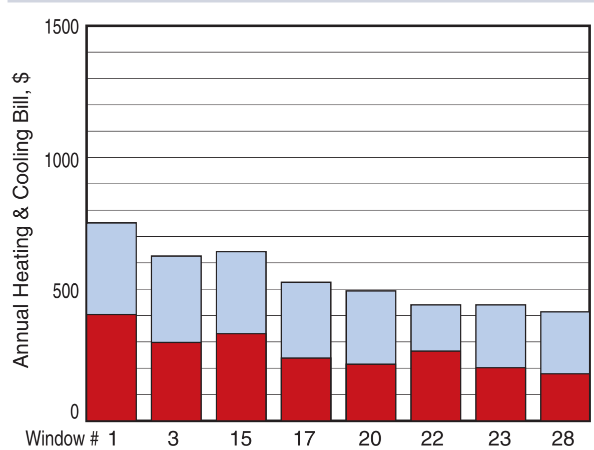
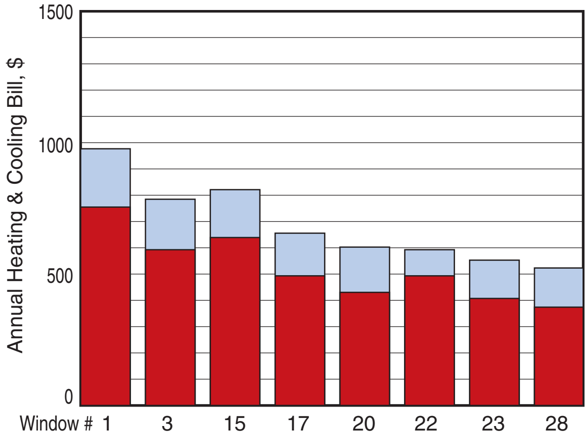
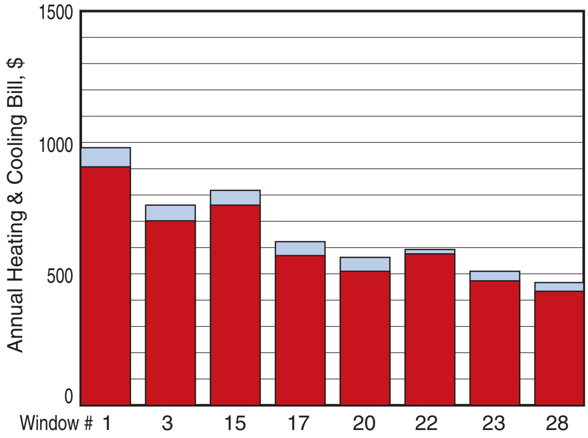


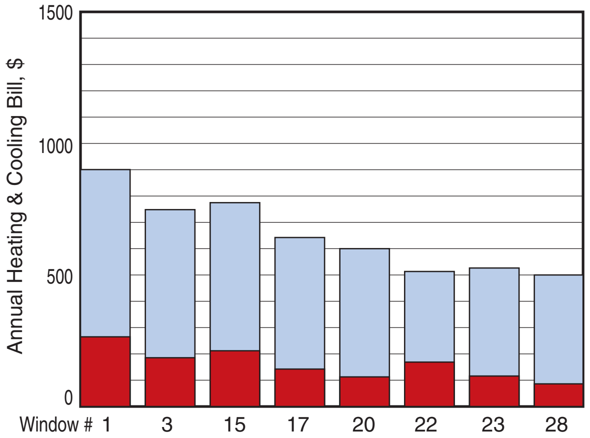
St Louis, Missouri



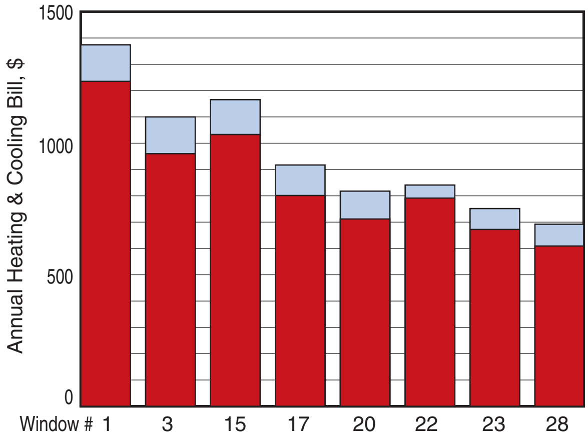
Great Falls, Montana



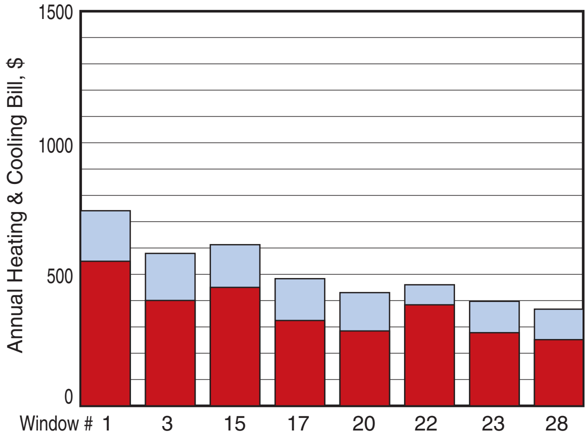
Las Vegas, Nevada



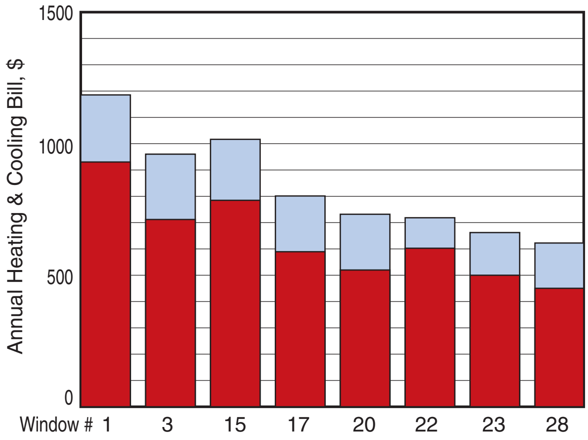
Concord, New Hampshire



Albuquerque, New Mexico



New York, New York



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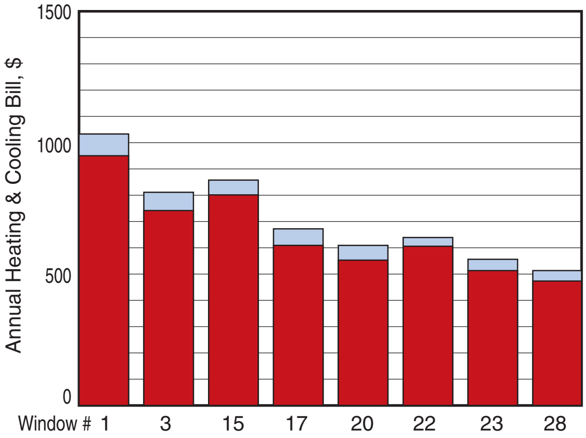
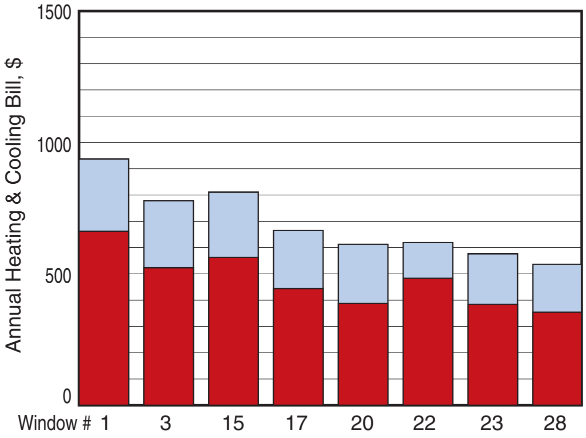
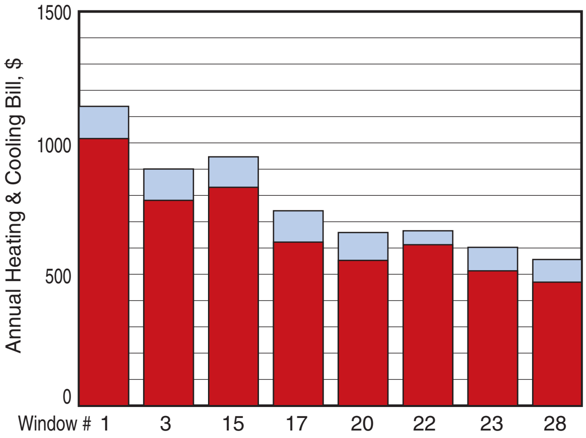


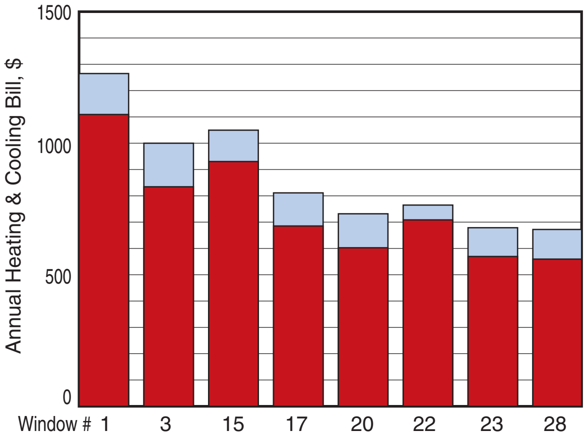
Tulsa, Oklahoma



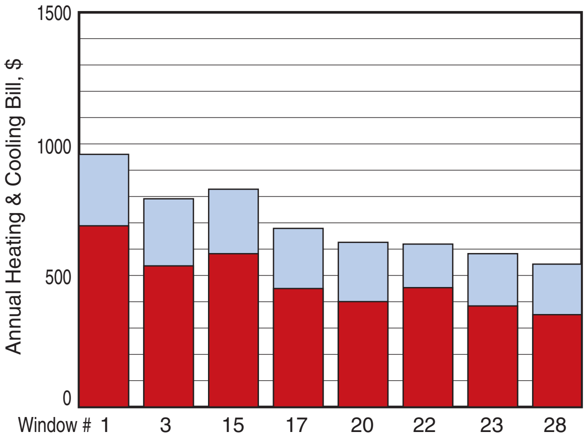
Pittsburgh, Pennsylvania



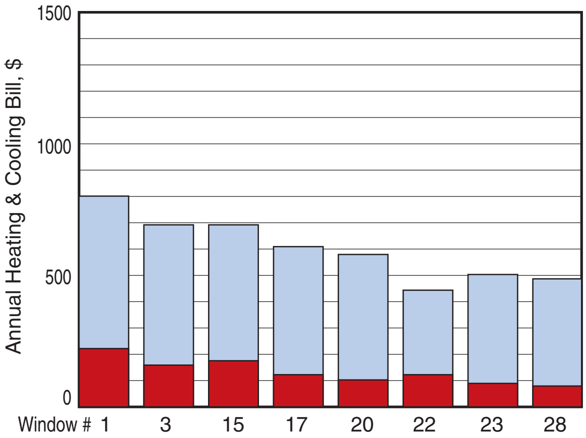
Providence, Rhode Island



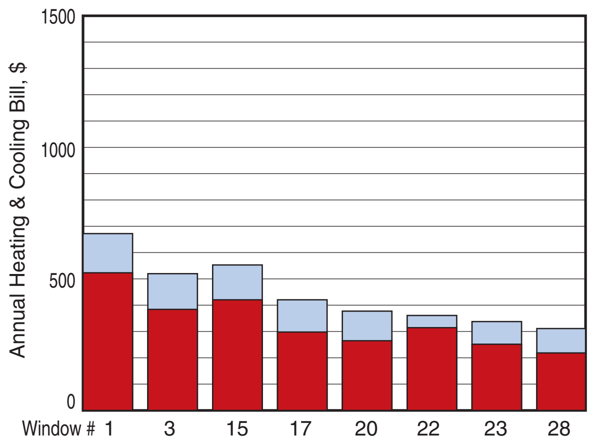
Nashville, Tennessee



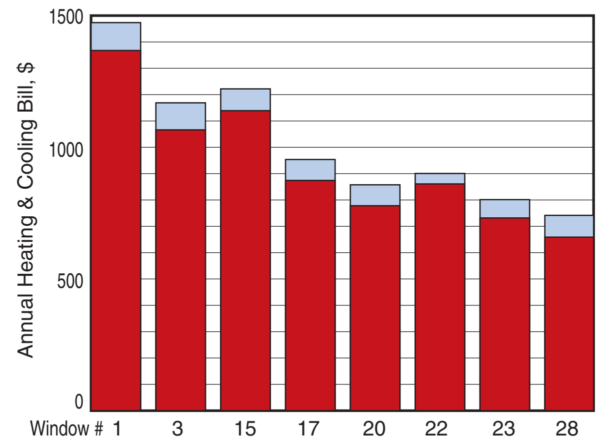
Houston, Texas



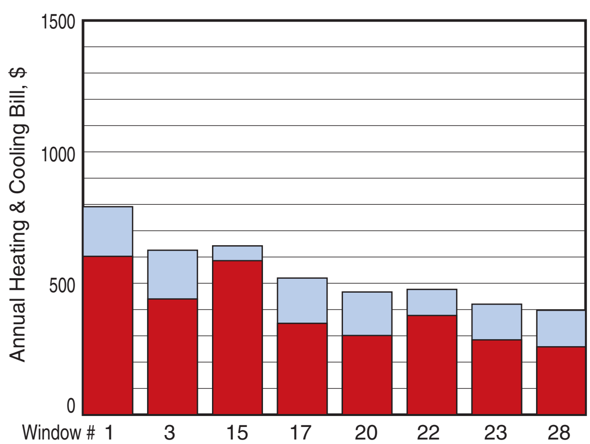
Salt Lake City, Utah



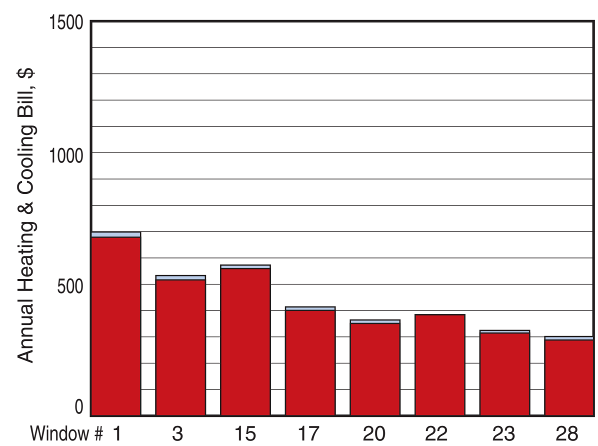
Burlington, Vermont



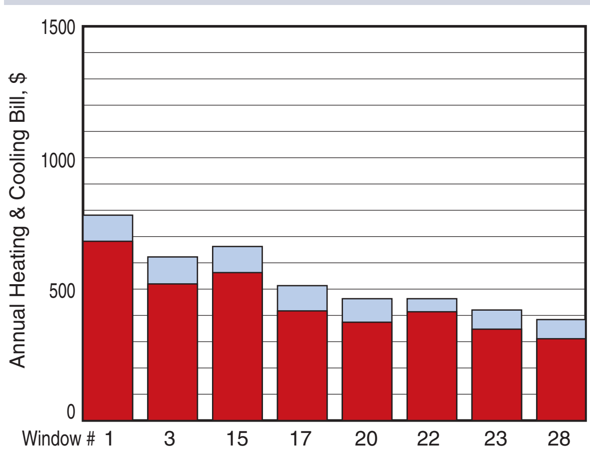
Richmond, Virginia



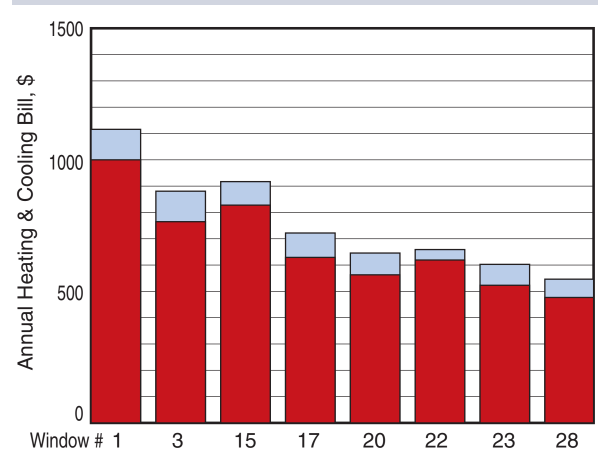
Seattle, Washington



Charleston, West Virginia



Madison, Wisconsin



Skylights

The illustrations and table below describe Velux® deck-mounted (most common application) roof windows and skylights. Velux also offers a similar assortment of curb-mounted units. Skylights may be fixed or pivot from the top.

The following models are available:

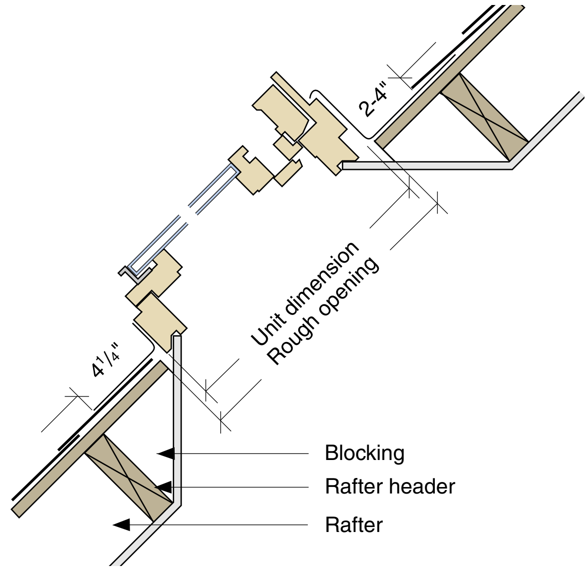
FS – fixed skylight
VS – ventilating skylight
VSE – electric ventilating skylight
VSS – solar ventilating skylight

The illustration below at left shows the definitions of unit dimension (outside frame dimensions) and rough opening. Rough opening in the roof sheathing is $^1/_2$ inch larger than the unit width and height.

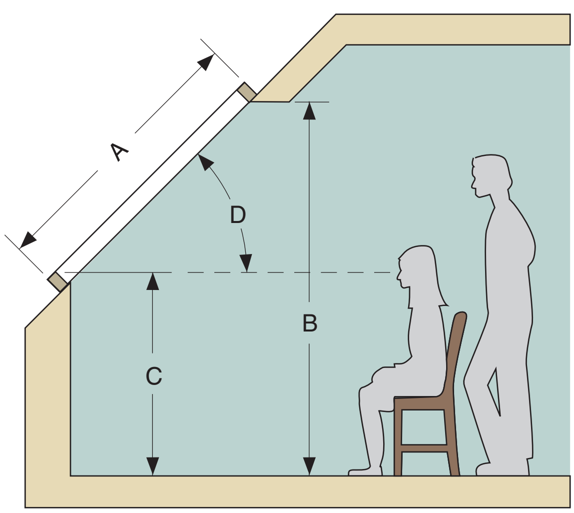
The illustration below at right and the table show critical installation measurements for units where sitting and standing views are important.

Several other manufacturers offer skylights and roof windows. Ask for more information at your local building supply center.

Skylight Dimensions



Sitting/Standing View Geometry



Installation Measurements for Different Roof Pitches, Inches

Size Numbers		C04, M04				A06, C06, M06, S06				C08, M08				C1			
A		$37^1/_2$				$45^1/_2$				54				$69^7/_8$			
B		74	76	78	80	74	76	78	80	74	76	78	80	74	76	78	80
C at **D** =	30°	60	62	64	66	56	58	60	62	52	54	56	58	44	46	48	50
	35°	58	59	62	64	53	55	57	59	48	50	52	54	38	40	42	44
	40°	55	57	59	61	50	52	54	56	44	46	48	50	33	35	37	39
	45°	52	54	56	58	47	49	51	53	41	43	45	47	30	32	34	36
	50°	50	52	54	56	44	46	48	50	37	39	41	43	24	26	28	30

Velux Deck-Mounted Skylight Rough Openings

Rough opening	14$^{1}/_{2}$"	21"	30$^{1}/_{16}$"	44$^{1}/_{4}$"
26$^{7}/_{8}$"		**C01** FS, VS VSE VSS		**S01** FS, VS VSE, VSS
30"			**M02** FS VSS	
37$^{7}/_{8}$"		**C04** FS VS VSE VSS	**M04** FS VS VSS	
45$^{3}/_{4}$"	**A06** FS	**C06** FS VS VSE VSS	**M06** FS VS VSE VSS	**S06** FS VS VSE VSS
54$^{7}/_{16}$"		**C08** FS VS VSE VSS	**M08** FS VS VSE	
70$^{1}/_{4}$"		**C12** FS		

NOTE: Bold numbers (**C01**, etc.) are sizes; lettered codes (FS, etc.) are models.

Site-Built Windows

When there is no need for a window to open, particularly if there are several such units, installing bare factory-sealed glazing units in the field will save money.

Insulated Glazing Units

Many glass companies manufacture both custom and standard-size patio door replacement units. Due to volume, standard tempered-glass patio door units offer the greatest value. Standard patio door glazing sizes include: 28×76, 33×75, 34×76, 46×75, and 46×76 inches.

Insulated glass units are assembled by bonding two panes of glass to an aluminum spacer. The spacer is filled with a desiccant material, designed to absorb moisture and keep the cavity condensation free for the life of the unit (generally guaranteed for 10 years). The sealant may be one or more of the following: silicone, urethane, polysulfide, or polyisobutylene. If the unit is of patio door size, the glazing will most often be tempered, since building codes require tempered or safety glass in doors, within 10 inches of doors, within 18 inches of the floor, and for overhead or sloped glazings.

The greatest drawback to site-built windows is the high rate of failure of the glass seals. Failure is usually due to one of three causes:

- improper installation, where the unit is subjected to stress
- sloped installation, where the span is too great for the glass thickness, resulting in shear
- the use of site sealants that are incompatible with the glazing unit sealant

As a rule, installation at slopes of greater than 20° from vertical voids manufacturers' warrantees. Units can be double-sealed for approximately 20 percent higher cost.

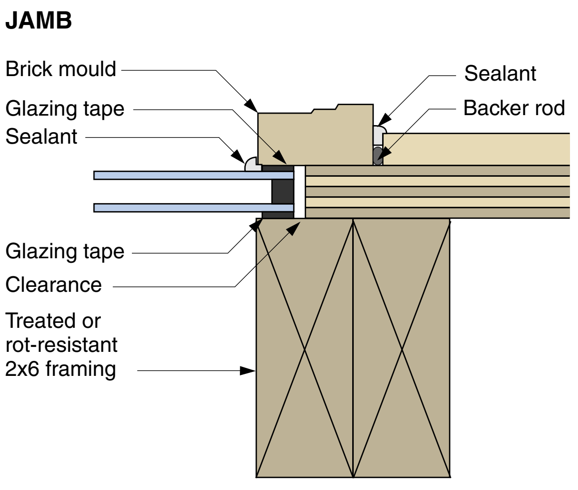
The facing page shows details for installation of glazing direct to framing and within separate frames (jambs). In both cases the keys to success are these:

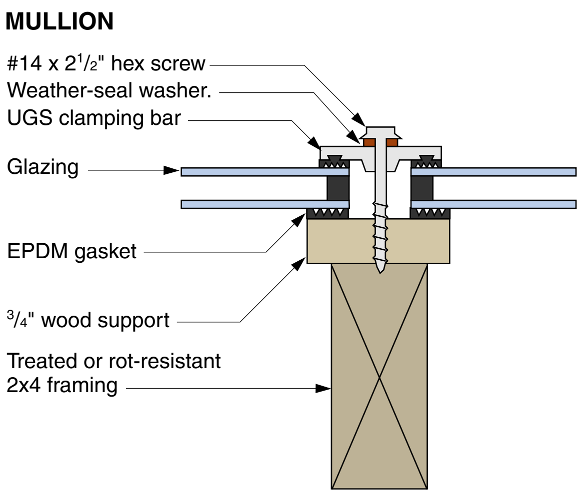
- Float the glazing unit within the frame. All of the weight of the unit should rest on two 4-inch-long strips of neoprene rubber (ask your glass supplier for setting blocks) placed one quarter of the unit width from each bottom comer.
- Don't let the glass surfaces touch wood anywhere. Glazing tape compressed between the unit and the wood stops distributes stresses, allows for seasonal movement, and seals the unit against infiltration.
- Seal against moisture incursion with a compatible sealant. Ask the unit manufacturer for a specific recommendation.
- Provide for moisture drainage. Outside sill and stop must slope away from the unit. Inside sills should also slope away if in a high-humidity environment. Angle 1/8-inch weep holes from both sides of the setting blocks to outside the siding.

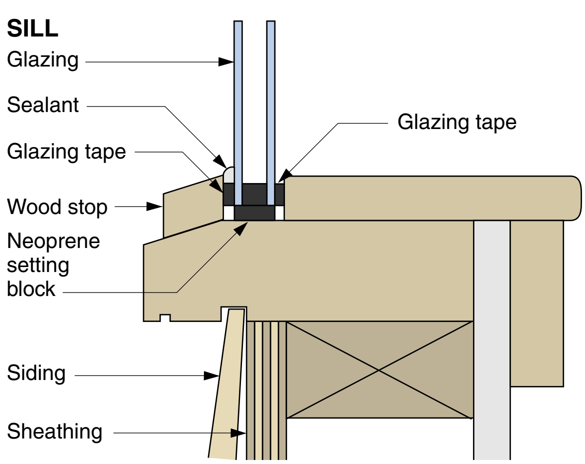
The use of pressure-treated lumber for the sills will result in longer life, but be aware that pressure-treated wood does not generally hold paint well until it has aged for about a year.

If the glazing is primarily for solar heat gain, as in a sunspace, read pp. 292–303 before selecting the type of glass.

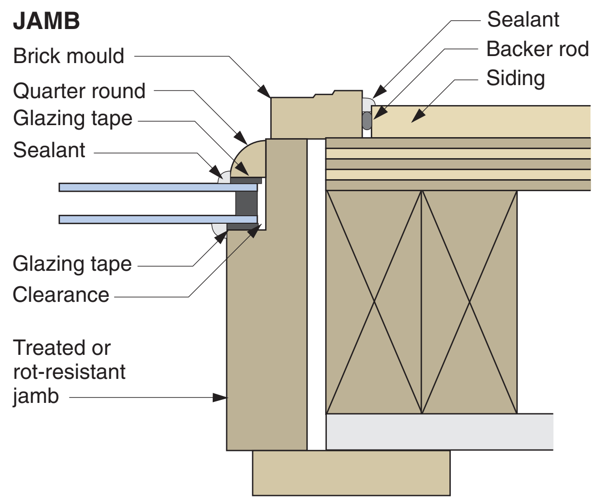
Installation Direct to Framing

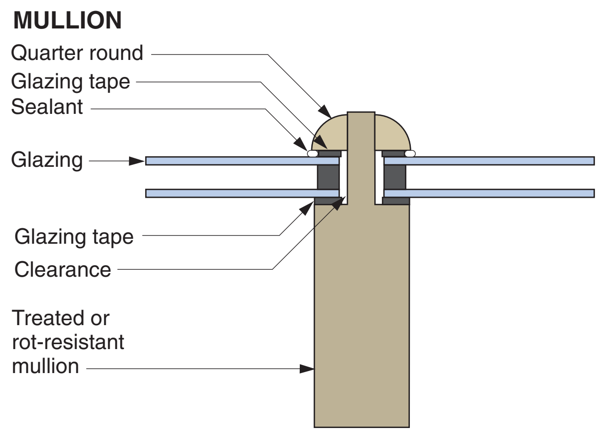


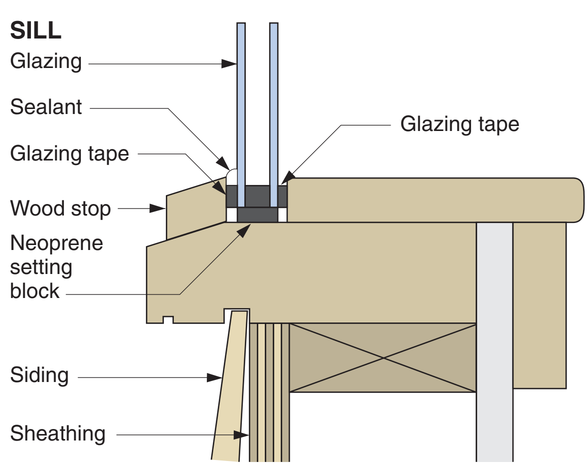




Installation in Jambs







About Doors

Functions

Exterior doors function in numerous ways:

1. They let people in and out. This is not as trivial as it may seem but relates to the design of a welcoming entryway—an architectural subject by itself.

2. They let large objects in and out. The minimum width for an entry door (and some interior doors as well) should be 3 feet to facilitate moving furniture and appliances.

3. They keep intruders out. All entrance doors should have quality dead-bolt locks as well as the common latch set. In urban areas an additional lock, operated only from the inside, would be worthwhile.

4. They keep out winter wind and cold. Except for custom doors intended for historic preservation, the great majority of exterior doors sold today are steel with foam-insulated cores. These represent a giant advance over the classic wood door, in thermal performance if not appearance. Compared with an R-value of 1.5 for the classic wood-paneled door, the foam core door has an R-value of 6 to 12, reducing conductive heat loss by 75 to 85 percent. The best metal doors also incorporate magnetic weatherstrips, virtually eliminating infiltration.

5. They let in summer breezes, winter solar gain, and natural daylight. The original function of the storm door was the same as the storm window: to reduce winter heat loss by conduction and infiltration. These losses have largely been eliminated by the steel door. However, a combination "storm" door may still be desirable for summer ventilation.

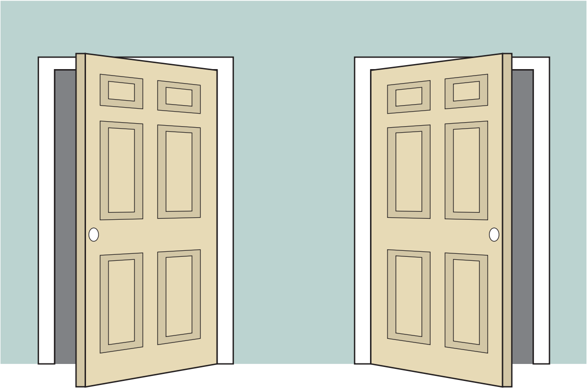
Handedness

When ordering a prehung door, you must specify its "handedness." The illustration below shows how handedness is defined.

If a door opens toward you and the door knob is on your left, the door is *left-handed*.

If a door opens toward you and the door knob is on your right, the door is *right-handed*.

Door Handedness

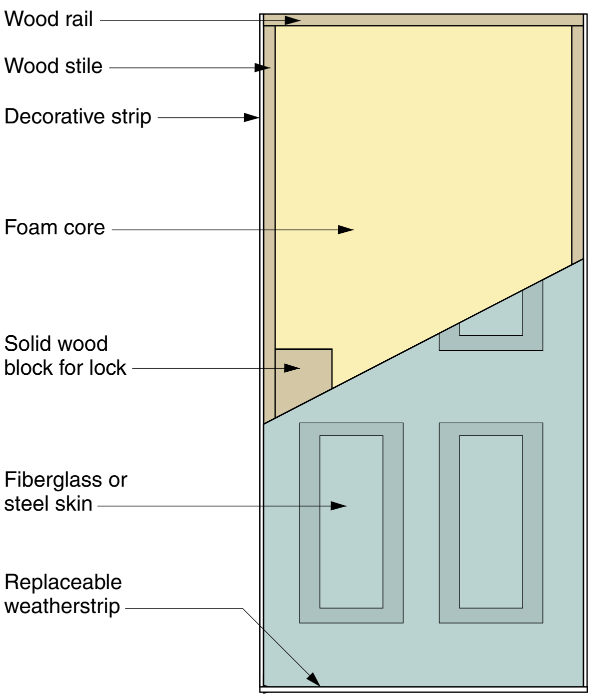


Construction

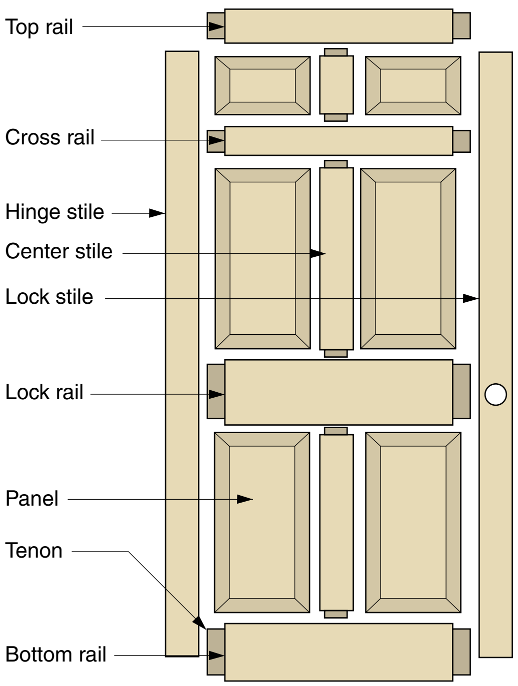
The illustration on the facing page shows how the five most common types of door are constructed. Fiberglass and steel doors are commonly used as entrance doors because of high R-value and dimensional stability. Wood panel doors are used primarily on the interior of classic-styled homes. The hollow-core door is used exclusively on the interior of low-end homes, whereas the more substantial solid-core door is common in modern, high-end homes.

How Doors Are Constructed

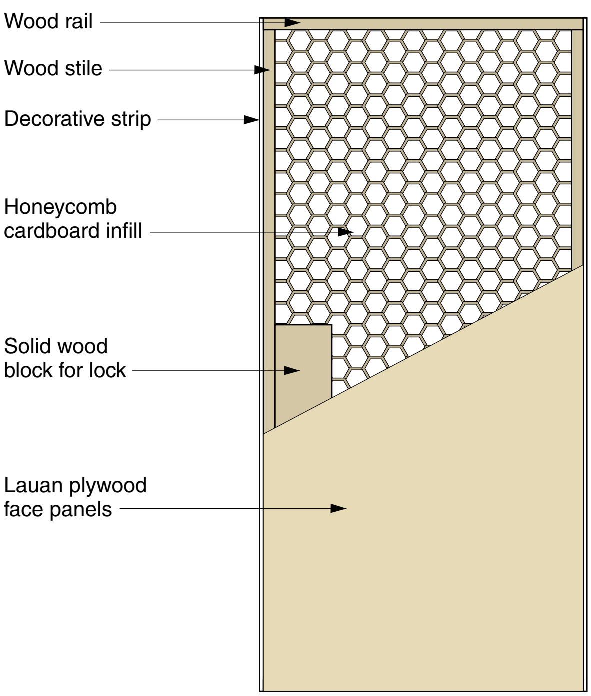
FIBERGLASS OR STEEL DOOR



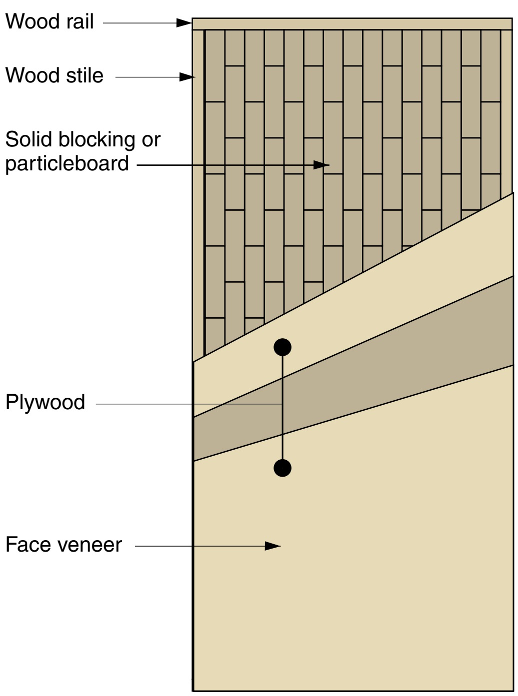
WOOD PANEL DOOR



HOLLOW-CORE DOOR



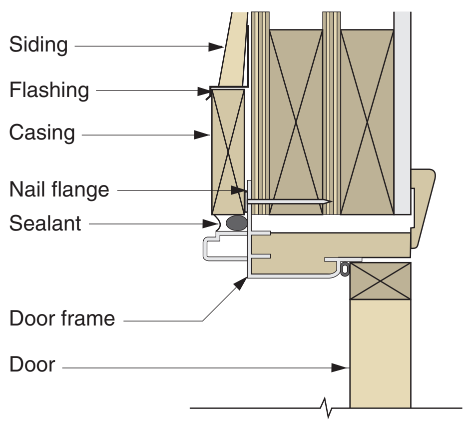
SOLID-CORE DOOR



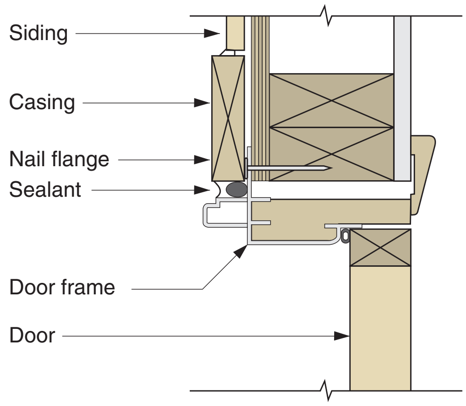
Door Installation

Modern Prehung Door Installation

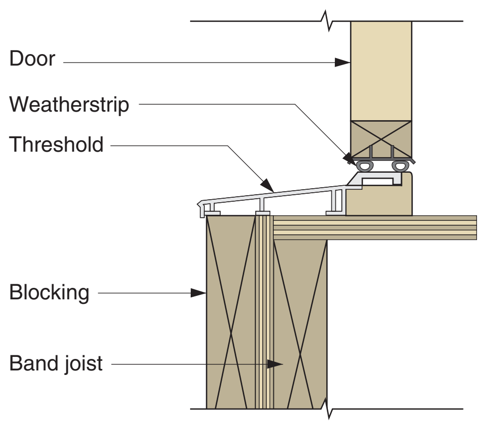
EXTERIOR PREHUNG DOOR



HEAD

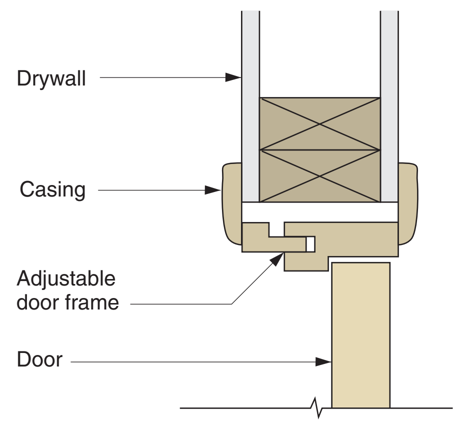


JAMB

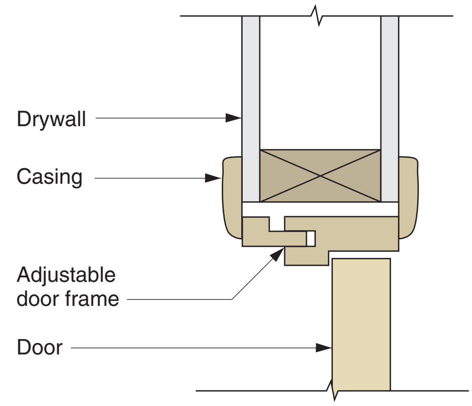


SILL

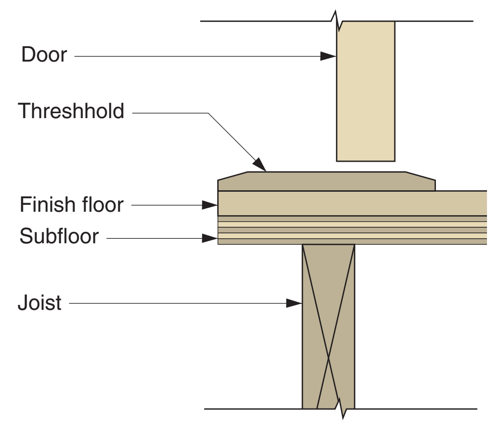
INTERIOR PREHUNG DOOR



HEAD



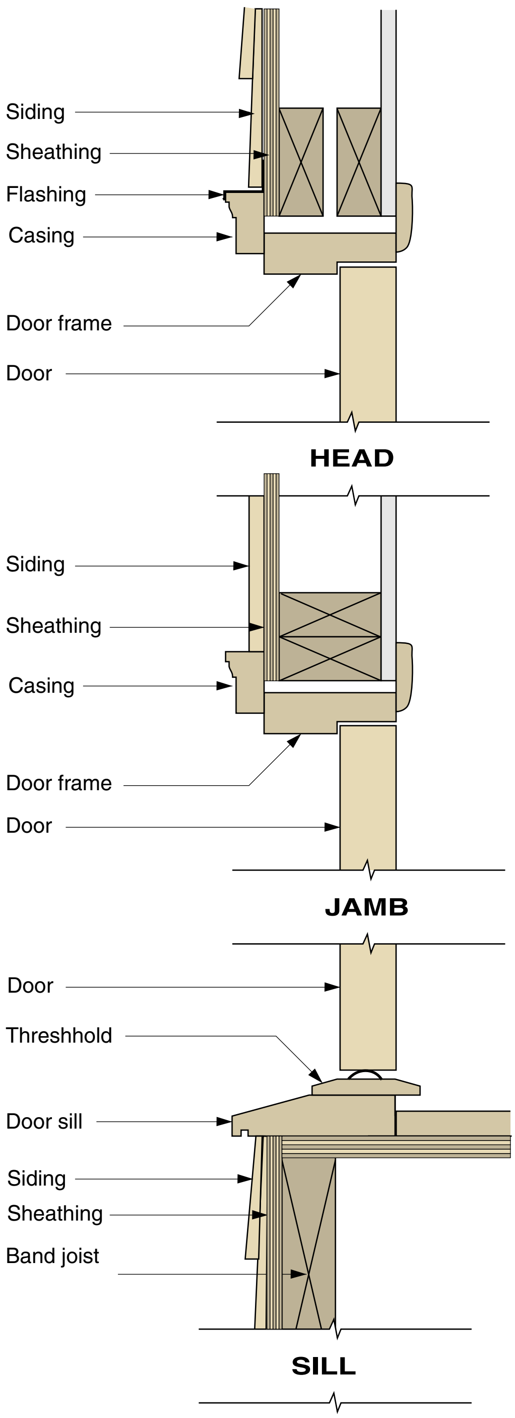
JAMB



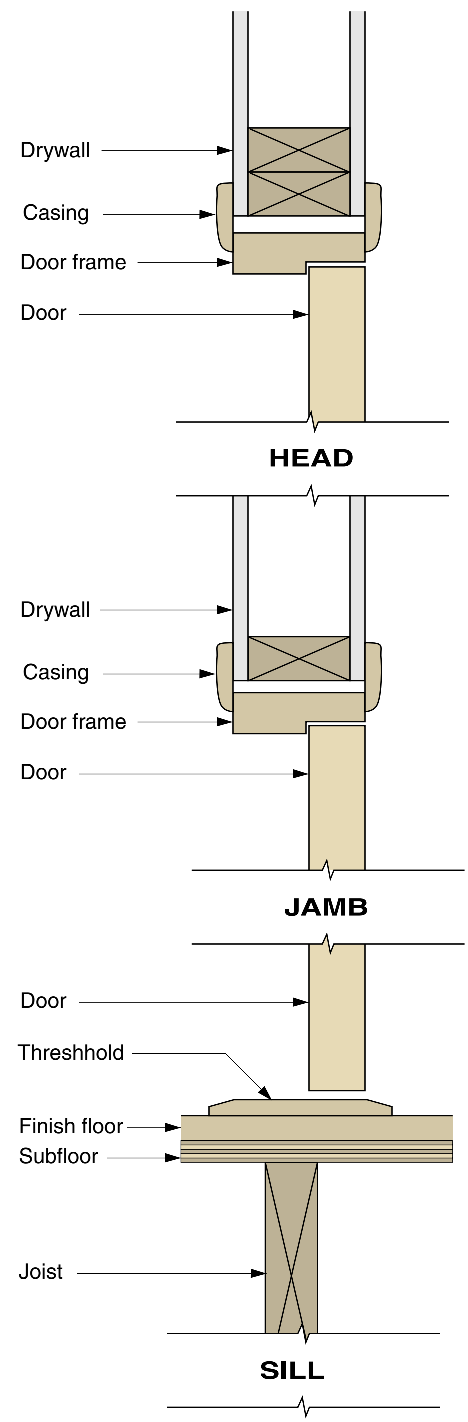
SILL

Older Slab Door Installation

OLDER EXTERIOR DOOR



OLDER INTERIOR DOOR



Bulkhead Doors

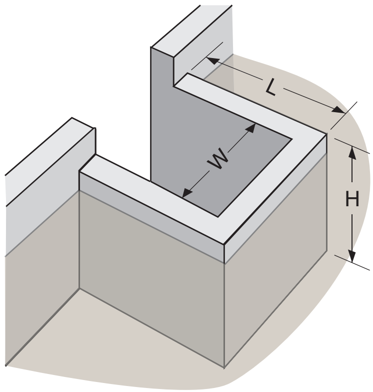
The table below and illustrations on the facing page describe steel bulkhead doors and stair stringers available from the Bilco® Company. To design a basement bulkhead installation, take the following steps:

1. Determine the height of grade above the finished basement floor.

2. Find the appropriate height range in the table below.

3. Read across the table to find the dimensions of the concrete areaway (illustration at right) and the recommended sizes (illustrations on the facing page).

Older Slab Door Installation



Areaway Dimensions for Bilco Basement Doors

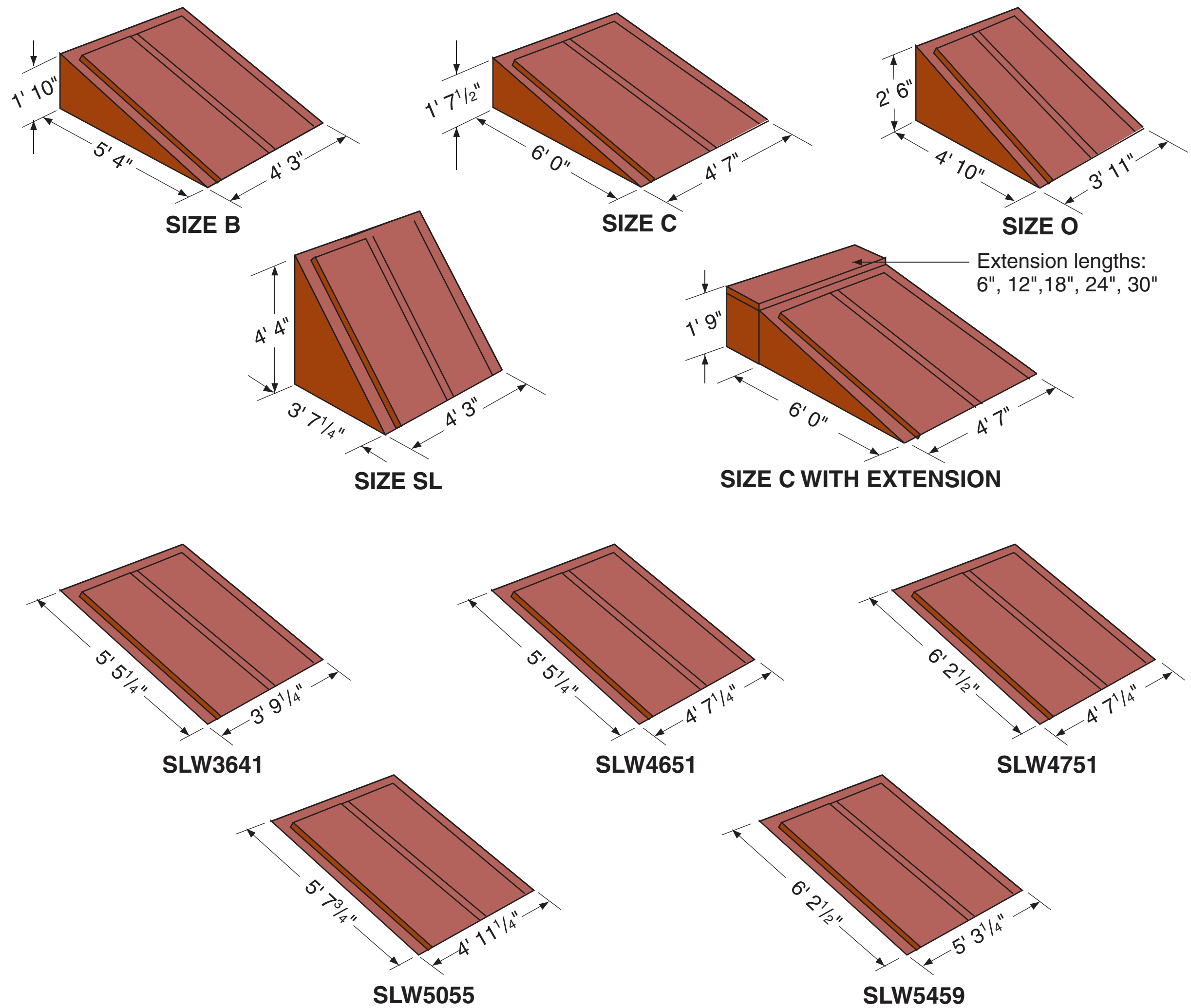
Height of Grade above Floor	H[1]	L	W	Door Style	Extension Required	Stringer Style	Number of Treads
2' 8" to 3' 3"	3' 5¼"	3' 4"	3' 8"	SL	none	SL	4
3' 4" to 3' 11"[3]	4' 1½"	3' 4"	3' 8"	SL	none	SL	4
4' 0" to 4' 7"[2]	4' 9¾"	4' 6"	3' 4"	O	none	O	6
4' 8" to 5' 4"[2]	5' 6"	5' 0"	3' 8"	B	none	B	7
5' 5" to 6' 0"	6' 2¼"	5' 8"	4' 0"	C	none	C	8
6' 1" to 6' 8"[3]	6' 10½"	5' 8"	4' 0"	C	none	C	8
6' 1" to 6' 8"	6' 10½"	6' 8"	4' 0"	C	12"	O + E	9
6' 9" to 7' 4"[3]	7' 6¾"	6' 8"	4' 0"	C	12"	O + E	9
6' 9" to 7' 4"	7' 6¾"	7' 2"	4' 0"	C	18"	B + E	10
7' 5" to 8' 1"[3]	8' 3"	7' 2"	4' 0"	C	18"	B + E	10
7' 5" to 8' 1"	8' 3"	7' 9"	4' 0"	C	24"	C + E	11

[1] Height above finished basement floor

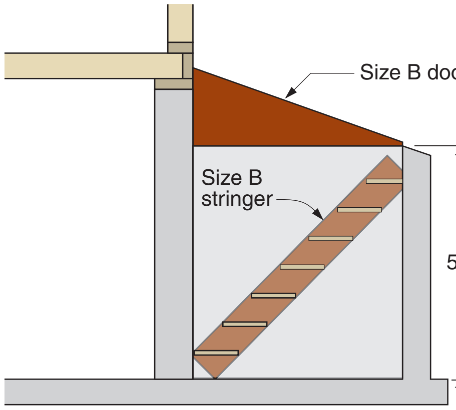
[2] Maximum height of house wall = 7' 4"

[3] Requires that one concrete step be added at finished basement floor

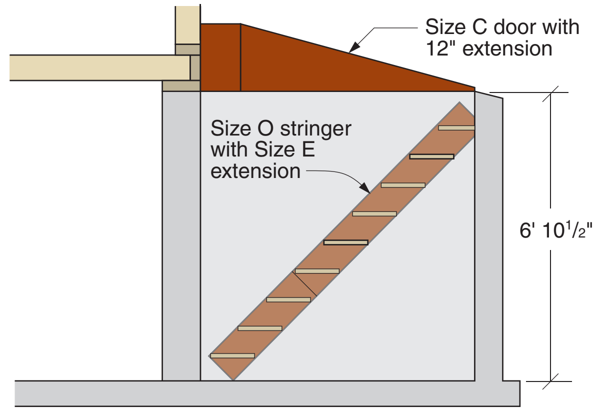
Bilco Basement Door Standard Sizes



STANDARD INSTALLATION



INSTALLATION WITH EXTENSION



Meet the Code (IRC)

The following is a partial list of requirements from the *2015 International Residential Code (IRC) for One- and Two-Family Dwellings.* Consult the publication for the full text and additional provisions.

Light, Ventilation & Heating (R303)

Habitable rooms:

- habitable rooms to have glazing area of ≥8% of the floor area
- natural ventilation to be through windows, doors, louvers, or other approved openings to outdoor air
- openable area to outdoors ≥4% of floor area

Exceptions:

1. glazed areas need not be openable with whole-house mechanical ventilation of 30 cfm for 0-1 bedrooms or 45 cfm for 2-3 bedrooms
2. glazing not necessary where ventilation and lighting of 6 footcandles at 30" height provided
3. sunrooms and patio covers OK if screened only or ≥40% of wall is open

Adjoining rooms:

- Any room may be considered part of adjoining room if ≥50% of common wall open and unobstructed and provides an opening of ≥10% of interior room floor area, but not less than 25 sq.ft.

Exception:

required opening permitted to open into a sunroom addition or patio cover, provided there is an openable area between the spaces of ≥10% of interior room floor area, but not less than 20 sq.ft.

- Openable area to the outdoors to be based on total floor area ventilated

Bathrooms:

- Bathrooms to have ≥3 sq.ft. window glazed area, half of which must be openable

Exception: glazed areas need not be openable if provided mechanical ventilation directly to outside of 50 cfm intermittent or 20 cfm continuous

Glazing (R308)

Identification:

- each pane of glazing in hazardous locations to be provided with a manufacturer's designation visible in the final installation
- designation may be etched, sandblasted, ceramic-fired, laser etched, embossed, or of a type which cannot be removed
- a label permitted in lieu of designation

Exceptions:

1. except for tempered glass, manufacturer's designations not required provided building official approves other evidence confirming compliance
2. tempered spandrel glass permitted to be identified by a removable paper designation

- assemblies with individual panes ≤1 sq.ft. to have at least one pane identified
- regular, float, wired, or patterned glass in jalousies and louvered windows ≥$^{3}/_{16}$" thick and ≤48" long
- wired glass with wire exposed on long edges shall not be used in jalousies or louvered windows
- glazed areas, including glass mirrors in hazardous locations, must pass the test requirements of Consumer Product Safety Commission (CPSC) 16 Code of Federal Regulations (CFR), Part 1201
- hazardous glazing locations include:
  1. swinging doors except jalousies
  2. sliding doors and bifold closet doors
  3. storm doors
  4. unframed swinging doors
  5. enclosures for hot tubs, whirlpools, saunas, steam rooms, bathtubs, and showers where bottom exposed edge of glazing is <60" above any standing or walking surface
  6. adjacent to a door where nearest vertical edge is within a 24" arc of the door in a closed position and whose bottom edge is <60" above floor
  7. where an individual pane ≥9 sq.ft., bottom edge <18" above the floor, top edge >36" above floor, and walking surface within 36" horizontally

8. in railings

9. in walls and fences enclosing indoor and outdoor swimming pools, hot tubs, and spas where bottom edge <60" above floor and within ≤60" horizontally of water

10. next to stairways, landings, and ramps <36" above walking surface

11. next to bottom landings <60" horizontally of bottom tread if glazing <36" above tread nose

Exceptions:

1. glazings ≥36" horizontally from walkway

2. glazings in items 7 & 10, if protective bar on accessible side(s) of glazing 34-38 inches above floor

Emergency Escape and Rescue Openings (R310)

Egress openings:

- basements, habitable attics, and every sleeping room to have at least one operable egress opening
- opening to open directly into a public street, public alley, yard, or court
- if basement contains >1 sleeping room, egress openings required in each
- sill height ≤44" above floor
- clear opening height ≥24"
- clear opening width ≥20"
- clear opening dimensions must be obtained by normal operation from inside
- net clear opening ≥5.7 sq.ft.

Exceptions: grade floor openings to have clear opening of ≥5 sq.ft.

- openings operational from the inside room without use of keys, tools, or special knowledge
- openings with sill height below adjacent ground to be provided with a window well

Exception: basements used only to house mechanical equipment and ≤200 sq.ft. floor area

- horizontal area of window well ≥9 sq.ft., with horizontal projection and width ≥36"
- window wells with a vertical depth >44" to be equipped with permanently affixed ladder or steps usable with window in fully open position
- ladders or rungs to have inside width of ≥12", project ≥3" from wall, and be spaced ≤18" o.c.
- bulkhead enclosures to provide direct access to basement
- bars, grilles, covers, screens, or similar devices permitted over openings, bulkhead enclosures, or window wells that serve openings, provided the minimum clear opening size complies, and are releasable from inside without use of key, tool, special knowledge, or force greater than required for normal operation of the opening
- egress window under deck or porch OK if window can be fully opened and provides a path ≥36" in height to a yard or court

Means of Egress (R311)

- stairways, ramps, exterior egress balconies, hallways, and doors to comply
- at least one exit door for each dwelling unit
- exit door to provide direct access from habitable portions of dwelling to exterior without travel through a garage
- exit may be by a ramp or a stairway
- exit door side-hinged, ≥32" wide, and ≥6'6" high
- landings required each side of exterior doors of width ≥width of door and ≥36" in length in direction of travel
- landing ≤1.5" lower than top of threshold
- landing slope ≤2%
- egress doors readily openable from inside without use of a key or special knowledge or effort

11

Plumbing

The piping in your basement may seem a maze. Viewing it as three separate systems (cold supply, hot supply, and waste) makes it a lot clearer. That's the approach of this chapter.

First we describe *water wells and pumps* for those who must supply their own water.

The next section looks at the *supply piping*—the pipes that bring water into the building. We look at the materials you are allowed to use and how they are placed in a trench. Then we show how to *size supply pipes* as a function of the loads they carry.

Homeowners in northern states with private wells have a unique worry: frozen pipes. We show how to *freezeproof supply pipes* without the use of electricity.

Nothing will gain you more respect at the hardware store than being able to ask for a "drop ell with threaded outlet," instead of a "bent gizmo about 2 inches long with threads at each end," so the next three sections are field guides to *copper, PVC, polyethylene, and PEX supply fittings*.

The other half of plumbing is the *drain, waste, and vent (DWV) system*. Rather than relying on water pressure, it depends on gravity to make its mixture of liquids and solids flow. For this reason, *sizing drainpipe* and *running drainpipe* are both subject to stringent rules.

Because the waste empties into a sewer, the DWV system also includes fixture *traps* to block sewer gas. The "V" in DWV stands for the *venting* system, which prevents pressure differences from emptying the traps.

A second field guide illustrates 80 species of *plastic DWV fittings.* Whether you are installing a new system or adapting to a cast-iron system, you'll find just the fittings you'll need.

How do you know where the pipes go before you have the fixtures in hand? The *roughing-in dimensions* guide shows you.

If your water comes from a private well, you need to know about *private well water standards and treatments.*

Finally, we provide you with a checklist to make sure your plumbing installations *meet the code (IRC).*

Water Wells and Pumps

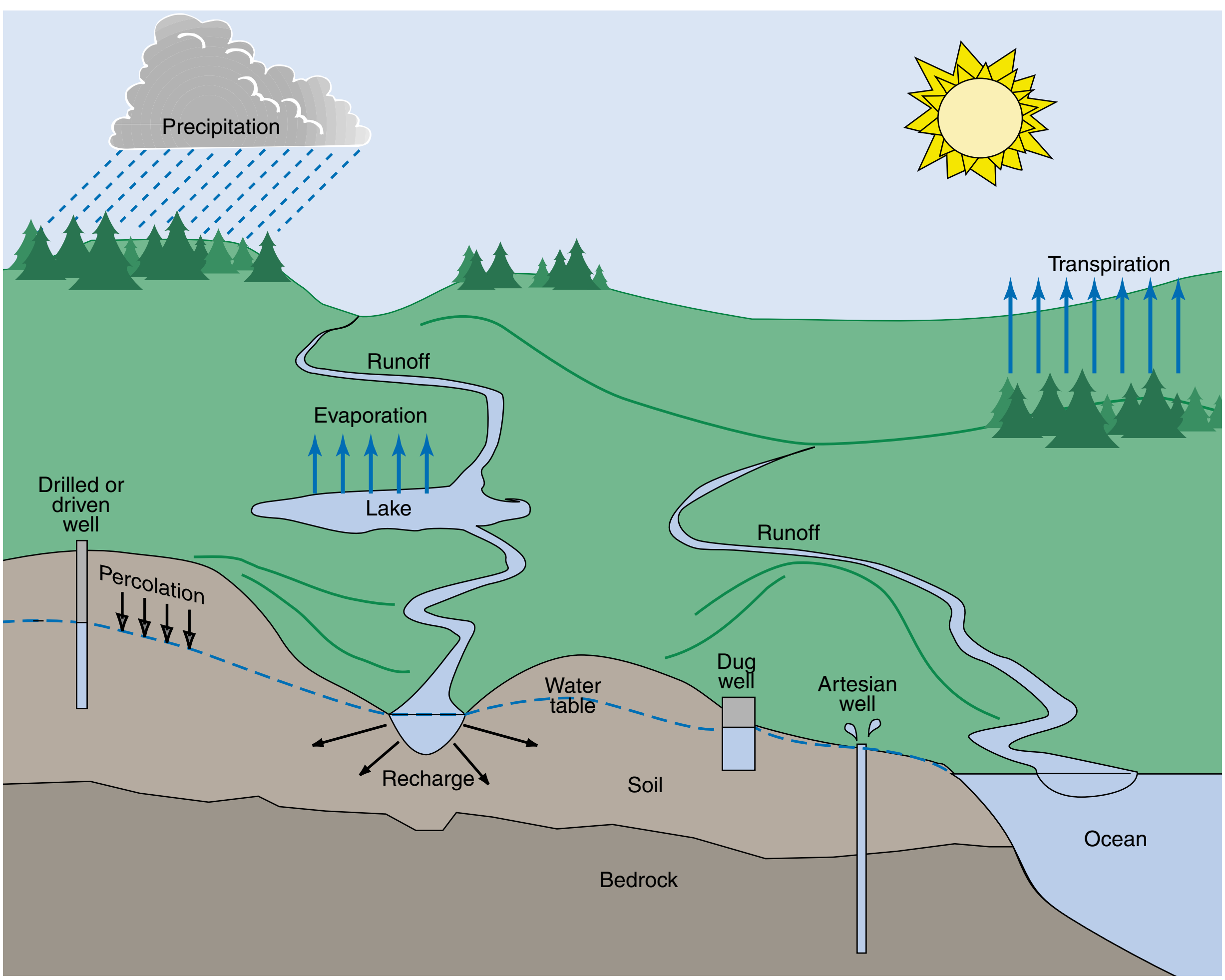
Groundwater is water that fills the cracks and pores of rocks and soil beneath the surface of the ground. The soil acts as a filter, so groundwater is usually clean and free from pollution.

Although found in nearly all areas, the quantity of groundwater available varies widely. Usable amounts might be found by digging just a few feet into soil. On the other hand, a hole might have to be drilled a thousand feet before penetrating an aquifer.

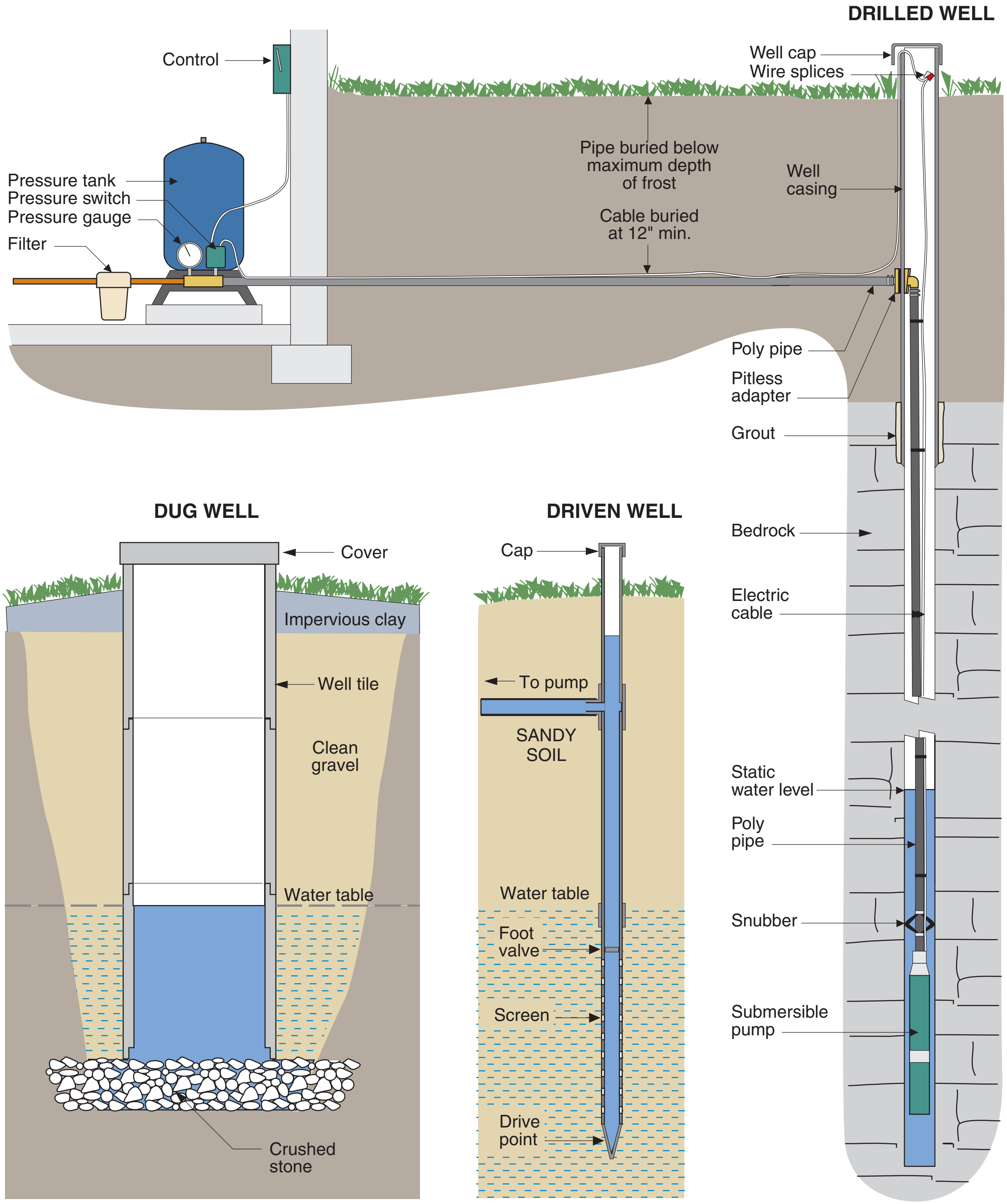
Groundwater, clouds, rain, snow, streams, rivers, lakes, and even the ocean are components of the hydrologic cycle (illustration below). Water evaporates from the surfaces of water bodies and vegetation and rises into the atmosphere as water vapor. When it cools to its dewpoint, excess vapor is squeezed out as clouds and precipitation. The precipitation returns to the ground and either percolates into the ground or runs off in streams and rivers into lakes and the ocean. Both evaporation and ground percolation act to return the water to its pure state.

Except in the most remote areas, water from lakes and streams requires treatment. Groundwater, however, is often clean enough to use untreated. The three common methods of tapping groundwater are shown on the facing page.

The Hydrologic Cycle



Three Types of Water Well



Supply Piping

The supply system is the network of piping or tubing that distributes cold and hot water under pressure from the city water main or home well to each fixture in the building. Both the water heater and any water treatment equipment are parts of the distribution system.

Supply water is under pressure of up to 160 pounds per square inch (psi) and may be consumed by humans, so the materials allowed are strictly specified by code. Materials allowed under the International Residential Code are listed in the table below.

Allowed Supply Piping Materials

Material	Form	Advantages	Disadvantages
Chlorinated PVC (CPVC)	10', 20' lengths	Approved to 180°F Joined by cement or threading Lightweight	More subject to freeze damage High thermal expansion Better support required
Cross-Linked Polyethylene (PEX)	100', 300' coils	Flexible, easy to run Approved to 200°F	Requires special tools
Copper Pipe Type K (thickest) green Type L (medium) blue Type M (thin) red	10', 20' lengths	Easily assembled	Susceptible to freeze damage Susceptible to water hammer
Copper Tubing Type K (thickest) green Type L (medium) blue	30', 60', 100' coils	Requires fewer fittings Flare and compression fittings may be used Withstands a few freezings	More expensive than pipe
Galvanized steel	21' lengths	Strong	High cost (due to threading) Corroded by soft water Susceptible to scaling Under-slab use only
Polyethylene (PE)	100, 120, 160 psi rated coils	Low cost Long lengths	For cold water only Allowed only to shutoff
Polyvinyl chloride (PVC)	10', 20' lengths	Low cost Joined by cement or threading Can be bent with heat	Approved only to 100°F

Both horizontal and vertical runs of supply and waste pipes are required by code to be supported against gravity. The maximum spacing of supports (see table below) is determined by both the pipe's diameter and its material. In areas of high seismic activity the allowed spacing may be reduced.

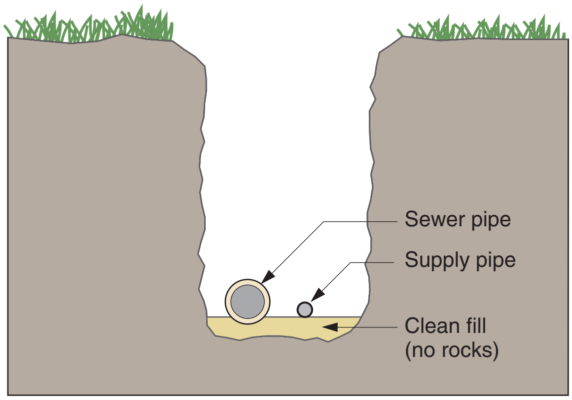
The code applies restrictions to service lines running in proximity to waste lines, as shown in the illustrations at right.

Minimum Support Spacing

Pipe Material	Horizontal Spacing	Vertical Spacing
ABS	48"	120"
Cast iron waste		
<10' lengths	60"	180" + base
10' lengths	120"	180" + base
CPVC supply		
≤1"	36"	120"
≥1¼"	48"	120"
PEX supply	32"	120"
PVC	48"	120"
Copper tubing		
≤1¼"	72"	120"
≥1½"	120"	120"
Steel supply		
½"	72"	180"
¾"	96"	180"
1"	96"	180"
≥1¼"	144"	180"
Polyethylene	not allowed	not allowed

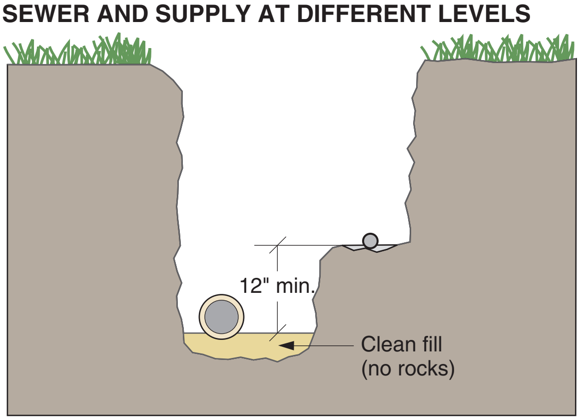
Service Lines in Trenches

SEWER AND SUPPLY IN SAME TRENCH



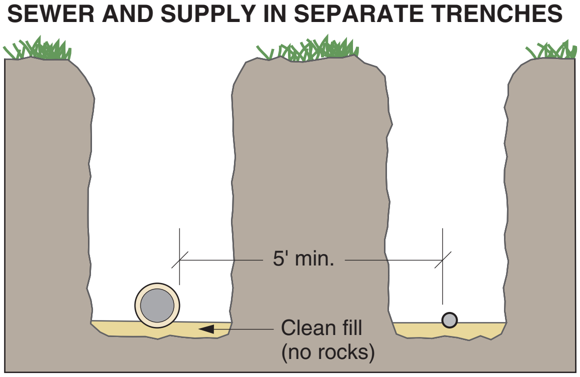
The building sewer and supply pipes may share a trench if both materials are approved for use within the building.

SEWER AND SUPPLY AT DIFFERENT LEVELS



The building sewer and supply pipes may share a trench if the supply runs on a shelf at least 12" above the sewer.

SEWER AND SUPPLY IN SEPARATE TRENCHES



A water supply pipe must be separated at least 5' from a clay sewer pipe.

Supply Pipe Sizing

Supply pipe sizes are a function of demand, pressure, and friction. To calculate the required sizes:

1. Find the service pressure at the outlet of the water meter or pressure-reducing valve.

2. Deduct 0.5 psi for each foot difference in height between the service to the highest fixture.

3. Deduct the pressure loss of equipment such as a water filter or water softener.

4. Find the resulting pressure range in Table 2.

5. "Maximum developed length" is the length of pipe between the service and the farthest fixture, multiplied by 1.2 to compensate for fitting losses.

6. In Table 1, add the combined fixture units for all of the fixtures in the building.

7. Find the size of service pipe and main distribution pipe under the "maximum developed length" column to a fixture unit equal to, or greater than, the total calculated in Step 6. Read the service pipe in the first column and the main distribution pipe in the second column on the same row.

8. To determine the sizes of branch distribution pipes, repeat Steps 5–7 for the total hot or cold (depending on branch) fixture units and maximum developed length between the main distribution pipe and the most distant fixture.

Table 1. Fixture Units for Plumbing Fixtures and Fixture Groups

Fixture or Fixture Group	Hot	Cold	Combined
Bathtub (with or without shower head)	1.0	1.0	1.4
Clothes washer	1.0	1.0	1.4
Dishwasher	1.4	—	1.4
Full bath group with bathtub or shower stall	1.5	2.7	3.6
Half-bath group (water closet and lavatory)	0.5	2.5	2.6
Hose bibb (sillcock)	—	2.5	2.5
Kitchen group (dishwasher and sink with or without garbage grinder)	1.9	1.0	2.5
Kitchen sink	1.0	1.0	1.4
Laundry group (clothes washer standpipe and laundry tub)	1.8	1.8	2.5
Laundry tub	1.0	1.0	1.4
Lavatory	0.5	0.5	0.7
Shower stall	1.0	1.0	1.4
Water closet (tank type)	—	2.2	2.2

Minimum Fixture Feed Pipe Sizes

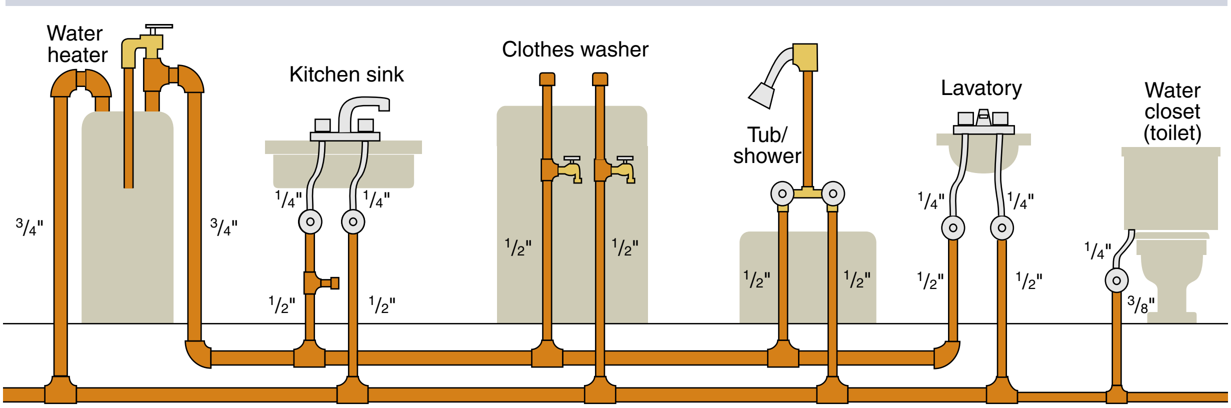


Table 2. Minimum Size of Mains and Distribution Piping (IRC Table P2903.7)

Service Pipe, inches	Distribution Pipe, inches	Maximum Development Length, feet									
		40	60	80	100	150	200	250	300	400	500
PRESSURE RANGE 30–39 PSI											
3/4	1/2	2.5	2	1.5	1.5	1	1	0.5	0.5	0	0
3/4	3/4	9.5	7.5	6	5.5	4	3.5	3	2.5	2	1.5
3/4	1	32	25	20	16.5	11	9	7.5	6.5	5.5	4.5
1	1	32	32	27	21	13.5	10	8	7	5.5	5
3/4	1 1/4	32	32	32	32	30	24	20	17	13	10.5
1	1 1/4	80	80	70	61	45	34	27	22	16	12
1 1/2	1 1/4	80	80	80	75	54	40	31	25	17.5	13
PRESSURE RANGE 40–49 PSI											
3/4	1/2	3	2.5	2	1.5	1.5	1	1	0.5	0.5	0.5
3/4	3/4	9.5	9.5	8.5	7	5.5	4.5	3.5	3	2.5	2
3/4	1	32	32	32	26	18	13.5	10.5	9	7.5	6
1	1	32	32	32	32	21	15	11.5	9.5	7.5	6.5
3/4	1 1/4	32	32	32	32	32	32	32	27	21	16.5
1	1 1/4	80	80	80	80	65	52	42	35	26	20
1 1/2	1 1/4	80	80	80	80	75	59	48	39	28	21
PRESSURE RANGE 50–59 PSI											
3/4	1/2	3	3	2.5	2	1.5	1	1	1	0.5	0.5
3/4	3/4	9.5	9.5	9.5	8.5	6.5	5	4.5	4	3	2.5
3/4	1	32	32	32	32	25	18.5	14.5	12	9.5	8
1	1	32	32	32	32	30	22	16.5	13	10	8
3/4	1 1/4	32	32	32	32	32	32	32	32	29	24
1	1 1/4	80	80	80	80	80	68	57	48	35	28
1 1/2	1 1/4	80	80	80	80	80	75	63	53	39	29
PRESSURE RANGE >60 PSI											
3/4	1/2	3	3	3	2.5	2	1.5	1.5	1	1	0.5
3/4	3/4	9.5	9.5	9.5	9.5	7.5	6	5	4.5	3.5	3
3/4	1	32	32	32	32	32	24	19.5	15.5	11.5	9.5
1	1	32	32	32	32	32	28	22	17	12	9.5
3/4	1 1/4	32	32	32	32	32	32	32	32	32	30
1	1 1/4	80	80	80	80	80	80	69	60	46	36
1 1/2	1 1/4	80	80	80	80	80	80	76	65	50	38

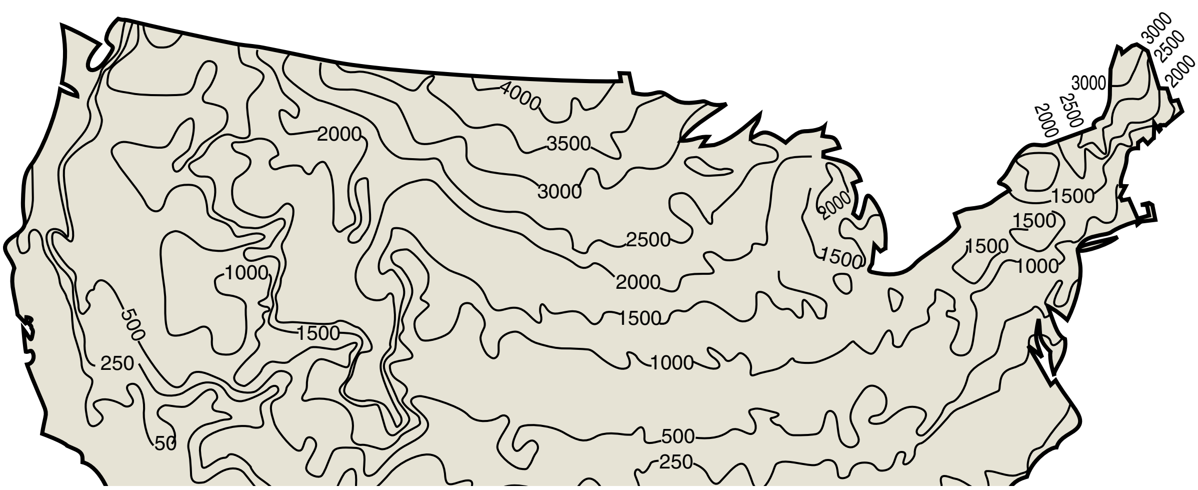
Freezeproofing Supply Pipes

In northern and mountain areas the earth can freeze to depths of over 8 feet, particularly in times of little or no snow cover. No supply pipe can withstand the extreme pressure created by freezing water without bursting, so supply pipes must be protected from freezing.

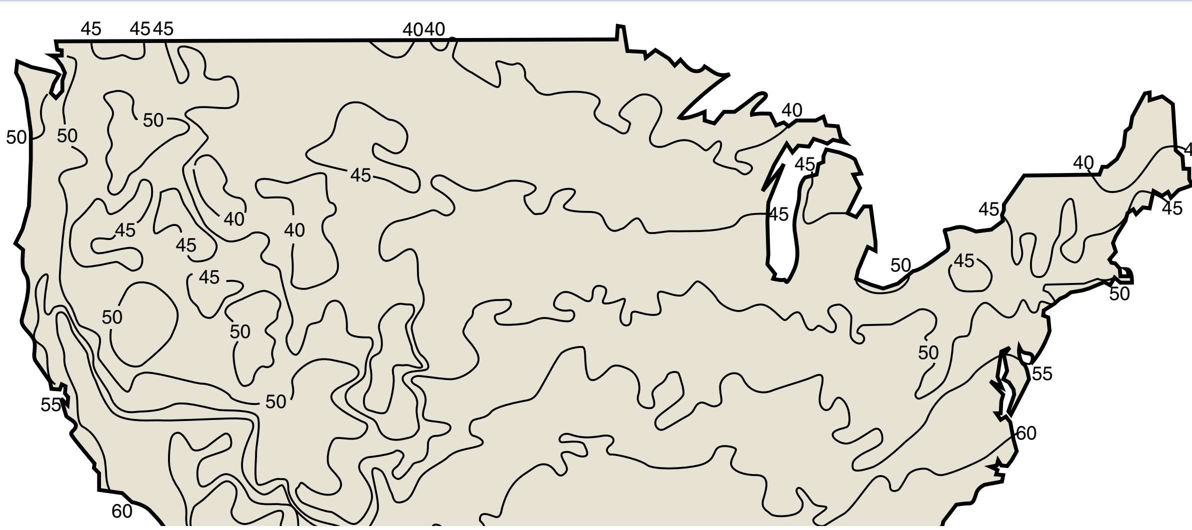
When possible, the best solution is burial below the maximum depth of frost. When the depth to bedrock is insufficient, another method must be found. Tubular insulations retard but do not prevent eventual freezing. Drawing a trickle of water may work by constantly replacing heat loss. Likewise, heat may be supplied by wrapping or inserting heat tapes around or inside the pipe. If the water supply is from a private well, however, a constant supply of electricity is required. An extended power outage can still result in frozen pipes.

Fortunately an alternative exists (facing page).

Mean Annual Air Temperature (°F)



Air Freezing Index (°F-Days)



Raising the Frost Depth

Foundation contractors in northern areas pray for early and constant snow cover. Snow is mostly dead air, so although cold, it acts as insulation limiting frost penetration. Although snow cannot be guaranteed, it can be replaced by a permanent layer of extruded polystyrene insulation placed over water pipes.

The illustration at right and chart below allow determination of the thickness and width of extruded polystyrene panels required to raise the maximum depth of frost to a specified depth in a clay soil.

Example: You are located on the coast of Maine with a soil depth of only 2'0".

1. From the maps on the previous page, your mean annual air temperature is 42°F and the air freezing index 1,500°F-Days.

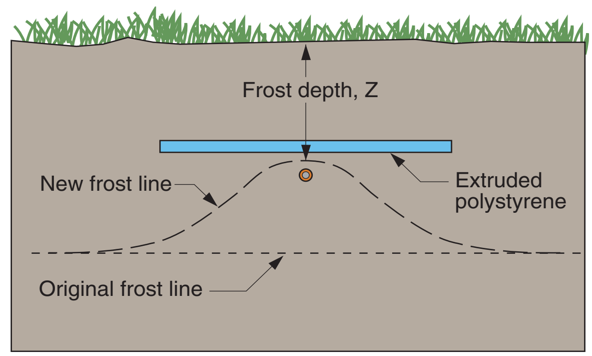
2. On the nomograph, draw a line up from 1,500°F-Days to the curve, "Annual Mean Temp. 42.8°F."

3. From the intersection, draw a horizontal line to the right intersecting two sets of blue curves representing the two frost depths: 1'8" and 2'7".

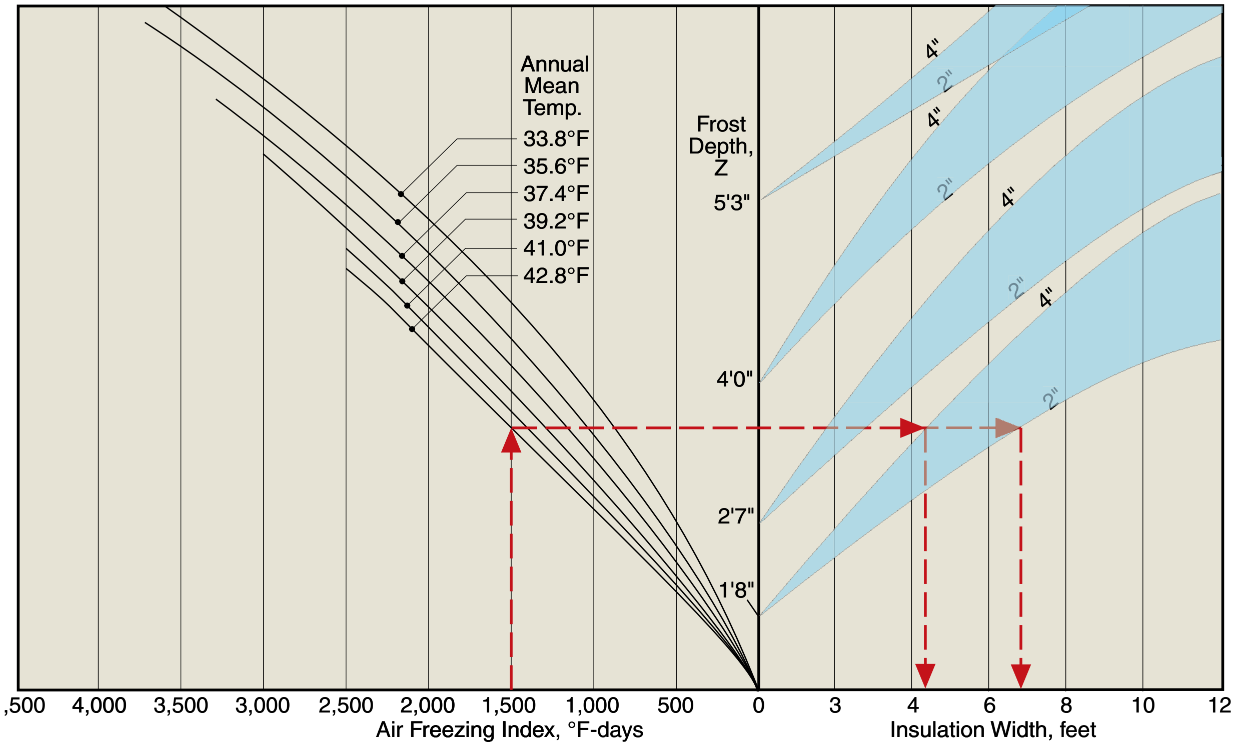
4. We require a frost depth no greater than 2'0", so select the set of curves for depth 1'8".

5. Dropping vertical lines from the upper and lower intersection, we find at bottom two solutions: 4" thick/4' wide foam, or 2" thick/7' wide foam.

Raising Frost Depths with Foam



Frost Depth Nomograph



Copper Supply Fittings

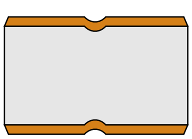
Copper Pipe and Fitting Sizes

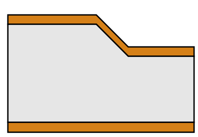
Matching fittings to copper pipe and tube can be confusing because of the dimensioning conventions. When a plumber refers to the size of either a pipe or a fitting, he is referring to its nominal size, which is, strangely, neither the inside nor the outside diameter! The outside diameter is always the nominal size plus $^1/_8$ inch. The inside diameter is close to the nominal size, but varies with the thickness of the wall. The table at right compares these dimensions.

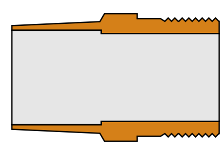
Type M Copper Pipe Dimensions

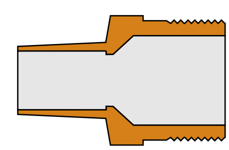
Nominal Size	Outside Diameter, inches	Inside Diameter, inches	Wall Thickness, inches
$^3/_8$	0.500	0.450	0.025
$^1/_2$	0.625	0.569	0.028
$^3/_4$	0.875	0.811	0.032
1	1.125	1.055	0.035

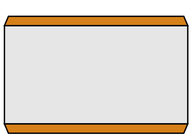
Copper Supply Fittings

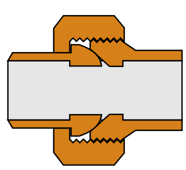

Coupling with Stop

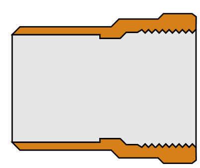

Eccentric Coupling

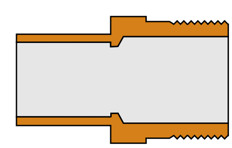

Male Adaptor,
Copper to Mnpt

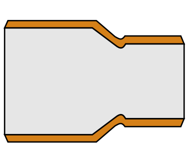

Reducing Male Adaptor,
Copper to Mnpt

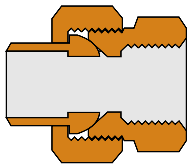

Coupling without Stop

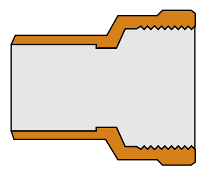

Union, Copper to Copper

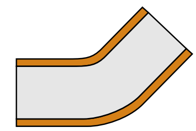

Female Adaptor,
Copper to Fnpt


Male Street Adaptor,
Fitting to Mnpt

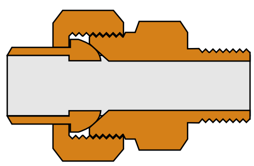

Reducing Coupling

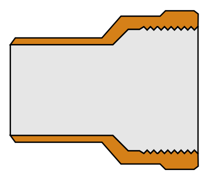

Union, Copper to Fnpt

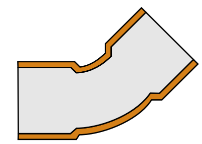

Reducing Female Adaptor,
Copper to Fnpt


45 Street Elbow,
Fitting to Fitting

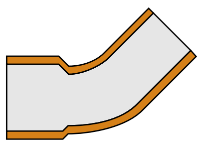
NOTE:
Mnpt = Male national pipe thread tapered
Fnpt = Female national pipe thread tapered

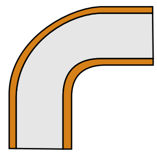

Union, Copper to Mnpt

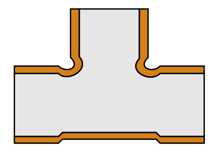

Female Street Adaptor,
Fitting to Fnpt

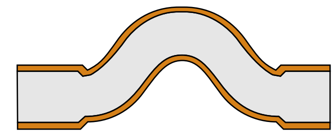

45 Street Elbow,
Fitting to Copper

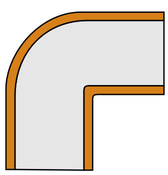
Copper Supply Fittings—*Continued*

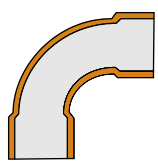

45 Street Elbow,
Fitting to Copper

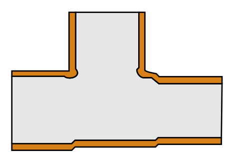

90 Street Elbow,
Fitting to Fitting

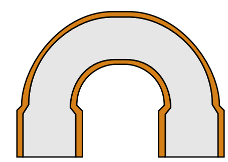

Tee,
All Copper

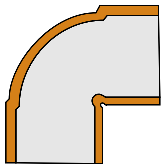

Cross-Over Coupling,
Copper to Copper

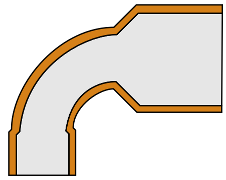

90 Street Elbow,
Fitting to Fitting

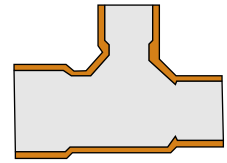

90 Elbow-Long Turn,
Copper to Copper

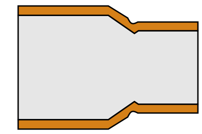

Street Tee,
Copper to Fitting to Copper

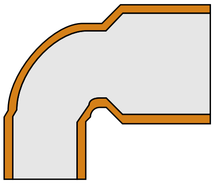

Return Bend,
Copper to Copper

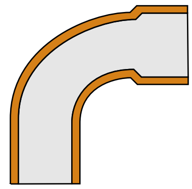

90 Elbow,
Copper to Copper

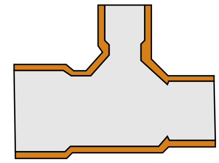

90 Reducing Elbow,
Copper to Copper

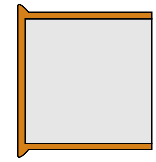

Reducing Tee,
by O.D. Sizes

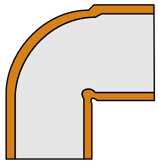

Reducer,
Fitting to Copper

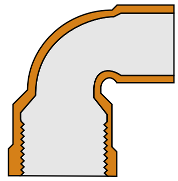

90 Reducing Elbow,
Copper to Copper

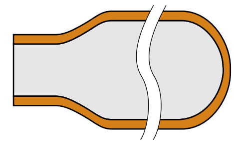

90 Street Elbow,
Fitting to Copper

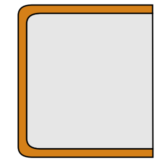

Reducing Tee,
Copper to Copper to Copper


End Plug,
Fitting End


90 Street Elbow,
Copper to Copper


90 Elbow,
Copper to Fnpt


Air Chamber,
Fitting End


Tube Cap,
Tube End

PVC Supply Fittings

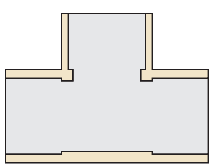
PVC Pipe and Fitting Sizes

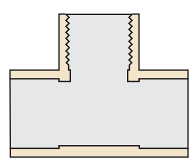
As is the case with other piping materials, matching PVC and CPVC fittings to pipe can be confusing because of the system of dimensions. The nominal size is neither the inside nor the outside diameter. The outside diameter is the nominal size plus approximately 0.3 inch. The inside diameter is close to the nominal size, but varies with the thickness of the wall. The table at right compares these dimensions.

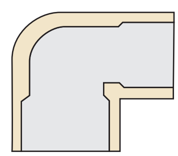
PVC Schedule 40 Pipe Dimensions

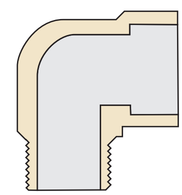
Nominal Size	Outside Diameter, inches	Inside Diameter, inches	Wall Thickness, inches
3/8	0.675	0.483	0.091
1/2	0.840	0.608	0.109
3/4	1.050	0.810	0.113
1	1.315	1.033	0.133

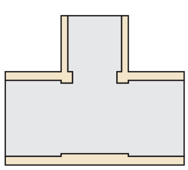
PVC Supply Fittings

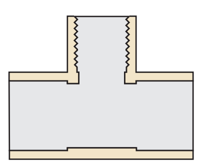

Tee,
Slip x Slip x Slip

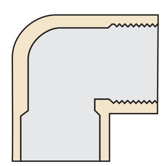

Tee,
Slip x Slip x Fipt

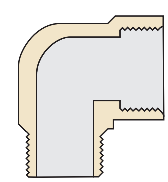

90 Ell Reducing,
Slip x Fipt

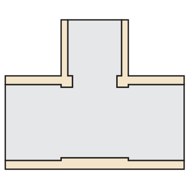

90 Street Ell,
Mipt x Slip

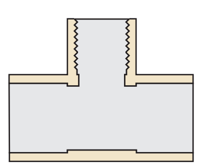

Reducing Tee,
Slip x Slip x Slip

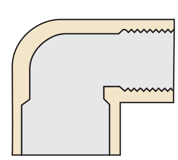

Reducing Tee,
Slip x Slip x Fipt

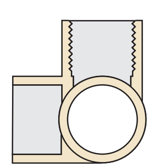

90 Ell,
Fipt x Fipt

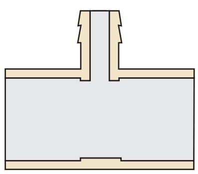

90 Street Ell,
Mipt x Fipt

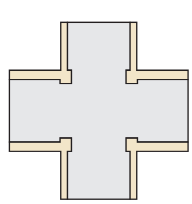

Reducing Tee,
Slip x Slip x Slip


Reducing Tee,
Slip x Slip x Fipt


90 Ell Reducing,
Slip x Fipt

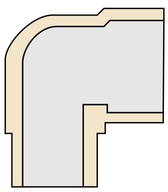

Side Outlet Ell,
Slip x Slip x Fipt


Transition Tee,
Slip x Slip x Insert

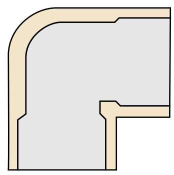

Cross,
Slip x Slip x Slip x Slip

NOTE:
Fipt = Female iron pipe thread
Mipt = Male iron pipe thread
Slip = Slip fitting end
Spig = Spigot end

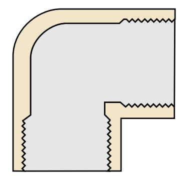
PVC Supply Fittings—*Continued*



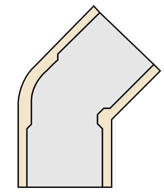
90 Street Ell,
Spig x Slip



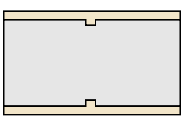
90 Ell,
Slip x Slip



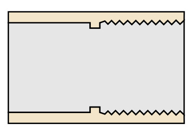
90 Ell,
Fipt x Fipt



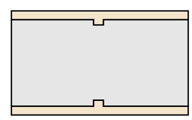
45 Ell,
Slip x Slip



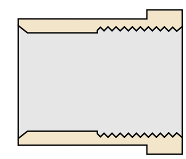
Coupling,
Slip x Slip



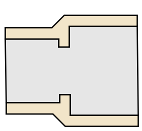
Female Adaptor,
Slip x Fipt



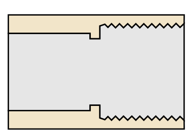
Deep Coupling



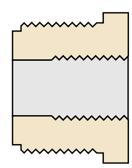
Reducer Bushing,
Spig x Fipt



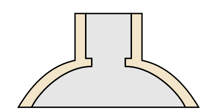
Reducer Coupling,
Slip x Slip



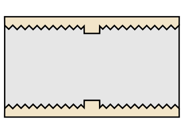
Female Adaptor Reducing,
Slip x Fipt



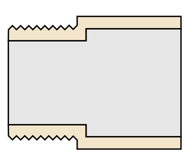
T.T. Bushing,
Mipt x Fipt



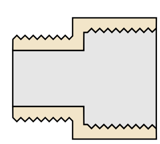
Saddle,
Pipe O.D. x Slip



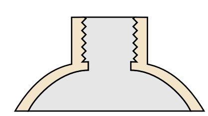
Coupling,
Fipt x Fipt



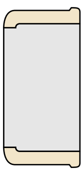
Male Adaptor,
Mipt x Slip



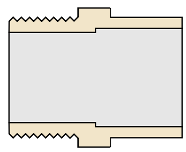
IPT Adaptor,
Mipt x Fipt



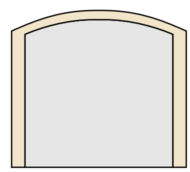
Saddle,
Pipe O.D. x Fipt



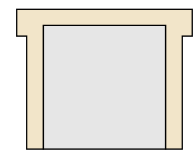
IPS to PIP Adaptor,
Spig x Slip



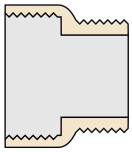
Male Adaptor Reducing,
Mipt x Slip



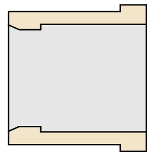
Cap,
Slip



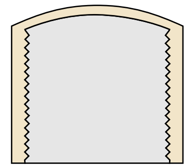
Plug,
Spig



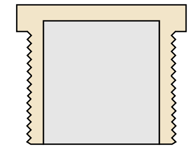
Riser Extension,
Fipt x Mipt



Reducer Bushing,
Spig x Slip



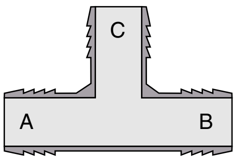
Cap,
Fipt



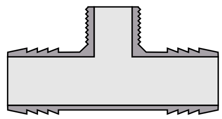
Plug,
Mipt

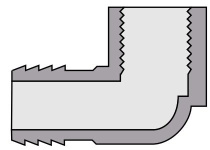
Polyethylene Supply Fittings

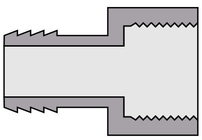
Polyethylene Supply Fittings

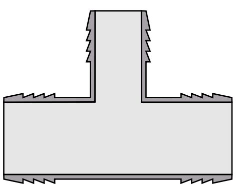


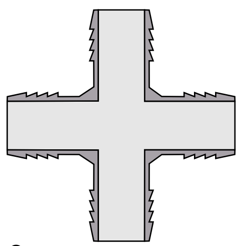
Tee (A x B x C)
Ins x Ins x Ins

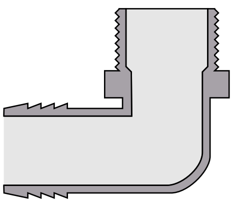

Tee
Ins x Ins x Mipt

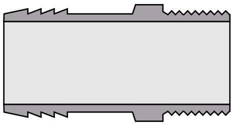

90 Reducing Ell
Ins x Fipt

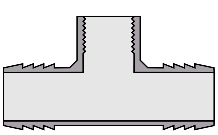

Female Adaptor
Ins x Fipt


Reducing Tee
Ins x Ins x Ins


Cross
Ins x Ins x Ins x Ins


90 Ell
Ins x Mipt


Male Adaptor
Ins x Mipt


Tee
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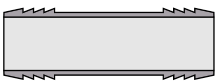
Coupling
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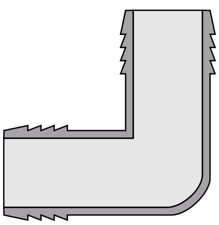
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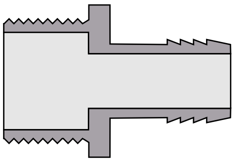
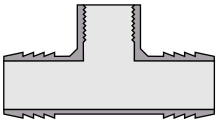
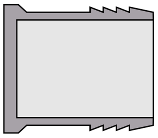
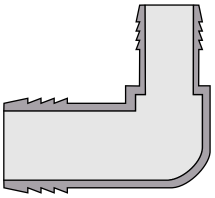
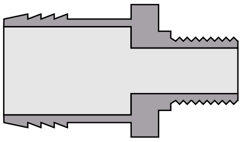

Male Adaptor Reducing
Mipt x Ins

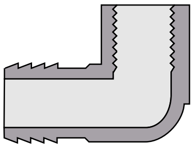

Reducing Tee
Ins x Ins x Fipt


Plug
Ins


90 Reducing Ell
Ins x Ins


Male Adaptor Reducing
Ins x Mipt

NOTE:
Ins = Insert thread
Fipt = Female iron pipe thread
Mipt = Male iron pipe thread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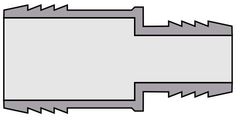
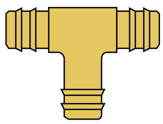

Reducer Coupling
Ins x Ins

PEX Supply Fittings

PEX Supply Fittings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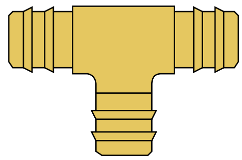
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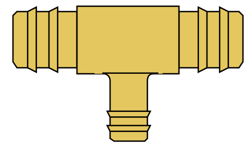
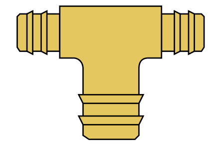

3/4" x 3/4" x 1/2" Barb Tee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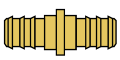
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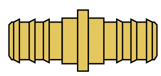
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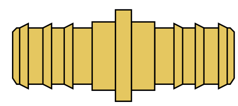
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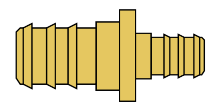
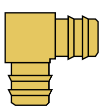
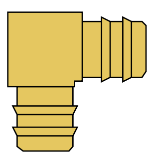
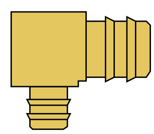
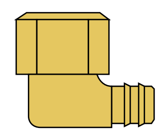
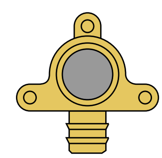

3/4" x 1/2" Barb Coupling


1/2" Barb Elbow


3/4" Barb Elbow


3/4" x 1/2" Barb Elbow


1/2" Barb x 1/2" Fpt
Swivel Cone Connector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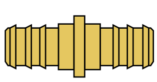
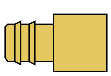
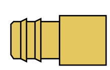
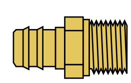
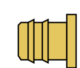
Drop Ear Elbow


1/2" Pex to Poly
Transition Fitting


1/2" Male Sweat x
1/2" Barb Brass Sweat


1/2" Female Sweat x
1/2" Barb Brass Sweat


1/2" Barb x 1/2" Mpt
Adaptor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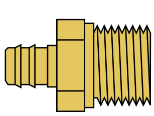
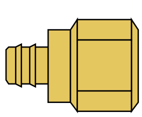

1/2" Barb x 3/4" Mpt
Adaptor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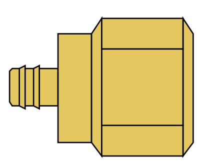
Swivel Cone Connector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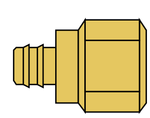
Non-Swivel Adaptor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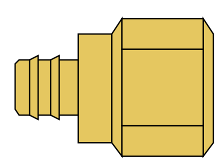
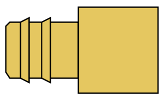
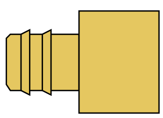
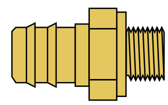
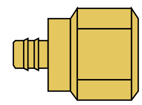
Non-Swivel Adaptor

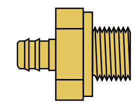

3/4" Barb x 3/4" Fpt
Swivel Cone Connector


3/4" Male Sweat x
3/4" Barb Brass Sweat


3/4" Female Sweat x
3/4" Barb Brass Sweat

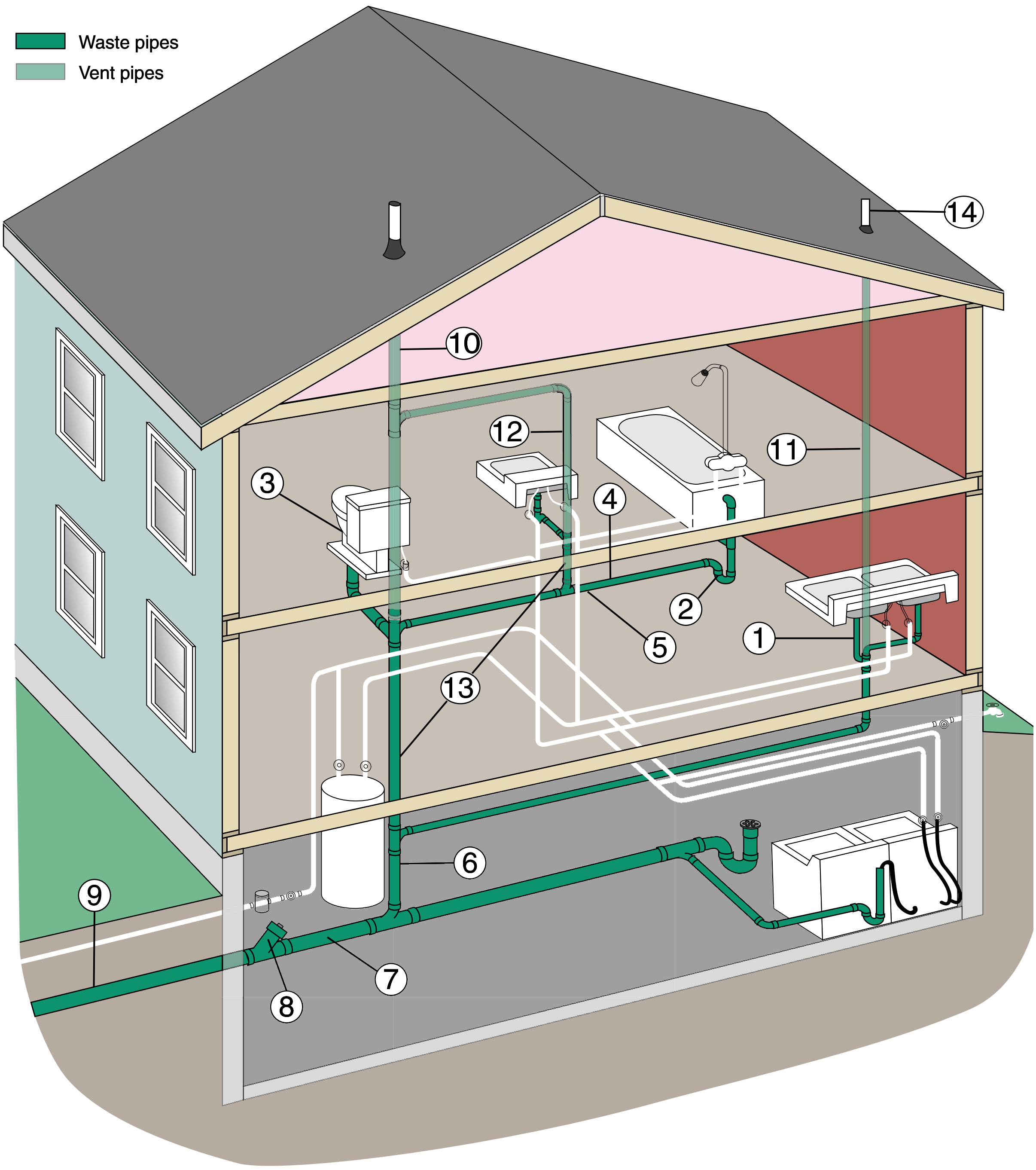

3/4" Barb x 1/2" Mpt
Adaptor


3/8" Barb x 1/2" Fpt
Swivel Cone Connector


3/8" Barb x 1/2" Mpt
Adaptor

Drain, Waste, Vent System

Features of the Drain, Waste, Vent System



The Waste System

The waste system is the assemblage of pipes that collects and delivers waste (used) water to either the municipal or private sewage system.

1. The pipe that drains away a fixture's waste is its drain. The minimum diameter of the drain is determined by the fixture's rate of discharge.

2. Every fixture drain must be "trapped." A trap passes water, but retains enough water to block noxious sewer gases.

3. Toilets (water closets) have the trap built into the base of the toilet.

4. The horizontal pipe between a trap and the first point of the drain pipe supplied with air is the "trap arm." Code limits trap-arm length to prevent siphon action from emptying the trap.

5. Smaller tributary drain pipes that feed into the main "house drain" are called "branches."

6. The largest vertical drain pipe, extending from the lowest point through the roof, and to which the smaller horizontal branch drains connect, is the "soil stack." In a very horizontally extended house, there may be more than one soil stack.

7. The bottom-most horizontal waste pipe is the "house drain." To optimize flow, all horizontal waste pipes) must be sloped at $^1/_8$" to $^1/_4$" per foot.

8. To allow unclogging of drain pipes, "cleanouts" are provided. There is a 4" diameter cleanout where the house drain exits the building. Additional cleanouts are required throughout the waste system for every 100' of horizontal run and every cumulative change of direction of 135°.

9. Waste pipe outside the building is termed the "house sewer." It is always at least 4" in diameter.

The Vent System

Fixture drains must be kept at atmospheric pressure so the water seals in their traps are not siphoned away. The vent system is the set of pipes that admits air to the drain system.

10. The primary vent is the upper section of the "stack." Below the highest point of waste discharge into it is the "waste stack." Above that point it is the "vent stack." If a waste stack also serves one or more toilets (and it usually does), it is sometimes called the "soil stack." Because it provides direct passage to the sewer, a vent stack must be terminated in the open air. And to keep the sewer gas as far as possible from people, it is usually terminated through the roof.

11. The permitted length of drain pipe from a trap to a vent (the trap arm) is a function of the pipe diameter. If the horizontal run of the drain is too long, a smaller-diameter vent stack may be provided close after the trap.

12. Another solution to a long horizontal drain is breaking it into legal lengths with "revents." A loop vent provides pressure relief by the volume of its contained air. An air check valve allows house air to flow into the drain but prevents sewer gas from escaping.

13. A vertical vent pipe serving both waste and vent is called a "wet vent."

14. The air in vent pipes is humid. In northern states frost can build up on the inside of exposed vents. To avoid frost blockage, local codes may specify a larger diameter above the roof. In addition, so that snow does not cover the vent pipe, a local code may also call for a vertical extension of the pipe beyond the code minimum of 6".

Sizing Drainpipe

The sizes (diameters) of all drain pipes, including traps, trap arms, branch drains, stacks, and building sewers, are based on the expected maximum rates of flow, measured in drainage fixture units (dfu). One dfu equals one cubic foot of water per minute.

The procedure for determining the size of pipe required at any point is as follows:

1. Draw a plan of the plumbing showing the fixtures and the connecting pipes.

2. Assign dfu figures for each fixture or fixture group using Table 1 below.

3. Starting at the fixture most remote from the building sewer, add the dfu flowing into the pipe. Use the group values wherever possible in order to hold down the total.

4. Use Table 2, below, to determine the sizes of pipes required for the number of accumulated dfu.

5. Use Table 3, below, to determine the required size and slope of the building drain and sewer.

Table 1. Drain Sizes and Fixture Units

Fixture or Fixture Group	Minimum Drain/Trap Size	Drainage Fixture Units[1]
Bar sink	1¼″	1
Bathtub	1½″	2
Bathroom group[2]	3″	6
Half-bathroom group[3]	3″	4
1.5 Baths	3″	7
2 Baths	3″	8
2.5 Baths	3″	9
3 Baths	3″	10
Bidet	1¼″	1
Clothes washer	2″	2
Dishwasher	1½″	2
Floor drain	2″	2
Kitchen sink	1½″	2
Laundry tub	1½″	2
Laundry group[4]	1½″	2
Lavatory	1¼″	1
Shower[5]	2″	2
Water closet	3″	4

[1] 1 drainage fixture unit (dfu) = 1 cubic foot per minute

[2] Tub or shower, water closet, bidet, and lavatory

[3] Water closet plus lavatory

[4] Clothes washer plus laundry tub

[5] Stand-alone shower stall

Table 2. Maximum Fixture Units Connected to Branches and Stacks

Nominal Pipe Size, inches	Any Horizontal Fixture Branch	Any Vertical Stack or Drain
1¼[1]	—	—
1½[2]	3	4
2[2]	6	10
2½[2]	12	20
3	20	48
4	160	240

[1] 1¼-inch limited to a single fixture drain or trap arm

[2] No water closets allowed

Table 3. Maximum Fixture Units Connected to Building Drain or Sewer

Nominal Pipe Size, inches	Slope per Foot ⅛ inch	¼ inch	½ inch
1½[1,2]	NA	Note 1	Note 1
2[2]	NA	21	27
2½[2]	NA	24	31
3	36	42	50
4	180	216	250

[1] 1½-inch limited to a building drain branch serving not more than two waste fixtures, or not more than one waste fixture if serving a pumped discharge fixture or garbage grinder

[2] No water closets allowed

Running Drainpipe

Other than traps (pp. 336–337) and vents (pp. 338–341), running drain pipes involves four principal issues: slope, direction changes, cleanouts, and physical protection.

Slope

As shown in Table 3 on the facing page, horizontal drain pipes are required to slope between $^1/_8$" and $^1/_2$" per foot, the reason being optimal drainage.

Direction Changes

Fittings permitted for changing direction are listed in Table 4 (at right) and illustrated on pp. 342–343. As can be seen from the illustrations, the intent is to create smooth flow and to keep the discharge of one drain from entering another.

Cleanout Requirements

Cleanouts are provided for clearing blockages. To that end, cleanouts must be provided:

- every 100' horizontally
- where direction changes >45°, except just one cleanout is required per 40' of run
- at the base of each vertical waste or soil stack
- near building drain/building sewer junction
- access without removal of permanent materials
- front clearance of 18" for 3" and 4" pipes and 12" for smaller pipes

Protection

Drainlines must be protected, as shown in the illustration at right, from:

- freezing by burial, insulation, or heat tape
- passing through foundation walls by sleeving with pipe two sizes larger
- passing under footings by a vertical clearance of 2" minimum
- damage from backfill containing rocks and other construction debris by bedding in sand or fine gravel as shown

Table 4. Fittings for Change of Direction

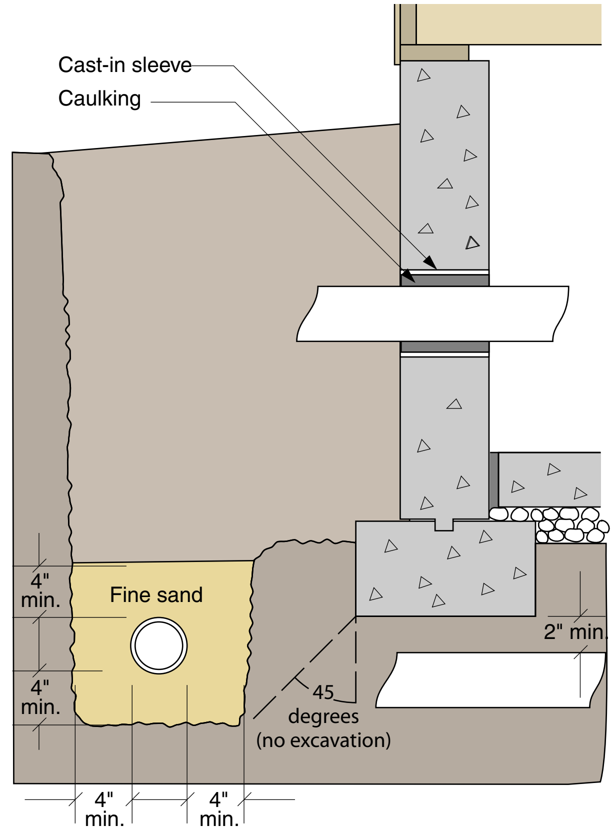
Fitting	Horizontal to Vertical	Vertical to Horizontal	Horizontal to Horizontal
$^1/_{16}$ bend	Y	Y	Y
$^1/_8$ bend	Y	Y	Y
$^1/_4$ bend	Y	Y[1]	Y[1]
Short sweep	Y	Y[1,2]	Y[1]
Long sweep	Y	Y	Y
Sanitary tee	Y[3]	N	N
Wye	Y	Y	Y
Comb. wye & $^1/_8$ bend	Y	Y	Y

1 Permitted only for 2-inch or smaller fixture drain

2 Three inches and larger

3 Double sanitary tees not allowed to receive discharge of back-to-back toilets or fixtures with pumped discharge

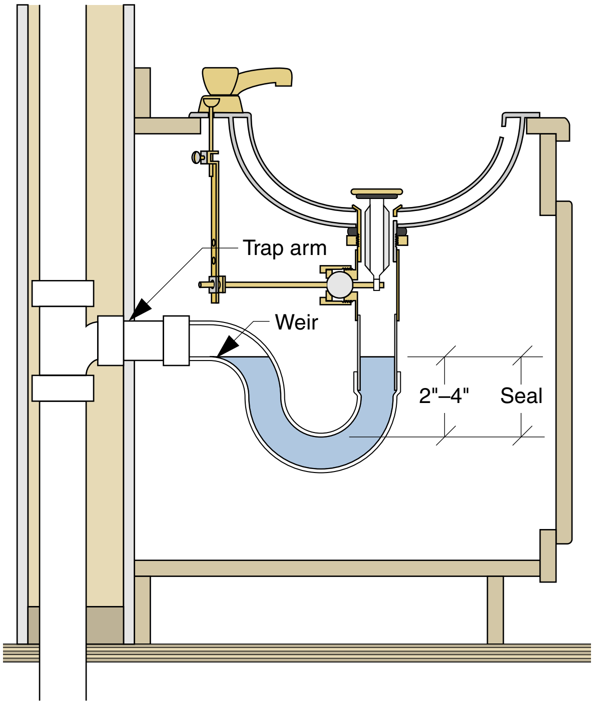
Drainline Protection



Traps

A trap is a fitting designed to trap a volume of water in order to block the back passage of sewer gas. The illustration at right shows a P-trap.

The Ubiquitous P-Trap



Trap Failures

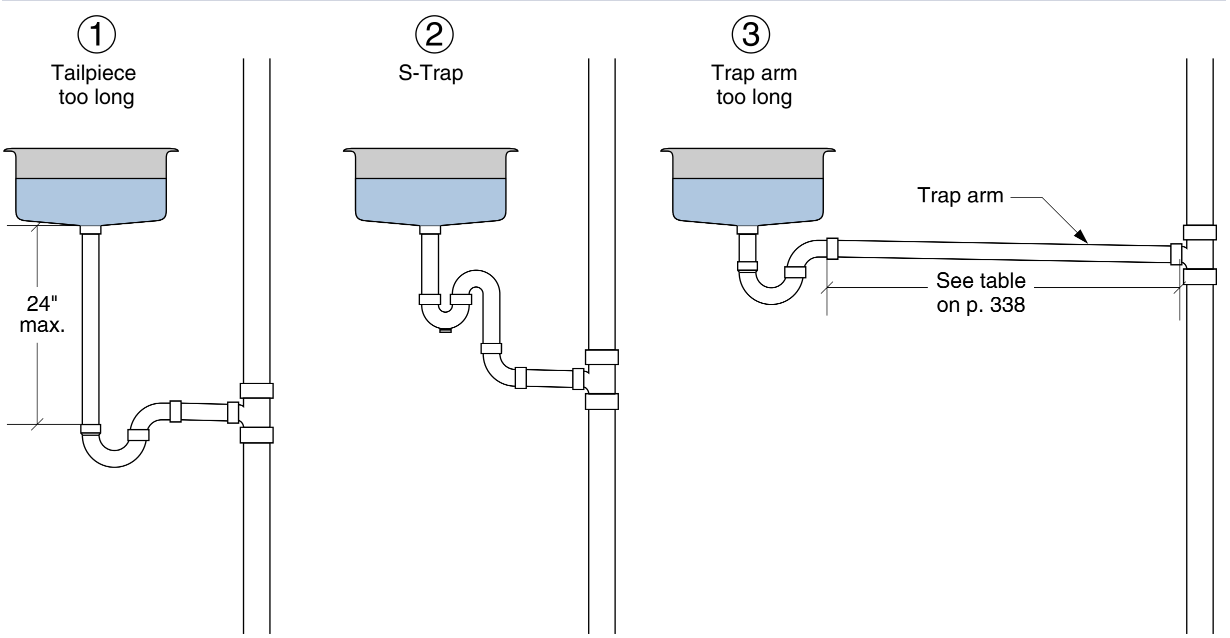
Traps can fail in three ways (see numbered illustrations of "Trap Failures" below):

1. If the fixture tailpiece is too long, the falling water may develop enough momentum to carry it past the outlet weir. For this reason, the code requires tailpieces to be as short as possible, but in no case longer than 24 inches (except clothes-washer standpipes, which may be between 18 and 42 inches).

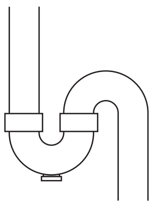
2. If the wastewater completely fills the trap and outlet arm to a point below the outlet, the weight of water in the outlet may siphon the water behind it out of the trap.

3. If the trap arm is too long for its diameter, fluid friction may cause the waste to back up until it completely fills the outlet, resulting in siphoning, as in case 2.

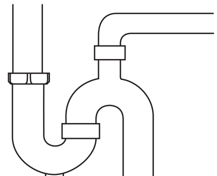
Trap Failures



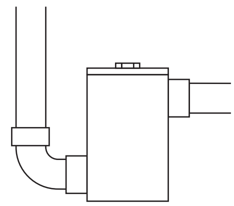
Prohibited Traps



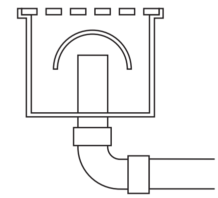
S-trap



Crown-vented trap



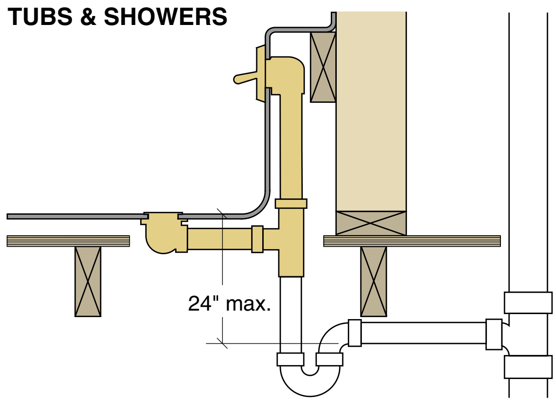
Trap larger than trap arm (drum trap)

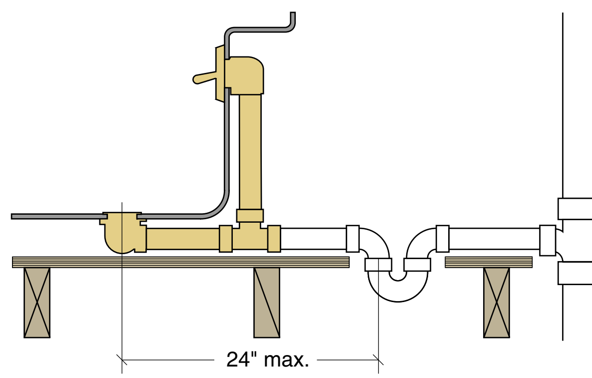


Bell trap

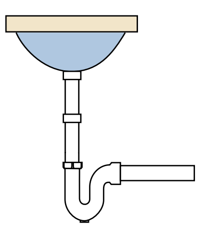
Approved Traps

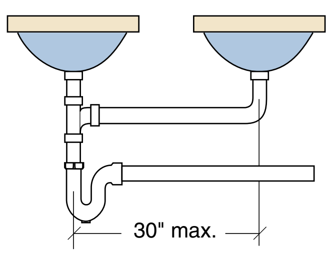
TUBS & SHOWERS

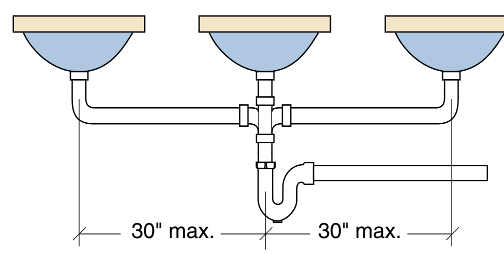




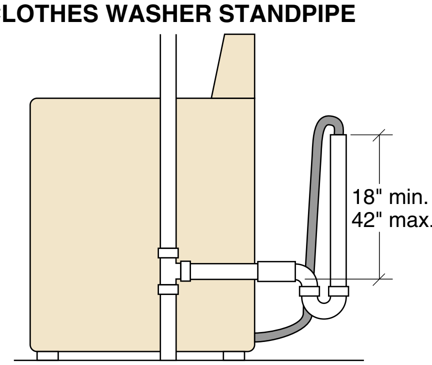
MULTIPLE SINKS (UP TO 3) ON A SINGLE TRAP



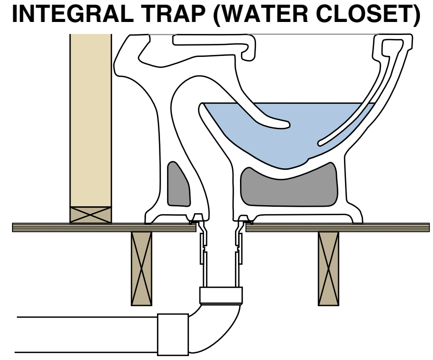




CLOTHES WASHER STANDPIPE



INTEGRAL TRAP (WATER CLOSET)



Venting

Every fixture is required to have a trap so that sewer gas does not find its way into the living space. The seal is effected by a slug of water trapped behind the trap's weir. As described on p. 336, the slug of water can be lost if the drain/trap develops a siphon. Vents are designed to introduce air into the drain pipe in order to prevent the siphon.

The most basic vent is one into which individual fixtures drain. The rules for this simple vent are shown in the illustration at right and the table below.

Maximum Lengths of Trap Arms

Trap Size, inches	Slope, inches/foot	Maximum Distance from Vent, feet
1 1/4	1/4	5
1 1/2	1/4	6
2	1/4	8
3	1/8	12
4	1/8	16

Common Vents

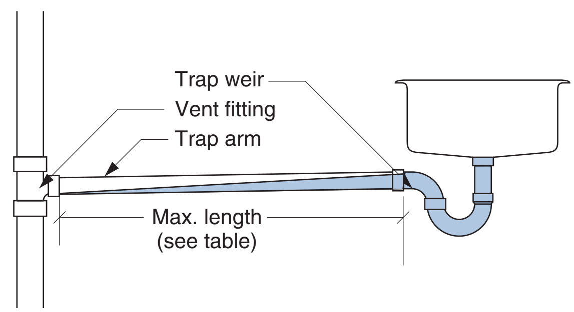
Separate vents through the roof for each and every fixture would be not only expensive but also unsightly. The Code therefore specifies a number of ways in which fixtures can share a single vent.

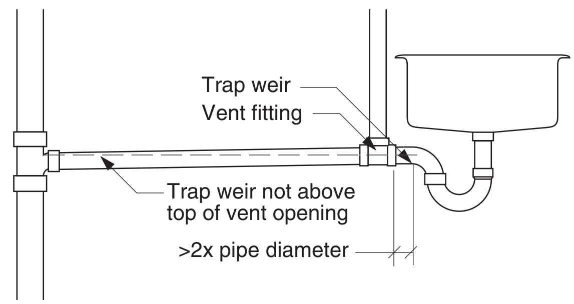
One method is to allow a section of vent pipe to serve either: 1) several fixture drains at the same level, or 2) as the vent for one group of fixtures and the drain for a higher group of fixtures, as long as all fixtures are on the same floor of the building and the upper group does not contain a water closet. The section of pipe serving dual purposes is a *wet vent*. Common vent sizes are dictated by the table below.

Common Vent Sizes

Pipe Size, inches	Maximum Discharge from Upper Fixture Drain, dfu
1 1/2	1
2	4
2 1/2 to 3	6

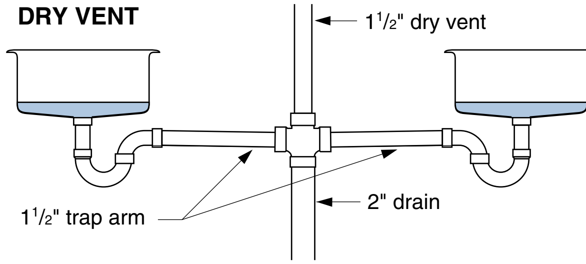
Basic Single-Fixture Vent Rules



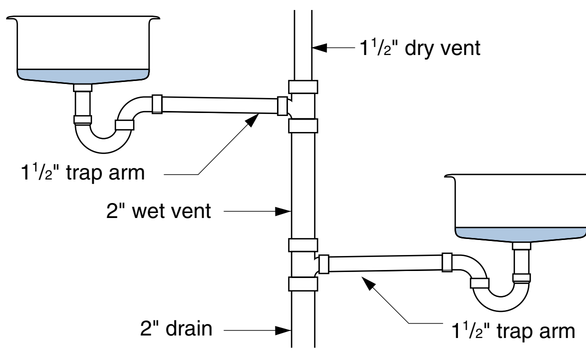


Common Vents

DRY VENT



WET VENT



Waste Stack Vents

A vertical pipe can serve as both drain and vent for any number of individual fixture drains, provided:

1. The vertical pipe (waste stack) is sized to the total dfu emptying into it (see table at right).

2. The pipe is straight, with no horizontal offsets between the highest and lowest drains it serves.

3. No water closet or urinal empties into it.

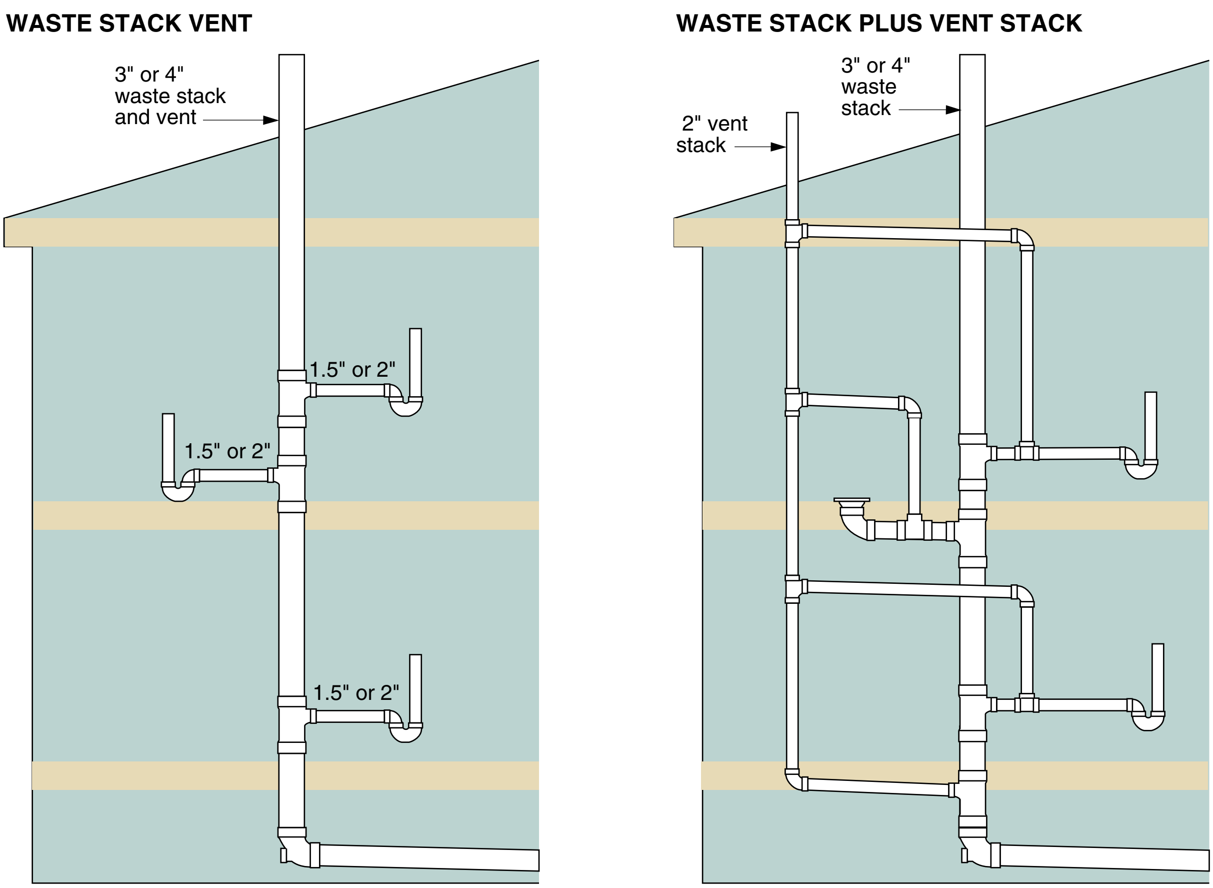
4. The waste stack is vented by a same-sized vent stack above the highest fixture drain (offsets are permitted in the vent stack).

Note that the alternative and preferred method, a waste stack plus vent stack, permits water closets and urinals to drain into the waste stack.

Waste Stack Vent Size

Stack Size, inches	Total Discharge into one branch interval	Total Discharge for Stack, dfu
$1^1/_2$	1	2
2	2	4
$2^1/_2$	No limit	8
3	No limit	24
4	No limit	50

Waste Stacks



Wet Venting

Any number of fixtures in up to two bathrooms on the same floor level are permitted to drain into and be vented by a horizontal vent, provided:

1. The horizontal and vertical wet vents are sized to the dfu emptying into them (see table at right).

2. Each fixture connects horizontally to the horizontal wet vent or has its own dry vent.

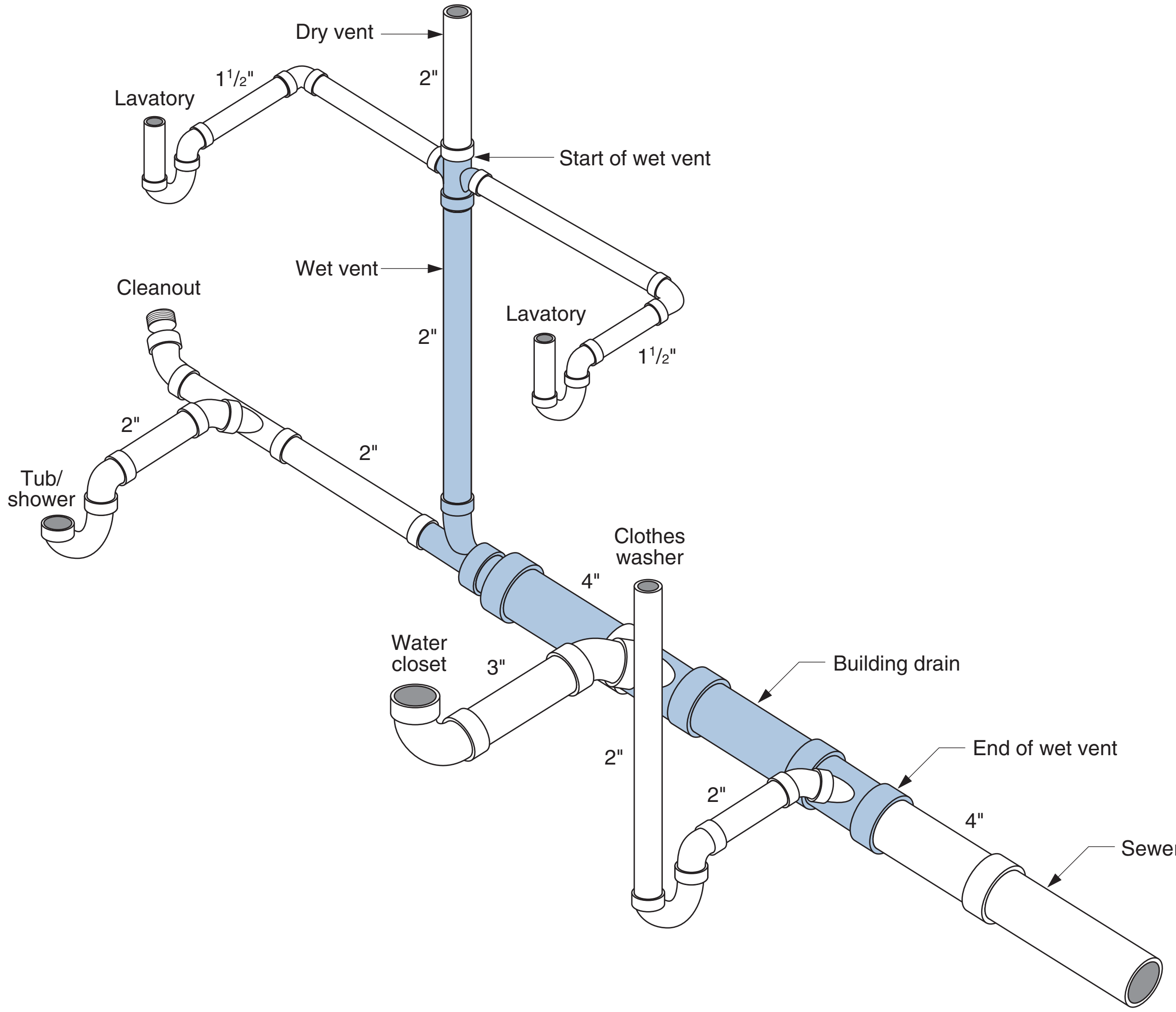
3. The dry-vent connection to the wet vent is an individual vent or a combination vent.

4. No more than one fixture drain connects upstream from the dry-vent connection.

Wet Vent Sizes

Wet Vent Pipe Size, inches	Fixture Unit Load, dfu
2	4
$2^1/_2$	6
3	12
4	32

Typical Wet Vent



Island Fixture Venting

The Code has special venting provisions for island fixtures, including sinks and dishwashers:

1. A loop vent must rise above its fixture drain.

2. Cleanouts must be provided that permit rodding of every part of the loop vent.

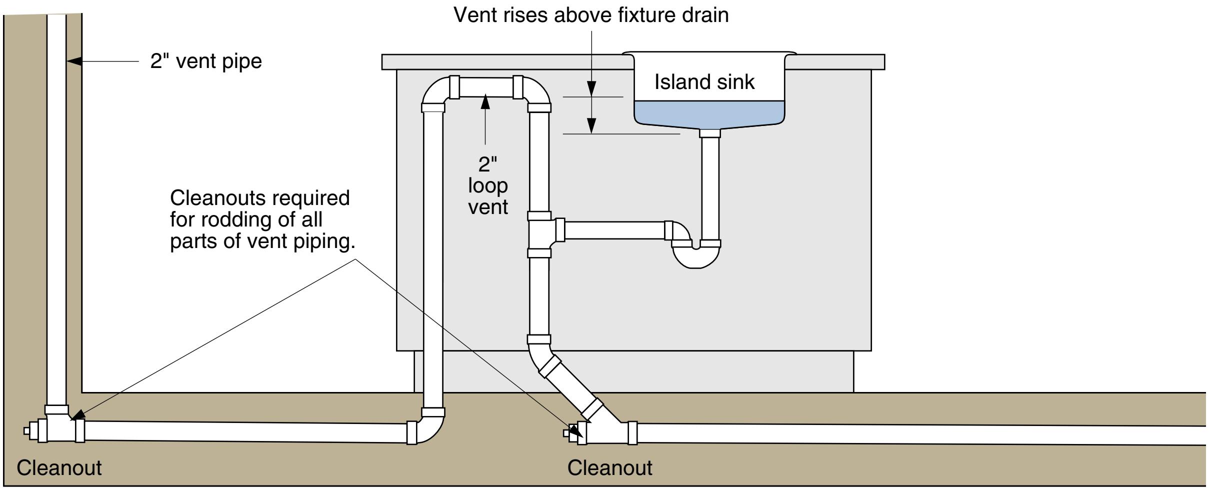
3. Air-admittance valves may only be installed after pressure testing of the DWV system.

4. Air-admittance valves must be at least 4" above the fixture drain being vented.

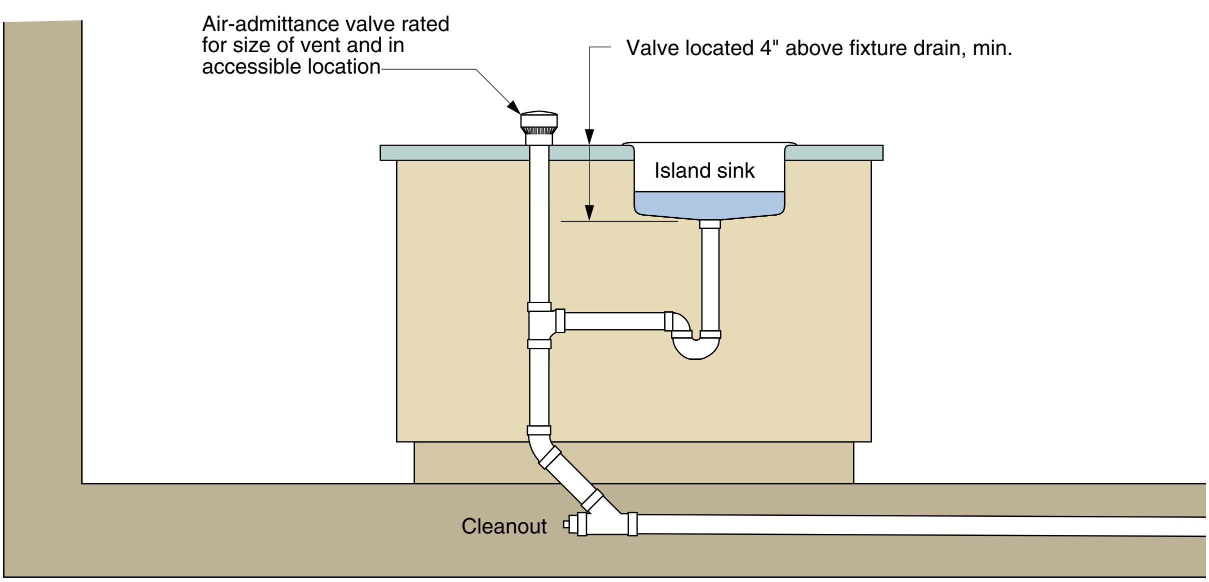
5. Air-admittance valves must be accessible and in a ventilated space.

Venting an Island Sink

LOOP VENT

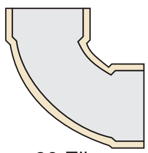


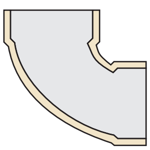
AIR-ADMITTANCE VALVE

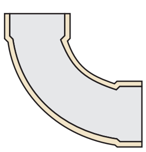


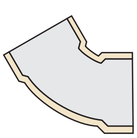
Plastic DWV Fittings

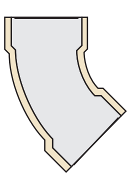
PVC/ABS DWV Fittings

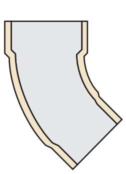

90 Ell
P x P


90 Closet Ell
P x P

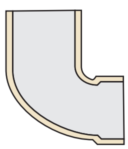

90 Long Turn Ell
P x P

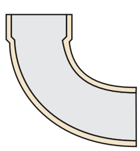

60 Ell
P x P

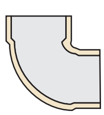

45 Ell, P X P

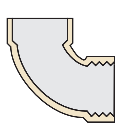

45 Fitting Ell
Fitting x P

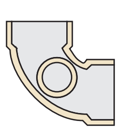

90 Fitting Ell
Fitting x P

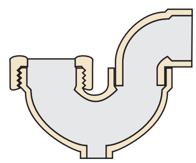

90 Fitting Closet Ell
Fitting x P

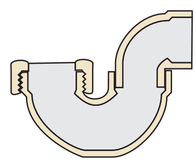

90 Fitting Long Turn Ell
Fitting x P

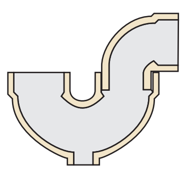

90 Fitting Vent Ell
Fitting x P

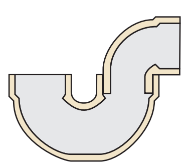

90 Ell
P x F

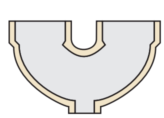

90 Ell with Side Inlet
P x P x P

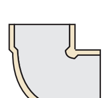

P-trap with Cleanout
P x SJ x Cleanout

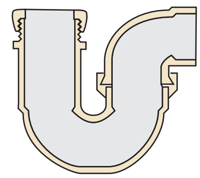

P-trap
P x SJ

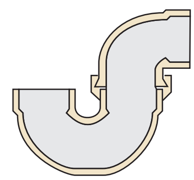

P-trap with Cleanout
P x P x Cleanout

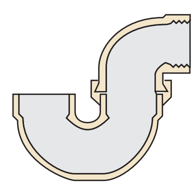

P-trap
P x P

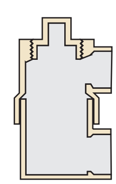

Return Bend w/ Cleanout
P x P x Cleanout

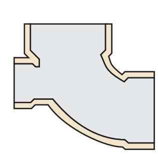

90 Vent Ell
P x P

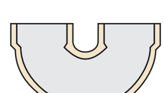

P-trap with Union
P x SJ

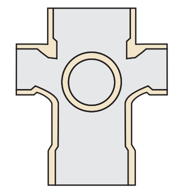

P-trap with Union
P x P

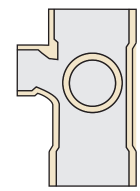

P-trap with Union
P x F

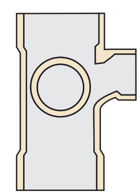

Swivel Drum Trap
P x P x Cleanout

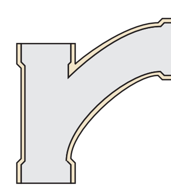

Ell w/ Hi Heel Inlet
P x P x P

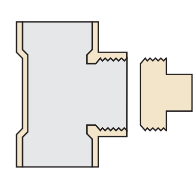

Return Bend
P x P

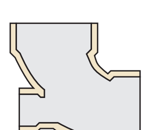

Tee w/ 90 R&L Inlets
P x P x P x P x P


Tee with 90 L Inlet
P x P x P x P


Tee with 90 R Inlet
P x P x P x P

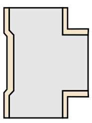

Long Radius TY
P x P x P

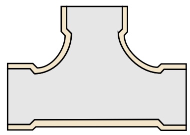

Test Tee
P x P x Cleanout

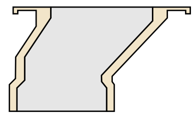

Ell w/ Lo Heel Inlet
P x P x P

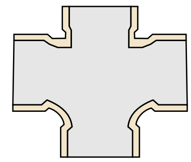
NOTE:
F = Female
M = Male
P = Plastic Weld
SJ = Slip Joint

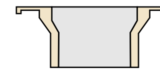
PVC/ABS DWV Fittings—*Continued*

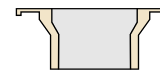

Vent Tee
P x P x P

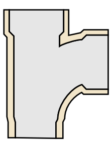

Two-Way Cleanout Tee
P x P x P

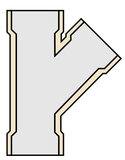

Offset Closet Flange, P

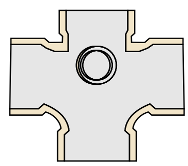

Double Tee
P x P x P x P

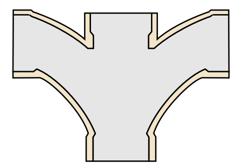

Closet Flange, P

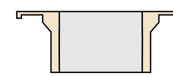

Adj. Closet Flange, P

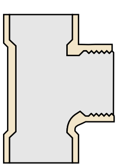

Fitting Tee
Fitting x P x P

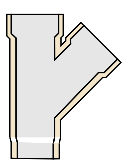

45 Y
P x P x P

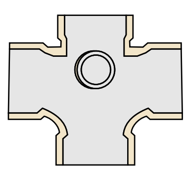

Dbl. Tee w/ 90 Side Inlet
P x P x P x P x P

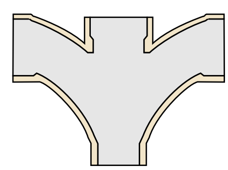

Double Fixture Tee
P x P x P x P

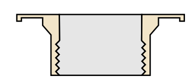

Fitting Adj. Closet
Flange Fitting

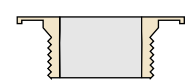

Fixture Tee
P x P x F

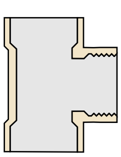

45 Y
Fitting x P x P

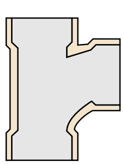

Dbl. Tee w/Two 90 Inlets
P x P x P x P x P x P


Fitting Dbl. Fixture Tee
Fitting x P x P x P


Closet Flange, F


Closet Flange, M


Test Tee
P x P x F


Tee
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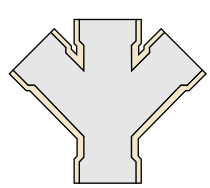
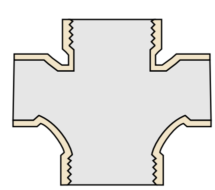

45 Double Y
P x P x P x P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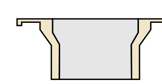
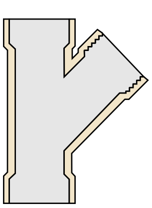

Closet Flange with
Knockout Test Plug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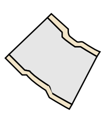
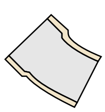

22-1/2 Ell
P x P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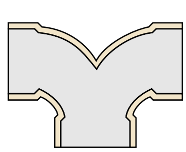
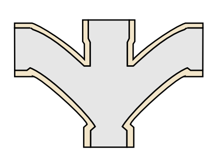
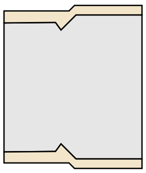
Fitting x P

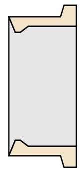

Double Ell
P x P x P

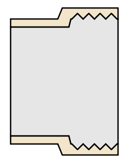

Dbl. Long Turn TY
P x P x P x P

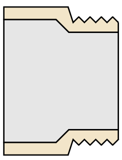
NOTE:
F = Female
M = Male
P = Plastic Weld
SJ = Slip Joint

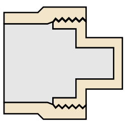
PVC/ABS DWV Fittings—*Continued*

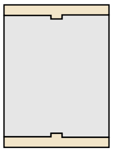

Sewer & Drain Adaptor
P x Sewer & Drain

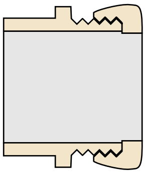

Fitting Flush Bushing
Fitting x P

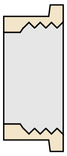

Fitting Adaptor
Fitting x F

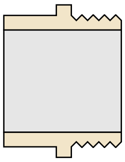

Adaptor
P x M

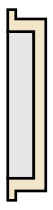

Fitting Cleanout
Fitting x Cleanout


Coupling
P x P


Fitting Trap Adaptor
Fitting x SJ


Fitting Flush Adaptor
Fitting x F


Fitting Adaptor
Fitting x M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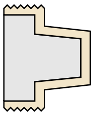
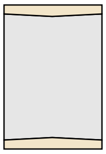
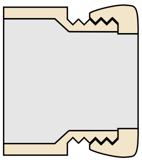
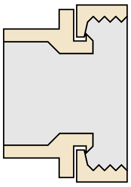
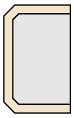
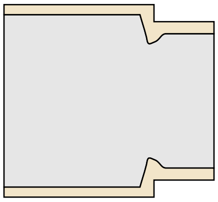

Plug, M

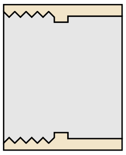

Repair Coupling
P x P

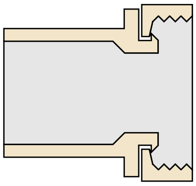

Trap Adaptor
P x SJ

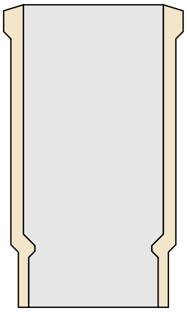

Fitting Swivel Adaptor
Fitting x F

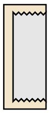

Fitting Plug
Fitting


Soil Pipe Adaptor
P x Hub

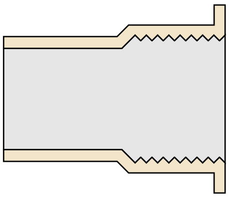

Adaptor
P x F

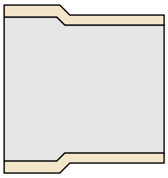

Fitting Swivel Adaptor
Fitting x F

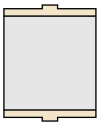

Soil Pipe Adaptor
P x Spigot


Cap, F

NOTE:
F = Female
M = Male
P = Plastic Weld
SJ = Slip Joint


Fitting Tray Plug Adaptor
Fitting x NPT Straight


No Hub Soil Pipe Adaptor
P x No Hub


Nipple
M x M

Roughing-In Dimensions

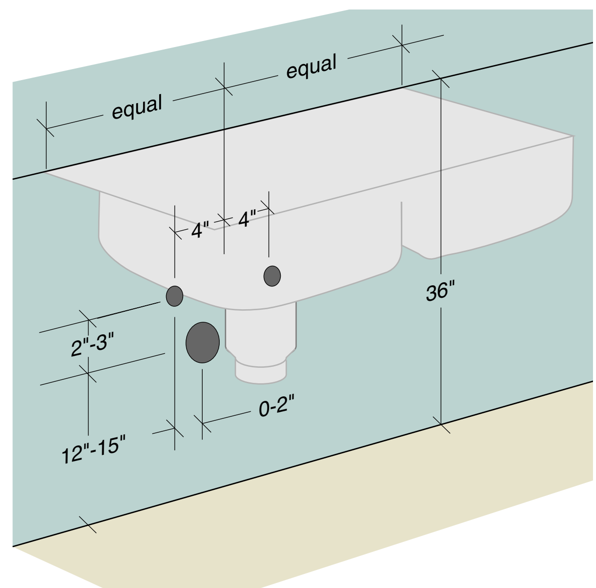
Both supply and DWV piping require cutting holes in floors, walls, and sometimes framing. The cutting of holes and running of pipes prior to installation of fixtures is called roughing-in.

The illustrations at right and below show the normal rough-in dimensions for standard kitchen and bath fixtures. All dimensions are shown as distances from the inside face of framing and vertical distance from the subfloor.

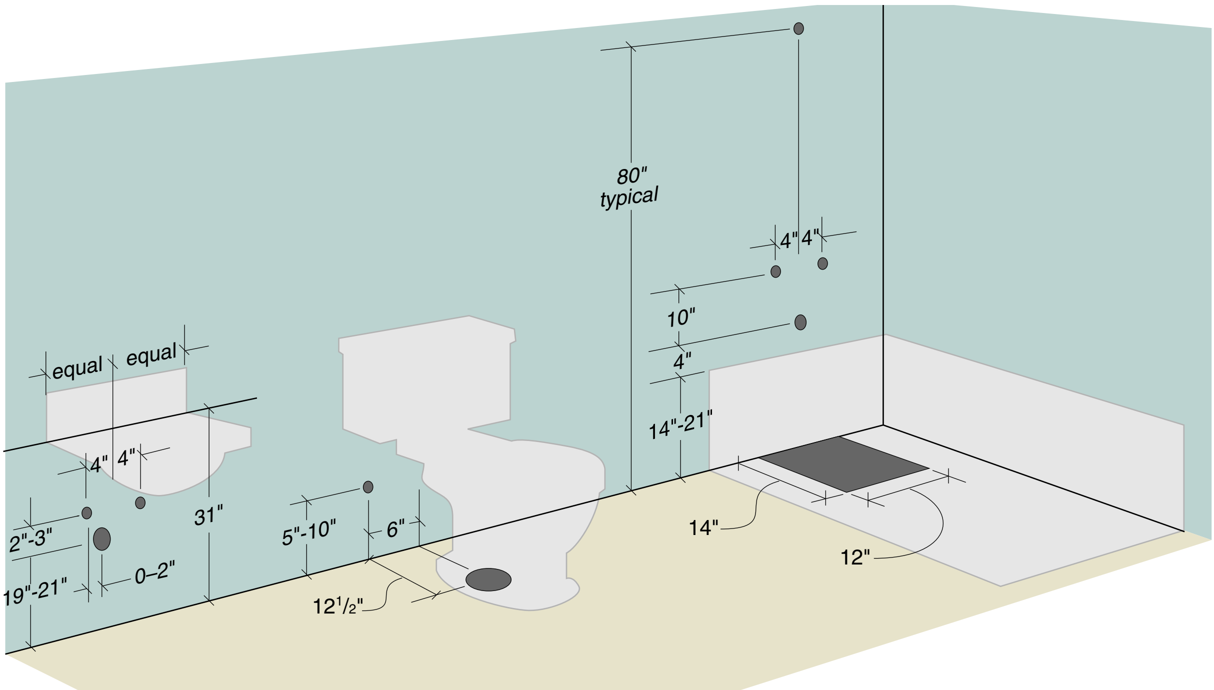
The most variable dimension is distance from the center of the toilet discharge to the wall. Assuming a wall finish of 1/2-inch drywall, this dimension is normally 12 1/2 inches. For bidets the equivalent distance is 15 1/2 inches.

To play it safe, however, double-check the rough-in dimensions specified by the manufacturer of the fixture before running pipe.

Kitchen Sink (Double) Rough-In



Bathroom Rough-In



Private Well Water Standards & Treatments

Water quality standards are the purview of state and local governments. Both adopt minimum standards set by HUD and the EPA for six basic contaminants (see Table below) and may or may not add contaminants particular to their areas of jurisdiction (see Table of Maine Private Well Standards below).

EPA Drinking Water Recommendations for Private Well Water Quality Testing

Contaminant	HUD Requirement[1]	Max. Contaminant Level MCL[2]	Title 40 Code of Federal Regulations Citation[3]	Treatment by Point of Use or Entry Devices[4]
Lead (First Draw)	0.015 mg/l	1.015 mg/l	141.80–141.91	1. Reverse osmosis 2. Activated alumina
Nitrate (as Nitrogen)	10 mg/l	10 mg/l	141.62	1. Ion exchange 2. Reverse osmosis 3. Electrodialysis
Nitrite (as Nitrogen)	1 mg/l	1 mg/l	141.62	1. Ion exchange 2. Reverse osmosis
Total Nitrate/Nitrite	10 mg/l	10 mg/l	141.62	1. Ion exchange 2. Reverse osmosis
Total Coliforms	<10/100 ml	<10/100 ml[4,5]	141.63[4]	1. Disinfection 2. Reverse osmosis
Fecal Coliforms or E.Coli	Zero	Zero[4,6]	141.63[4]	1. Disinfection 2. Reverse osmosis

[1] HUD requirement is based on EPA's MCL (Maximum Contaminant Level). Where other contaminants of local concern or occurrence are tested, the HUD requirement shall be the same as EPA's MCL for that contaminant.

[2] MCL stands for Maximum Contaminant Level, the level at which public water supplies are required to take action.

[3] CFR citations apply only to MCLs for the contaminants.

[4] Devices should meet third party certification standards such as NSF International.

[5] Density of total coliforms should be less than 10 organisms/100 ml water sample. This value is not the MCL because the MCL is based on the results of more than one sample.

[6] Each total coliform-positive colony or culture tube should be tested for either fecal coliform or E.Coli. If this test is performed, a separate water sample for fecal coliform/E.Coli testing is not needed.

State Standard Example

As noted above, states, and in some cases municipalities, set their own standards. These consist of the EPA basic six in the table above plus locally common contaminants. The table at right lists the State of Maine standards for private wells.

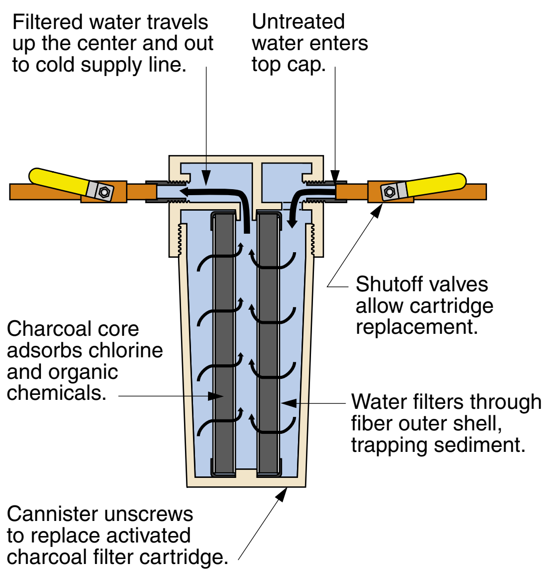
Because these standards must be met for existing home as well as new home sales, contact your local real estate agent for your local well water standards.

Maine Private Well Standards

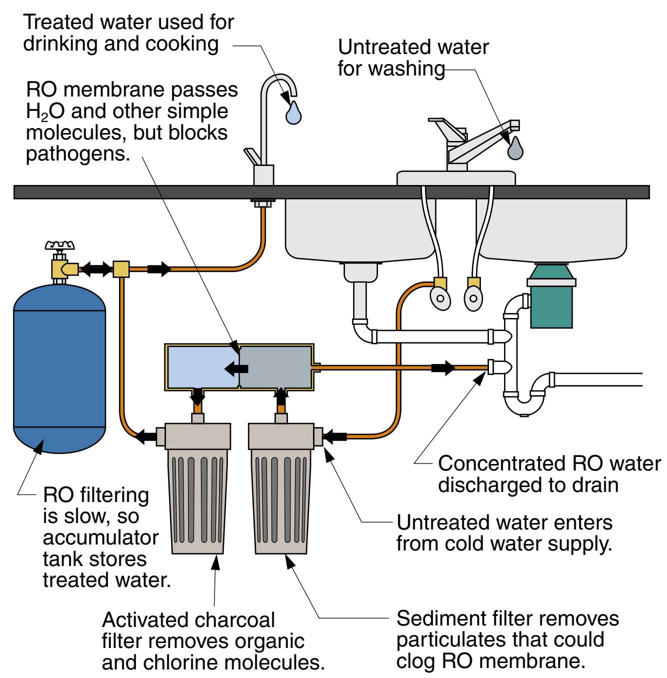
Contaminant	Can Cause	Safe Level (MCL)
Lead (First Draw)	Brain damage	10 µg/l
Nitrate	Infant blood problems	10 mg/l
Nitrite	Infant blood problems	1 mg/l
Coliform, E.Coli	Diarrhea, vomiting	0
Arsenic	Cancer Low birth weight	10 µg/l
Fluoride	Tooth decay	0.6–2 mg/l
Radon	Cancer	4,000 pCi/l
Uranium	Kidney problems	10 µg/l

Water Treatment Equipment

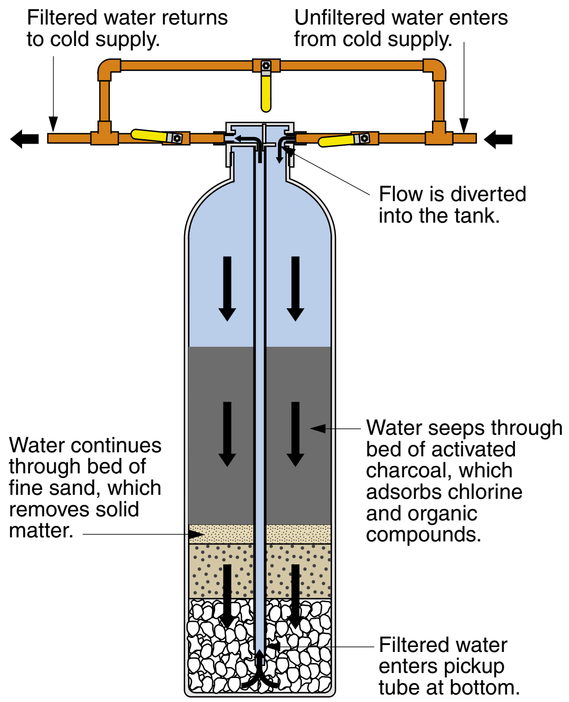
CARBON CARTRIDGE FILTER



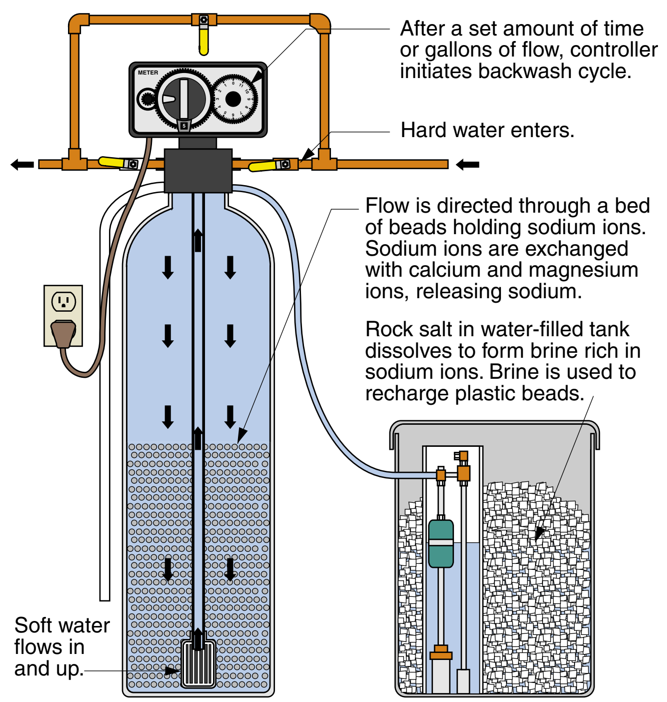
REVERSE OSMOSIS (RO) FILTER



CARBON WHOLE-HOUSE FILTER



ION-EXCHANGE WATER SOFTENER



Meet the Code (IRC)

The following is a partial list of requirements from the *2015 International Residential Code (IRC) for One- and Two-Family Dwellings.* Consult the publication for the full text and additional provisions.

Piping Protection (P2603)

Drilling and notching:

- wood structural members not to be drilled, notched, or altered in any structurally unsafe manner
- cutting/notching of flanges and lips of cold-formed steel-framed load-bearing members not permitted
- concealed piping $<1\frac{1}{4}$" from edges of studs, joists, or rafters to be protected by $\frac{1}{16}$" steel plates

Breakage and corrosion:

- metal pipes, except cast iron and galvanized iron, passing through concrete or cinder walls and floors or other corrosive material to be protected by plastic sheathing or wrapping of thickness 0.008" min.
- space between foundation and pipes to be sealed
- pipe under a footing or through a foundation to be provided with an arch or pipe sleeve two sizes greater

Freezing:

- water, soil, or waste pipe not to be installed outside, in exterior walls, attics, or crawl spaces, or in any place subjected to freezing temperature unless protected from freezing by insulation or heat or both
- service pipe ≥12" deep and ≥6" below frost line

Trenching and bedding:

- continuous load-bearing pipe support required
- backfill with compacted earth, sand, fine gravel, or similar granular material
- backfill to be free from rocks for 12" of cover
- trenching parallel to footings not below 45° bearing plane from bottom edge of wall or footing

Support:

- hangers and straps to be of approved material that will not promote galvanic action
- piping to be supported as shown on p. 321

Showers (P2708)

- ≥900 sq in interior area.
- ≥30" inside dimension (25" if area ≥1,300 sq in)
- hinged shower doors to open outward
- shower valves to be pressure-balance, thermostatic-mixing, or combination pressure-balance/ thermostatic-mixing type set to maximum of 120°F

Protection of Supply (P2902)

- supply system to prevent contamination from nonpotable liquids, solids, or gases
- supply lines and fittings to prevent backflow
- air gap measured from the lowest end of supply outlet to flood level rim of fixture
- air gap to be ≥2× diameter of outlet opening
- dishwashers and clothes washers require air gap devices
- sillcocks and hose bibbs require vacuum breaker

Water Supply System (P2903)

Maximum fixture flow rates:

- lavatory faucet 2.2 gpm at 60 psi
- shower heads 2.5 gpm at 80 psi
- sink faucet 2.2 gpm at 60 psi
- water closet 1.6 gallons per flushing cycle

Pressure:

- maximum 80 psi
- water-hammer arrestors for quick-closing valves

Service pipe:

- rated at 160 psi at 73°F
- permitted in the same trench with building sewer if sewer of material listed for use within building. If not, service pipe to be separated horizontally by ≥5' earth or on a ledge ≥12" above sewer

Shutoff valves:

- main shutoff near entrance to building
- at inlet to water heater
- at every fixture except tubs and showers
- all shutoffs to be readily accessible

Drainage System (P3005)

Drainage fittings and connections:

- fittings for changes in direction (see pp. 342-343)
- dfu for *future* fixture rough-ins to be included in determining required drain sizes
- size of the drainage piping shall not be reduced in size in the direction of the flow

Cleanouts:

- must be brass or plastic
- spaced ≤100' in horizontal lines
- at each horizontal fitting with direction change >45°

Exception: only one cleanout required in 40'

- ≤6" cleanouts require 18" clearance
- required near bases of vertical waste or soil stacks
- required near building drain and sewer junction

Horizontal drainage piping slope:

- uniform ≥$^1/_8$" per 12" for ≥3" piping
- uniform ≥$^1/_4$" per 12" for ≤2$^1/_2$" piping

Drain pipe sizing: see procedure on p. 334.

Vent Terminals (P3103)

- termination ≥6" above roof or snow accumulation
- termination ≥7' where roof is trafficked
- ≥3" diameter where design min. temp. ≤0°F
- prohibited <4' beneath door, opening window, or air intake, and <10' horizontal from such opening unless ≥3' above top of opening
- wall terminals to terminate ≥10' from lot line and ≥10' above any point within 10' horizontally
- wall terminals prohibited under roof overhangs with soffit vents

Connections & Grades (P3104)

- vent pipes to drain back to soil or waste pipe
- dry vents to connect above centerline of a horizontal drain pipe
- dry vents to rise ≥6" above flood level rim of highest trap or trapped fixture being vented

Fixture Vents (P3105)

- trap arm length (see p. 338)
- total fall in a fixture drain <pipe diameter
- no vent <two pipe diameters from trap weir

Common Vent (P3107)

- individual vent permitted to vent two traps on the same floor level
- where two drains connect at different levels, vent to connect as a vertical extension of the vertical drain
- upper fixture cannot be a water closet

Wet Venting (P3108)

- any combination of fixtures in two bathroom groups on same floor may be vented by a horizontal wet vent
- each fixture drain to connect horizontally to the horizontal branch being wet vented or have a dry vent
- dry-vent connections to wet vent to be individual or common vent to lavatory, bidet, shower, or bathtub
- upstream fixture drain in vertical wet-vent system to be a dry-vented fixture drain connection
- in horizontal wet-vent systems, only one wet-vented fixture drain can discharge upstream of the dry-vented fixture drain connection
- wet-vent sizing (see p. 340)

Waste Stack Vent (P3109)

- vertical between lowest and highest fixture drain
- not to receive water closets or urinals
- stack vent size ≥size of waste stack
- offsets permitted in stack vent ≥6" above flood level of highest fixture

Circuit Venting (P3110)

- maximum of 8 fixtures to be circuit vented
- connection to be located between the two most upstream fixture drains
- circuit vent pipe not to receive any soil or waste
- slope ≤1 unit vertical in 12 units horizontal
- individually or common-vented fixtures other than circuit-vented fixtures permitted to discharge to horizontal branch if located on the same floor

0 1 2 3 4 5

12

Wiring

As with most things in life, wiring is scary only if you don't understand it. That is why this chapter begins with a simple analogy between an *electrical circuit* and water in a hose. The theory is simple, but it explains the functions of all of the elements in a typical residential system: *service drop*, *grounding*, *ground- and arc-fault circuit interrupters*, *panels and subpanels*, receptacles, and switches.

Next we give you an *overview of required circuits* in the code. *Kitchen circuits* and *bathroom circuits* deserve, and get, special attention.

Load Calculations explains how to determine the size of the service entrance your home needs.

Wire and Cable and *Electrical Boxes* explain the color code for wire insulation, the current-carrying capacity of each wire and cable size, and the number of wires electrical boxes are allowed to contain.

Running Cable and *Running Conduit* illustrate the code requirements for the two common ways of getting electricity to the *receptacles* and the *switches.*

Whether you are adding circuits or troubleshooting a defective circuit, you should find the illustrations in *Wiring Switches, Receptacles, and Lights* a clear guide to which wire goes where.

An extensive new section allows you to determine whether *solar electricity* makes economic sense for your home.

Finally, we provide you with a checklist to make sure your wiring techniques *meet the code.*

Electrical Circuit

Volts, Amps, and Ohms

A useful analogy can be made between the flow of water and electric current. In the illustration below, the pump creates water pressure in the pipe; the faucet turns the flow on and off; the energy in the falling water is converted to work in the paddle wheel; and the spent (zero-energy) water flows back to the pump intake.

Similarly, in an electrical circuit, a generator creates an electrical pressure (measured in volts); a switch turns the current of electrons (measured in amps) on and off; the current flowing through the motor is converted to physical work; and the spent (zero-energy) current flows back to the generator.

All of the useful theory in residential wiring can be summed up in two simple relationships:

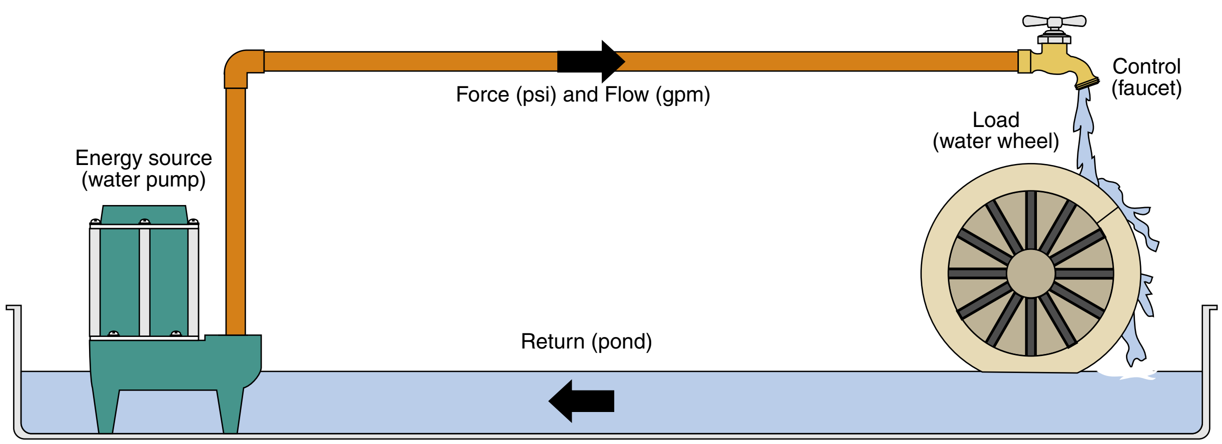
Watts = *volts* × *amps* (the power formula)

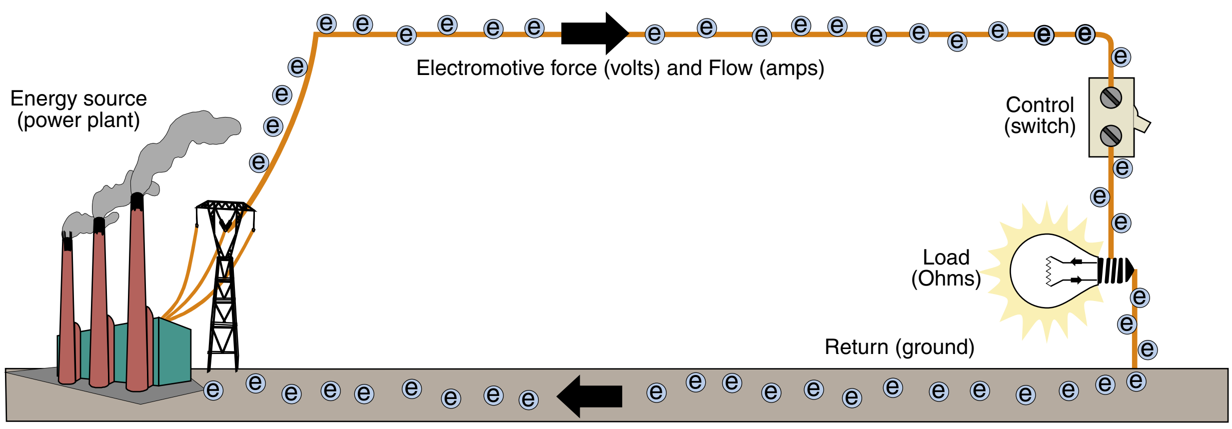
Amps = *volts/ohms* (Ohm's law)

The first relationship, the power formula, allows us to convert wattage ratings, found on electric devices such as lights and appliances, to amps of current draw. We need amps because this is the way wires and circuits are sized.

The second relationship, Ohm's law, allows us to understand why lights and appliances may draw different amperage even though connected to the same voltage.

A Water/Electricity Analogy





An Actual Circuit

The utility power lines actually terminate in the home's breaker panel. From there, electricity is distributed to individual circuits, each protected by circuit breakers against overload.

This 120 VAC (volts alternating current) circuit serves multiple loads, of which two are shown in the illustration below.

The first load is a 60-watt lamp having an electrical resistance of 240 Ohms. By Ohm's law, the lamp draws 0.5 amps

Amps = 120V/240 Ohms = 0.5

The switch is used to connect the lamp into or out of the circuit, thereby turning the lamp on or off.

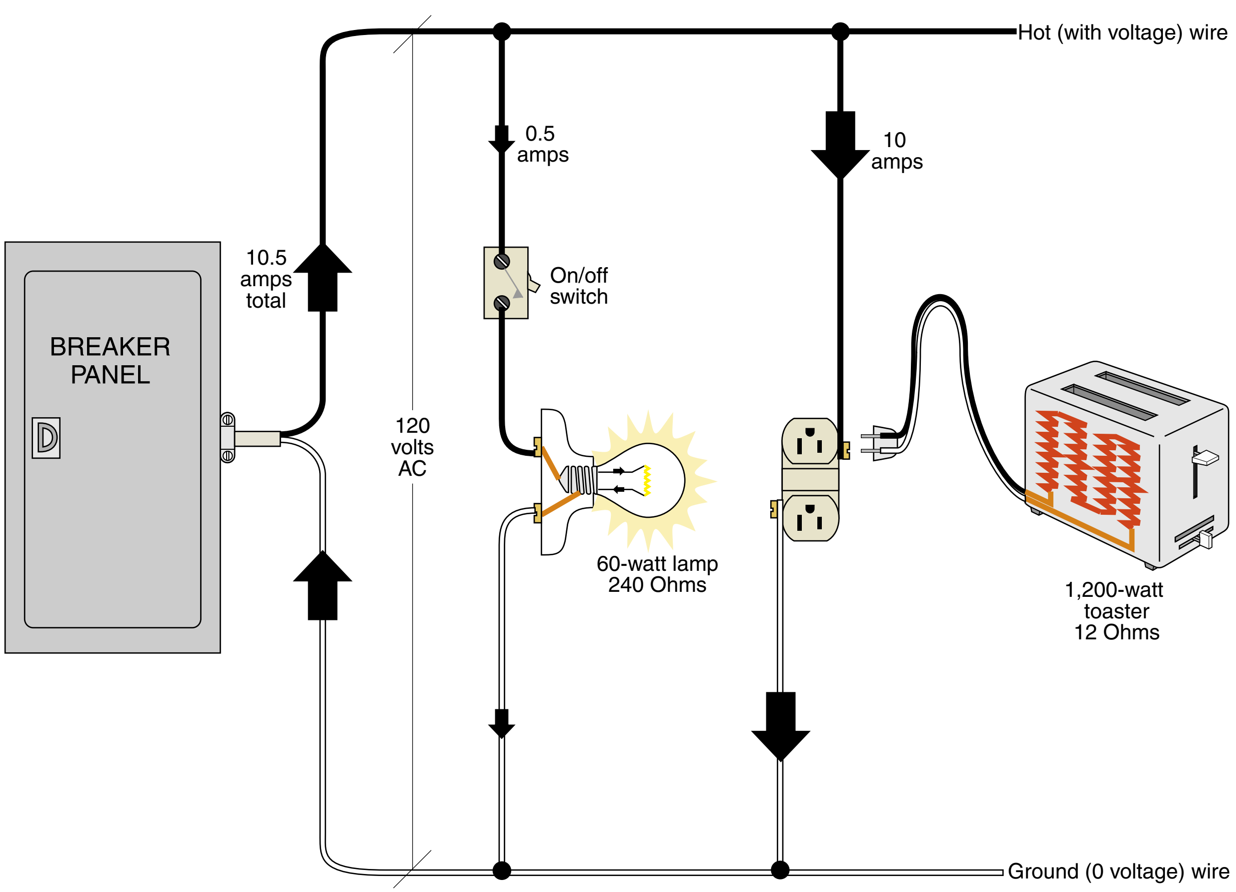
The second load is a 1200-watt toaster (which can be read from the label under the appliance). From the power formula on the facing page, we can calculate the current the toaster draws:

Amps = Watts/volts = 1,200/120 = 10

The receptacle provides a convenient way to connect a portable load—here the toaster—into a circuit.

The number of receptacles and loads in a circuit is limited only by the total current drawn.

A Water/Electricity Analogy



Service Drops

The *service drop* is the portion of wiring from the electric utility company's secondary distribution system (generally overhead wires on poles) to the first point of attachment on the building.

The *service entrance conductors* are the wires extending from the point of attachment of the service drop to the building's *service entrance equipment* (service entrance box).

The information presented here is based on the National Electrical Code. All local utilities adhere to the code, but some have even stricter requirements. So check with your local utility before installing a service drop or entrance.

The type of service installed depends on capacity (maximum amps), height of the building, type of exterior building surface, and whether the owner or zoning calls for underground service.

The illustrations on the following pages show the specifications for various types of service:

Temporary Service is used while a building is under construction. It generally ceases as soon as the building's service entrance equipment has been installed and inspected.

Cable Service is commonly used on wood-sided buildings when the building height is sufficient to provide the required clearance above the ground.

Conduit Service is used for capacities over 200 amps and for buildings with metal, stucco, or masonry siding. The conduit may be made of steel, aluminum, or PVC plastic.

Rigid Steel Masts are used when the building is too low to provide clearance for the service drop.

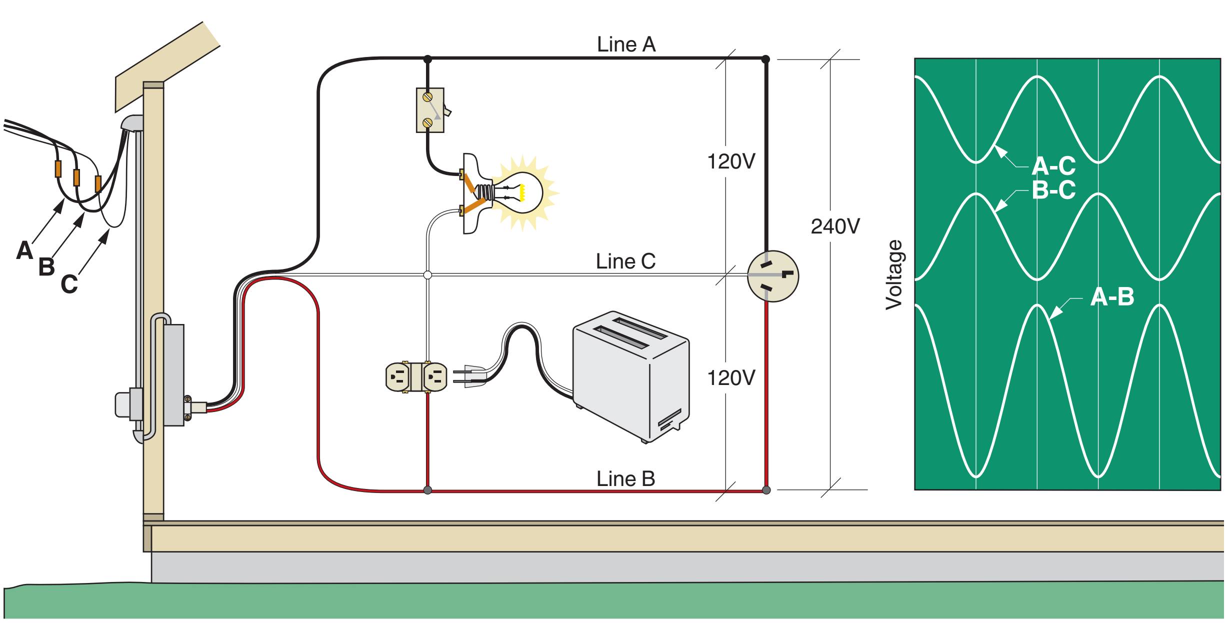
Mobile-Home Service is used when the building (in most cases a mobile home) is temporary, subject to excessive movement, or structurally inadequate to support a rigid steel mast.

Underground service is provided at the owner's discretion (and added cost sometimes) or to comply with local zoning.

Minimum clearances for all service drops are:

- 10 feet above ground
- 10 feet above sidewalks
- 15 feet above residential driveways
- 18 feet above public ways (streets)

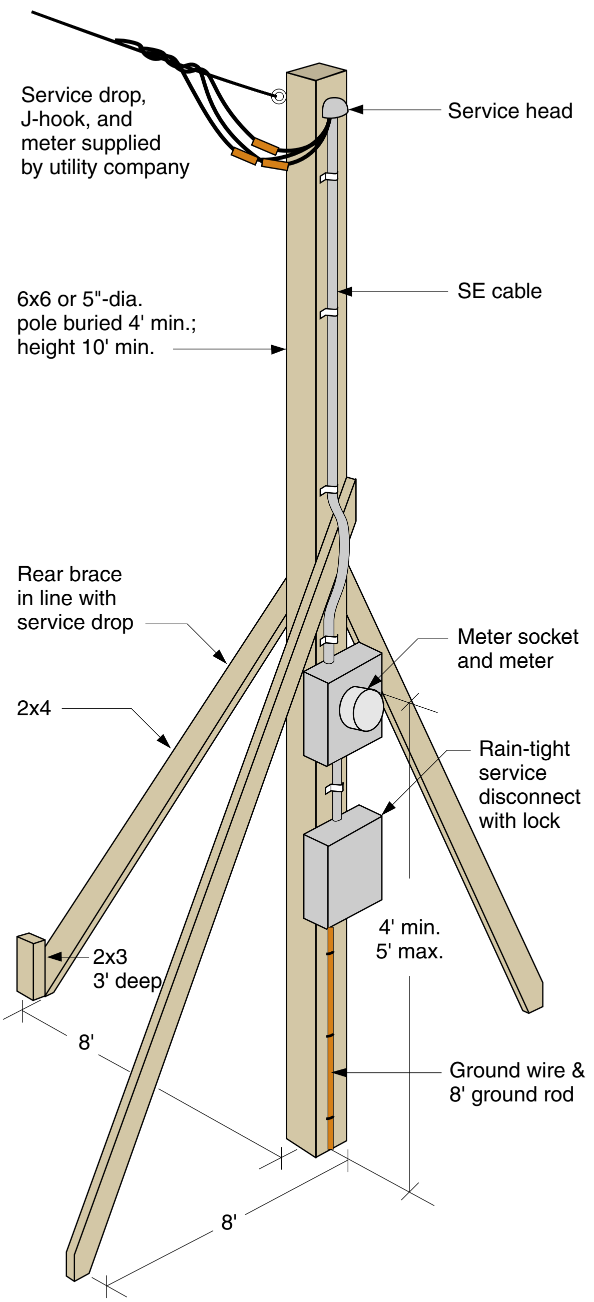
A 120/240 VAC Service Drop



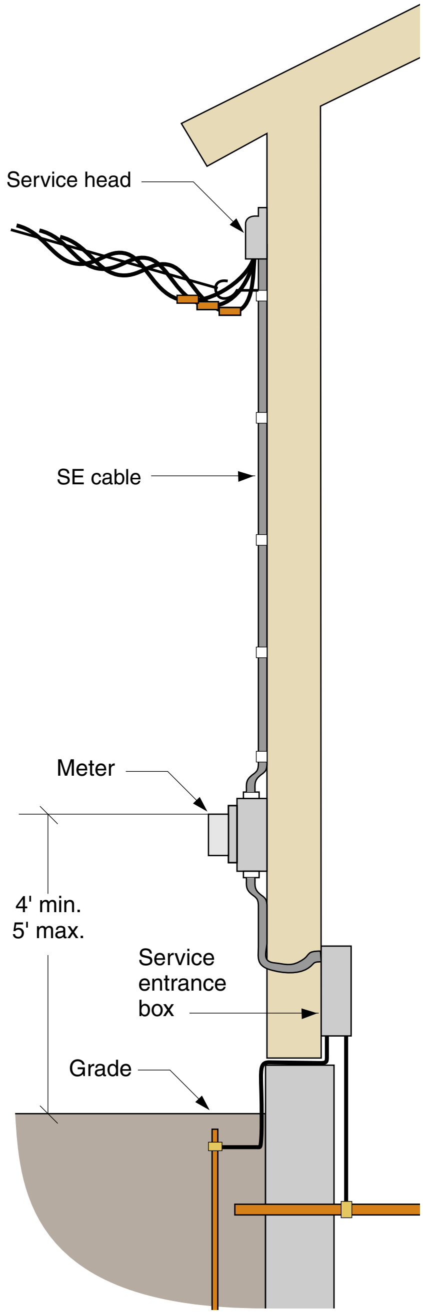
Electric Service Specifications

Temporary Service

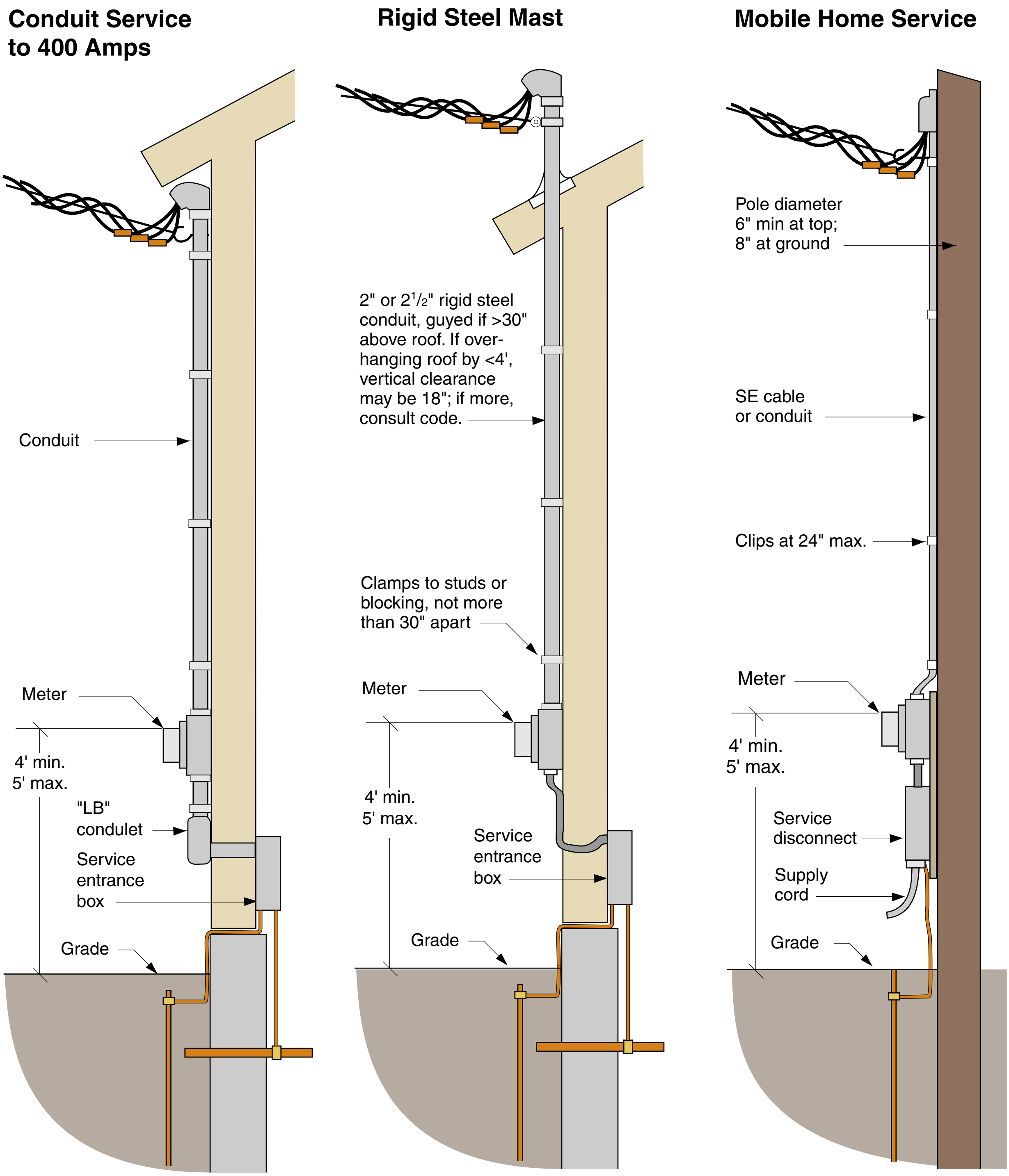
Suitable tree or building may be substituted for pole



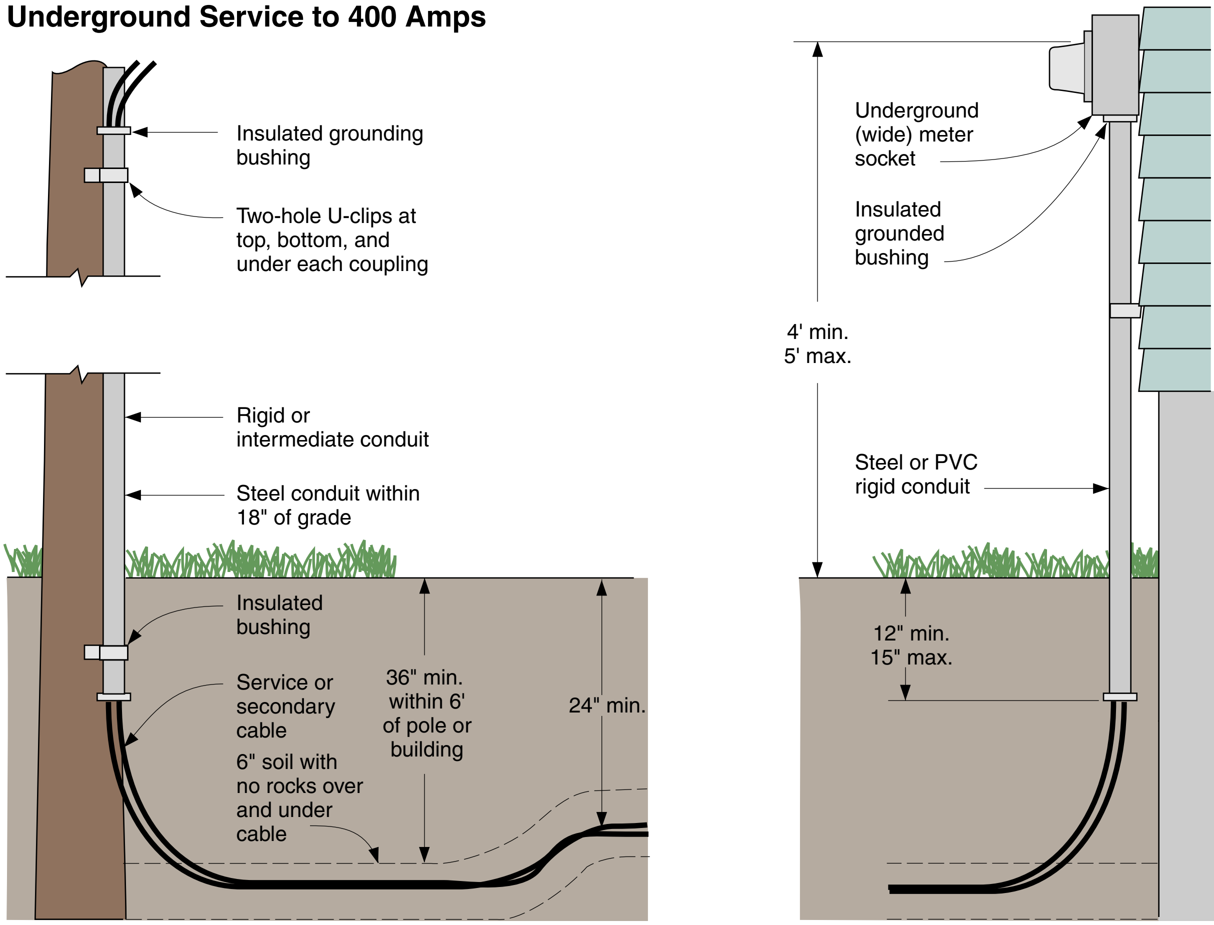
Cable Service to 200 Amps



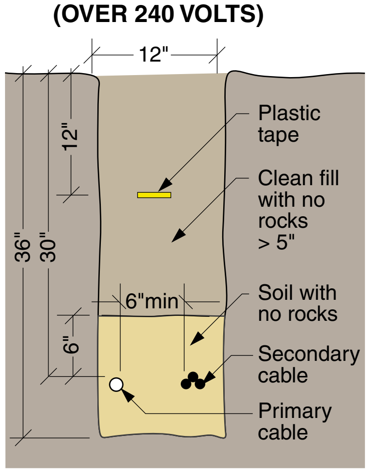
Electric Service Specifications—*Continued*



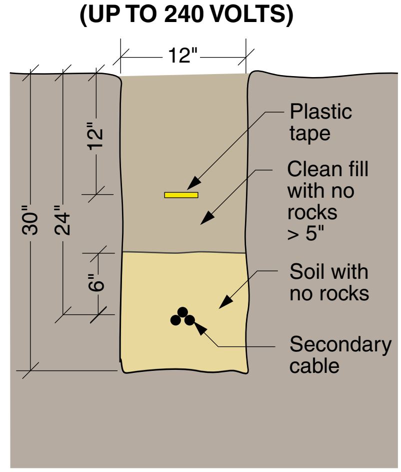
Underground Service to 400 Amps



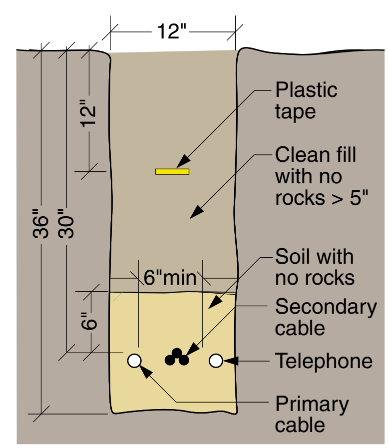
PRIMARY CABLE (OVER 240 VOLTS)



SECONDARY CABLE (UP TO 240 VOLTS)



JOINT ELECTRIC AND TELEPHONE



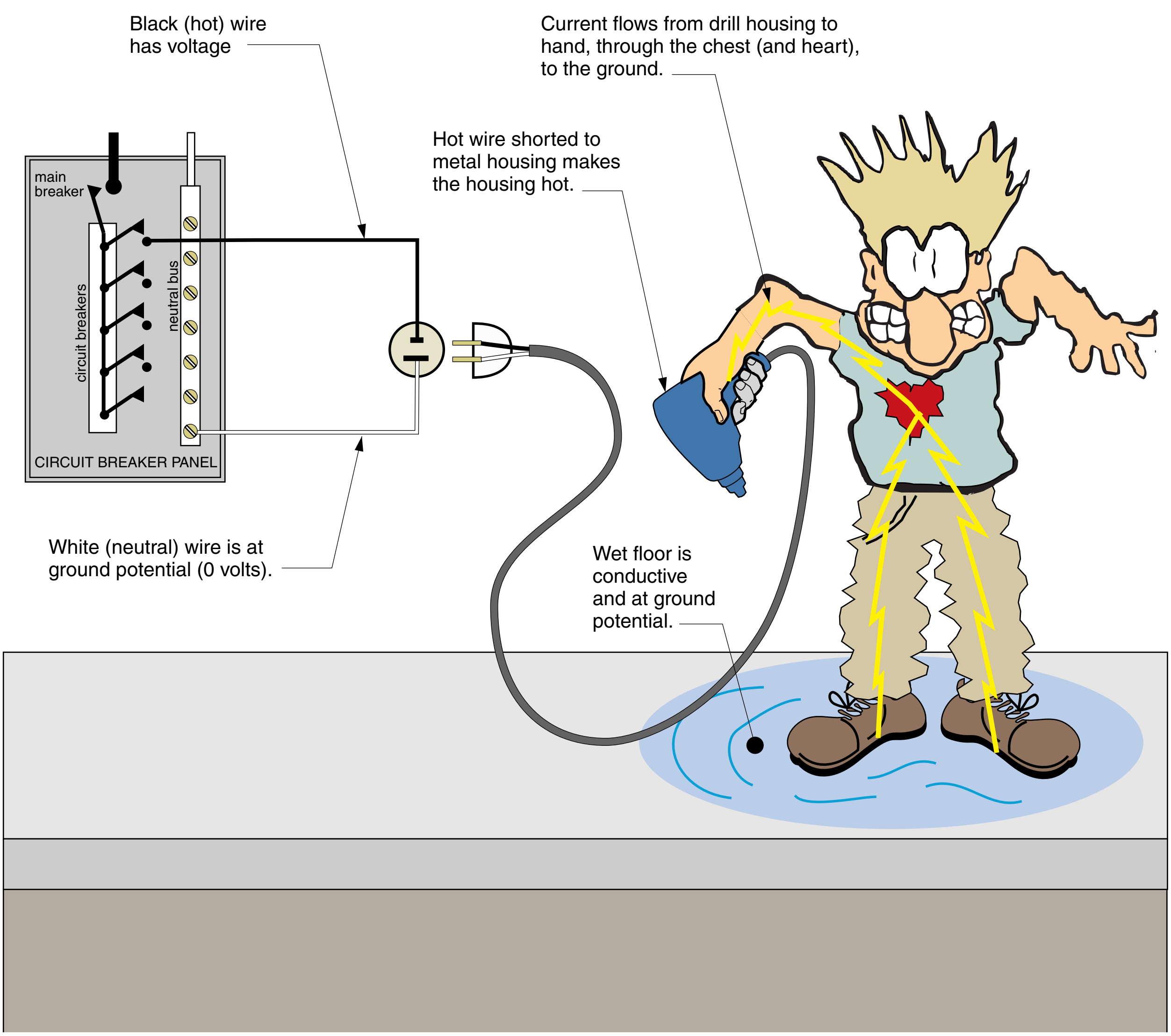
Grounding

Because the electrical system uses the earth as its return path, and because the human body is quite electrically conductive (due to its salt content), a person standing on the ground and touching a live wire may serve as a current path. If the current is great enough, it can cause the heart muscle to spasm and possibly lead to death.

The current is especially dangerous when it flows through the chest from arm to arm. Current flow is also greater when shoes are absent or wet and when the ground (including a concrete slab-on-grade) is wet. For these reasons electricians are careful to wear rubber-soled shoes, stand on a dry surface, and sometimes work with one hand behind their backs.

The better solution, however, is the grounded circuit, as shown on the facing page.

An Ungrounded Circuit Poses Risk of Electrocution



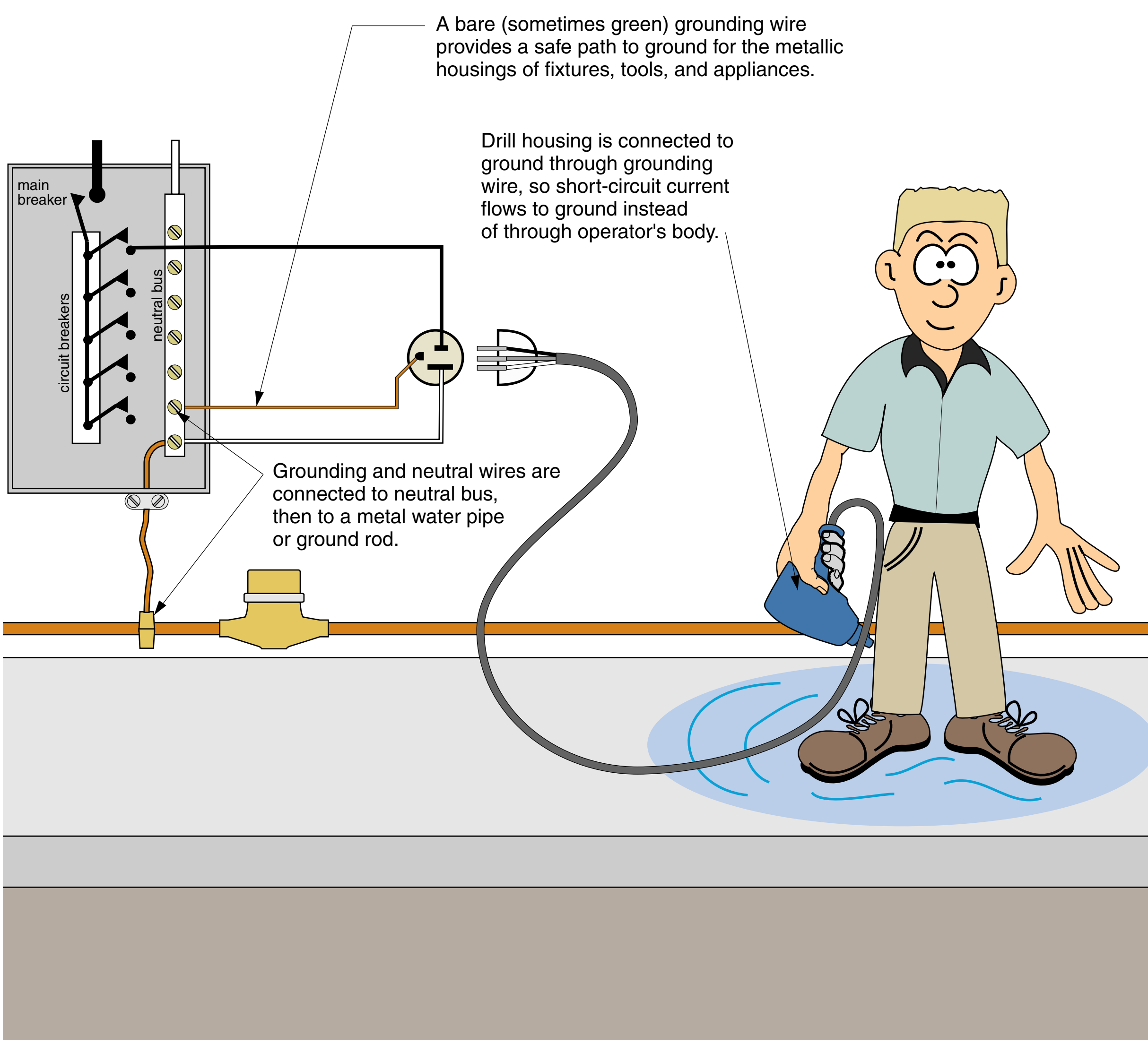
Grounding a circuit consists of adding a bare or green "grounding wire" to the black (hot) and white (neutral) wires.

The grounding wire and the neutral wire connect, in the service entrance box, to a neutral bus bar, which is further connected to either an underground metal water pipe or a metal rod driven into the ground.

Connected to the metal cabinet or housing of appliances and tools, the grounding wire provides a path to ground in case the housing becomes live.

In the illustration below, the drill housing is connected directly to ground through the grounding wire, so short-circuit current now flows safely to ground through it rather than through the operator's body.

Grounded, the Same Circuit Is Safe



Ground- and Arc-Fault Circuit Interrupters

Unfortunately, simply providing a grounding wire, even properly connecting that grounding wire to metal tool and appliance cases, fails to protect against several other threats to life.

Ground Faults

Normally, all current flowing in the line conductor (either black or red) is returned by the neutral (white) conductor. Any difference is either returned by the grounding wire or by the earth. If that difference current flows to ground through your body, you may be electrocuted. The *ground-fault circuit interrupter (GFCI)* compares the currents flowing in the line and neutral conductors. Any difference exceeding 0.005A opens the circuit, eliminating the danger. GFCIs are available in receptacle form and in breaker form combining overcurrent plus arc-fault protection.

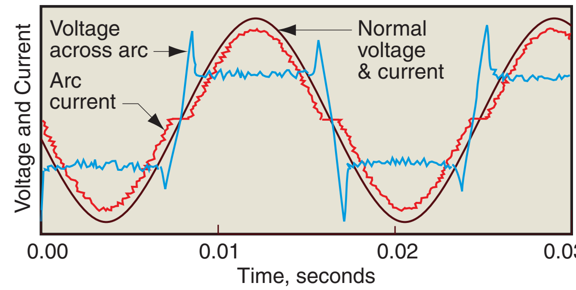
Arc Faults

An electric arc is the flow of electrons across an air gap. It can happen between switch contacts upon opening or closing. It can also happen when a line (live) conductor contacts either the neutral conductor or ground. A short circuit (strong contact) will trip the fuse or circuit breaker. Lighter contact may result in less current flow, but arcing. If the arc is in the presence of combustible material such as wood or paper, the arc may cause a fire.

Normal 60-cycle voltage and current consist of smooth, sinusoidal waveforms (see the illustration at top right). Arcing is intermittent and results in irregular waveforms. The voltage waveform becomes more like a square wave with spikes; the current waveform becomes noisy and displays flat spots around zero voltage. *The arc-fault circuit interrupter (AFCI)* analyzes one or both waveforms and, upon detecting an arc, opens the circuit. AFCIs are available in receptacle form and in breaker form combining overcurrent plus arc-fault protection.

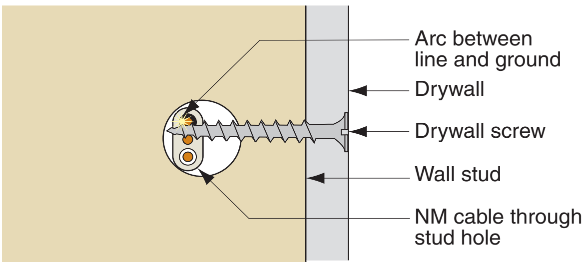
The illustration at bottom right shows some of the most common causes or electric arcs.

Arc-Fault Characteristics

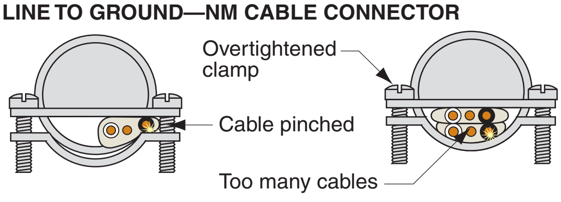


Common Arc-Fault Causes

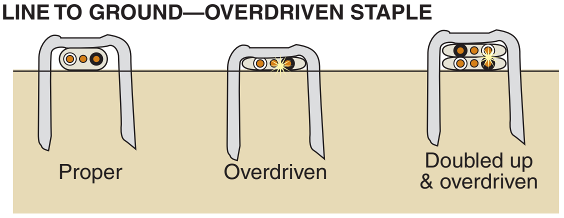
LINE TO GROUND—PENETRATION BY FASTENER



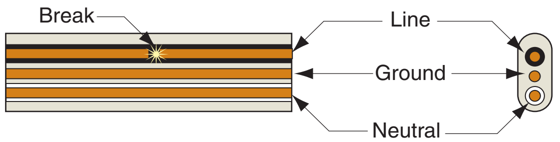
LINE TO GROUND—NM CABLE CONNECTOR



LINE TO GROUND—OVERDRIVEN STAPLE



LINE TO LINE—BROKEN CONDUCTOR



Code-Required GFCIs

Both the NEC and IRC require receptacles to be GFCI protected wherever there is danger of a human becoming the path to ground of a leakage current. Such locations are associated with dampness. Specifically, GFCIs are required in bathrooms, utility rooms, kitchens (countertop and any other receptacle within 6 feet of a sink), exterior locations, decks, outbuildings, garages, unfinished basements, crawl spaces, and areas around swimming pools and hot tubs. Excepted are electric ranges, ovens, and other cooking appliances. In addition, exterior receptacles must be weather-resistant and have weatherproof-in-use covers.

Note that GFCI protection is not required or recommended for lighting unless located within a tub or shower enclosure.

As the illustration at right shows, a receptacle circuit may be protected by either a breaker GFCI, which protects all receptacles in the circuit, or a receptacle GFCI, which protects itself and all receptacles downstream. However, GFCI receptacles must be readily accessible and not hidden.

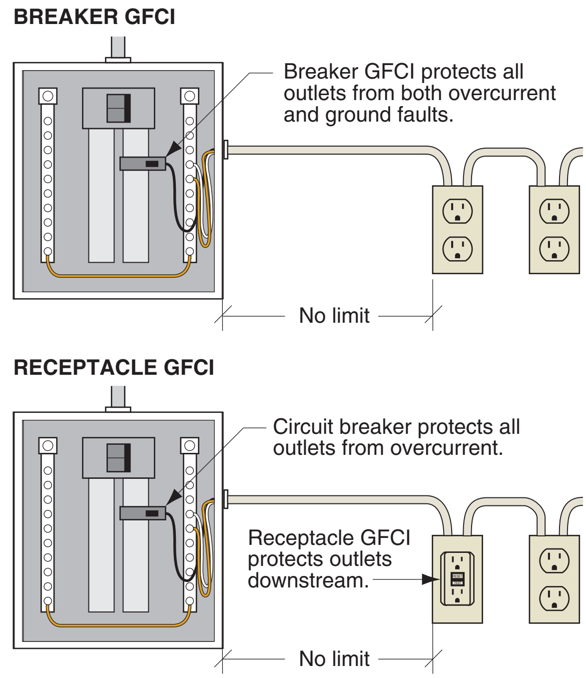
Code-Required AFCIs

Both the NEC and IRC require circuits feeding receptacles or other electrical devices in dwelling kitchens (other than those requiring GFCIs as seen above), living rooms, bedrooms, dining rooms, family rooms, libraries, dens, parlors, hallways, laundry rooms, and sunrooms. In other words, all of the receptacles in habitable spaces except those protected by GFCIs.

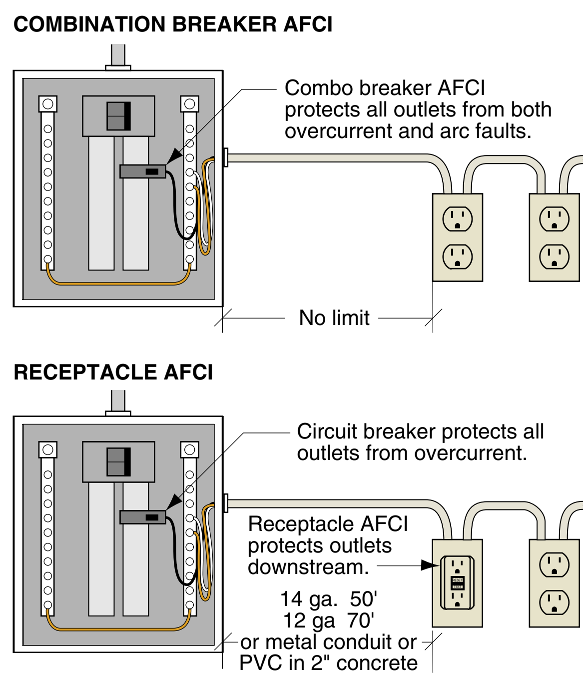
As with GFCIs, receptacle circuits may be protected by either breaker AFCIs, which protect all receptacles in the circuit, or receptacle AFCIs, which protect all receptacles downstream. Receptacle AFCIs also must be accessible.

Exception: Although not specifically exempted by code, a receptacle serving life-sustaining medical equipment should not be GFCI- or AFCI-protected. Instead, with permission from your code official, install a regular receptacle and label it for medical equipment use only.

Ground-Fault Wiring



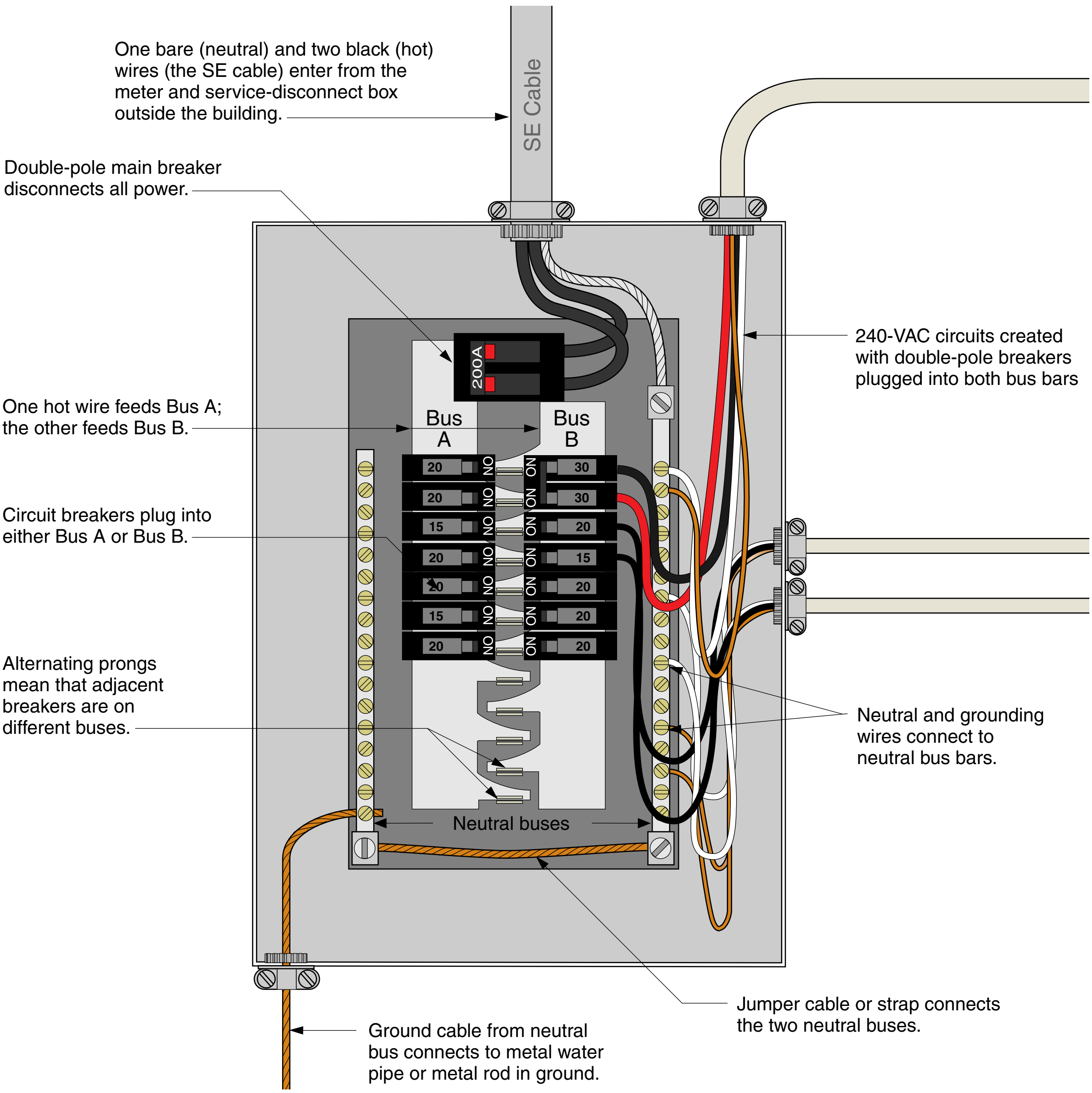
Arc-Fault Wiring



Panels and Subpanels

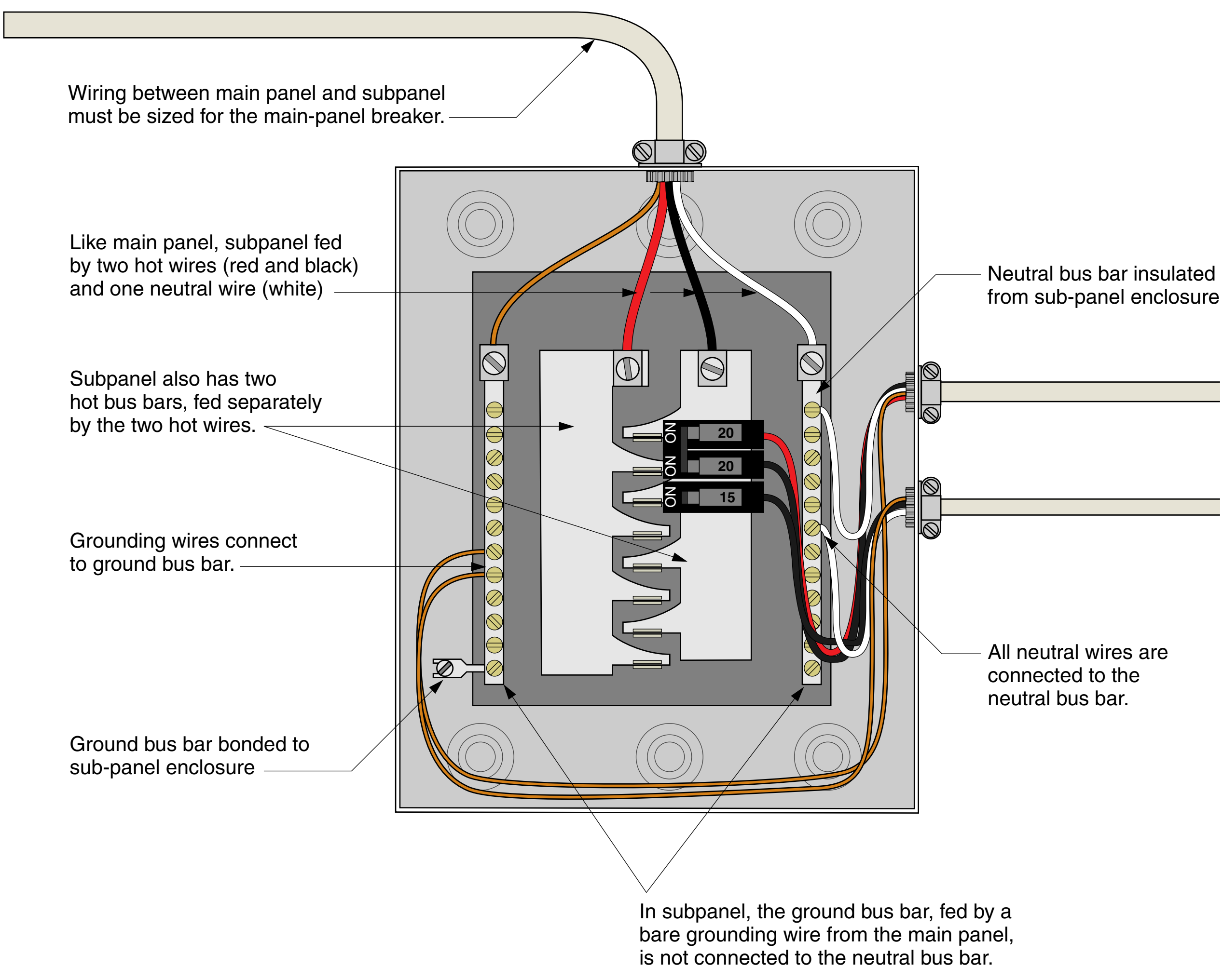
The main distribution panel provides a single, convenient location for controlling all of the electricity usage in a building. This is an important safety consideration for anyone working on the wiring anywhere downstream of the main circuit breaker.

Main Distribution Panel



Subpanels (there may be any number) reduce the cost of wiring by eliminating long runs for individual circuits back to the main panel. They also provide the safety feature of being able to turn off all of the circuits in the area they serve, such as a workshop, a separate apartment, or an outbuilding.

Subpanel (Fed by Main Panel at Left)



Overview of Required Circuits

The IRC (the "Code") requires breaking a building's load into several categories and many individual breaker-protected circuits.

Lighting

The Code requires a lighting allowance of 3 watts per square foot of living space. A 15A circuit can carry 15A × 120V, or 1,800 watts. The requirement is thus one 15A circuit for every 600 square feet.

Because much lighting is with lamps plugged into receptacles, "lighting circuits" may also include the general-purpose receptacles in a room. In any habitable room, no point along a wall may be farther than 6 feet horizontally from a receptacle. This includes any wall 2 feet or more in width, peninsulas, islands, and freestanding railings.

Small Appliances

Small kitchen-type appliances draw more power than lamps and radios, so the Code requires two 20A circuits in the area of kitchen, pantry, and dining room. Except for a kitchen clock and the oven light/ignition system of a gas range, no lighting may be on these circuits. Although the circuits are rated 20A, receptacles may be rated either 15A or 20A.

Individual Appliances

Larger, power-hungry appliances should be served by separate circuits. These include clothes washer, clothes dryer, dishwasher, waste disposer, water heater, water pump, electric range, electric wall oven, electric cooktop, oil burner, furnace blower, any permanently connected appliance over 1,000 watts, and any permanently connected motor over $^1/_8$ horsepower.

Safety

In locations where water, metal plumbing, or earth make electric shock potentially more lethal, receptacles are required to be protected by GFCI circuit breakers. A GFCI can protect just one receptacle (at the point of use) or a whole circuit (installed in the service box). The Code specifies the following GFCI locations: kitchen counters within 6 feet of a sink, bathrooms, garages (whether attached or separate), unfinished basements, crawl spaces, around swimming pools, and outdoor decks, patios, and porches. At a minimum, protected exterior receptacles are required at both front and rear of the house.

As a safety precaution against fire, all receptacles in habitable spaces except those protected by GFCIs must be protected by arc-fault circuit breakers.

Room Lighting and Receptacles

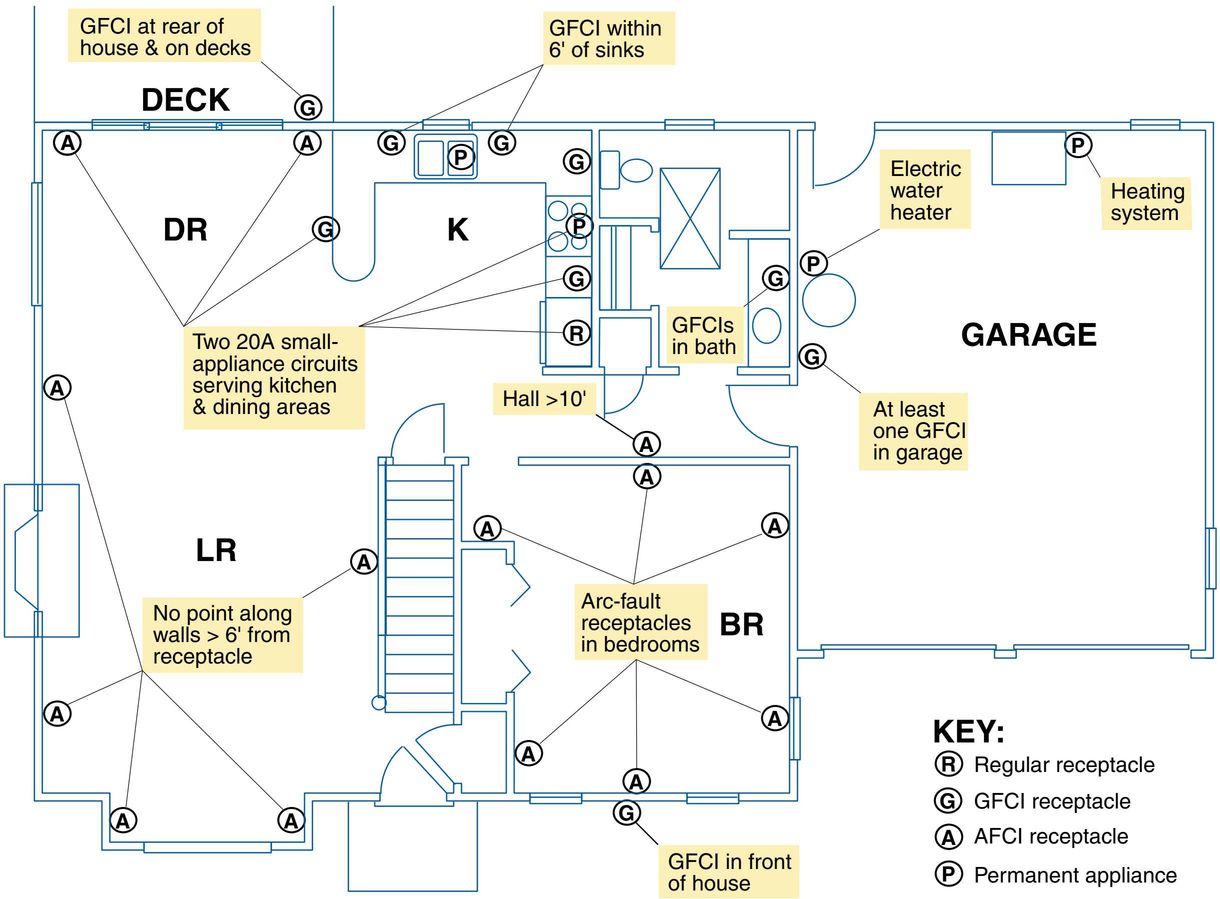
Kitchen As pointed out above, the kitchen requires two separate 20A small-appliance receptacle circuits. Receptacles should be located 6 to 10 inches above counter surfaces so that no point of the counter is more than 24 inches from a receptacle. Peninsulas and islands are exceptions, requiring just one receptacle each. Remember that receptacles within 6 feet of a sink must be GFCI-protected. Lighting in a kitchen should be both general (one or more overhead fixtures) and task (under wall cabinets or spots from ceiling) to illuminate work surfaces. If there are two entrances to the kitchen the overhead lights should be controlled by a pair of three-way switches.

Dining Room and Pantry At least one of the two kitchen small-appliance circuits must make an appearance in any adjacent dining room, breakfast area, or pantry.

Bathrooms A GFCI-protected receptacle must be provided within 36 inches of all lavatories (bathroom sinks). A switch-operated ceiling fixture and lights to either side of each lavatory generally provide effective lighting. An important, but often overlooked, prohibition is ceiling fixtures and ceiling fans within 3 feet horizontally and 8 feet vertically of tubs and showers.

Living Rooms and Bedrooms The "no more than 6 feet from a receptacle" rule applies here, but a little planning will ensure that receptacles don't fall behind couches or dressers where they can't be accessed and that there will always be a convenient receptacle for vacuuming. As pointed

Code-Required Residential Circuits



out under "Safety," all receptacles in these habitable spaces must be AFCI-protected. Living room lighting can be provided either by a switch-controlled ceiling light or by switch-controlled receptacles into which lamps are plugged. A common practice is to switch just the top or bottom halves of several lighting receptacles. Again, if the room has more than one entrance, use three-way switches so the lights can be switched on and off again as you pass through the room.

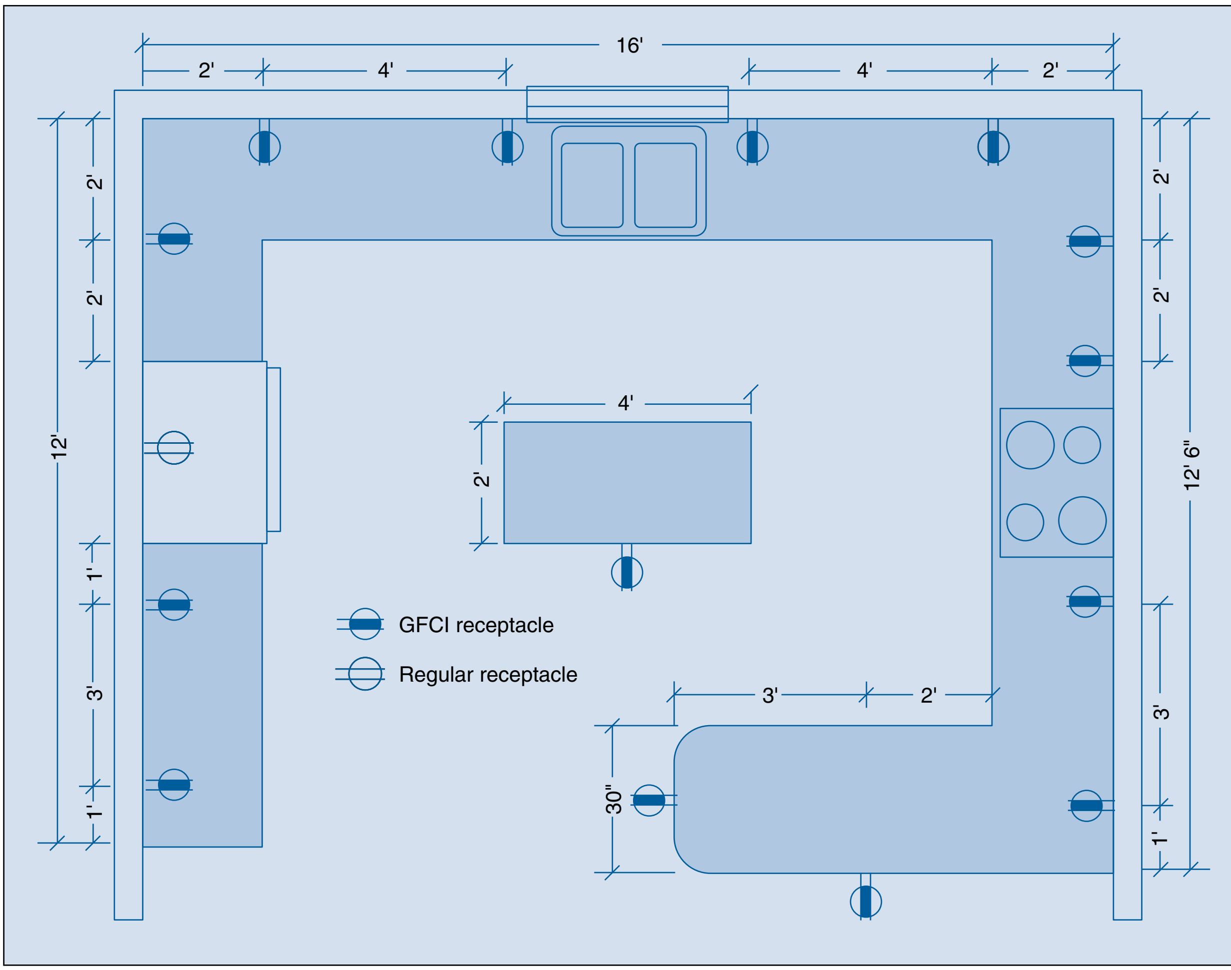
Closets There should be a light in every closet, but incandescent bulbs must be enclosed in fixtures (bare fluorescent bulbs are OK). In any case, the light fixture must be separated from stored clothes and other objects by a minimum of 12 inches horizontally and vertically. Separation may be reduced to 6 inches for recessed fixtures.

Stairways For safety's sake, make sure that every step is illuminated. Stairway lights should, without exception, be controlled by three-way switches at top and bottom landings.

Garages The Code requires garage receptacles, except for garage-door openers and those dedicated to appliances, to be GFCI-protected (a minimum of one). At least one switch-controlled light should be provided, preferably three-way-controlled from both the house and the entrance door to the garage.

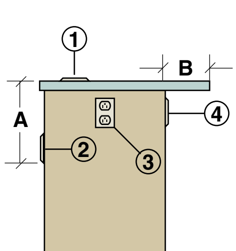
Kitchen Circuits

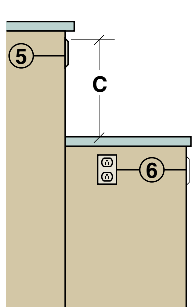
Placement of Kitchen Receptacles



ISLANDS AND PENINSULAS

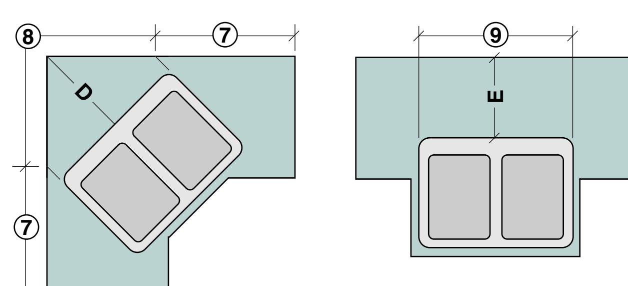
1. Face-up receptacles prohibited
2. Prohibited if A >12"
3. OK
4. Prohibited if B > 6"
5. Prohibited if C > 20"
6. Prohibited where above-counter mounting is possible





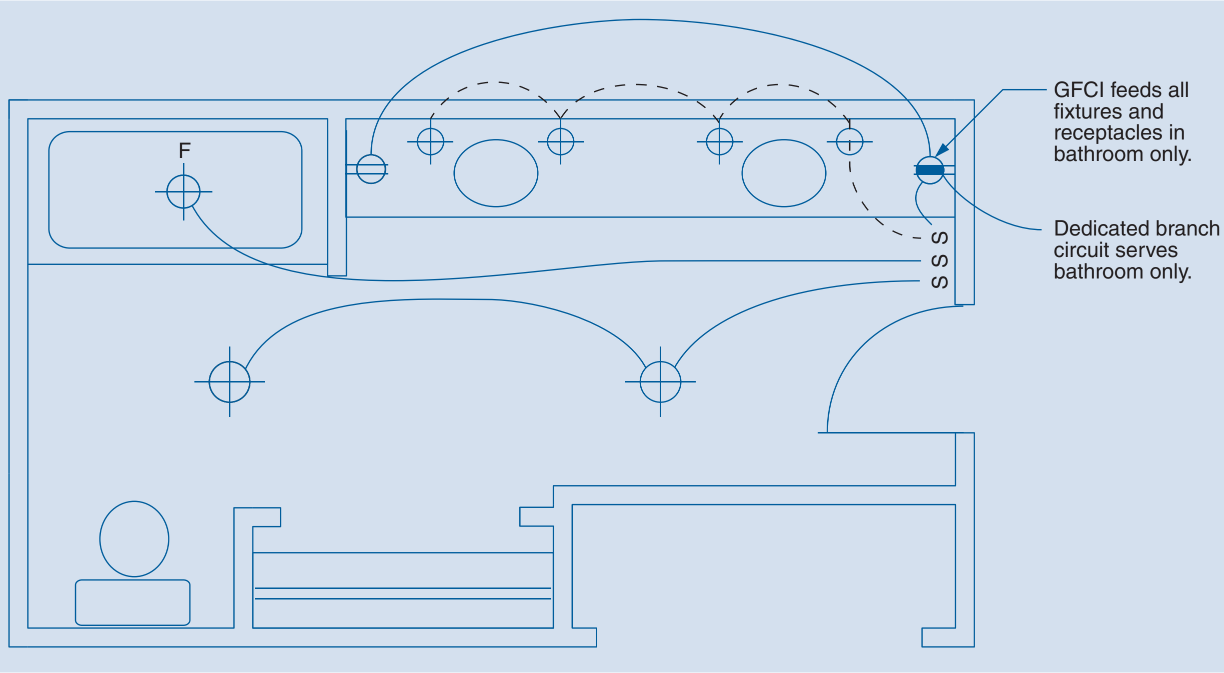
COUNTER BEHIND SINKS

7. Receptacle required within 24"
8. Receptacle not required if D < 18"
9. Receptacle not required if E < 12"

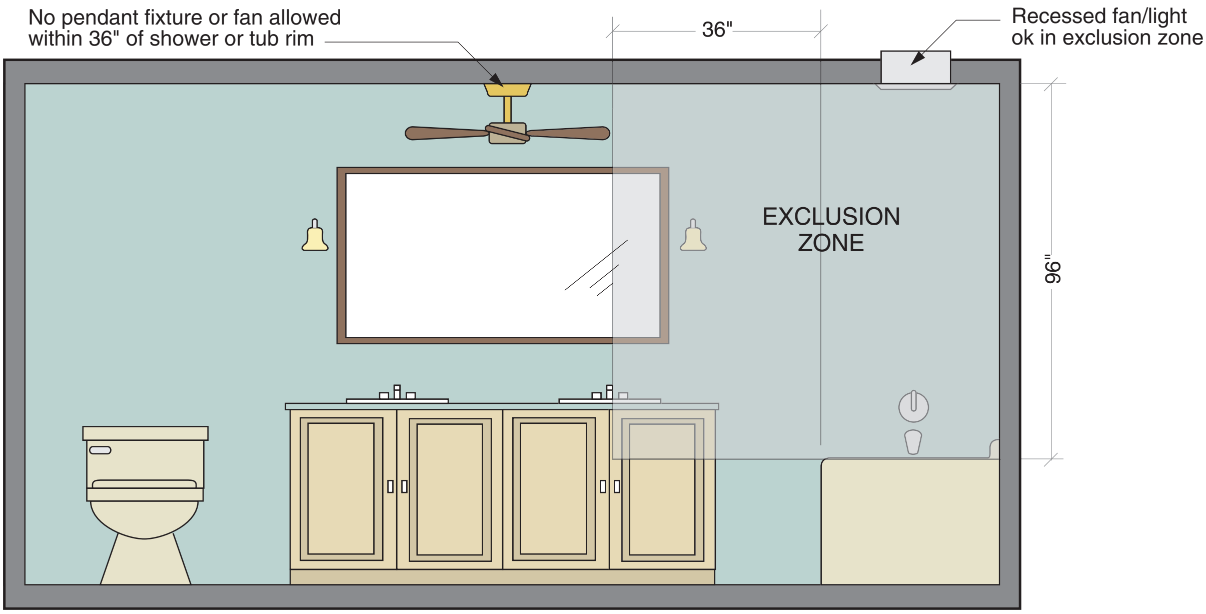


Bathroom Circuits

Dedicated GFCI-Protected Circuit



Tub and Shower Exclusion Zone



Load Calculations

The IRC specifies a method for computing a *building's electrical load*, which then determines the required capacity of the service entrance and service entrance cable:

1. Compute the *heating, ventilating, and air-conditioning (HVAC) load*, which is the larger of 65 percent of central electric heating (not including electric baseboards) or 100 percent of air conditioning (AC).

2. List and total the *other loads*: baseboard or radiant electric heating, general lighting at 3 watts per square foot, small appliance circuits at 1,500 watts each, and the other remaining major appliances.

3. Compute the *total derated load*, which is 10,000 watts, plus 40 percent of the total of other loads less 10,000 watts, plus the HVAC load.

4. Find the required service entrance amperage by dividing total derated load by 240 volts.

The example below demonstrates the method for a typical electrically heated house.

Appliance wattages are always listed on the equipment nameplate, which is usually found on the back or the bottom of the appliance. Alternatively, use the figures from the table on the facing page.

Example Building-Load Calculation

Load		Calculation	Watts
HVAC	65% of central electric heat (none)	0.65	0
	100% of 35,000 Btu/hr AC (5,000 watts)	1.00 × 5,000	5,000
		Total HVAC Load	5,000
Other Loads	Electric baseboard, 70 lin feet	70 × 250 watts/ft	17,500
	General lighting for 2,000 sq ft	2,000 sq ft × 3 watts/ sq ft	6,000
	Small appliances, 2 circuits	2 × 1,500 watts	3,000
	Laundry circuit	1 × 1,500 watts	1,500
	Clothes dryer		5,800
	Water heater		4,500
	Range/oven		12,000
		Total Other Loads	50,300
Derated Load	10,000 watts		10,000
	0.40 × (Total Other Loads – 10,000 watts)	0.40 × 40,300	16,120
	HVAC Load		5,000
		Total Derated Load	31,120

Service amps = Total Derated Load ÷ 240 volts
= 31,120 ÷ 240
= 130 amps (150-amp service entrance)

Typical Appliance Wattages

Appliance	Spacing	Watts
Air conditioner	Room, 7,000 Btu/hr	800
	Central, 35,000 Btu/hr	5,000
Aquarium	Small	100
	Large	500
Blender		375
Clothes dryer	Electric	5,000
	Gas	500
Clothes washer		500
Coffee maker		1,000
Computer	CPU	100
	monitor	150
	Laptop	50
Copy machine		1,500
Dehumidifier	25 pint/day	575
Dishwasher		1,200
DVD player		25
Electric blanket	Single	60
	Double	100
Electric heat	Baseboard/foot	250
Fan	Attic	500
	Bath	100
	Kitchen	250
	Ceiling	50
	Window, 20-inch	275
Freezer		500
Fryer, deep fat		1,500
Frying pan		1,200
Furnace	Blower	1,000
	Burner	300
Garbage disposer		400
Hair curler		1,200
Hair dryer		1,200
Heat lamp		250
Heater	Portable radiant	1,500
Heating pad		75
Hot plate	Per burner	800

Appliance	Spacing	Watts
Humidifier	Portable	80
Iron		1,100
Light bulb		wattage
Microwave	smallest	800
	medium	1,200
	largest	1,800
Mixer		200
Motor, running	$1/4$ hp	600
	$1/3$ hp	660
	$1/2$ hp	840
	$3/4$ hp	1,140
	1 hp	1,320
	$1\,1/2$ hp	1,820
	2 hp	2,400
	3 hp	3,360
Projector	Slide	500
	LCD	300
Range	Electric	12,000
	Gas	100
Refrigerator	Frost-free	350
	Regular	300
Sewing machine		90
Stereo	40 watts/channel	225
Sunlamp		275
Television	21-inch CRT	120
	32-inch LCD	140
	40-inch plasma	300
	50-inch plasma	400
Toaster oven		1,200
Vacuum cleaner		650
Waffle iron	Single	600
	Double	1,200
Water bed	Heater/no cover	200
Water heater		4,500
Water pump	Shallow	660
	Deep	1,320

Wire and Cable

Color Code

The Code specifies the colors or wire insulation so that it is obvious which wires serve which functions (hot, neutral, or grounding):

Black—hot; connects to the darkest terminal screw on a receptacle or switch

Red—second hot wire when there are two, as in a 240-volt circuit

White—neutral wire; connects to the silver terminal screw on a receptacle or switch

Bar or green—grounding wire; connects to the green-tinted screw on a receptacle, switch, fixture, or appliance

The Code allows a white wire to be used as a black wire if visibly painted or taped black.

Wire and Cable Types

All wire insulation must also be labeled, identifying the type of insulation:

H—heat resistant
R—rubber
T—thermoplastic
W—water resistant

All wire insulation must also be labeled, identifying the type of insulation:

AC—armored (metal jacket) cable
C—corrosion resistant
F—feeder
NM—nonmetallic
U—underground
SE—service entrance

Wire (Single-Lead) Labels

Wire Type	Label	Specifications
Thermoplastic vinyl	T	General purpose to 140°F (60°C)
	TW	General purpose to 140°F (60°C) and water resistant
	THW	General purpose to 167°F (75°C) and water resistant
Rubber	R	General purpose indoor-only to 140°F (60°C)
	RW	General purpose indoor-only to 140°F (60°C) and water resistant
Rubber and cotton braid	RH	General purpose to 167°F (75°C)
	RHH	General purpose to 194°F (90°C)
	RHW	General purpose to 167°F (75°C) and water resistant
	RH/RW	General purpose to 167°F (75°C) dry and 140°F (60°C) wet
Cotton braid	WP	Weatherproof for overhead outdoors

Cable (Multiple-Lead) Labels

Wire Type	Label	Specifications
Thermoplastic vinyl	T	General purpose to 140°F (60°C)
	TW	General purpose to 140°F (60°C) and water resistant
	THW	General purpose to 167°F (75°C) and water resistant
Rubber	R	General purpose indoor-only to 140°F (60°C)
	RW	General purpose indoor-only to 140°F (60°C) and water resistant
Rubber and cotton braid	RH	General purpose to 167°F (75°C)
Cotton braid	WP	Weatherproof for overhead outdoors

Ampacity

Because all wire has electrical resistance, the flow of electrons (current) generates heat and raises the temperature of the conductor, posing a fire danger.

The IRC specifies the current-carrying capacity (ampacity) of wires depending on their size, insulation type, and temperature rating, as shown in the table below.

Ampacity of Copper Wire in Cable and Conduit

	Conductor Temperature Rating					
	60°C	75°C	90°C	60°C	75°C	90°C
	TW, UF	RHW, THHW THW, THWN, XHHW, USE	RHW-2, THHN, THHW THW-2, THWN-2 XHHW, XHHW-2, USE-2	TW, UF	RHW, THHW THW, THWN, XHHW, USE	RHW-2, THHN, THHW THW-2, THWN-2 XHHW, XHHW-2, USE-2
Size, AWG	Copper			Aluminum or Copper-Clad Aluminum		
18	—	—	14	—	—	—
16	—	—	18	—	—	—
14	20	20	25	—	—	—
12	25	25	30	20	20	25
10	30	35	40	25	30	35
8	40	50	55	30	40	45
6	55	65	75	40	50	60
4	70	85	95	55	65	75
3	85	100	110	65	75	85
2	95	115	130	75	90	100
1	110	130	150	85	100	115
1/0	125	150	170	100	120	135
2/0	145	175	195	115	135	150
3/0	165	200	225	130	155	175
4/0	195	230	260	150	180	205

Recommended Maximum Length of Branch Circuits, Feet

	Circuit Amperage						
Size, AWG	5	10	15	20	30	40	50
14	234	117	78	—	—	—	—
12	517	187	124	93	—	—	—
10	595	298	198	149	99	—	—
8	—	—	—	236	157	118	—
6	—	—	—	—	—	183	146
4	—	—	—	—	—	—	234

Electrical Boxes

All wire connections, whether to switches, receptacles, and light fixtures or as junctions between branch circuits, must be made within a code-approved box having an approved cover plate. The code specifies the number of conductors allowed on the basis of box volume.

By conductor, the code means anything that occupies an equivalent volume. To arrive at the number of conductors, add:

- each wire terminating in the box
- each wire running unbroken through the box
- each device, such as a switch or receptacle
- each cable clamp or fixture stud
- all grounding wires lumped as one

Box volume is usually stamped on the box. If not, compute the volume from the inside dimensions. Box extensions and covers having volume add to the total volume.

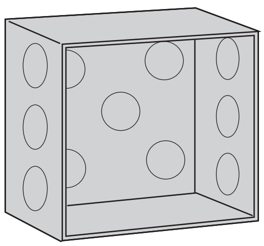
The table below lists the conductor capacities of most available boxes.

Maximum Number of Conductors in Metal Boxes

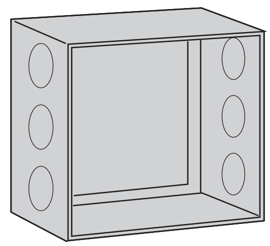
		Maximum Number of Conductors[1]						
Box Dimensions, inches	**Capacity, cu in**	**No. 18**	**No. 16**	**No. 14**	**No. 12**	**No. 10**	**No. 8**	**No. 6**
4 × 1¼ round or octagonal	12.5	8	7	6	5	5	4	2
4 × 1½ round or octagonal	15.5	10	8	7	6	6	5	3
4 × 2⅛ round or octagonal	21.5	14	12	10	9	8	7	4
4 × 1¼ square	18.0	12	10	9	8	7	6	3
4 × 1½ square	21.0	14	12	10	9	8	7	4
4 × 2⅛ square	30.3	20	17	15	13	12	10	6
4 11/16 × 1¼ square	25.5	17	14	12	11	10	8	5
4 11/16 × 1½ square	29.5	19	16	14	13	11	9	5
4 11/16 × 2⅛ square	42.0	28	24	21	18	16	14	8
3 × 2 × 1½ device	7.5	5	4	3	3	3	2	1
3 × 2 × 2 device	10.0	6	5	5	4	4	3	2
3 × 2 × 2¼ device	10.5	7	6	5	4	4	3	2
3 × 2 × 2½ device	12.5	8	7	6	5	5	4	2
3 × 2 × 1¾ device	14.0	9	8	7	6	5	4	2
3 × 2 × 3½ device	18.0	12	10	9	8	7	6	3
4 × 2⅛ × 1½ device	10.3	6	5	5	4	4	3	2
4 × 2⅛ × 1⅞ device	13.0	8	7	6	5	5	4	2
4 × 2⅛ × 2⅛ device	14.5	9	8	7	6	5	4	2
3¾ × 2 × 2½ masonry box/gang	14.0	9	8	7	6	5	4	2
3¾ × 2 × 3½ masonry box/gang	21.0	14	12	10	9	8	7	4

[1] Where no volume allowances are made for clamps, fixture studs, hickeys, etc., as described in IRC Sections E3805.12.2.2 through E3805.12.2.5.

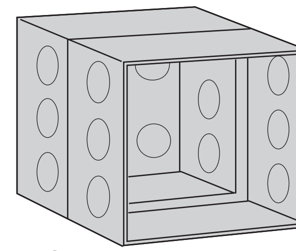
Common Electrical Boxes



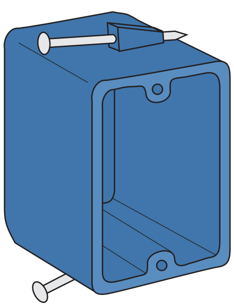
Square



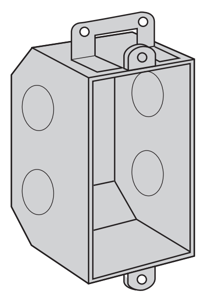
Square extender



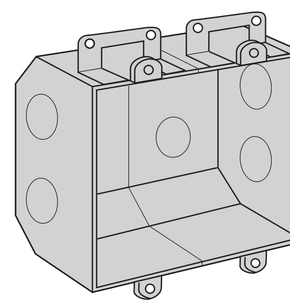
Square box with extender



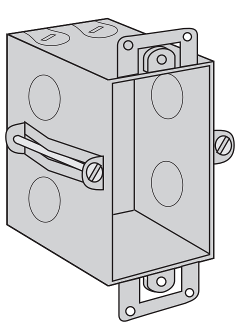
Plastic handy box



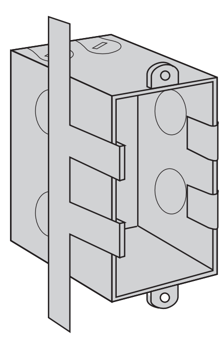
Bevelled switch



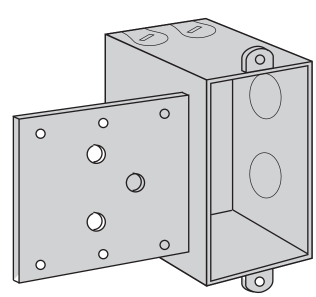
Ganged bevelled switch



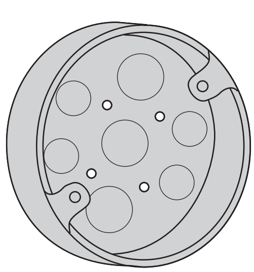
Box with ears and clamps



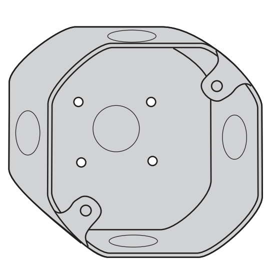
Wall box with brackets



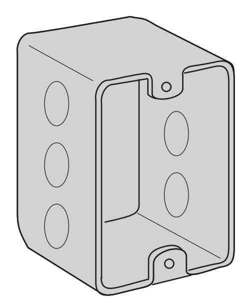
Box with side bracket



Round pancake



Octagon box



Metal handy box

Running Cable

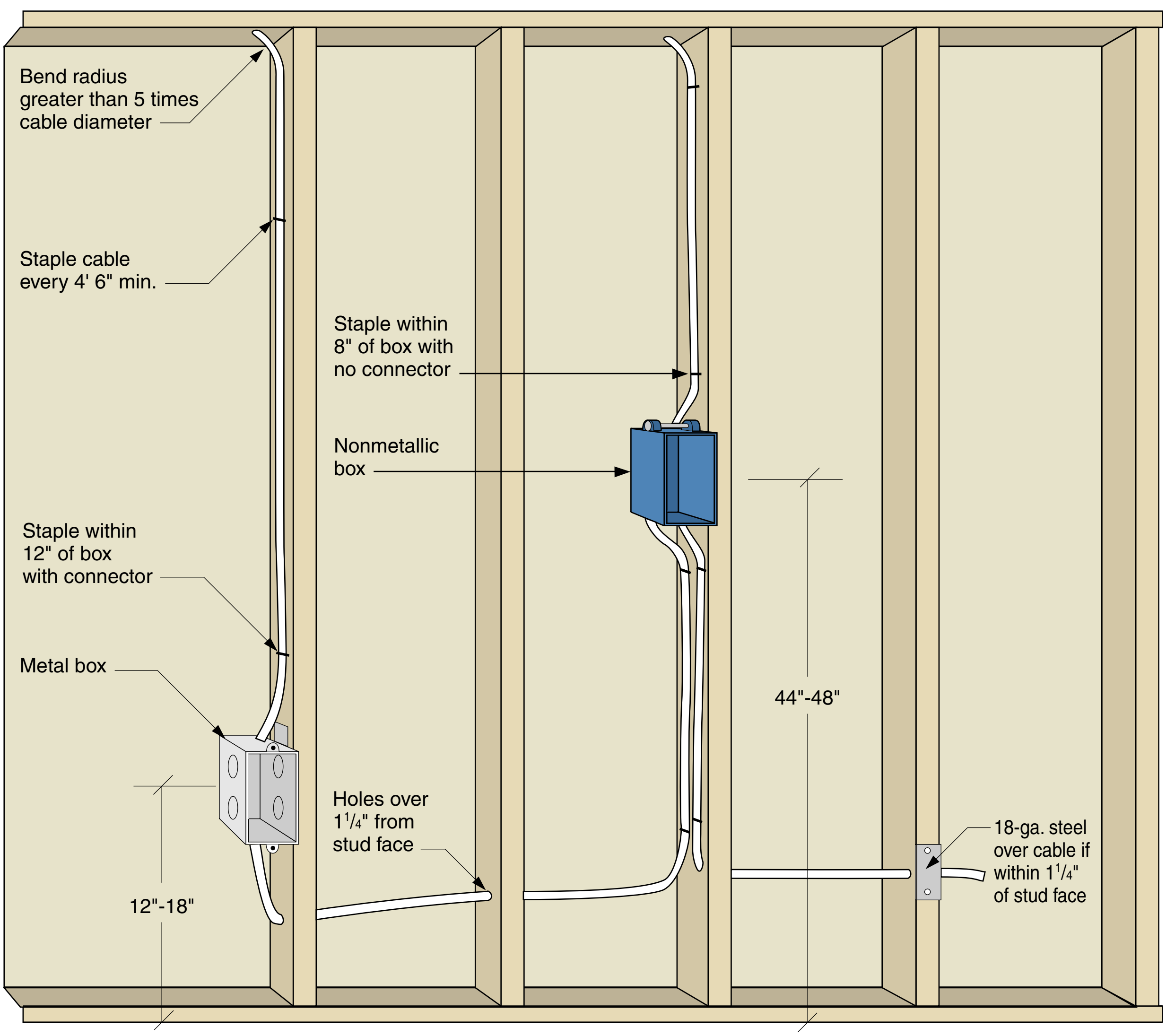
With nonmetallic (NM) cable and plastic boxes, running cable through walls and ceilings is fairly simple. The more difficult part will be in fitting batt insulation around the cable and boxes.

The illustration below shows the key provisions in the International Residential Code:

- staple within 8" of a plastic box
- staple within 12" of a metal box
- staple every 4' 6" minimum along framing
- bore holes in middle of framing
- cable within $1^1/_4$" of stud face to be protected by 18-gauge metal plate
- radius of cable bends 5x cable diameter, min.
- bore holes in middle of framing

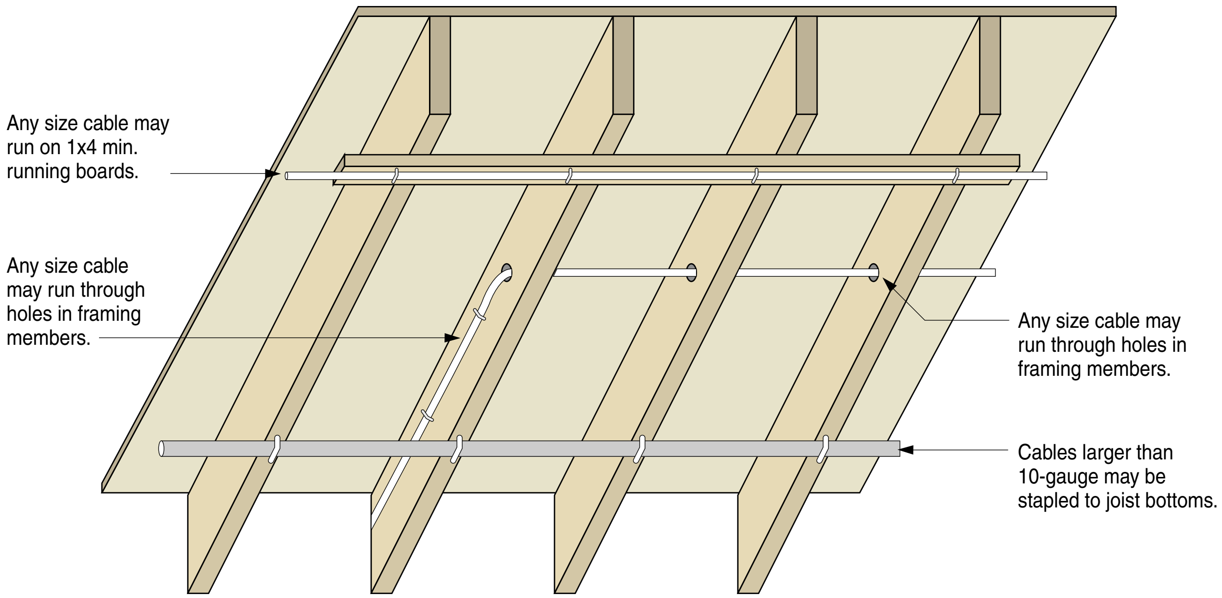
Rules for ceilings and floors are illustrated on the facing page.

Running NM Cable in Walls

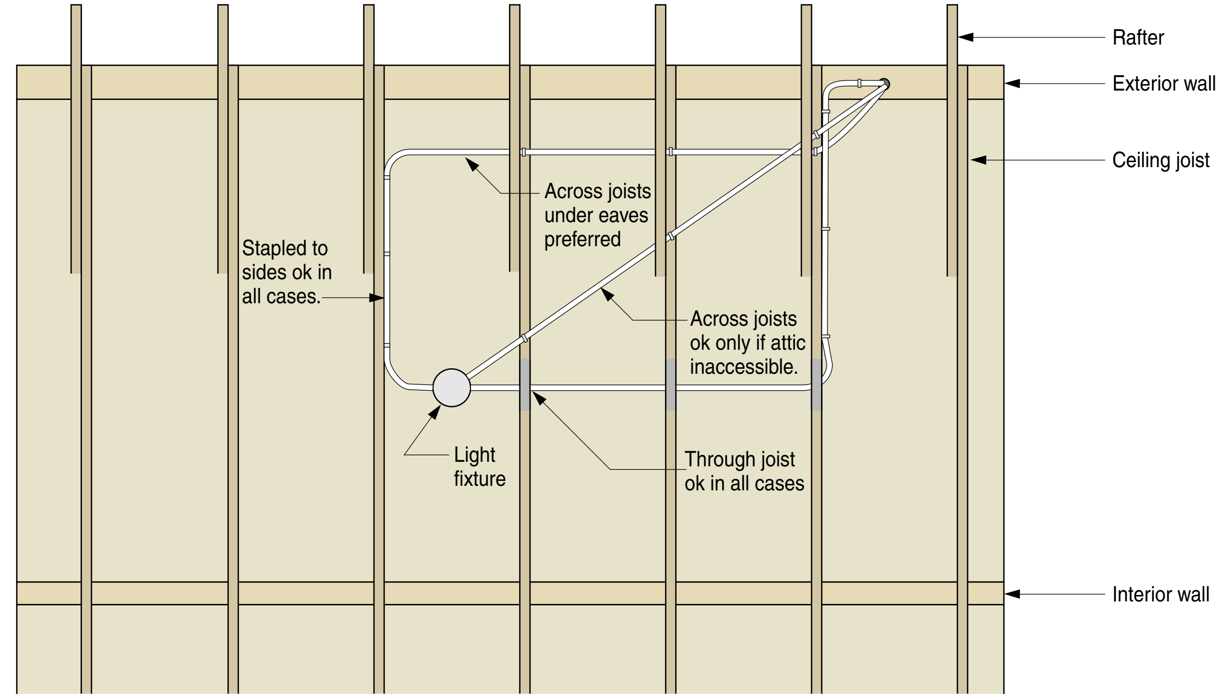


Running NM Cable in Floors and Ceilings

UNFINISHED BASEMENT CEILING



ATTIC FLOOR WITHOUT LADDER OR STAIRS



Running Conduit

The International Residential Code calls for wires to be protected by conduit when run through concrete or when otherwise exposed to physical damage. Two types of conduit predominate in residential construction: electrical metallic tubing (EMT) and Schedule 80 PVC rigid nonmetallic conduit (RNC).

EMT is the easiest to use and the most common. All conduit comes in straight 10-foot lengths and must be connected using only fittings appropriate for the application. Fittings (see the top illustration on the facing page) are designed for either dry inside locations or wet outside locations. Outside fittings may be used either inside or outside.

Rules for Running Conduit

- Conduit is always run before the wire it will contain. Wires are pulled though the conduit one section at a time, using a special pulling wire.
- A special pulling fitting must be provided for every 360° of accumulated bend in the conduit.
- Metal conduit is grounded, so no separate grounding wire is required; the white grounded-neutral wire is required, however.
- The size of a conduit is dictated by the number and type of wires it contains (see table below).

Bending EMT

Always use a conduit bender specifically designed for the size conduit being installed. The bottom illustration on the facing page shows the operation of bending conduit:

1. Measure the desired finished distance of the bend. This is usually the distance to a wall.

2. For 1/2-inch conduit, add 2 1/4 inches to the finished distance and mark the conduit. For other sizes, see the markings on the conduit bender.

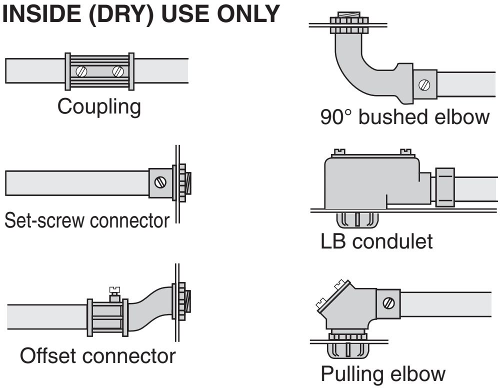
3. Line up the mark with the arrow on the bender and pull back until the conduit makes a 90° angle with no pull on the bender handle.

Maximum Number of Conductors in Electrical Metallic Tubing (EMT)

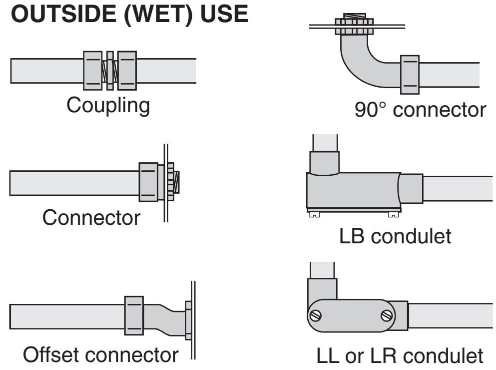
Wire Type	Size, AWG	Trade Size, inches 1/2	3/4	1	1 1/4	1 1/2	2
TW	14	8	15	25	43	58	96
	12	6	11	19	33	45	74
	10	5	8	14	24	33	55
	8	2	5	8	13	18	30
	6	1	3	4	8	11	18
	4	1	1	3	6	8	13
	2	1	1	2	4	6	10
	1	1	1	1	3	4	7
THW	14	6	10	16	28	39	64
	12	4	8	13	23	31	51
	10	3	6	10	18	24	40
	8	1	4	6	10	14	24
	6	1	3	4	8	11	18
	4	1	1	3	6	8	13
	2	1	1	2	4	6	10
	1	1	1	1	3	4	7

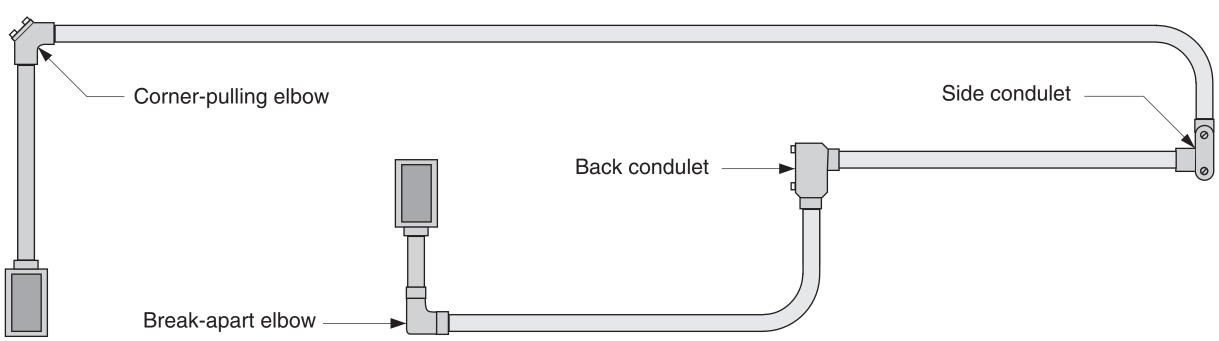
Conduit Fittings

INSIDE (DRY) USE ONLY



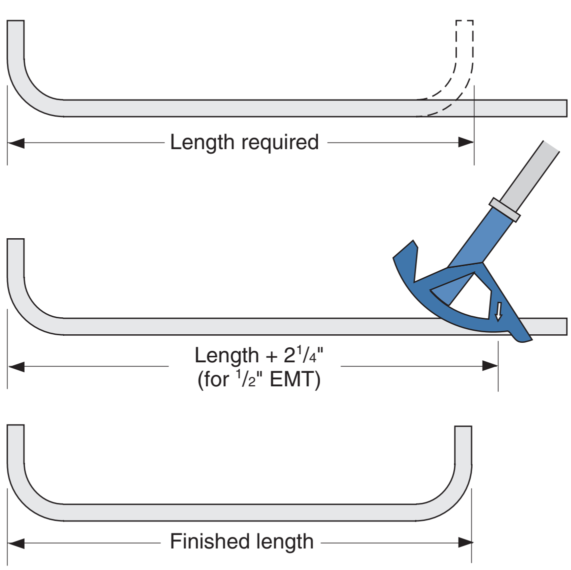
OUTSIDE (WET) USE



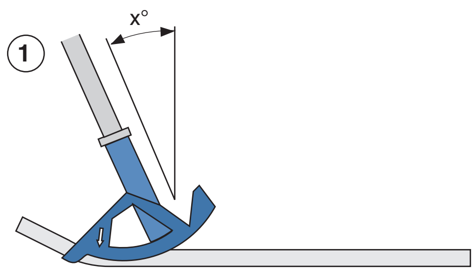


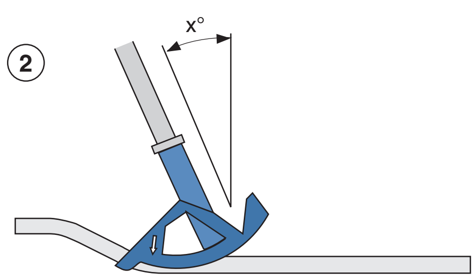
Bending Conduit

BENDING CONDUIT



MAKING A KICKBEND (OFFSET)

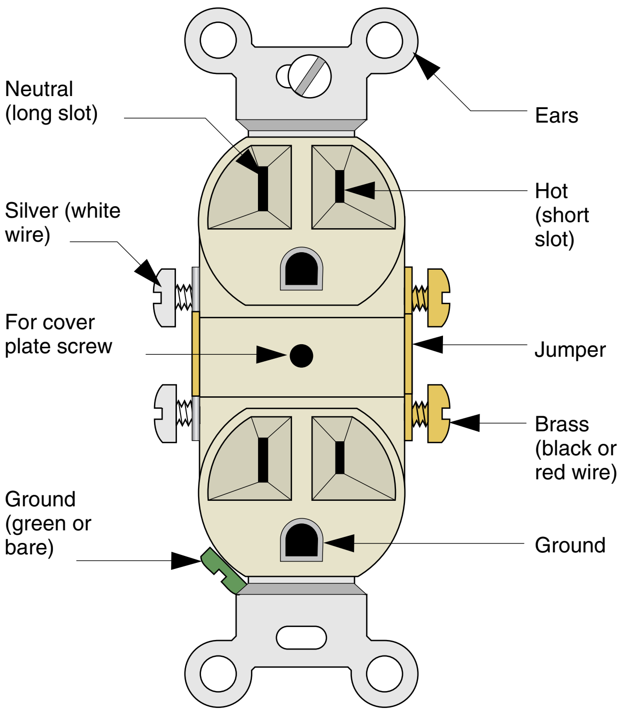




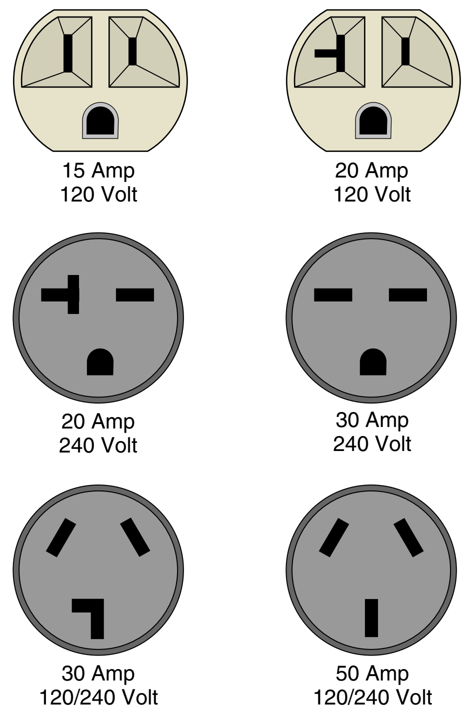
Receptacles

Common Electrical Boxes

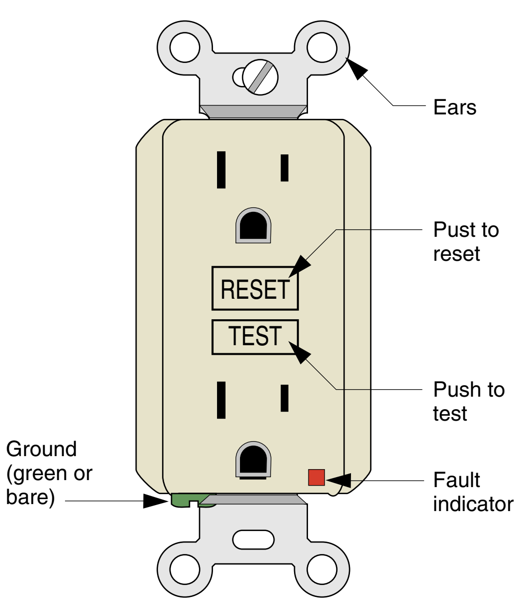
120 VAC RECEPTACLE



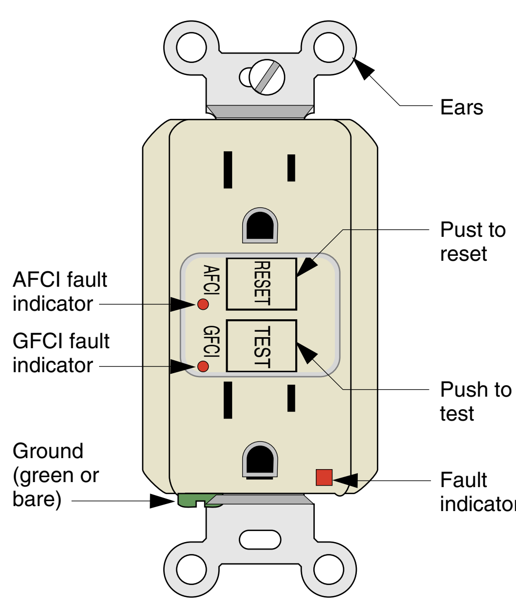
OTHER COMMON RECEPTACLES



GROUND FAULT (GFCI) RECEPTACLE

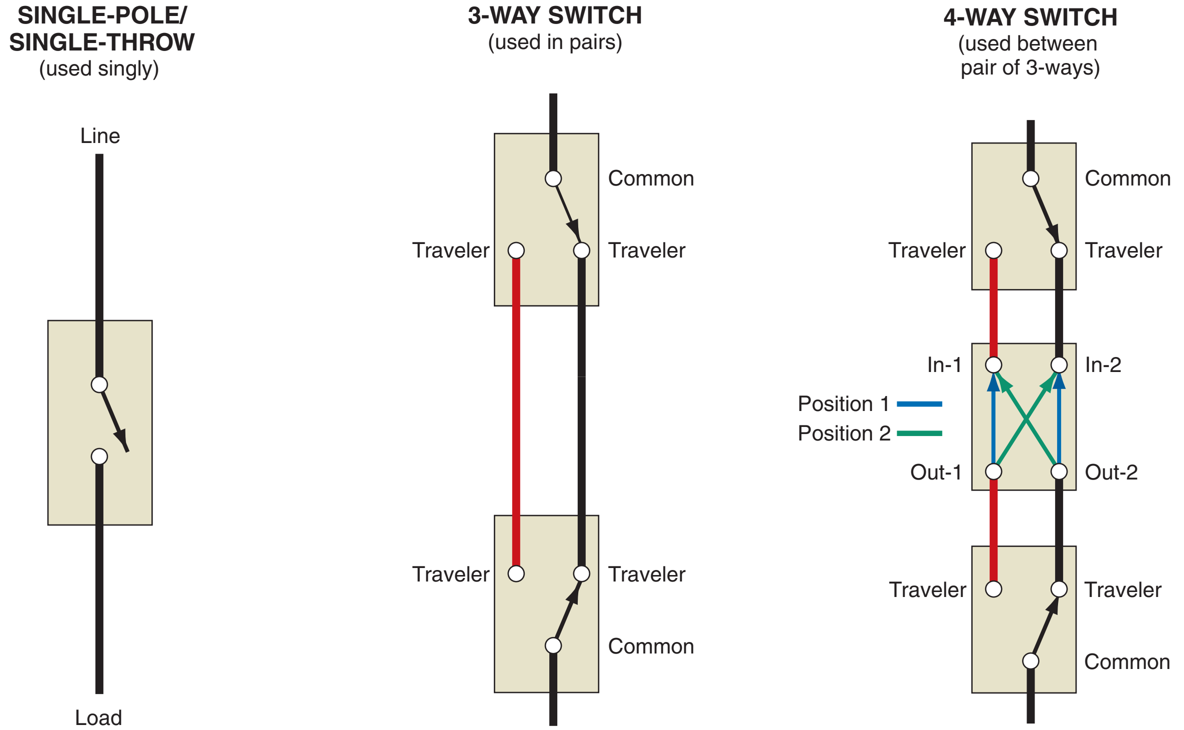


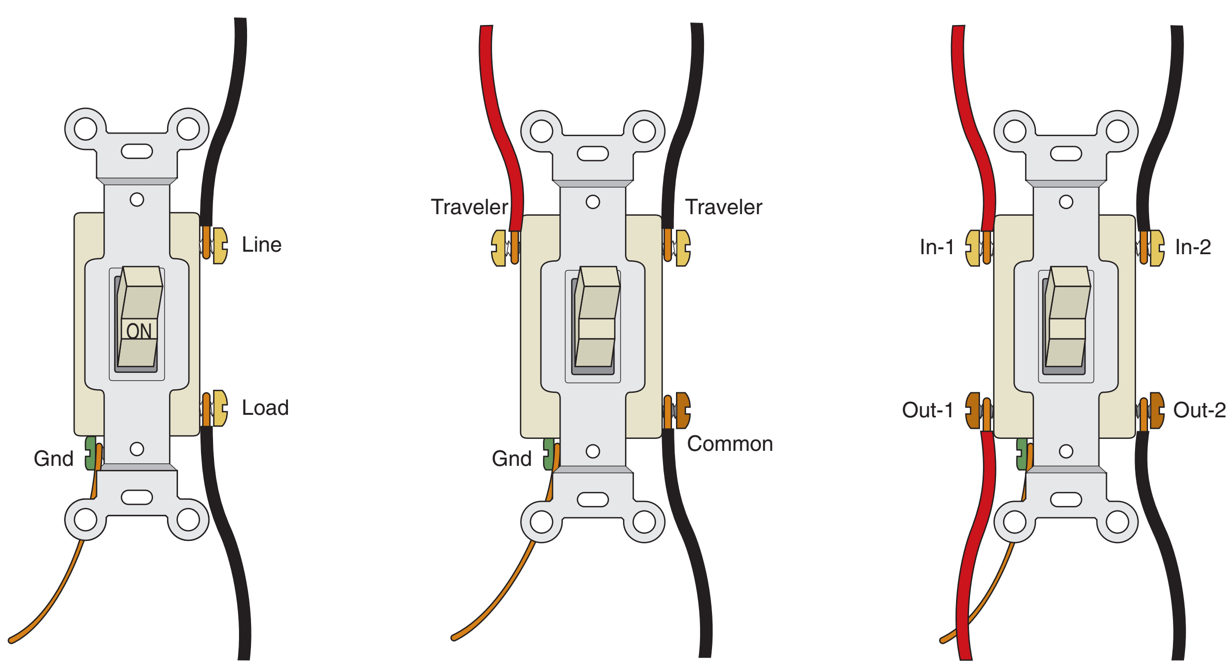
DUAL ARC FAULT (AFCI) RECEPTACLE



Switches

Switch Types

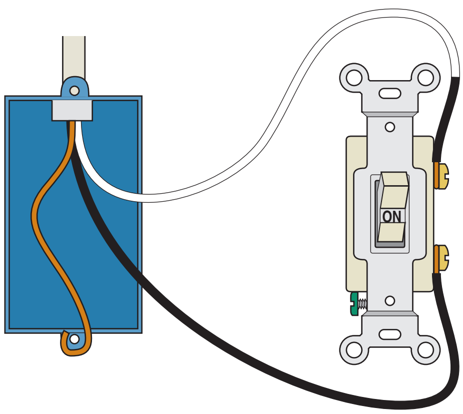




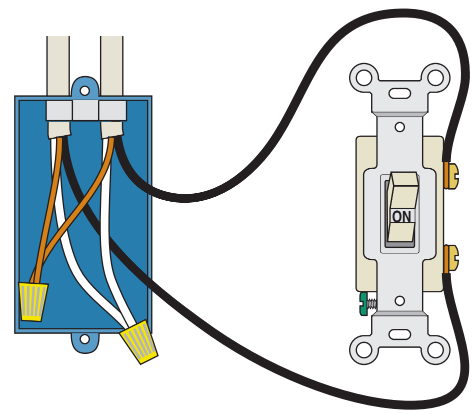
Wiring Switches, Receptacles, and Lights

What to Do with the Grounding Conductor

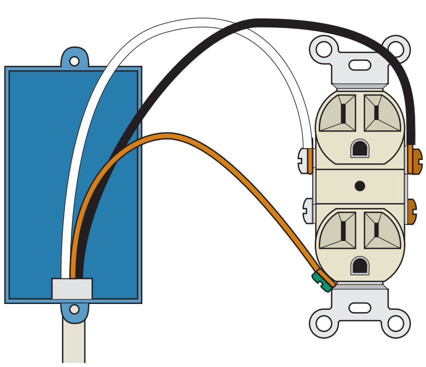
PLASTIC BOX, END OF CIRCUIT



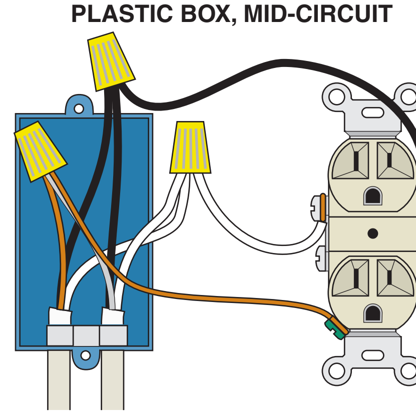
PLASTIC BOX, MID-CIRCUIT



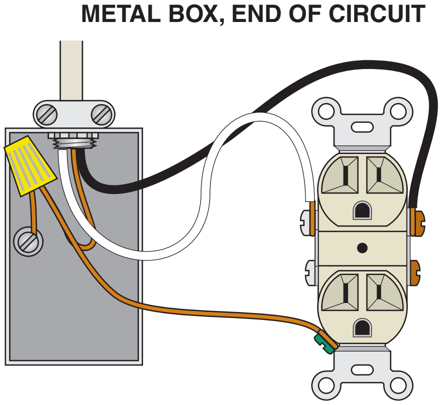
PLASTIC BOX, END OF CIRCUIT



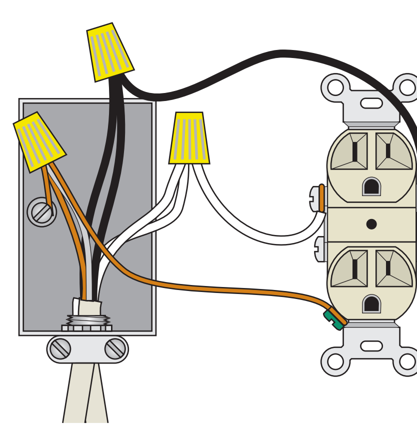
PLASTIC BOX, MID-CIRCUIT



METAL BOX, END OF CIRCUIT

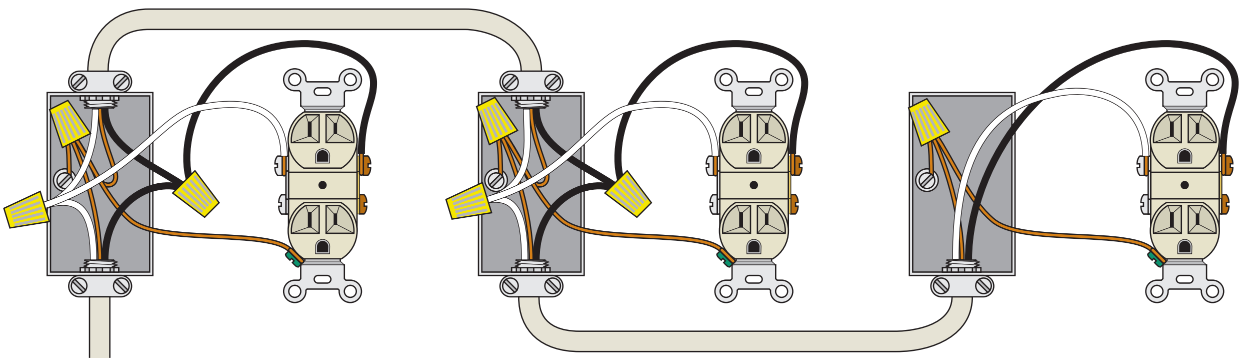


METAL BOX, MID-CIRCUIT



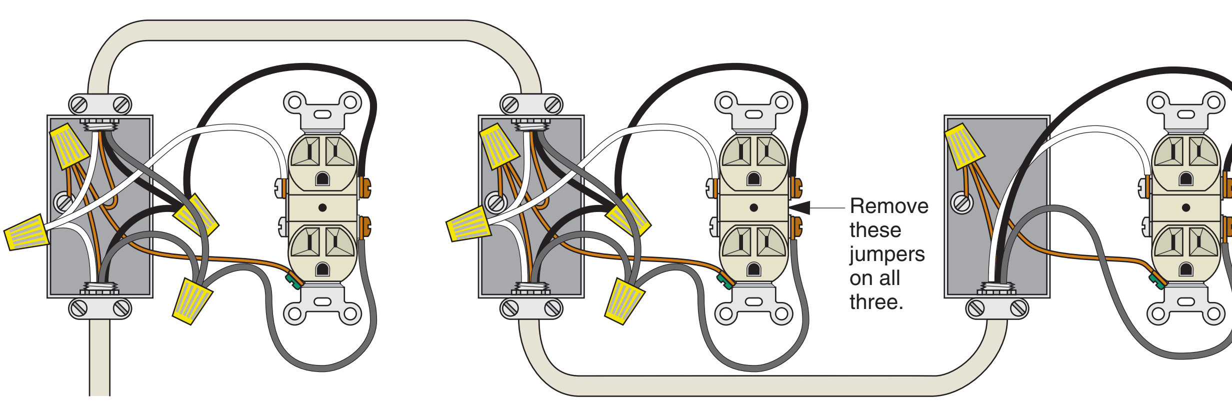
Receptacle Circuits

SERIES OF RECEPTACLES



SPLIT-SWITCHED RECEPTACLE
(top receptacle switched)

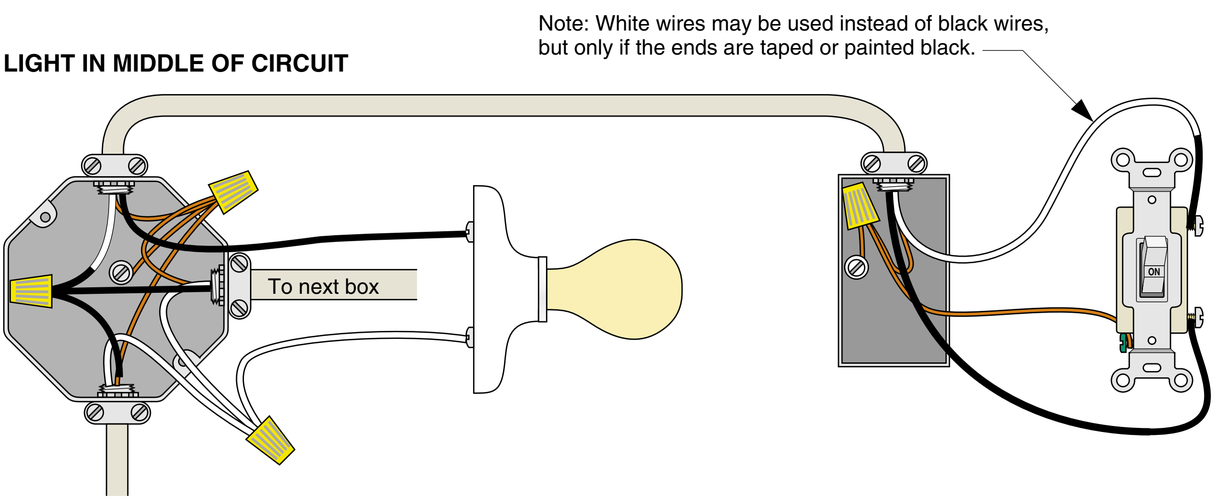
SPLIT-CIRCUIT RECEPTACLE
(two separate circuits)



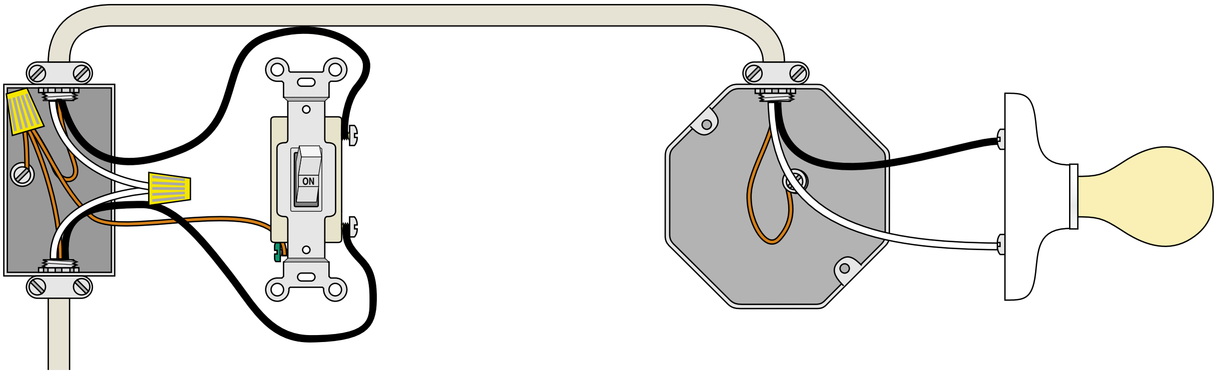
Single-Pole Single-Throw Switches

SPLIT-CIRCUIT RECEPTACLE

LIGHT IN MIDDLE OF CIRCUIT

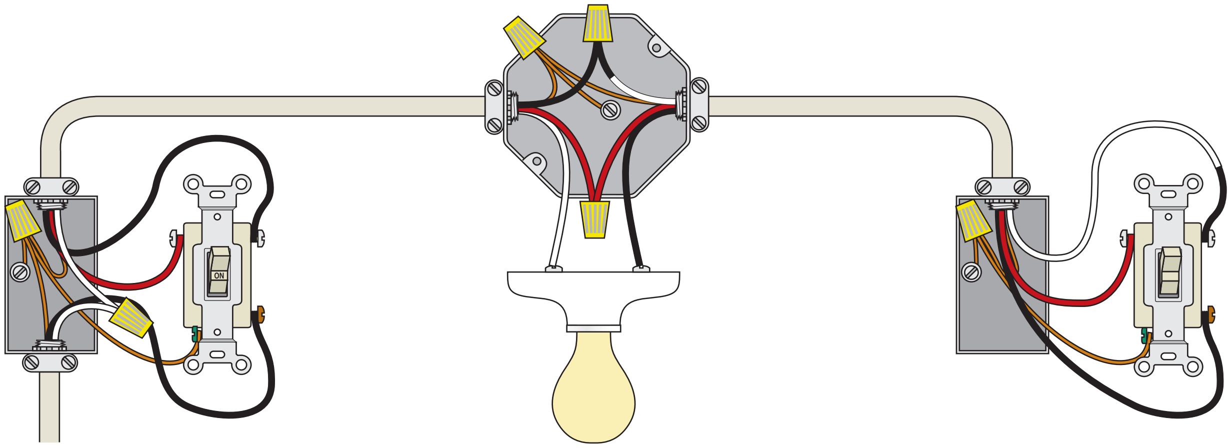


LIGHT AT END OF CIRCUIT

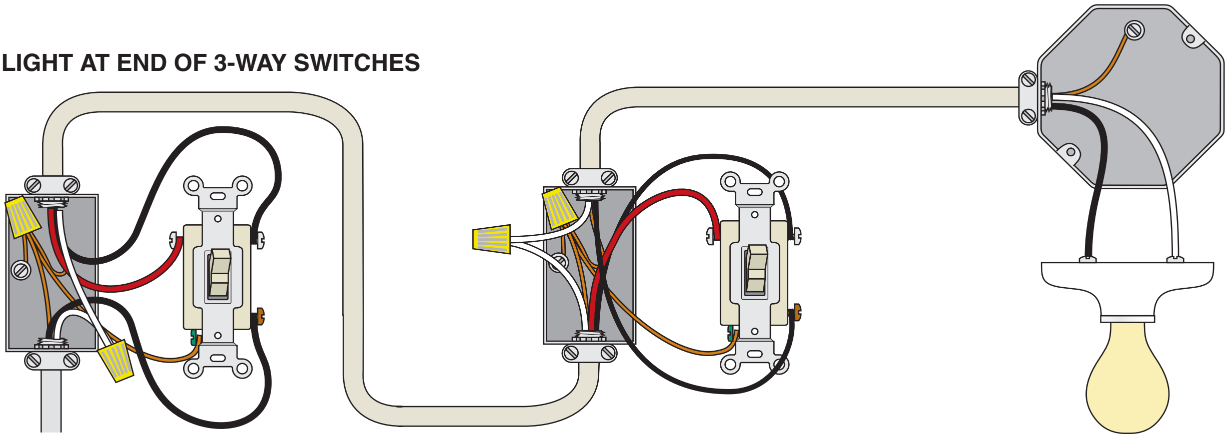


Three- and Four-Way Switches

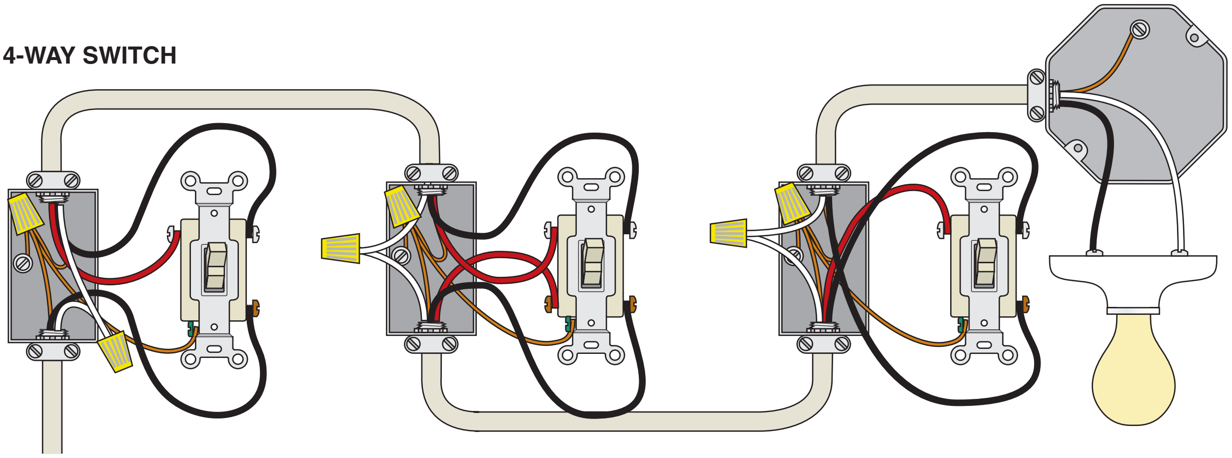
LIGHT IN MIDDLE OF 3-WAY SWITCHES



LIGHT AT END OF 3-WAY SWITCHES



4-WAY SWITCH



Solar Electricity

The amount of solar energy falling on the Earth's surface in two hours is greater than the total energy consumed worldwide in a whole year! And it produces zero carbon dioxide! Many scientists—even those working for utility companies—believe electricity generated from the sun will someday become our major source of energy. The next 12 pages provide the information required to evaluate the practicality of solar electricity for your home.

The Sun's Path

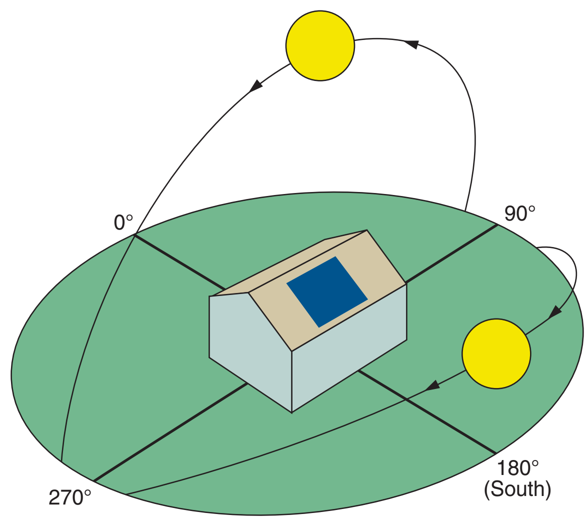
The illustration at right shows the paths of the sun through the sky at winter and summer solstices when it is lowest and highest above the horizon. Radiation received on the roof-mounted collector is obviously greatest when the collector is perpendicular to the sun's rays and facing true south. The total radiation received during a day thus depends on both the horizontal direction (azimuth) and the tilt (altitude) of the collector.

The optimum azimuth and tilt of a flat plate collector are: azimuth 180° (facing true south) and tilt above horizontal equal to the latitude. The table at right shows the decreases in daily gain for a collector at latitude 30°N at other azimuths and tilts. The good news: deviations in azimuth of up to ±45° from true south and tilt of up to ±15° from latitude result in losses of 7% or less.

Annual Insolation

The amount of daily solar radiation received at a location depends not only on latitude but also on cloudiness. The National Solar Radiation Data Base 1961–1990 (NSRDB) contains 30 years of measured solar radiation from 237 National Weather Service sites in the U.S. plus Guam and Puerto Rico (see the map at right). For convenience in calculating estimated solar electric system performance, a subset of data is presented as the annual average radiation on flat plate collectors tilted south at latitude angle in kWhr/m²/day. The table on the facing page lists the values for 120 of the 237 locations.

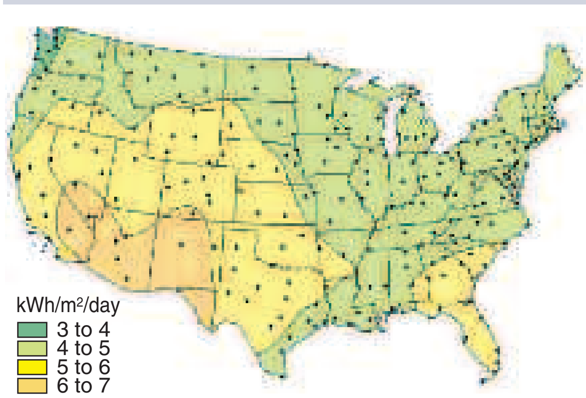
The Sun's Path, Summer and Winter



Fraction of Maximum Solar Gain for Flat Plate Solar Collectors at 30°N

	Tilt, degrees from horizontal					
Azimuth	0	15	30	45	60	90
S (South)	0.89	0.97	1.00	0.97	0.89	0.58
SSE, SSW	0.89	0.89	0.99	0.96	0.88	0.59
SE, SW	0.89	0.95	0.96	0.93	0.85	0.60
ESE, WSW	0.89	0.92	0.91	0.87	0.79	0.57
E, W	0.89	0.88	0.84	0.78	0.70	0.52

Average Insolation, kWh/m²/day



Annual Average Radiation on Flat Plate Collectors Tilted South at Latitude Angle

State, City	kWhr/m²/day
ALABAMA, Mobile	4.9
Montgomery	5.1
ALASKA, Anchorage	3.0
Barrow	2.5
Big Delta	3.4
Fairbanks	3.3
Kodiak	3.1
Nome	3.3
ARIZONA, Flagstaff	6.0
Phoenix	6.5
ARKANSAS, Fort Smith	5.1
Little Rock	5.0
CALIFORNIA, Arcata	4.4
Fresno	5.7
Los Angeles	5.6
San Diego	5.7
San Francisco	5.4
COLORADO, Alamosa	6.3
Boulder/Denver	5.5
Pueblo	5.9
CONNECTICUT, Bridgeport	4.4
Hartford	4.4
DELAWARE, Wilmington	4.6
FLORIDA, Daytona Beach	5.2
Key West	5.5
Miami	5.2
Tampa	5.3
GEORGIA, Atlanta	5.1
Augusta	5.1
Savannah	5.1
HAWAII, Hilo	4.8
Honolulu	5.7
IDAHO, Boise	5.1
Pocatello	5.0
ILLINOIS, Chicago	4.4
Peoria	4.6
Springfield	4.8
INDIANA, Evansville	4.7
South Bend	4.2
IOWA, Des Moines	4.8
Waterloo	4.6
KANSAS, Dodge City	5.6
Topeka	4.9
KENTUCKY, Lexington	4.5
Louisville	4.6
LOUISIANA, Baton Rouge	4.9
New Orleans	5.0
MAINE, Caribou	4.2
Portland	4.6
MARYLAND, Baltimore	4.6
MASSACHUSETTS, Boston	4.6
Worcester	4.5
MICHIGAN, Detroit	4.2
Flint	4.1
Grand Rapids	4.2
Lansing	4.2
MINNESOTA, Duluth	4.4
International Falls	4.3
Minneapolis/St. Paul	4.6
MISSISSIPPI, Jackson	5.1
Meridian	4.9
MISSOURI, Kansas City	4.9
St. Louis	4.8
MONTANA, Billings	5.0
Missoula	4.3
NEBRASKA, North Platte	5.3
Omaha	4.9
NEVADA, Las Vegas	6.5
Reno	5.8
NEW HAMPSHIRE, Concord	4.6
NEW JERSEY, Atlantic City	4.6
NEW MEXICO, Albuquerque	6.4
Tucumcari	6.0
NEW YORK, Albany	4.3
Buffalo	4.1
New York City	4.6
NO. CAROLINA, Asheville	4.9
Raleigh/Durham	5.0
NO. DAKOTA, Bismarck	4.9
Fargo	4.6
OHIO, Akron/Canton	4.1
Cleveland	4.1
Toledo	4.4
OKLAHOMA, Oklahoma City	5.4
Tulsa	5.1
OREGON, Astoria	3.6
Eugene	4.1
Portland	3.9
Redmond/Bend	5.1
PENNSYLVANIA, Allentown	4.4
Philadelphia	4.6
Pittsburgh	4.2
PUERTO RICO, San Juan	5.5
RHODE ISLAND, Providence	4.5
SO. CAROLINA, Charleston	5.1
Columbia	5.1
SO. DAKOTA, Huron	4.8
Rapid City	5.2
TENNESSEE, Memphis	5.0
Nashville	4.9
TEXAS, Austin	5.3
Brownsville	5.0
El Paso	6.5
Houston	4.8
San Antonio	5.4
UTAH, Cedar City	5.9
Salt Lake City	5.3
VERMONT, Burlington	4.3
VIRGINIA, Norfolk	4.8
Richmond	4.8
Roanoke	4.8
WASHINGTON, Seattle	3.7
Spokane	4.5
Yakima	4.8
WEST VIRGINIA, Charleston	4.4
Elkins	4.2
WISCONSIN, Green Bay	4.4
Milwaukee	4.5
WYOMING, Casper	5.3
Cheyenne	5.3

Shading

The annual average radiation values on p. 385 assume that there's nothing blocking the sun's direct rays. Solar photovoltaic panels are sensitive to even small degrees of shading, so trees, nearby buildings, even chimneys and roof vent pipes can decrease output. For this reason it is important to survey the monthly paths of the sun from the location of the panels.

Professionals use equipment that costs hundreds to several thousand dollars to assess the shading through the year. These devices speed the analysis, but the same results can be obtained with simpler, less expensive tools. These are: 1) either a Theodolite® app or a simple protractor and weight on a string, and 2) a sun chart (pp. 388–392) for the latitude of the site. Remember that on a sun chart the height scale represents *altitude* from 0° to 90°, the angle of the sun above the horizon; the horizontal scale represents *azimuth*, the number of degrees east or west of true south.

Using the Theodolite App

If you have a smart phone or pad, the Theodolite app provides instant readings of altitude and azimuth (see the screen save example at top right). Snap a series of screen shots and transcribe the outlines of shading objects onto the chart at a later time.

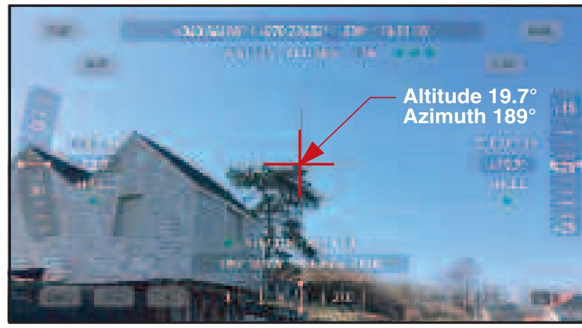
Using a Protractor and Weight

To measure altitude with a protractor, sight the top of an object along the straight edge of a protractor and read altitude where the weighted string crosses the outside of the scale.

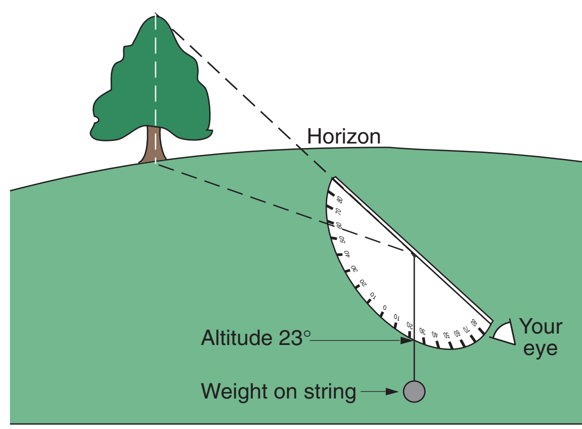
To find azimuth, find true north-south as described on p. 38, then use the protractor and weighted string as shown in the bottom illustration. Point the 180° mark on the protractor to true south and hold the end of the string up to the object. The string will cross the protractor at the azimuth reading.

Take as many readings as you need to plot the outlines of all obstructing objects, as shown in the charts on the facing page.

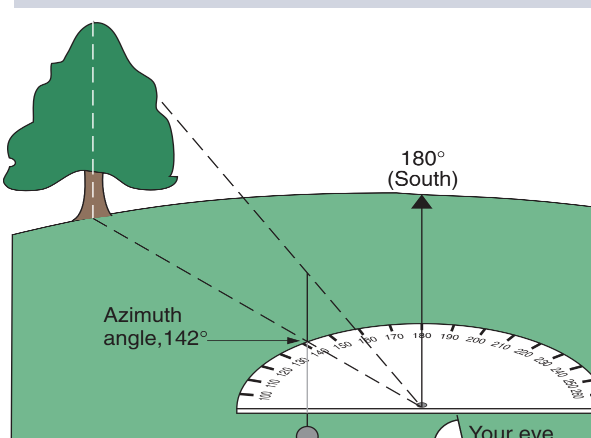
Theodolite App for Smart Phones



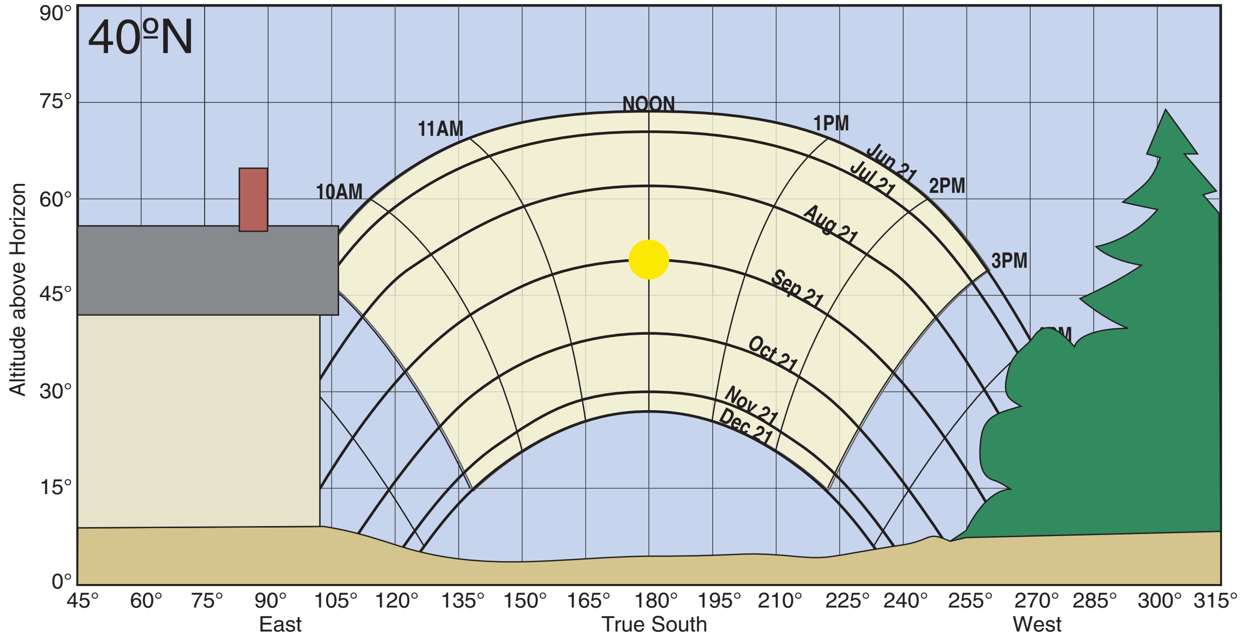
Altitude with a Protractor



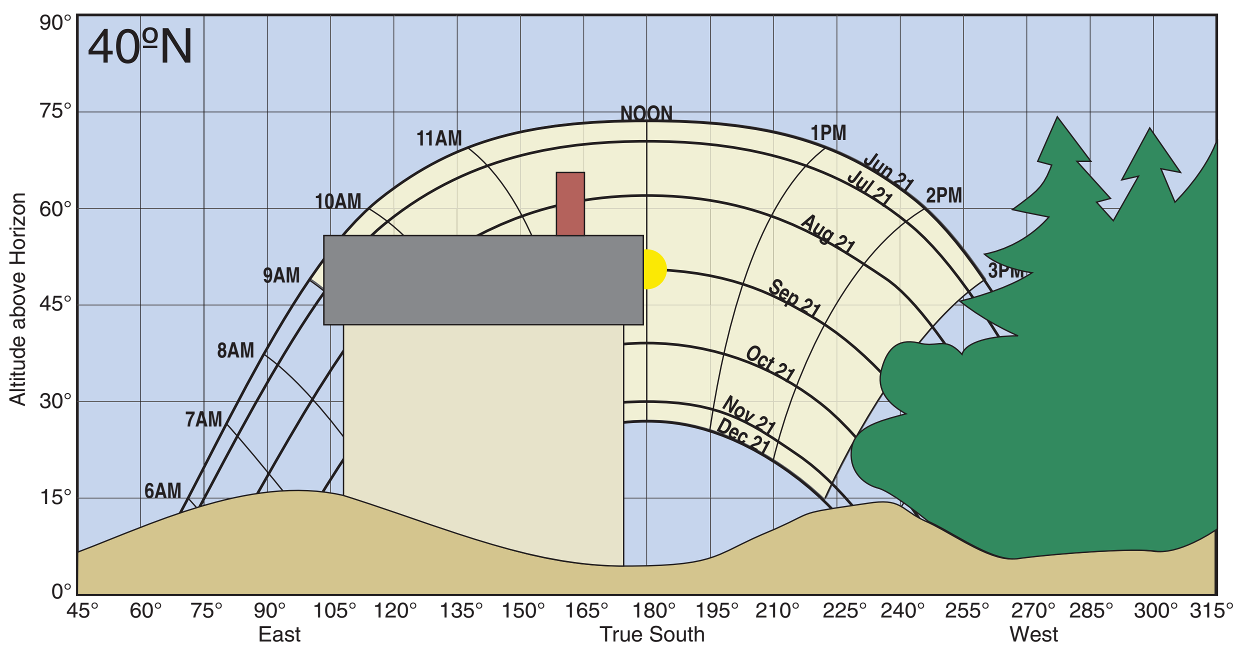
Azimuth with a Protractor



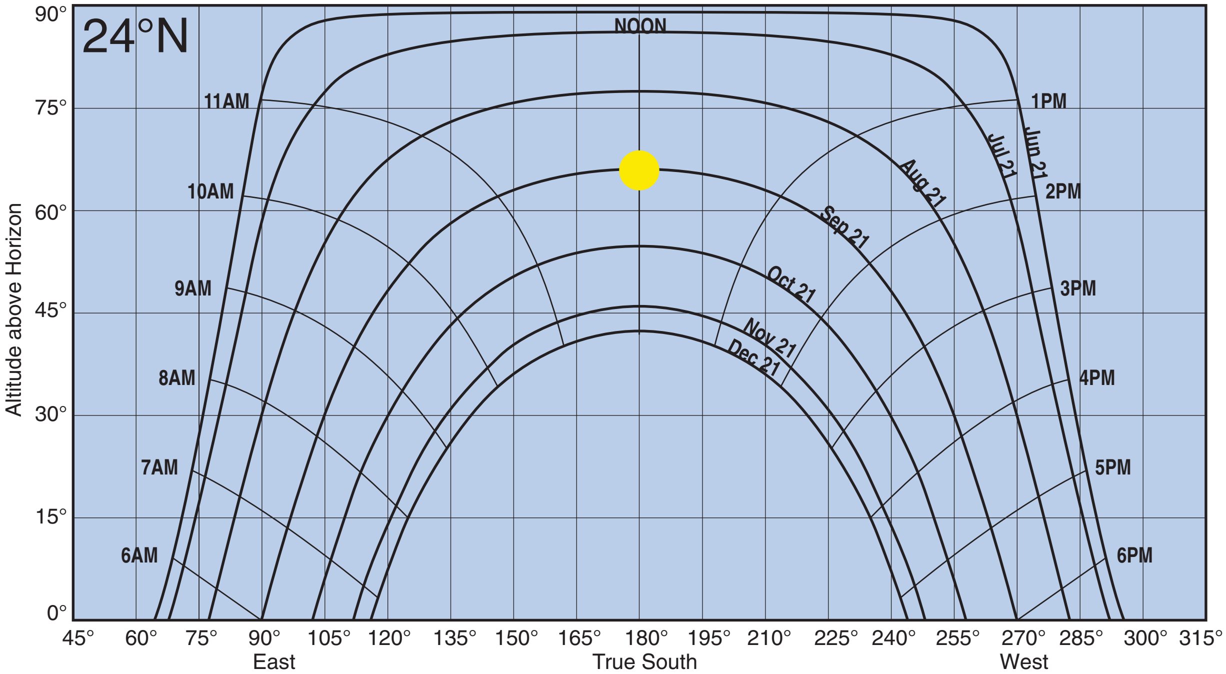
An Example of Good Solar Access



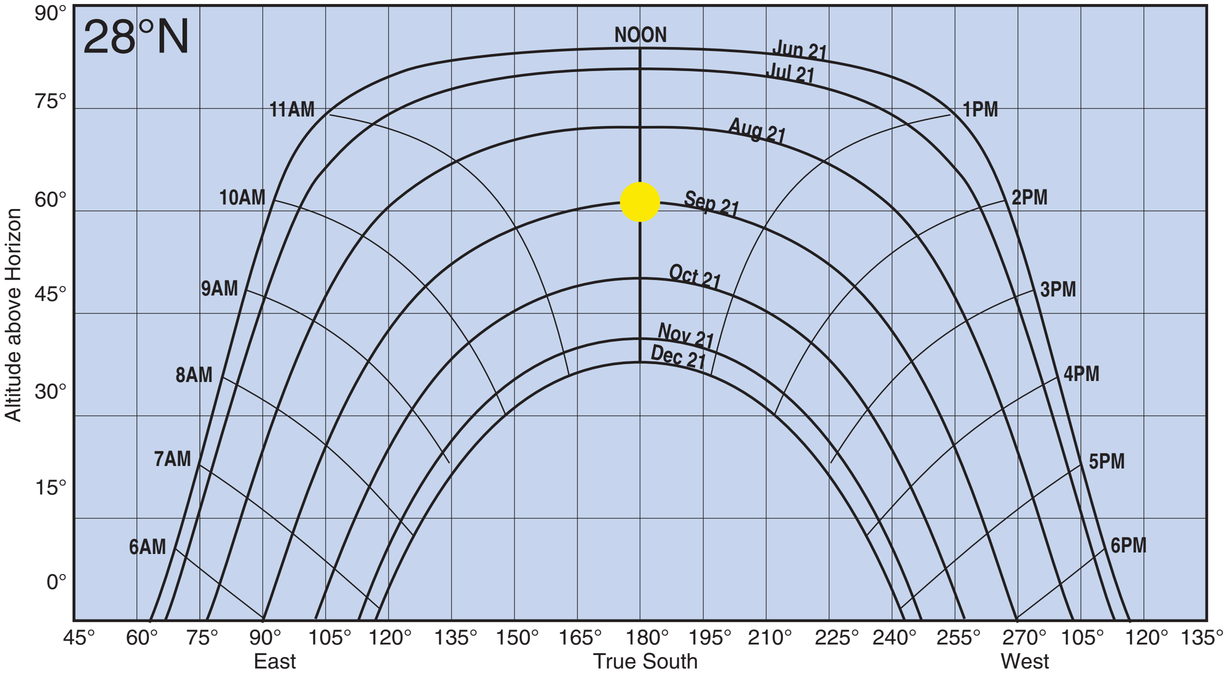
An Example of Poor Solar Access



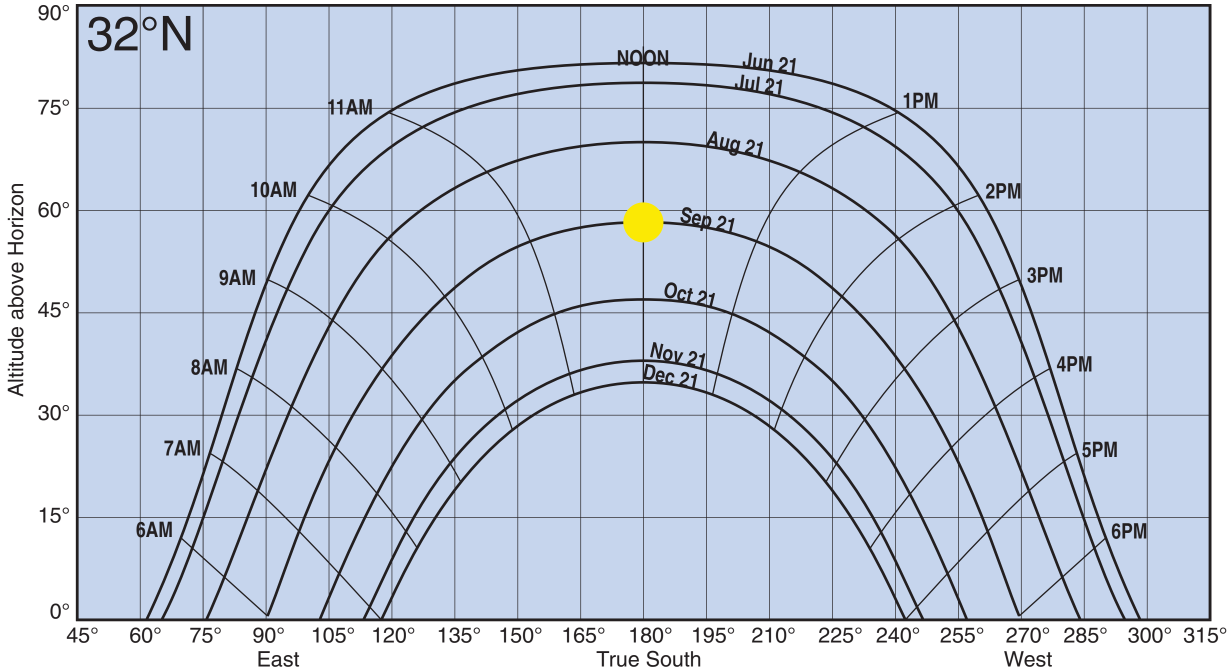
Sun Chart for Latitude 24° North



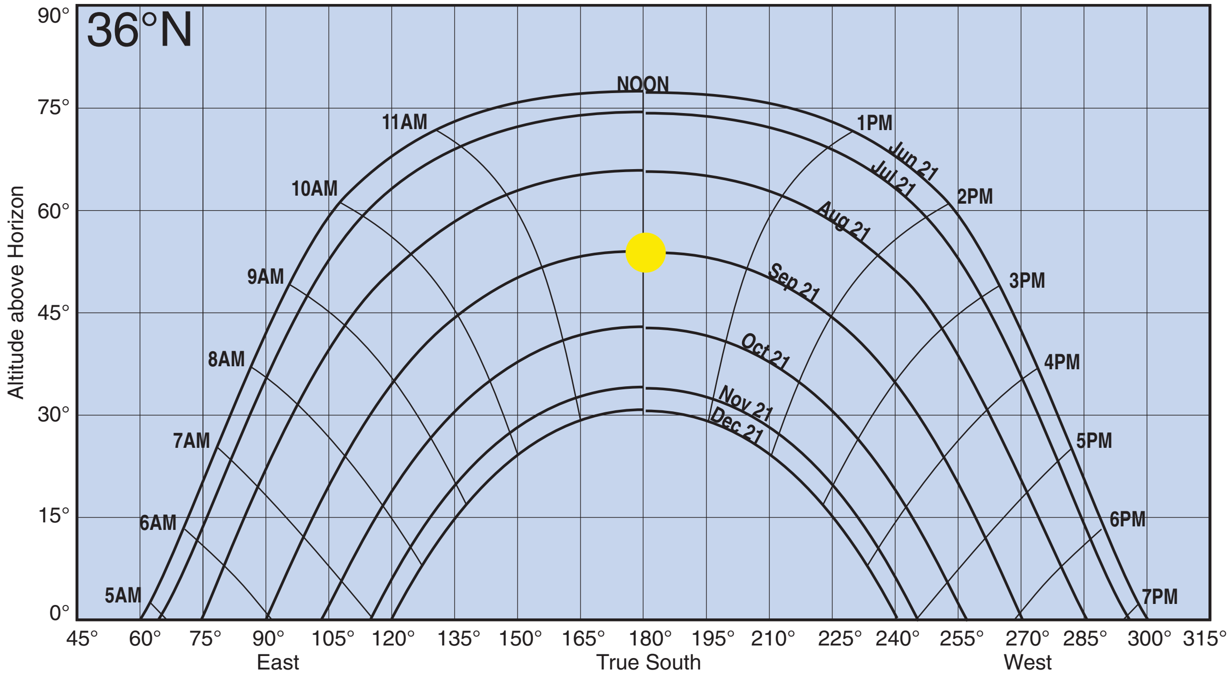
Sun Chart for Latitude 28° North



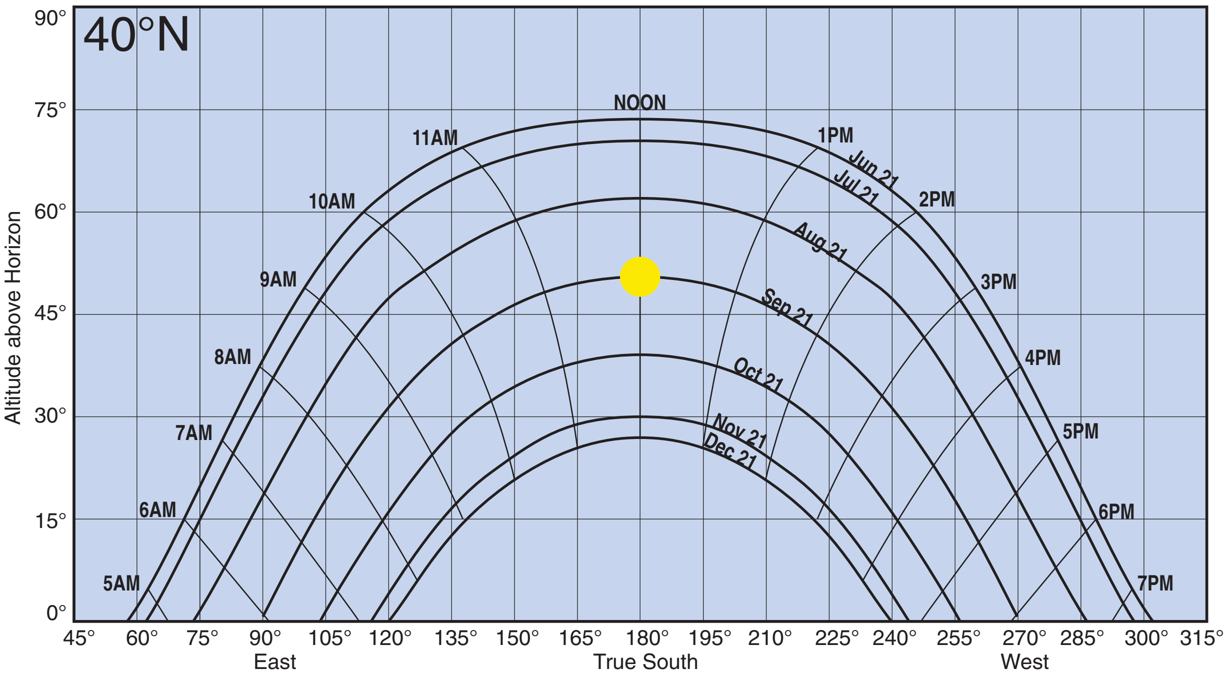
Sun Chart for Latitude 32° North



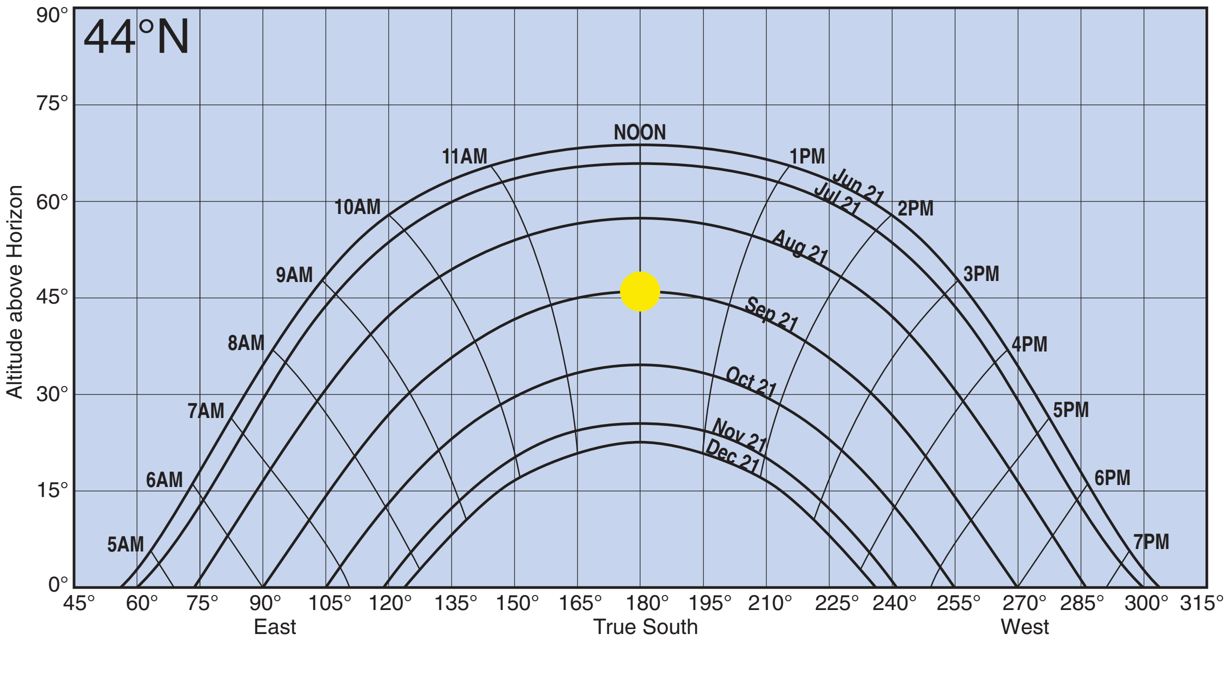
Sun Chart for Latitude 36° North



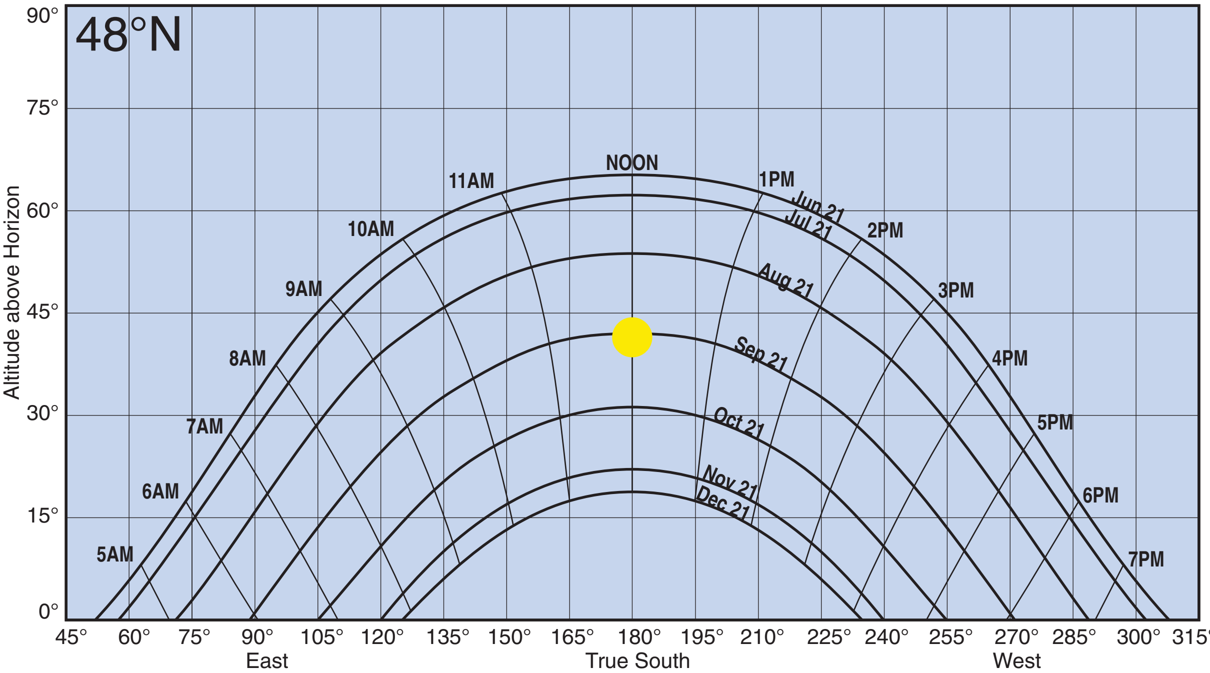
Sun Chart for Latitude 40° North



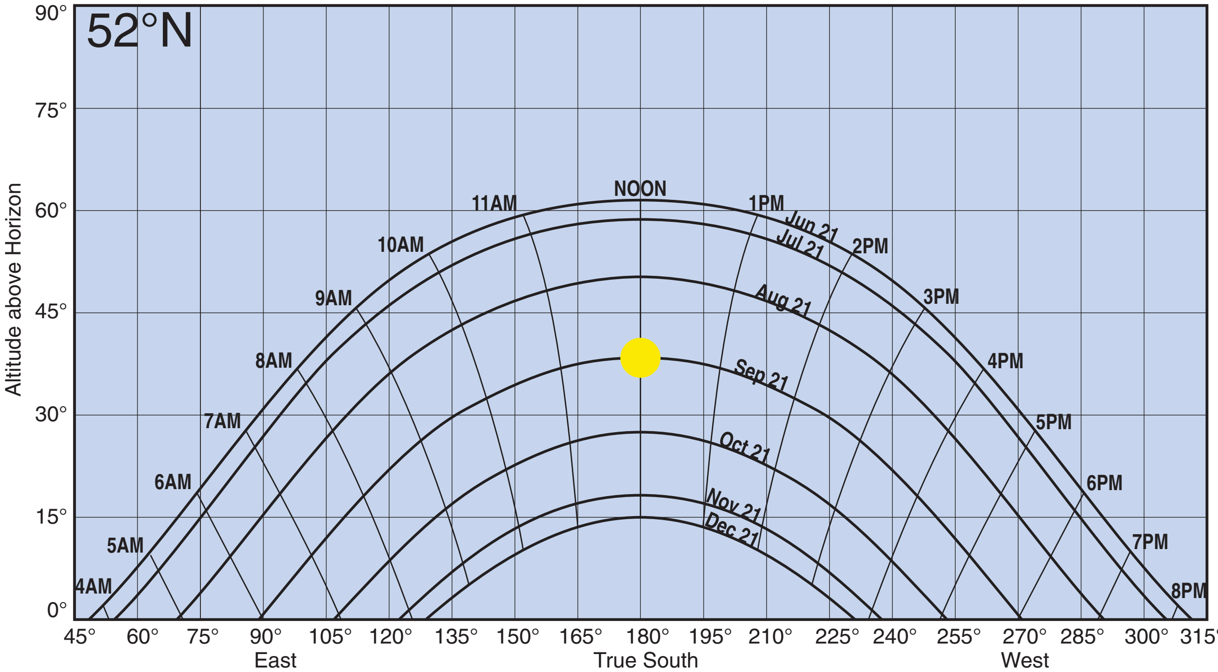
Sun Chart for Latitude 44° North



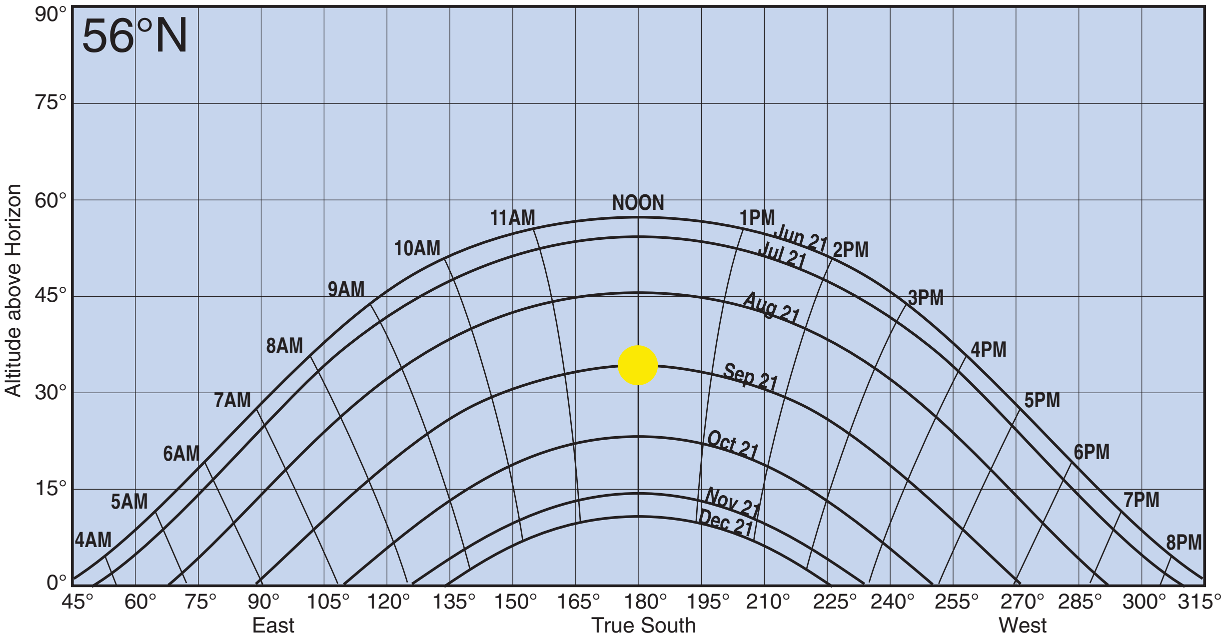
Sun Chart for Latitude 48° North



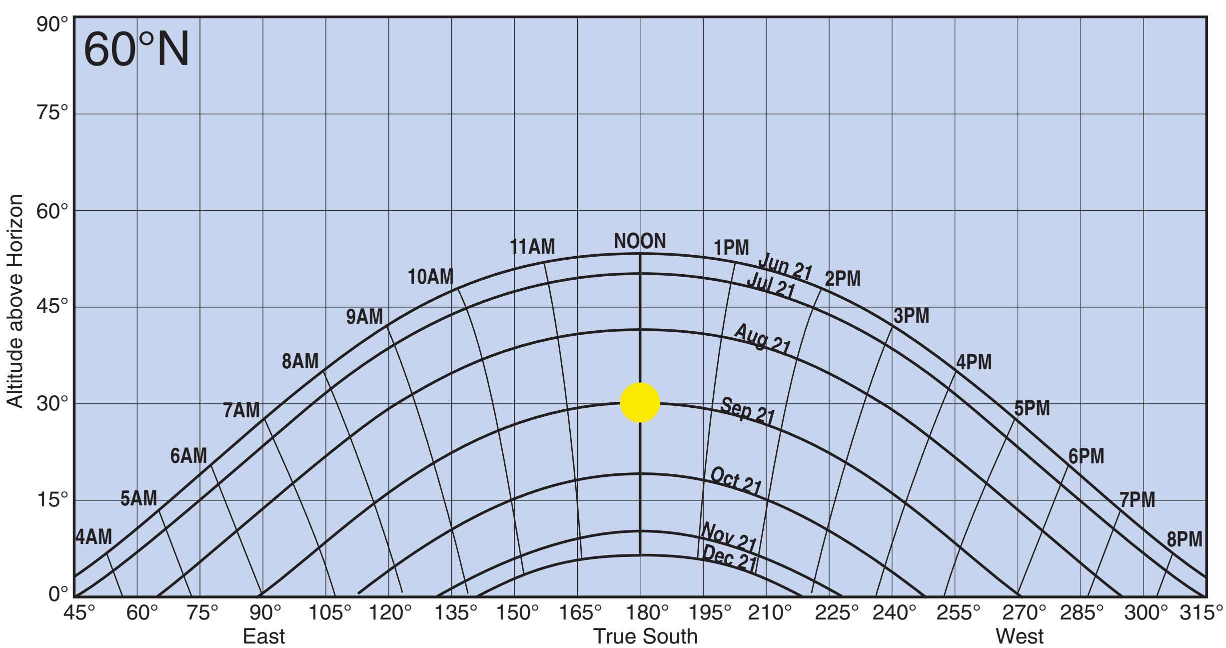
Sun Chart for Latitude 52° North



Sun Chart for Latitude 56° North



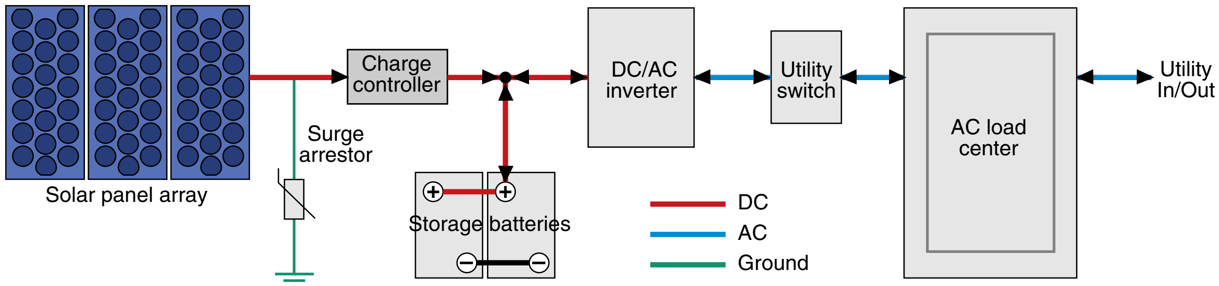
Sun Chart for Latitude 60° North



Elements of a PV System

PV applications range from the simplest DC-only system for boats, RVs, and remote cabins to the most complex grid-tied system with battery backup and utility buy back of excess power. All systems utilize at least some of the basic elements shown in the illustration and described below.

Principal Elements of PV Systems



Solar Panel Array PV panels can be wired in parallel (summing currents) and series (summing voltages). Small systems are connected in parallel, resulting in 12VDC output. Large systems are usually connected in both parallel and series, resulting in outputs of 24VDC or 48VDC. Power (Watts) flowing through a conductor equals current (Amps) times voltage (Volts). Doubling voltage doubles the power carried by the conductor without increasing its size.

Panel arrays are most often mounted on roofs because they are shaded less, occupy no space, and generally look better. As seen in the table on p. 384, deviations from ideal tilt and azimuth are forgiving, so the most common mount is fixed to the roof with a 4-inch standoff for air circulation.

Surge Arrestor Wiring high on a roof invites lightning strikes. The surge from a strike could wipe out all of the electronics in the system. Surge arrestors shunt the extreme currents safely to ground to protect the rest of the system.

Charge Controller Batteries require regulation of charging voltage and current. Charge controllers are of two types: 3-stage pulse width modulation (PWM) and maximum power point tracking (MPPT). MPPT controllers are more expensive, but they typically deliver at least 10% more current to the batteries.

Storage Batteries Unless tied into the utility, you need to store electrical energy for the times the sun is not shining. The two basic battery types are *automotive* (inexpensive, primarily for engine starting, and short lived if discharged deeply) and *deep cycle* (expensive, but capable of 80% discharge hundreds of times). If your battery is used only for the occasional power outage, go with automotive batteries. If your battery will be drawn down as much as 50% every day, you need deep-cycle batteries.

DC/AC Inverter Inverters convert 12, 24, or 48VDC power to 120VAC for household lighting and appliances. Inverters may produce square waves, modified sine waves, or pure sine waves. Square-wave inverters are small, cigarette-lighter devices. Modified sine wave inverters are economical and will operate most household devices, but pure sine wave inverters duplicate utility power and are the most efficient.

Inverter/chargers reverse operation and charge the storage batteries when supplied power either from the utility or from a generator.

Utility Switch This is a utility-supplied box that allows excess solar-generated power to flow back into the utility system and reduce your bill.

AC Load Center This is the common circuit breaker box everyone is familiar with.

Introducing PVWatts®

PVWatts is a web-based calculator from the National Renewable Energy Laboratory (NREL) that estimates the output of roof- or ground-mounted photovoltaic systems. You provide the system's location, basic design parameters, and cost of electricity, and *PVWatts* calculates the system's estimated annual and monthly electricity production and the monetary value of the electricity.

PVWatts is suitable for preliminary studies of a photovoltaic system that uses crystalline silicon or thin film photovoltaic modules. The calculations necessarily do not account for every system factor. Before committing to a project you should work with a qualified professional using more detailed engineering design and financial analysis tools.

Example PVWatts Analysis

As an illustrative example, we will estimate the performance of a simple 4K (total panel rated Watts) system in Portland, Maine. Follow the data inputs on the facing page. We begin with the *System Loss Breakdown:*

Soiling Depending on location and panel accessibility, soiling (dust, salt, etc.) can block a significant percentage of insolation. We assume an average of 5%.

Shading This is the critical factor discussed on p. 387. Don't even consider a system where annual average shading exceeds 10%. We insist on 0%.

Snow In Maine, snow is inevitable. However, on an annual basis we should be able to keep our panels clear except for maybe three days per year (1%).

Mismatch This refers to the panel manufacturing precision. We go with the *PVWatts* default, 2%.

Wiring Electrical resistance in the system conductors results in voltage (and therefore power) loss. The loss depends on both conductor sizes and lengths. Again, we go with the calculator's default, 2%.

Connections Unless perfectly executed and protected from weather, electrical connections corrode and increase in resistance. The default value is 0.5%.

Light-Induced Degradation This is an unavoidable initial reduction in a panel's output caused by light-induced degradation of photovoltaic cells. The default value is 1.5%.

Nameplate Rating This acknowledges that the real-world output is probably slightly less than the output tested under ideal laboratory conditions. The default value is 1%.

Aging Most PV panels are warranted for 25 years, However, everything degrades over time. We accept an often-estimated 1% per year. With a 25-year life, the lifetime average aging loss would be about 12%.

Availability While the system is being worked on, the output is unavailable. The calculator default value is 3% (11 days per year). We think this is excessive, so we go with 1%.

Estimated System Losses Total system losses are calculated not as the sum of the percentages above, but as 1.00 minus the product of all of the efficiency factors: 1.00 – sum of ×%/100.

$$1.00 - 0.95 \times 1.00 \times 0.99 \times 0.98 \times 0.98 \times 0.995 \times 0.985 \times 0.99 \times 0.88 \times 0.99 = 0.2403 \text{ or } \mathbf{24.03\%}$$

Next we enter the *System Info:*

DC System Size Most inverters are rated 1, 2, or 4kW. Pick the largest, 4kW.

Module Type Modules are: standard crystalline silicon, premium crystalline silicon, or thin film. Standard is the most cost-effective.

Array Type Panels may be fixed or tracking. Fixed are the most cost-effective.

Estimated System Losses *PVWatts* has already calculated and entered this number for us.

Collector Tilt As shown on p. 384, tilt equal to latitude is ideal, so we enter our latitude.

Azimuth Angle As also shown on p. 384, the ideal azimuth angle is 180°. If not possible for your system enter any angle between 180° ± 45°.

DC to AC Size Ratio Enter default value, 1.1.

Inverter Efficiency Efficiencies range from 92% to 97% for modified sine wave and pure sine wave inverters. We go for a 96% efficient pure sine wave.

Ground Coverage Ratio This applies only to tracking systems. Leave at the default value, 0.4.

System Type The choices are residential or commercial. Our example is residential.

Cost of Electricity This can be found from your monthly electric bill, or use the value for your state shown in the table below.

Results *PVWatts* returns the estimated annual average *solar radiation* (4.69 kWh/m²/day), output *AC energy* (4,927 kWh), and *energy value* ($800). Without inflation, the 25-year lifetime savings total $20,000. What we don't know are: system installed cost, the value of utility, state and federal subsidies, and the future price of electricity.

If this preliminary analysis shows your site has solar potential, get professional analyses and estimates from one or more certified solar installers.

Average Residential Rates (Nov. 2016)

State	¢/kWh	State	¢/kWh
Alabama	12.29	Montana	11.06
Alaska	21.18	Nebraska	10.73
Arizona	11.66	Nevada	11.80
Arkansas	10.08	New Hampshire	19.11
California	17.97	New Jersey	15.29
Colorado	12.16	New Mexico	11.98
Connecticut	19.66	New York	17.75
Delaware	13.87	No. Carolina	11.22
Florida	11.30	No. Dakota	10.30
Georgia	10.93	Ohio	12.22
Hawaii	28.48	Oklahoma	9.40
Idaho	10.08	Oregon	10.75
Illinois	12.86	Pennsylvania	14.24
Indiana	12.42	Rhode Island	18.17
Iowa	12.00	So. Carolina	12.54
Kansas	13.16	So. Dakota	11.71
Kentucky	11.01	Tennessee	10.95
Louisiana	9.16	Texas	11.11
Maine	16.24	Utah	10.71
Maryland	14.33	Vermont	17.84
Massachusetts	19.15	Virginia	11.52
Michigan	15.46	Washington	9.51
Minnesota	13.15	West Virginia	11.72
Mississippi	11.04	Wisconsin	14.40
Missouri	10.79	Wyoming	11.30

Example Analysis Using PVWatts

System Loss Breakdown

Soiling (%)	5
Shading (%)	0
Snow (%)	1
Mismatch (%)	2
Wiring (%)	2
Connections (%)	1
Light-Induced Degradation (%)	1.5
Nameplate Rating (%)	1
Aging (%)	12
Availability (Downtime) (%)	1
Estimated System Losses (%)	24.03

System Info

DC System Size (kW)	4
Module Type	Standard
Array Type	Fixed
Estimated System Losses	24.03
Collector Tilt (degrees)	40
Azimuth Angle (degrees)	180
DC to AC Size Ratio	1.1
Inverter Efficiency (%)	96
Ground Coverage Ratio	0.4
System Type	Residential
Cost of Electricity ($/kWh)	0.1624

Initial Annual Economics

Ave. Radiation kWh/m²/day	AC Energy kWh	Value $
4.69	4,927	$800

Meet the Code (IRC)

The following is a partial list of requirements from the *2015 International Residential Code (IRC) for One- and Two-Family Dwellings.* Consult the publication for the full text and additional provisions.

Equipment Location (E3405)

Working space and clearances for panels:

- ≥36” in front
- ≥30” wide
- ≥width of equipment
- from floor or platform to a height of 6.5'

Location:

- not in clothes closets or bathrooms
- artificial illumination to be provided indoors
- working space headroom ≥6.5'

Conductors/Connections (E3406)

- dissimilar metals not allowed where physical contact occurs except where device is listed for purpose
- inhibitors/compounds to be suitable for application
- terminals to not damage conductors
- terminals for more than one conductor and for aluminum conductors to be identified
- splicing devices to be listed for the purpose
- splices and conductor ends to be insulated
- direct burial splices to be listed for such use
- continuity of grounded conductor not to be through devices such as receptacles
- removal of a receptacle from box to not interrupt grounding continuity
- ≥6" of free conductor to be provided at boxes
- conductors to extend ≥3" outside box opening

General Services (E3601)

- 1- and 2-family dwellings supplied by 1 service
- service conductors not to pass through interior of another building
- service disconnects to be marked
- individual meter enclosures not service equipment
- service disconnect to be accessible outside or inside nearest point of entry of the service conductors

Service Size (E3602)

- for 1-family dwellings, ampacity ≥100A, 3 wire
- for other installations, ampacity ≥60A
- load to be computed as shown on p. 368

Overhead Service Drop (E3604)

Clearances on buildings:

- ≥3' from sides of doors, porches, decks, stairs, ladders, fire escapes, and balconies, and from sides and bottom of windows that open
- ≥8' above roof surface and 3' in all directions from edge of roof

Exceptions:

1. clearance above roof subject to pedestrian traffic to be same as that above grade
2. ≥3' for roof slope ≥4' in 12'

- ≥10' at service entrance to building, at lowest point of drip loop, and above pedestrian areas
- ≥12' over residential property and driveways
- ≥18' over public streets, alleys, roads, or parking areas subject to truck traffic

System Grounding (E3607)

- grounding electrode conductor to be connected to grounded service conductor from load end of service drop to terminal or bus to which grounded service conductor is connected at service disconnect
- structures supplied by feeder(s) or branch circuit(s) to have grounding electrode.

Exception: where one branch circuit supplies the structure and the branch circuit includes grounding conductor

- equipment grounding conductor to be run with supply conductors and connected to structure disconnecting means and grounding electrode(s)
- a main bonding jumper to connect equipment grounding conductor(s) and service-disconnect enclosure to the grounded conductor within enclosure
- a metal underground water pipe in direct contact with earth ≥10', including a well casing, to be considered a grounding electrode

- continuity of bonding connection to interior piping not to rely on water meters, filtering devices, and similar equipment

Required Branch Circuits (E3703)

- central heating, fixed AC equipment, and auxiliary associated equipment
- at least two 20A receptacle circuits in kitchen, pantry, breakfast, and dining areas
- one 20A receptacle circuit for laundry area
- at least one 20A receptacle circuit for bathrooms
- lighting and general receptacle load of 3 watts/sq ft based on outside dimensions and excluding open porches, garages, and spaces not adaptable for future use

Wiring Methods (E3802)

- guard strips required for cable crossing floor joists or framing members within 7" of floor in attics with permanent access by stairs or ladder
- guard strips required only for cable within 6' of edges of attic entrances without permanent access
- no protection required for cable through or parallel to framing
- cable exposed to damage to be protected by conduit
- cable exposed to direct sun be listed "sunlight resistant" or covered with approved material
- SE 6/2 and 8/3 OK across joist bottoms
- inner bend radius ≥5× diameter of NM&SE cable

Required Receptacles (E3901)

- no point along wall >6' from a receptacle, where wall is defined as:
  1. ≥2' unbroken
  2. panels in exterior walls, excluding sliding panels
  3. room dividers, railings, and freestanding counters
- one for countertops ≥12" wide (no point along countertop >24" from a receptacle)
- one for island and peninsula counters ≥12" × 24"
- face-up countertop receptacles prohibited
- receptacles ≤20" above and 12" below countertops
- one ≤36" from lavatory in bathroom
- one front and back of dwelling ≤6' above grade
- one for basement in addition to that for laundry
- one in attached garage
- one in detached garage having electricity
- one in hallways ≥10' long
- ≤25' of HVAC equipment, not on same circuit

Required GFCIs (E3902)

- all bathroom receptacles
- all kitchen countertop receptacles
- all 15&20A receptacles ≤6' from a sink
- accessible receptacles in garages and grade-level unfinished storage or work buildings
- outdoor receptacles
- crawl-space receptacles
- accessible receptacles in unfinished basement
- electrically heated floors in baths, kitchens, and spas
- receptacles serving dishwashers
- receptacles serving boathouses
- circuit supplying power to a boat hoist
- receptacles ≤6' from tub or shower enclosure

Required AFCIs (E3902)

- except for receptacles requiring GFCIs (see above), receptacles in kitchen, family room, dining room, living room, parlor, library, laundry, and other similar rooms

Switched Lighting (E3903)

- at least one in all habitable rooms and bathrooms
- switched receptacles OK except in kitchen and bath
- occupancy-sensor light switches permitted except in bath and kitchen
- hallways, stairways, and garages with power
- on exterior of outdoor egress doors at grade level, including garages
- all storage and equipment spaces
- a switch at each floor level of stairs with ≥6 risers
- automatic light OK at egress doors, halls, and stairs

13

Insulation and R-Value

All insulation products are labeled with an R-value. *Heat transfer and R-value* explains the significance of this number in reducing your home's heat loss or gain. As an aid to both planning and shopping, we offer a comprehensive listing of the *R-values of insulation products* as well as their performance characteristics.

Insulation is just one component of a floor, wall, or ceiling. To compute the total thermal resistance of a construction we need to include *R-values of surfaces and air spaces*, as well as *R-values of building materials*.

Unfortunately, the total R-value of a floor, wall, or ceiling is not the simple sum of component R-values, so we explain (and give examples of) the methods for *calculating effective R-values*.

And because this is a handbook, we offer an extensive catalog of the *effective R-values of typical constructions*.

Heat Transfer and R-Value

If heat were immovable, it would simply remain in the furnace, boiler, woodstove, or air conditioner and do nothing to keep us warm in winter or cool in summer. But heat obeys the Second Law of Thermodynamics, which, in layman's terms, says energy flows from higher concentrations toward areas of lower concentrations. Because heat energy concentration is what we call "temperature," heat always flows from hot to cold.

There are three natural heat flow mechanisms, all of which obey the "hot to cold" principle: radiation, convection, and conduction.

Radiation

Radiation is the transfer of energy through space. Radio waves, cellphone signals, warming rays from the sun, and heat felt from a fire—all are examples of the very same thing: electromagnetic radiation. The only difference is the wavelengths of the radiation.

While not intuitive to anyone but a physicist, all matter in the universe continually and simultaneously emits and absorbs radiation. The intensity of emitted radiation is proportional to the matter's absolute temperature raised to the fourth power. Putting this into perspective, matter having twice the surface temperature emits 16 times as much radiation.

The woodstove in the top illustration on the facing page is warmer than the surrounding room surfaces, so there is a net transfer of heat by radiation from the stove to the room.

Convection

Convection is the mass movement of atoms and molecules in a liquid or a gas. Wind, the uprush of a thunderhead, the circulation of tea leaves in a cup of tea, and the warm air rising from a woodstove are examples of convection. In moving from a warmer area to a cooler area, the molecules comprising the mass transfer heat energy in the direction of the motion.

The middle illustration on the facing page shows a wood- or coal stove in a room in winter. The room is heated to an average air temperature of 70°F, while the outdoor temperature is 0°F. Room air in contact with the stove is heated and expands. Because the room air is less dense than the surrounding air, it rises like a hot air balloon to the ceiling. At the same time, room air in contact with the cold window gives up some of its heat, contracts, and falls to the floor. The convection loop is continuous, resulting in a net transfer of heat from the stove to the window.

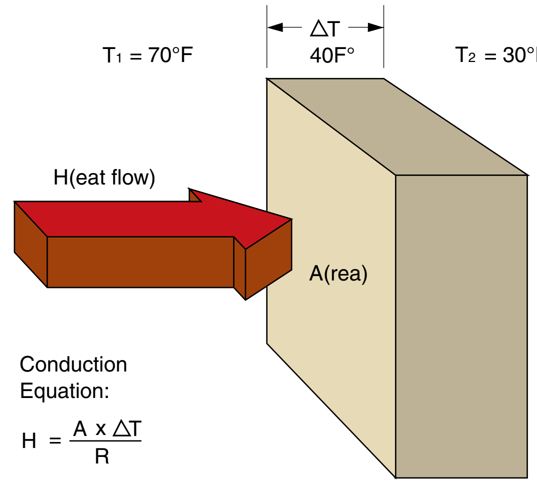
Conduction

Conduction is the transfer of heat through solids. The frying pan handle in the bottom illustration on the facing page provides a familiar example. The handle is not in the flame, yet it becomes warm. The molecules of the metal pan and handle are jostling each other and passing vibrational energy down the line to their cooler neighbors. Since the intensity of vibration is greatest in the area heated by the flame, the net transfer of energy is from that area toward the handle.

Materials that transfer heat readily are known as conductors; materials that resist the transfer of heat are insulators. The insulation products sold at home centers and lumberyards, such as fiberglass, cellulose, and the various types of foam, are especially good at resisting heat flow by conduction.

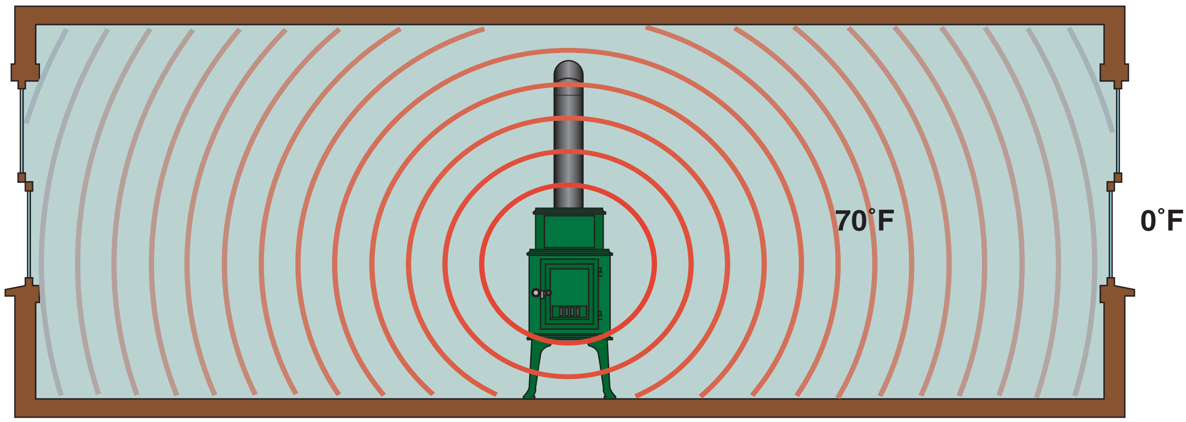
Heat transfer by conduction through homogeneous solid materials is simple to calculate, as shown in the illustration below. In the thermal conductance equation, R is the measure of the material's thermal resistance.

The Conduction Equation and R

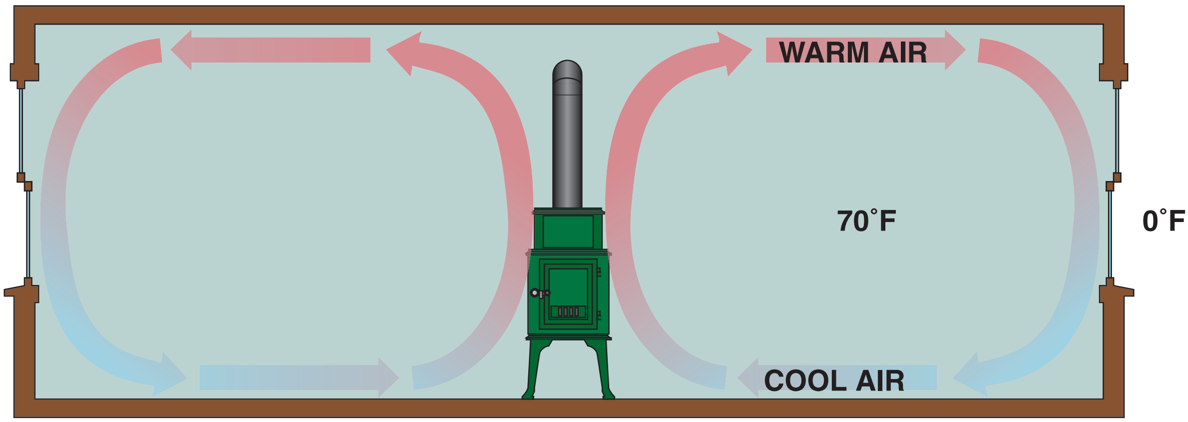


Three Heat Transfer Mechanisms

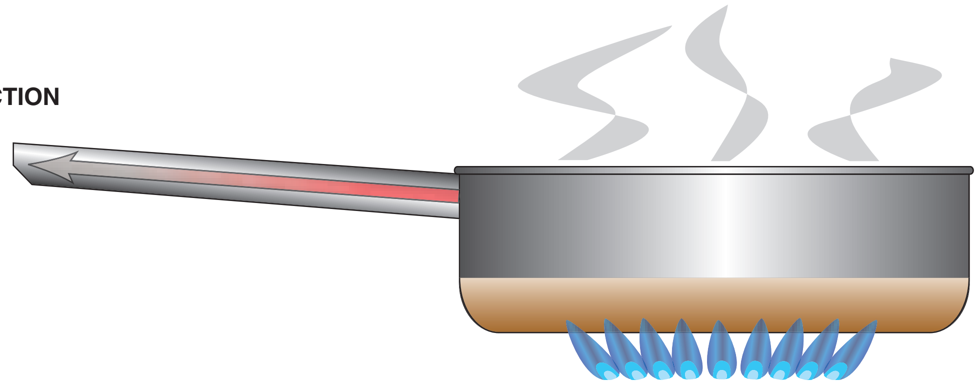
RADIATION



CONVECTION



CONDUCTION



R-Values of Insulation Products

Characteristics of Insulation Materials

Type of Insulation	Rated R/in.	Max. Temp., °F	Vapor Barrier	Resistance to Water Absorption	Moisture Damage	Direct Sunlight	Fire
Roll, Blanket, or Batt							
Fiberglass	3.2 (2.9–3.8)	180	unfaced: P	G	E	E	G
Fiberglass, high-density	4.0 (3.8–4.2)	180	unfaced: P	G	E	E	G
Rock wool	3.2 (2.9–3.8)	>500	unfaced: P	G	E	E	E
Loose Fill							
Cellulose	3.5 (3.2–3.8)	180	P	P	P	G	F
Fiberglass	2.5 (2.2–2.7)	180	P	G	E	E	G
Perlite	2.4	200	P	F	G	E	G
Polystyrene beads	2.3	165	P	P	G	P	P
Rock wool	3.1 (3.0–3.3)	>500	P	G	E	G	G
Vermiculite	2.4	>500	P	G	E	E	G
Rigid Board							
Expanded polystyrene	3.8 (3.6–4.0)	165	P	P	G	P	P
Extruded polystyrene	4.8 (4.5–5.0)	165	G	E	E	P	P
Polyurethane	6.2 (5.5–6.5)	165	G	E	E	P	P
Polyisocyanurate, foil-faced	7.0	180	F	G	E	E	G
Polyisocyanurate, unfaced	5.6	200	G	G	E	P	P
Sprayed or Foamed in Place							
Cellulose	3.5 (3.0–3.7)	165	P	P	F	G	F
Fiberglass, high-density	4.2	180	P	G	E	E	G
Phenolic	4.8	300	G	G	E	E	P
Polyurethane, closed-cell	6	165	G	E	E	P	P
Polyurethane, open-cell	3.6	165	P	P	E	P	P

Note: E = excellent; G = good; F = fair; P = poor

R-Values of Surfaces and Air Spaces

R-Values of Building Surfaces

		Type of Surface	
Surface	**Heat Flow Direction**	**Nonreflective**	**Foil-Faced**
	Still Air		
Horizontal	Upward	0.61	1.32
Sloped 45°	Upward	0.62	1.37
Vertical	Horizontal	0.68	1.70
Sloped 45°	Upward	0.61	1.32
Horizontal	Upward	0.62	1.37
	Moving Air, Any Orientation		
7.5 mph wind	Any	0.25	—
15 mph wind	Any	0.17	—

Source: *Handbook of Fundamentals* (Atlanta: American Society of Heating, Refrigeration, and Air-Conditioning Engineers, 1989).

R-Values of Trapped Air Spaces

			Type of Surface	
Thickness, in.	**Heat Flow**	**Season**	**Nonreflective**	**One Foil-Faced**
		Horizontal		
¾	Upward	Winter	0.87	2.23
¾	Downward	Winter	1.02	3.5
4	Upward	Winter	0.94	2.73
4	Downward	Winter	1.23	8.94
		Sloped 45		
¾	Upward	Winter	0.94	2.78
¾	Downward	Summer	0.84	3.24
4	Upward	Winter	0.96	3.00
4	Downward	Summer	0.90	4.36
		Horizontal		
¾	Outward	Winter	1.01	3.48
¾	Inward	Summer	0.84	3.28
4	Outward	Winter	1.01	3.45
4	Inward	Summer	0.91	3.44

Source: *Handbook of Fundamentals* (Atlanta: American Society of Heating, Refrigeration, and Air-Conditioning Engineers, 1989).

R-Values of Building Materials

Building Material R-Values

Material	R/in.	R-value
Boards and Panels		
Gypsum drywall, 1/2 in.	0.90	0.45
3/8 in.	0.90	0.34
1/2 in.	0.90	0.45
5/8 in.	0.90	0.56
Hardboard		
Medium density	1.37	
High-density underlay	1.22	
High-density tempered	1.00	
Laminated paperboard	2.00	
Particleboard		
Low density	1.41	
Medium density	1.06	
High density	0.85	
Underlayment	1.31	
Plywood, fir	1.25	
Fiberboard	2.64	
Wood		
Hardwoods	0.90	
Softwoods	1.25	
Doors		
Hollow-core flush lauan, 1 3/4 in.		1.80
Solid-core flush, 1 3/4 in.		2.17
Urethane-filled, steel or fiberglass		5.30
Storm door		
aluminum, 50% glazed		1.00
wood, 50% glazed		1.25
Flooring		
Carpet with fibrous pad		2.08
Carpet with foam rubber pad		1.23
Cork tile, 1/8 in.	2.24	0.28
Terrazzo	0.08	
Tile, linoleum, or vinyl, 1/8 in.	0.40	0.05
Wood		
Hardwood	0.90	
Softwood	1.25	

Material	R/in.	R-value
Framing Lumber		
2 in. nominal (1 1/2 in.)	1.25	1.88
4 in. nominal (3 1/2 in.)	1.25	4.38
6 in. nominal (5 1/2 in.)	1.25	6.88
8 in. nominal (7 1/4 in.)	1.25	9.06
10 in. nominal (9 1/4 in.)	1.25	11.56
12 in. nominal (11 1/4 in.)	1.25	14.06
Masonry		
Cement mortar	0.20	
Gypsum fiber concrete	0.60	
Sand and gravel aggregate	0.09	
Lightweight aggregate		
120 lb./cu. ft.	0.09–0.18	
80 lb./cu. ft.	0.29–0.40	
40 lb./cu. ft.	0.90–1.08	
20 lb./cu. ft.	1.43	
Perlite, expanded	1.08	
Stucco	0.20	
Masonry Units		
Brick		
90 lb./cu. ft.	0.20	
120 lb./cu. ft.	0.11	
Clay tile, hollow		
One-cell, 3 in.		0.80
One-cell, 4 in.		1.11
Two-cell, 6 in.		1.52
Two-cell, 8 in.		1.85
Two-cell, 10 in.		2.22
Three-cell, 12 in.		2.50
Concrete block, normal weight		
8 in. empty cores		0.97–1.11
8 in. perlite cores		2.00
8 in. vermiculite cores		1.37–1.92
12 in. empty cores		1.23

Building Material R-Values—*Continued*

Material	R/in.	R-value
Concrete block, medium weight		
8 in. empty cores		1.28–1.71
8 in. perlite cores		2.3–3.7
8 in. vermiculite cores		3.3
8 in. expanded polystyrene beads		3.2
Concrete block, medium weight		
6 in. empty cores		1.65–1.93
6 in. perlite cores		4.2
6 in. vermiculite cores		3.0
8 in. empty cores		1.9–3.2
8 in. perlite cores		4.4–6.8
8 in. vermiculite cores		3.9–5.3
8 in. expanded polystyrene beads		4.8
12 in. empty cores		2.3–2.6
12 in. perlite cores		6.3–9.2
12 in. vermiculite cores		5.8
Stone	0.08	
Plasters		
Cement, sand aggregate	0.64	
Gypsum		
Lightweight aggregate	0.20	
Perlite aggregate	0.67	
Sand aggregate	0.18	
Vermiculite aggregate	0.59	
Roofing		
Asbestos-cement shingle		0.21
Asphalt roll (90 lb.)		0.15
Asphalt shingle		0.44
Built-up asphalt, 3/8 in.		0.33
Slate, 1/2 in.		0.05
Wood shingles (not furred)		0.94

Material	R/in.	R-value
Sheathing, Plywood, or OSB		
1/4 in. panel	1.25	0.31
3/8 in. panel	1.25	0.47
½ in. panel	1.25	0.63
5/8 in. panel	1.25	0.77
3/4 in. panel	1.25	0.94
Siding		
Shingles		
Asbestos-cement		0.21
Wood, 16 in. (7 in. exposure)		0.87
Wood		
Drop, 1 in. × 8 in.		0.79
Bevel, 1/2 in. × 8 in.		0.81
Bevel, 3/4 in. × 10 in.		1.05
Aluminum or steel		
Hollow		0.61
With 3/8 in. backer		1.82
With 3/8 in. backer and foil		2.96
Windows (Use window ratings values if available)		
Single ordinary glazing		0.91
Single glazing plus storm panel		2.00
Double-glazed		
3/16 in. air space		1.61
1/4 in. air space		1.69
1/2 in. air space		2.04
3/4 in. air space		2.38
1/2 in. Low-E		3.13
Suspended film plus Low-E		4.05
Triple-glazed		
1/4 in. air spaces		2.56
1/2 in. air spaces		3.23

Calculating Effective R-Values

Uniform Materials

The thermal conduction equation, shown on p. 400, is marvelous in its simplicity. Nothing could be more intuitive than a rate of heat transfer:

- proportional to the area through which it flows
- proportional to the temperature difference
- inversely proportional to R, resistance to flow

Equally marvelous, the total R-value of a layered assembly of uniform materials is simply the sum of the R-values of the component layers!

$$R_{total} = T_1 + T_2 + T_3 + \ldots$$

When applied to constructions faced with air, the appropriate surface or trapped-air-space R-values must be included in the calculation.

The illustration below demonstrates the calculation of total R-value through a section of wall cavity filled with fiberglass insulation.

Non-Uniform Parallel Paths

Few building assemblies consist of a simple layering of uniform materials as in the example below. Structural Insulating Panels (SIPs) are the only ones that come to mind. Most floors, walls, and roofs contain framing. In calculating building heat loads, what we need is the average, or effective, R-value for the entire floor, wall, or roof.

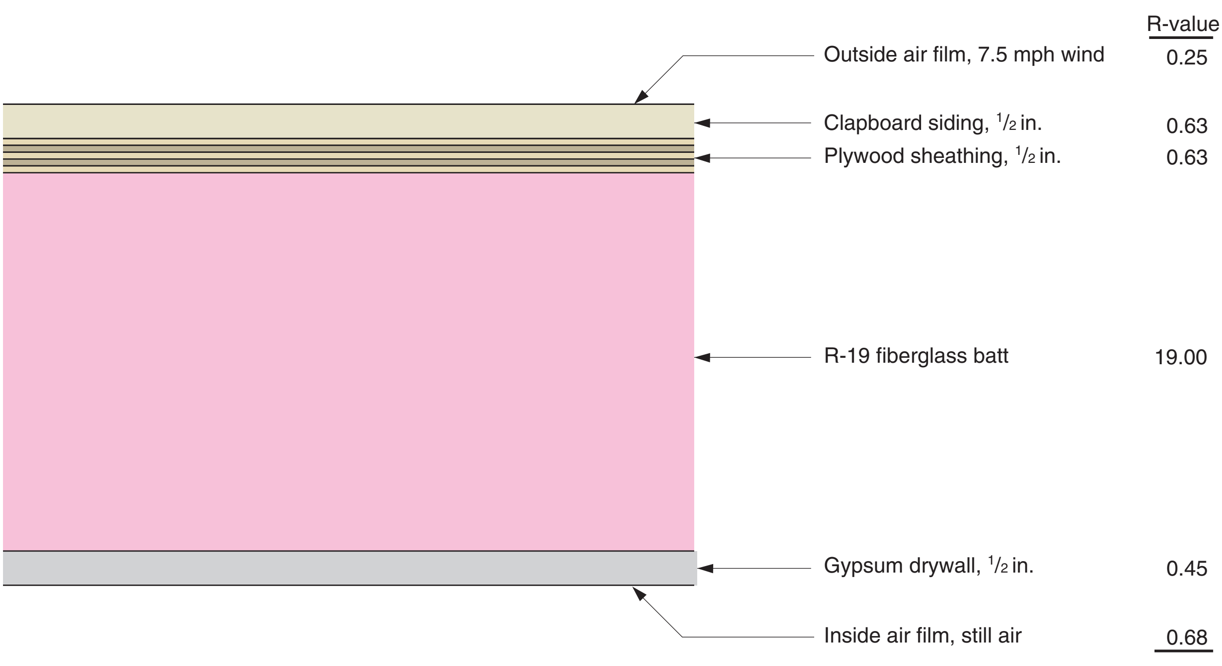
Fortunately, the effective R-value of the combined parallel heat paths is fairly simple to calculate. The process, shown in the illustrations on the facing page, consists of:

1. Calculating the fractions of wall area occupied by framing, F_f, and by insulation, F_i

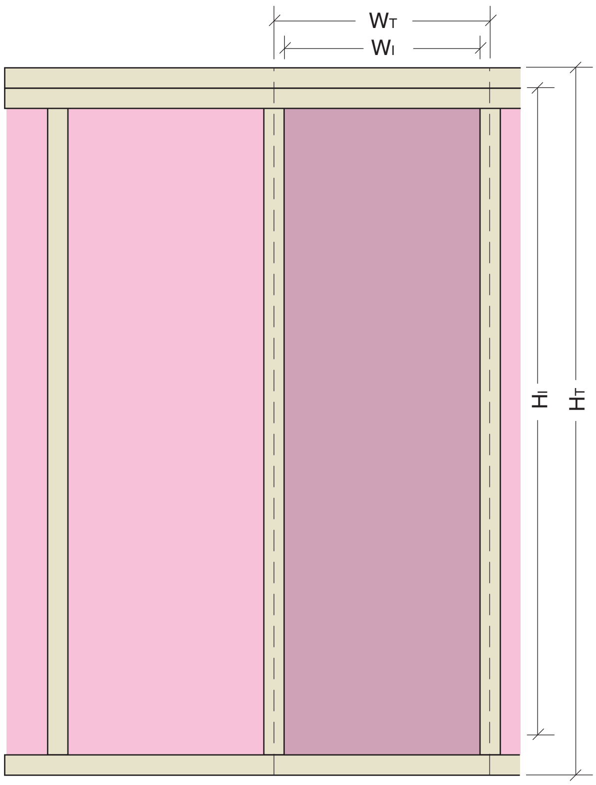
2. Calculating the total R- and U-values (U = 1/R) through the framing and through the insulation

3. Multiplying each U-value by its corresponding area fraction and summing the products to get U_{eff}. R_{eff} is simply $1/U_{eff}$

Calculating the Total R-Value through Uniform Materials



Calculating the Effective R-Value of Construction with Parallel Paths



FRAMING 16 IN. ON-CENTER

Total Area, $A_T = W_T \bullet H_T$
$= 16 \text{ in.} \bullet 96 \text{ in.} = 1{,}536 \text{ in.}^2$

Insulation Area, $A_I = W_I \bullet H_I$
$= 14.5 \text{ in.} \bullet 91.5 \text{ in.} = 1{,}327 \text{ in.}^2$

Framing Area, $A_F = A_T - A_I$
$= 1{,}536 \text{ in.}^2 - 1{,}327 \text{ in.}^2 = 209 \text{ in.}^2$

Insulation Fraction, $F_I = A_I/A_T$
$= 1{,}327 \text{ in.}^2 / 1{,}536 \text{ in.}^2 = 0.864$

Framing Fraction, $F_F = A_F/A_T$
$= 209 \text{ in.}^2 / 1{,}536 \text{ in.}^2 = 0.136$

OVE FRAMING 24 IN. ON-CENTER
(single top plate)

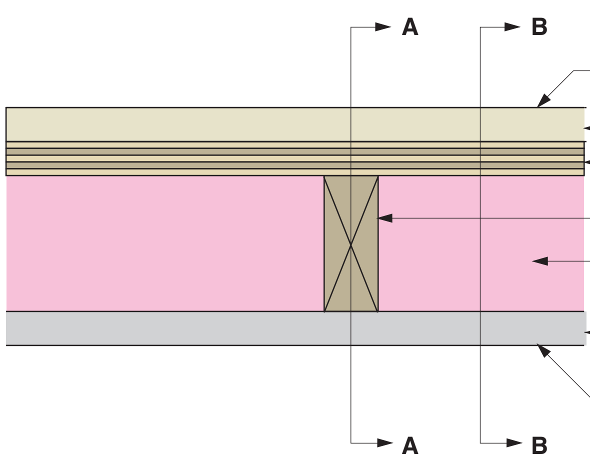
$A_T = W_T \bullet H_T$
$= 24 \text{ in.} \bullet 96 \text{ in.} = 2{,}304 \text{ in.}^2$

$A_I = W_I \bullet H_I$
$= 22.5 \text{ in.} \bullet 93 \text{ in.} = 2{,}093 \text{ in.}^2$

$A_F = A_T - A_I$
$= 2{,}304 \text{ in.}^2 - 2{,}093 \text{ in.}^2 = 211 \text{ in.}^2$

Insulation Fraction, $F_I = A_I/A_T$
$= 2{,}093 \text{ in.}^2 / 2{,}304 \text{ in.}^2 = 0.908$

Framing Fraction, $F_F = A_F/A_T$
$= 211 \text{ in.}^2 / 2{,}304 \text{ in.}^2 = 0.092$



	Section A - A	Section B - B
Outdoor surface, e = .90	0.17	0.17
Clapboard siding, 1/2 in.	0.63	0.63
Plywood sheathing, 1/2 in.	0.63	0.63
2 x 4 stud, 16 in. o.c.	4.38	—
R-11 fiberglass batt	—	11.00
Gypsum drywall, 1/2 in.	0.45	0.45
Indoor surface, e = .90	0.68	0.68
Section R-value	6.94	13.56
Section U (1/R)	0.1441	0.0737
Area fraction: F_i, F_f	0.136	0.864
U contribution	0.0196	0.0637
U (Total	0.0833	
Reff (1/Ueff)	12.0	

Metal Framing

The parallel path method works well for ordinary wood-frame construction because the framing member cross sections are simple rectangles and because the wood framing and cavity insulation R-values are not too dissimilar.

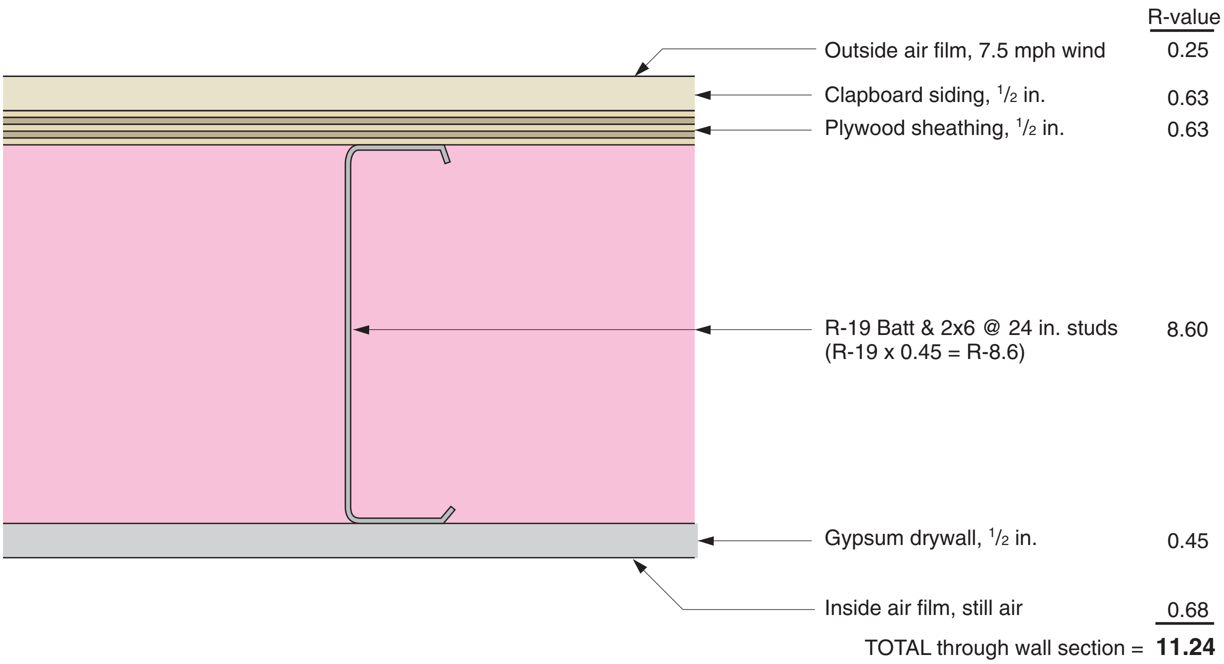
Floors, walls, and ceilings framed with steel are a different matter, however. The thermal conductivity of steel is much greater than that of framing lumber and insulation. In fact, the conductivity of carbon steel is about 350 times that of softwoods and 1,300 times that of extruded polystyrene. Compounding the calculation, the cross section of a steel stud is that of a thin C, with 16- or 18-gauge webs and 1½-in. flanges.

An alternate method is to use the correction factors published in *ASHRAE Standard 90.1* and listed in the table below. The illustration at the bottom of the page provides an example calculation.

Steel Wall-Framing Correction Factors

Stud Size	Stud Spacing	Cavity Insulation	Correction Factor	Effective R-value
2×4	16 in. o.c.	R-11	0.50	R-5.5
		R-13	0.46	R-6.0
		R-15	0.43	R-6.4
2×4	24 in. o.c.	R-11	0.60	R-6.6
		R-13	0.55	R-7.2
		R-15	0.52	R-7.8
2×6	16 in. o.c.	R-19	0.37	R-7.1
		R-21	0.35	R-7.4
2×6	24 in. o.c.	R-19	0.45	R-8.6
		R-21	0.43	R-9.0
2×8	16 in. o.c.	R-11	0.31	R-7.8
2×8	24 in. o.c.	R-11	0.38	R-9.6

Calculating the Effective R-Value For Steel Framing

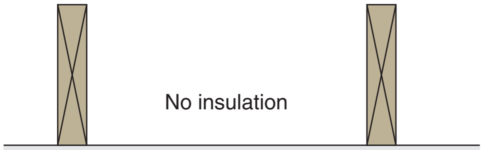


Effective R-Values of Typical Constructions

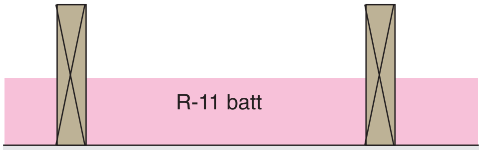
Oak Ridge National Laboratory (ORNL), maintains an interactive website, the ZIP-Code Insulation Program (*http://web.ornl.gov/sci/buildings/tools/zip/*) for calculating economic optimum levels of insulation, taking account of climate, heating and cooling system efficiencies, fuel type and price, and building construction. The Zip software draws upon a database of calculated effective R- and U-values of standard insulation options for roofs, attics, walls, and floors. These options and their R- and U-values are illustrated in the following illustrated table.

The table also contains effective R- and U-values for concrete masonry wall assemblies from the National Concrete Masonry Association.

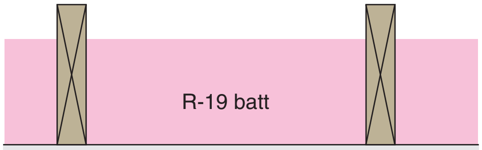
Wood-Framed Attics



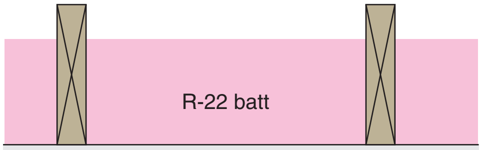
R_{eff} = 3.9 U_{eff} = 0.254



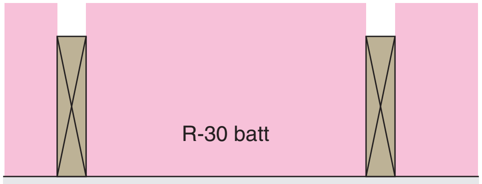
R_{eff} = 14.5 U_{eff} = 0.0688



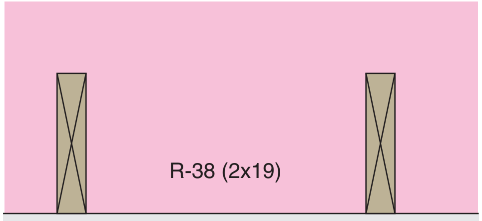
R_{eff} = 22.0 U_{eff} = 0.0455



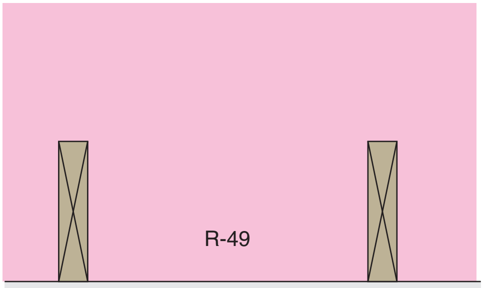
R_{eff} = 25.0 U_{eff} = 0.0400



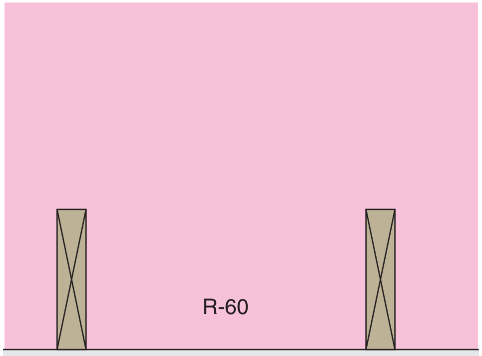
R_{eff} = 30.0 U_{eff} = 0.0333



R_{eff} = 41.5 U_{eff} = 0.0241

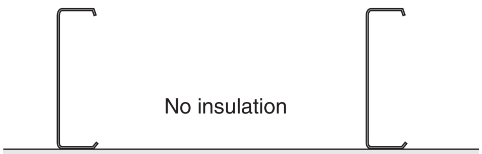


R_{eff} = 50.0 U_{eff} = 0.0199

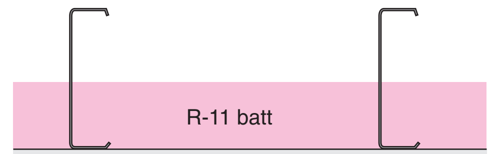


R_{eff} = 51.8 U_{eff} = 0.0193

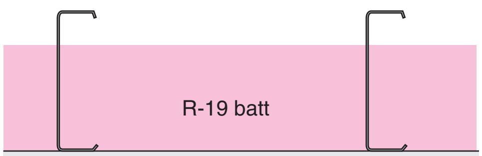
Metal-Framed Attics



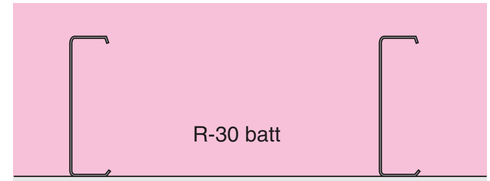
$R_{eff} = 1.7$ $U_{eff} = 0.592$



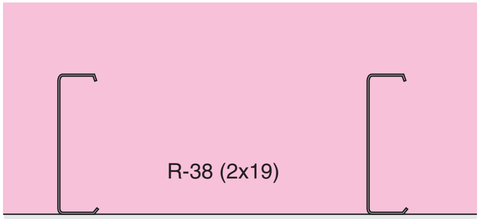
$R_{eff} = 10.9$ $U_{eff} = 0.092$



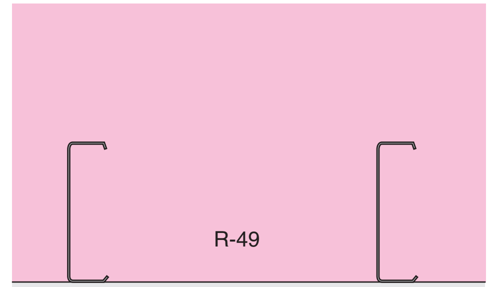
$R_{eff} = 16.1$ $U_{eff} = 0.062$



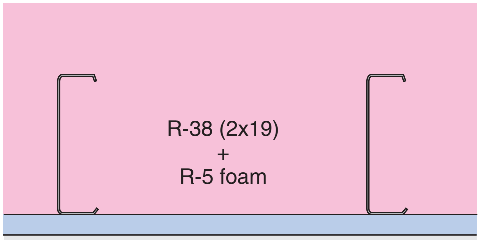
$R_{eff} = 22.2$ $U_{eff} = 0.045$



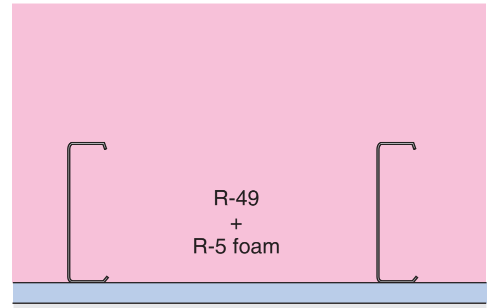
$R_{eff} = 25.6$ $U_{eff} = 0.039$



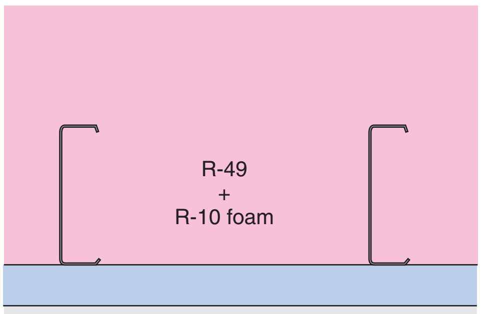
$R_{eff} = 30.0$ $U_{eff} = 0.033$



$R_{eff} = 35.7$ $U_{eff} = 0.028$

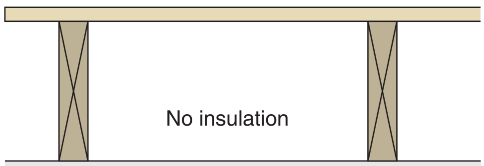


$R_{eff} = 43.5$ $U_{eff} = 0.023$

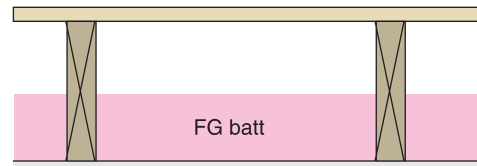


$R_{eff} = 50.0$ $U_{eff} = 0.020$

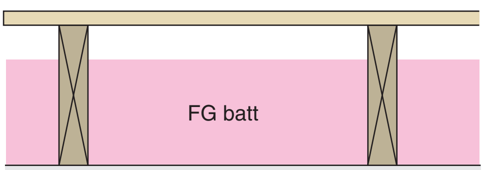
Cathedral Ceilings



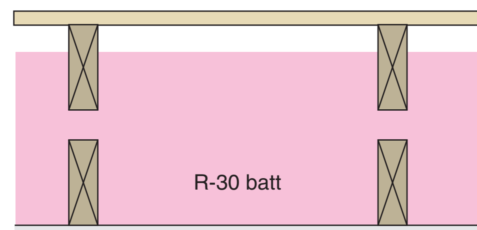
$R_{eff} = 3.8$ $U_{eff} = 0.2616$



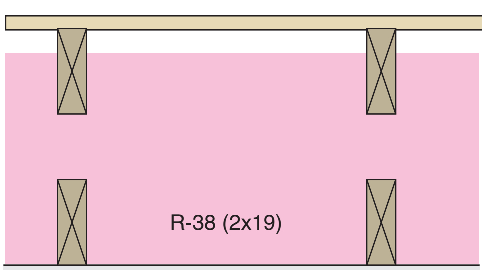
Batt = R-11	$R_{eff} = 13.5$	$U_{eff} = 0.0742$
Batt = R-13	$R_{eff} = 15.0$	$U_{eff} = 0.0666$
Batt = R-15	$R_{eff} = 16.5$	$U_{eff} = 0.0607$



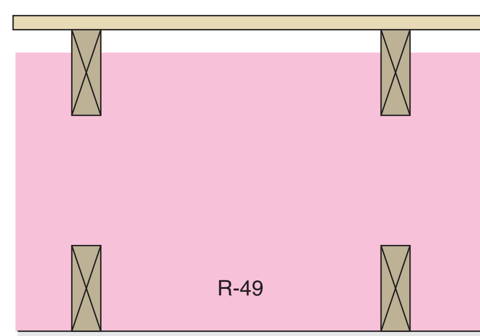
Batt = R-19	$R_{eff} = 20.3$	$U_{eff} = 0.0493$
Batt = R-21	$R_{eff} = 21.7$	$U_{eff} = 0.0460$
Batt = R-22	$R_{eff} = 23.0$	$U_{eff} = 0.0434$



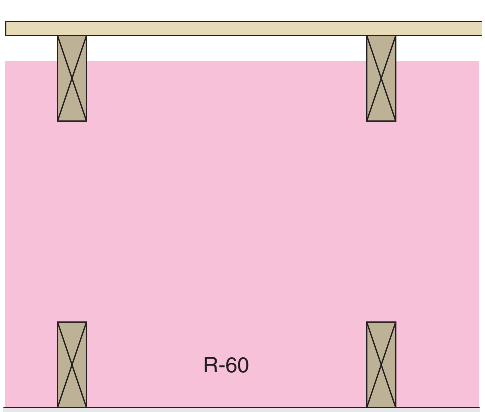
$R_{eff} = 30.1$ $U_{eff} = 0.0332$



$R_{eff} = 37.0$ $U_{eff} = 0.0270$



$R_{eff} = 46.3$ $U_{eff} = 0.0216$

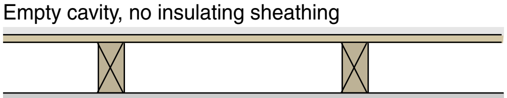


$R_{eff} = 56.2$ $U_{eff} = 0.0178$

Wood-Framed Walls

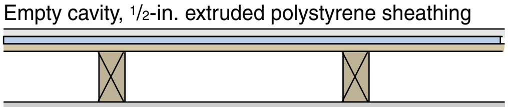
2 x 4, 16-in. o.c. WOOD-FRAMED WALL, 1/2-in. WOOD SHEATHING, SIDING, 1/2-in. DRYWALL FINISH

Empty cavity, no insulating sheathing



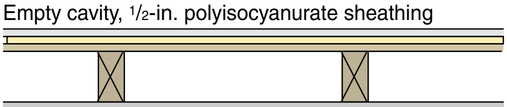
R_{eff} = 4.9 U_{eff} = 0.2052

Empty cavity, 1/2-in. extruded polystyrene sheathing



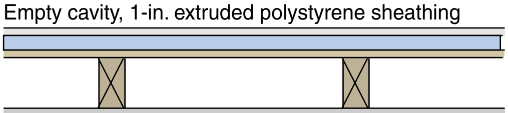
R_{eff} = 7.5 U_{eff} = 0.1341

Empty cavity, 1/2-in. polyisocyanurate sheathing



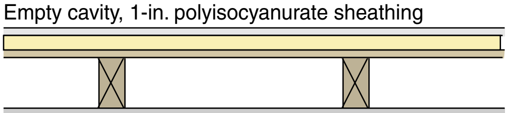
R_{eff} = 8.5 U_{eff} = 0.1179

Empty cavity, 1-in. extruded polystyrene sheathing



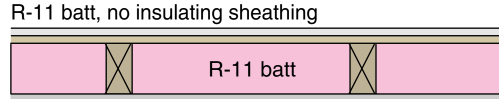
R_{eff} = 10.0 U_{eff} = 0.0999

Empty cavity, 1-in. polyisocyanurate sheathing



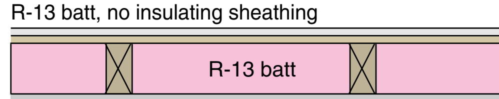
R_{eff} = 12.0 U_{eff} = 0.0831

R-11 batt, no insulating sheathing



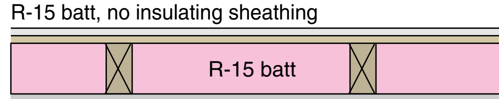
R_{eff} = 11.9 U_{eff} = 0.0840

R-13 batt, no insulating sheathing



R_{eff} = 12.9 U_{eff} = 0.0777

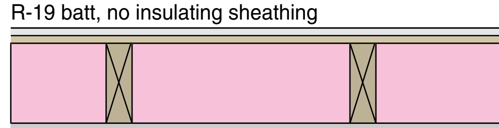
R-15 batt, no insulating sheathing



R_{eff} = 13.8 U_{eff} = 0.0727

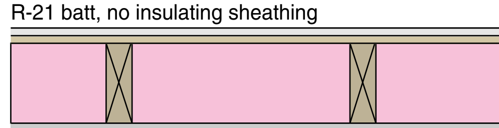
2 x 6 WOOD-FRAMED WALL, 1/2-in. WOOD SHEATHING, SIDING, 1/2-in. DRYWALL FINISH

R-19 batt, no insulating sheathing



R_{eff} = 17.3 U_{eff} = 0.0577

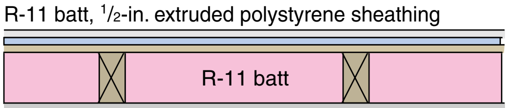
R-21 batt, no insulating sheathing



R_{eff} = 18.2 U_{eff} = 0.0550

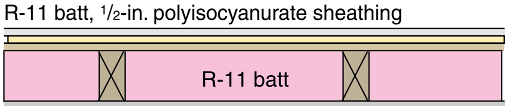
2 x 4, 16-in. o.c. WOOD-FRAMED WALL, 1/2-in. WOOD SHEATHING, SIDING, 1/2-in. DRYWALL FINISH

R-11 batt, 1/2-in. extruded polystyrene sheathing



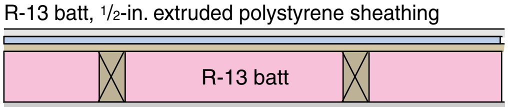
Reff = 14.6 Ueff = 0.0686

R-11 batt, 1/2-in. polyisocyanurate sheathing



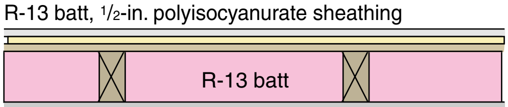
R_{eff} = 15.6 U_{eff} = 0.0639

R-13 batt, 1/2-in. extruded polystyrene sheathing



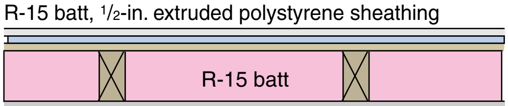
R_{eff} = 15.6 U_{eff} = 0.0639

R-13 batt, 1/2-in. polyisocyanurate sheathing



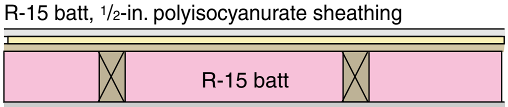
R_{eff}f = 16.8 U_{eff} = 0.0597

R-15 batt, 1/2-in. extruded polystyrene sheathing



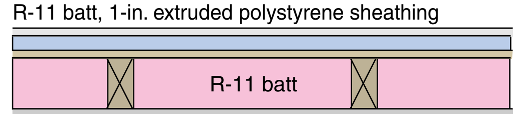
R_{eff} = 16.6 U_{eff} = 0.0601

R-15 batt, 1/2-in. polyisocyanurate sheathing



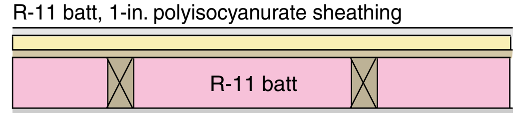
R_{eff} = 17.8 U_{eff} = 0.0563

R-11 batt, 1-in. extruded polystyrene sheathing



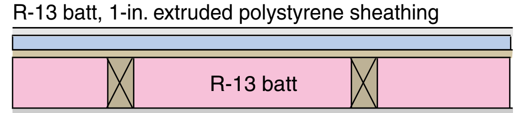
Reff = 17.2 Ueff = 0.0581

R-11 batt, 1-in. polyisocyanurate sheathing



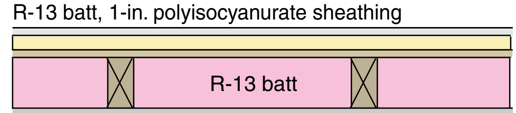
R_{eff} = 19.3 U_{eff} = 0.0519

R-13 batt, 1-in. extruded polystyrene sheathing



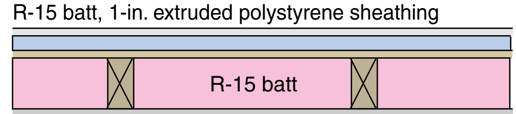
R_{eff} = 18.3 U_{eff} = 0.0545

R-13 batt, 1-in. polyisocyanurate sheathing



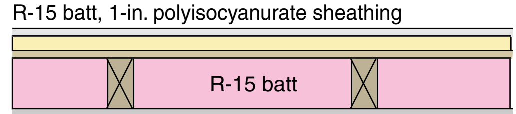
R_{eff} = 20.4 U_{eff} = 0.0489

R-15 batt, 1-in. extruded polystyrene sheathing



R_{eff} = 19.4 U_{eff} = 0.0515

R-15 batt, 1-in. polyisocyanurate sheathing

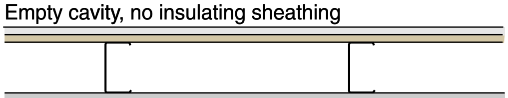


R_{eff} = 21.6 U_{eff} = 0.0464

Metal-Framed Walls

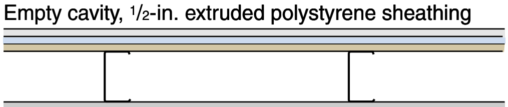
2 x 4, 16-in. o.c. METAL-FRAMED WALL, 1/2-in. WOOD SHEATHING, SIDING, 1/2-in. DRYWALL FINISH

Empty cavity, no insulating sheathing



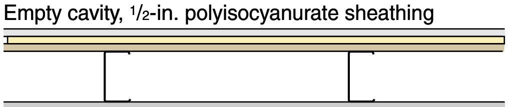
R_{eff} = 4.2 U_{eff} = 0.2362

Empty cavity, 1/2-in. extruded polystyrene sheathing



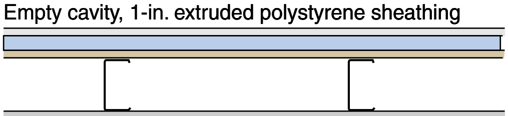
R_{eff} = 6.7 U_{eff} = 0.1486

Empty cavity, 1/2-in. polyisocyanurate sheathing



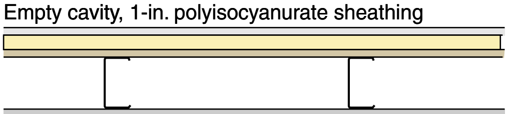
R_{eff} = 7.7 U_{eff} = 0.1293

Empty cavity, 1-in. extruded polystyrene sheathing



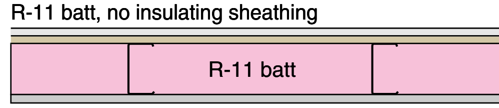
R_{eff} = 9.2 U_{eff} = 0.1084

Empty cavity, 1-in. polyisocyanurate sheathing



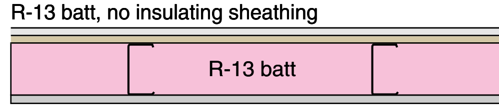
R_{eff} = 11.2 U_{eff} = 0.0891

R-11 batt, no insulating sheathing



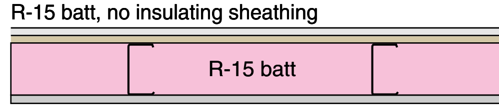
R_{eff} = 9.5 U_{eff} = 0.1049

R-13 batt, no insulating sheathing



R_{eff} = 10.1 U_{eff} = 0.0988

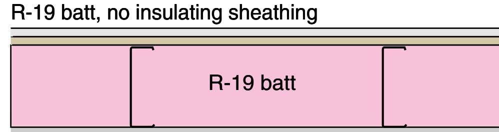
R-15 batt, no insulating sheathing



R_{eff} = 10.6 U_{eff} = 0.0942

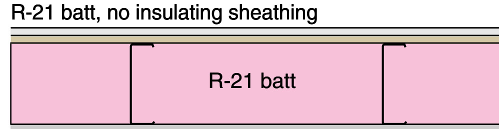
2 x 6 METAL-FRAMED WALL, 1/2-in. WOOD SHEATHING, SIDING, 1/2-in. DRYWALL

R-19 batt, no insulating sheathing



R_{eff} = 11.6 U_{eff} = 0.0864

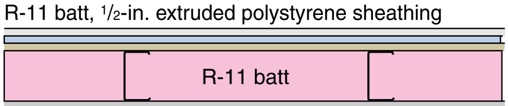
R-21 batt, no insulating sheathing



R_{eff} = 11.9 U_{eff} = 0.0841

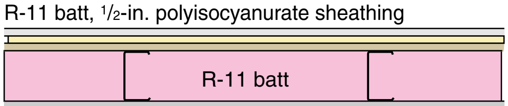
2 x 4, 16-in. o.c. METAL-FRAMED WALL, 1/2-in. WOOD SHEATHING, SIDING, 1/2-in. DRYWALL FINISH

R-11 batt, 1/2-in. extruded polystyrene sheathing



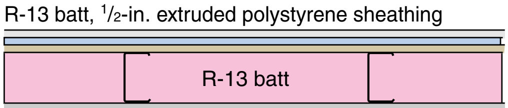
R_{eff} = 12.4 U_{eff} = 0.0808

R-11 batt, 1/2-in. polyisocyanurate sheathing



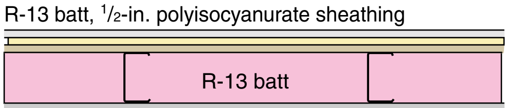
R_{eff} = 13.7 U_{eff} = 0.0731

R-13 batt, 1/2-in. extruded polystyrene sheathing



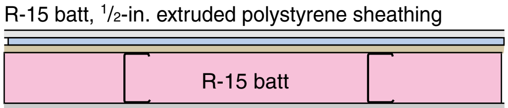
R_{eff} = 13.1 U_{eff} = 0.0766

R-13 batt, 1/2-in. polyisocyanurate sheathing



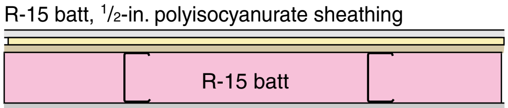
R_{eff} = 14.4 U_{eff} = 0.0693

R-15 batt, 1/2-in. extruded polystyrene sheathing



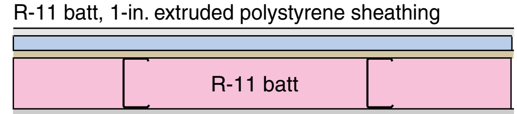
R_{eff} = 13.6 U_{eff} = 0.0733

R-15 batt, 1/2-in. polyisocyanurate sheathing



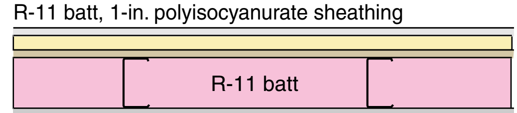
R_{eff} = 15.1 U_{eff} = 0.0662

R-11 batt, 1-in. extruded polystyrene sheathing



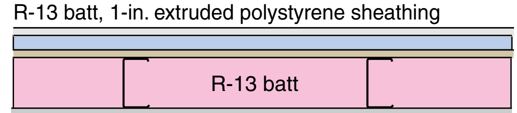
R_{eff} = 14.9 U_{eff} = 0.0672

R-11 batt, 1-in. polyisocyanurate sheathing



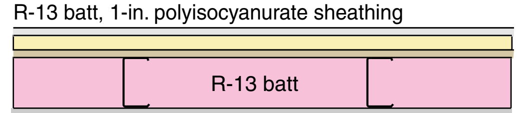
R_{eff} = 17.2 U_{eff} = 0.0580

R-13 batt, 1-in. extruded polystyrene sheathing



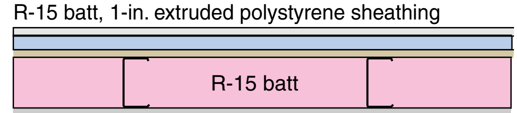
R_{eff} = 15.6 U_{eff} = 0.0642

R-13 batt, 1-in. polyisocyanurate sheathing



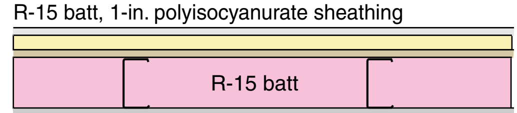
R_{eff} = 18.1 U_{eff} = 0.0554

R-15 batt, 1-in. extruded polystyrene sheathing



R_{eff} = 16.2 U_{eff} = 0.0618

R-15 batt, 1-in. polyisocyanurate sheathing

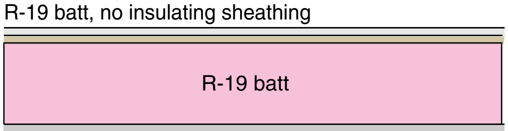


R_{eff} = 18.8 U_{eff} = 0.0533

OVE Wood-Framed Walls

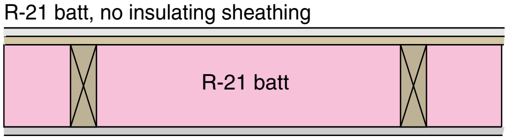
2 x 6, 24-in. o.c. WOOD-FRAMED OVE WALL, 1/2-in. WOOD SHEATHING, SIDING, 1/2-in. DRYWALL FINISH

R-19 batt, no insulating sheathing



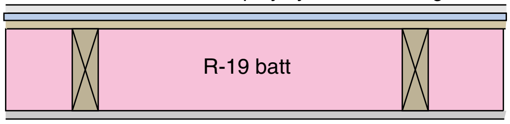
R_{eff} = 17.9 U_{eff} = 0.056

R-21 batt, no insulating sheathing



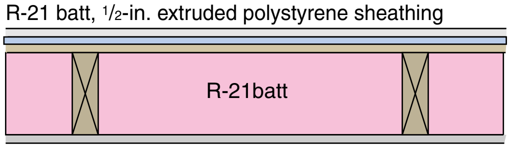
R_{eff} = 18.9 U_{eff} = 0.053

R-19 batt, 1/2-in. extruded polystyrene sheathing



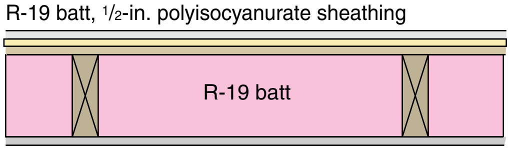
R_{eff} = 20.4 U_{eff} = 0.049

R-21 batt, 1/2-in. extruded polystyrene sheathing



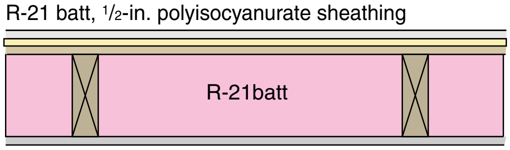
R_{eff} = 21.4 U_{eff} = 0.047

R-19 batt, 1/2-in. polyisocyanurate sheathing



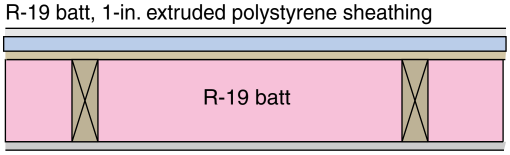
R_{eff} = 21.6 U_{eff} = 0.046

R-21 batt, 1/2-in. polyisocyanurate sheathing



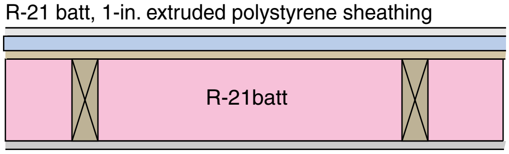
R_{eff} = 22.6 U_{eff} = 0.044

R-19 batt, 1-in. extruded polystyrene sheathing



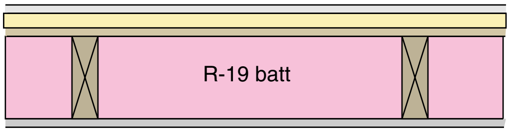
R_{eff} = 22.9 U_{eff} = 0.044

R-21 batt, 1-in. extruded polystyrene sheathing



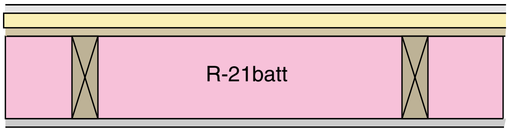
R_{eff} = 23.9 U_{eff} = 0.042

R-19 batt, 1-in. polyisocyanurate sheathing



R_{eff} = 25.1 U_{eff} = 0.040

R-21 batt, 1-in. polyisocyanurate sheathing

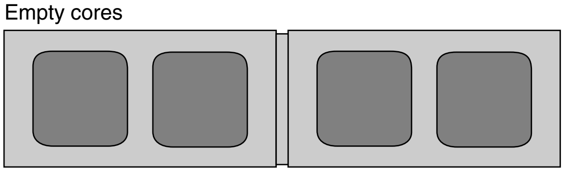


R_{eff} = 26.1 U_{eff} = 0.038

Single-Wythe Concrete Masonry Walls

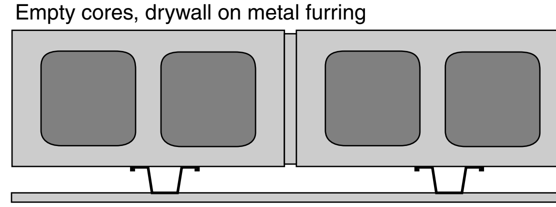
8 x 16 BLOCK, 135 PCF

Empty cores



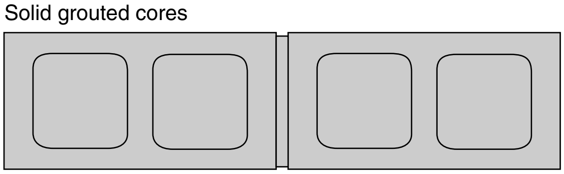
R_{eff} = 1.9 U_{eff} = 0.537

Empty cores, drywall on metal furring



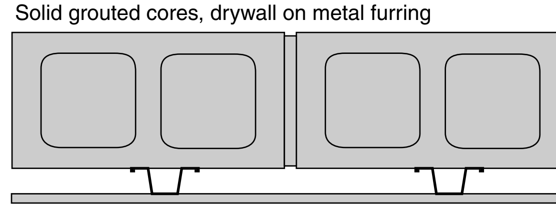
R_{eff} = 3.3 U_{eff} = 0.303

Solid grouted cores



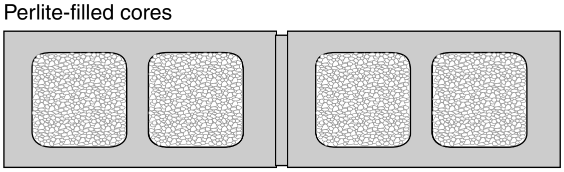
R_{eff} = 1.5 U_{eff} = 0.684

Solid grouted cores, drywall on metal furring



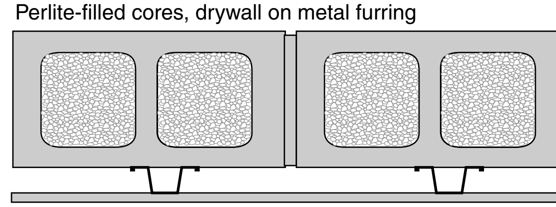
R_{eff} = 2.9 U_{eff} = 0.345

Perlite-filled cores



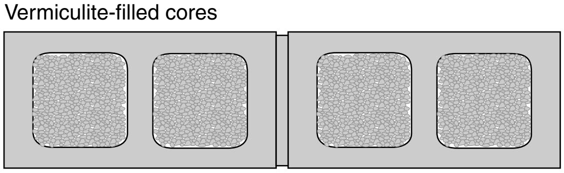
R_{eff} = 3.2 U_{eff} = 0.309

Perlite-filled cores, drywall on metal furring



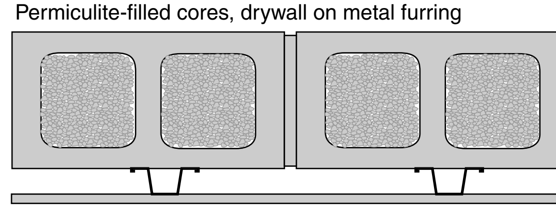
R_{eff} = 4.6 U_{eff} = 0.217

Vermiculite-filled cores



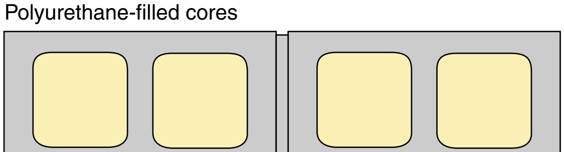
R_{eff} = 3.2 U_{eff} = 0.317

Permiculite-filled cores, drywall on metal furring



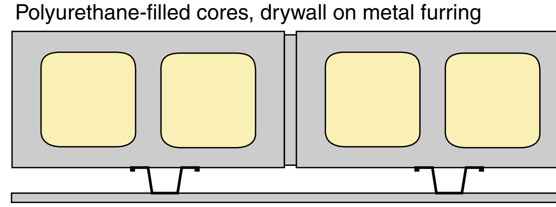
R_{eff} = 4.6 U_{eff} = 0.217

Polyurethane-filled cores



R_{eff} = 3.4 U_{eff} = 0.298

Polyurethane-filled cores, drywall on metal furring

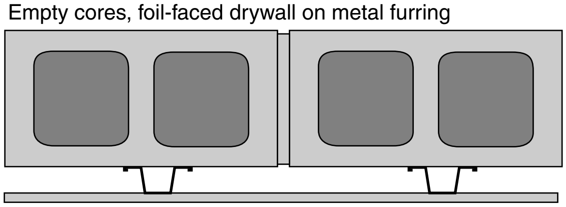


R_{eff} = 4.8 U_{eff} = 0.208

Single-Wythe Concrete Masonry Walls—*Continued*

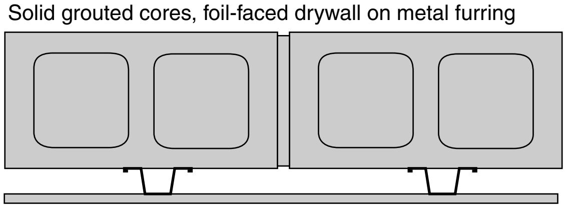
8 x 16 BLOCK, 135 PCF

Empty cores, foil-faced drywall on metal furring



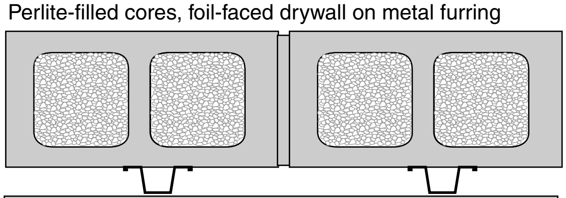
$R_{eff} = 4.8$ $U_{eff} = 0.208$

Solid grouted cores, foil-faced drywall on metal furring



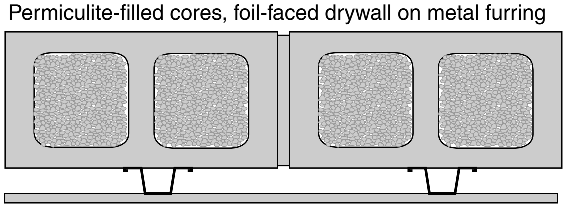
$R_{eff} = 4.4$ $U_{eff} = 0.227$

Perlite-filled cores, foil-faced drywall on metal furring



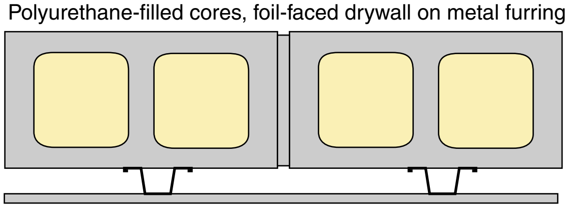
$R_{eff} = 6.1$ $U_{eff} = 0.164$

Permiculite-filled cores, foil-faced drywall on metal furring



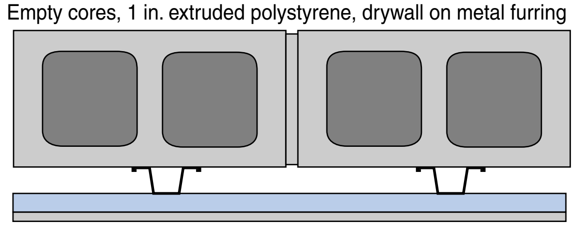
$R_{eff} = 6.1$ $U_{eff} = 0.164$

Polyurethane-filled cores, foil-faced drywall on metal furring



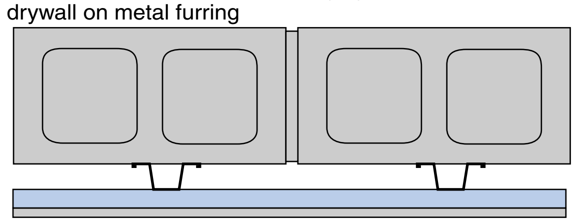
$R_{eff} = 6.3$ $U_{eff} = 0.159$

Empty cores, 1 in. extruded polystyrene, drywall on metal furring



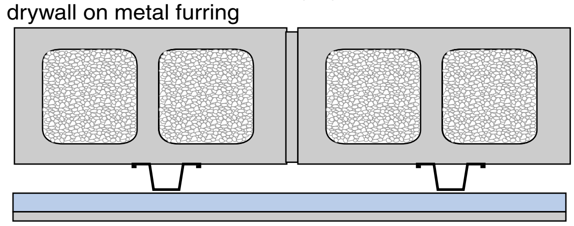
$R_{eff} = 8.3$ $U_{eff} = 0.120$

Concrete cores, 1 in. extruded polystyrene, drywall on metal furring



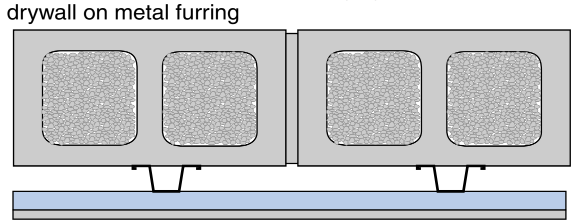
$R_{eff} = 7.9$ $U_{eff} = 0.127$

Perlite cores, 1 in. extruded polystyrene, drywall on metal furring



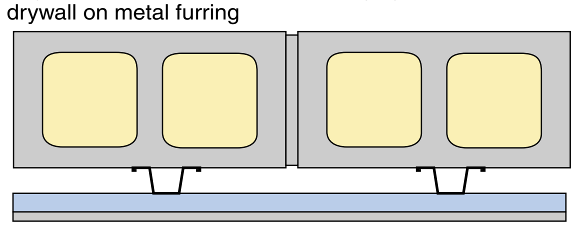
$R_{eff} = 9.6$ $U_{eff} = 0.104$

Vermiculite cores, 1 in. extruded polystyrene, drywall on metal furring



$R_{eff} = 9.6$ $U_{eff} = 0.104$

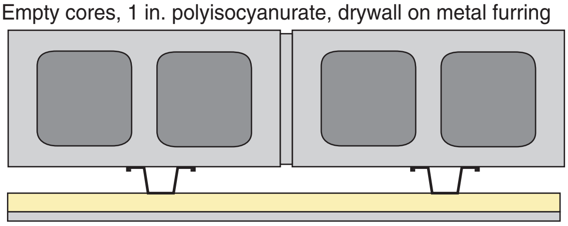
Polyurethane cores, 1 in. extruded polystyrene, drywall on metal furring



$R_{eff} = 9.8$ $U_{eff} = 0.102$

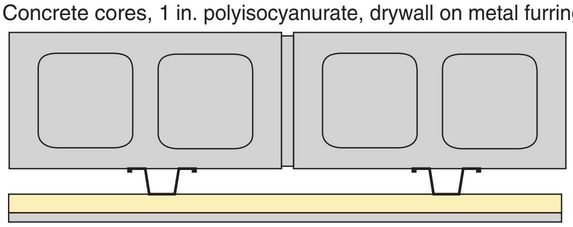
8 x 16 BLOCK,

Empty cores, 1 in. polyisocyanurate, drywall on metal furring



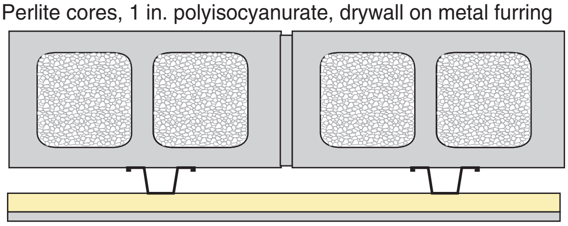
R_{eff} = 11.7 U_{eff} = 0.085

Concrete cores, 1 in. polyisocyanurate, drywall on metal furring



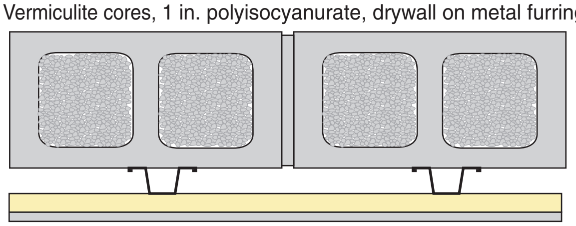
R_{eff} = 11.3 U_{eff} = 0.088

Perlite cores, 1 in. polyisocyanurate, drywall on metal furring



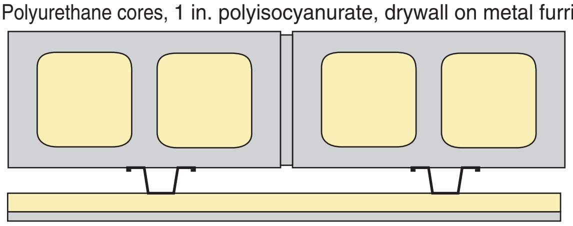
R_{eff} = 13.0 U_{eff} = 0.077

Vermiculite cores, 1 in. polyisocyanurate, drywall on metal furring



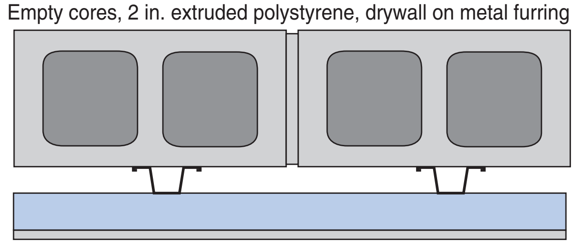
R_{eff} = 13.0 U_{eff} = 0.077

Polyurethane cores, 1 in. polyisocyanurate, drywall on metal furring



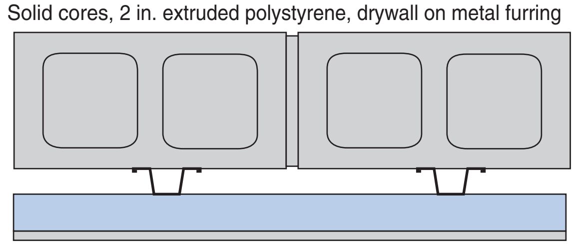
R_{eff} = 13.2 U_{eff} = 0.076

Empty cores, 2 in. extruded polystyrene, drywall on metal furring



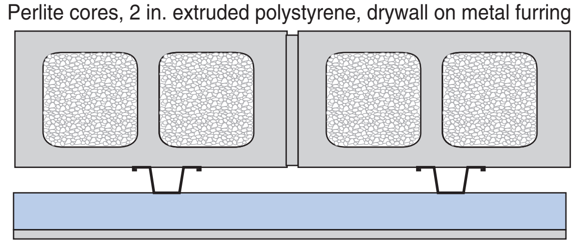
R_{eff} = 13.3 U_{eff} = 0.075

Solid cores, 2 in. extruded polystyrene, drywall on metal furring



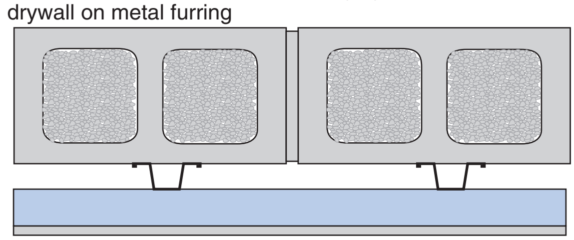
R_{eff} = 12.9 U_{eff} = 0.078

Perlite cores, 2 in. extruded polystyrene, drywall on metal furring



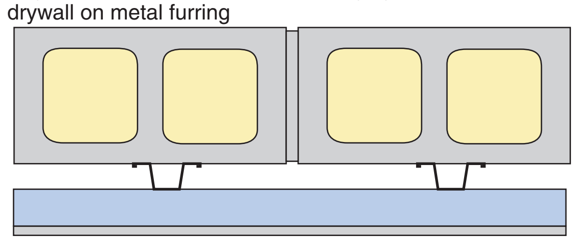
R_{eff} = 14.6 U_{eff} = 0.068

Vermiculite cores, 2 in. extruded polystyrene, drywall on metal furring



R_{eff} = 14.6 U_{eff} = 0.068

Polyurethane cores, 2 in. extruded polystyrene, drywall on metal furring

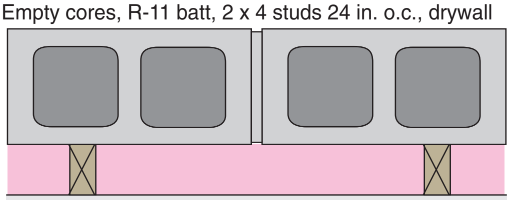


R_{eff} = 14.8 U_{eff} = 0.068

Single-Wythe Concrete Masonry Walls—*Continued*

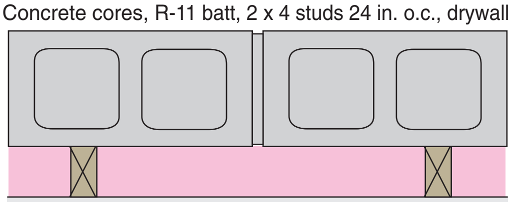
8 x 16 BLOCK, 135 PCF

Empty cores, R-11 batt, 2 x 4 studs 24 in. o.c., drywall



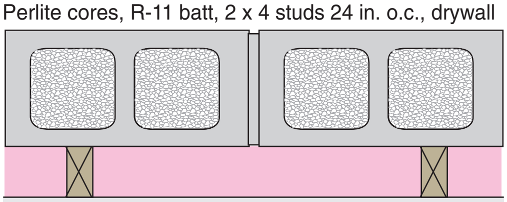
R_{eff} = 12.1 U_{eff} = 0.083

Concrete cores, R-11 batt, 2 x 4 studs 24 in. o.c., drywall



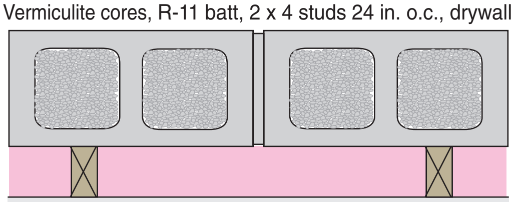
R_{eff} = 11.7 U_{eff} = 0.085

Perlite cores, R-11 batt, 2 x 4 studs 24 in. o.c., drywall



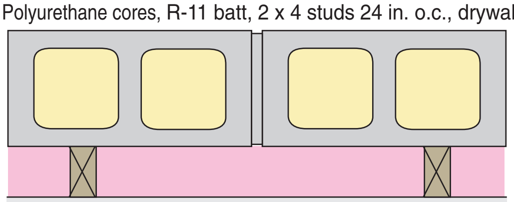
R_{eff} = 13.4 U_{eff} = 0.075

Vermiculite cores, R-11 batt, 2 x 4 studs 24 in. o.c., drywall



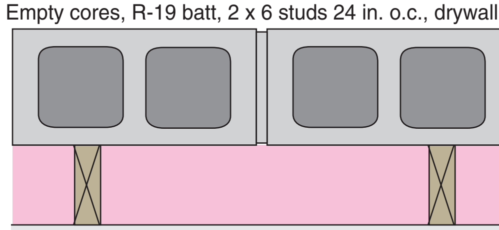
R_{eff} = 13.4 U_{eff} = 0.075

Polyurethane cores, R-11 batt, 2 x 4 studs 24 in. o.c., drywall



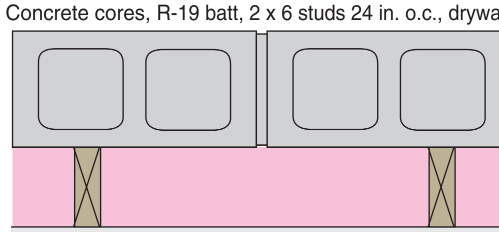
R_{eff} = 13.6 U_{eff} = 0.074

Empty cores, R-19 batt, 2 x 6 studs 24 in. o.c., drywall



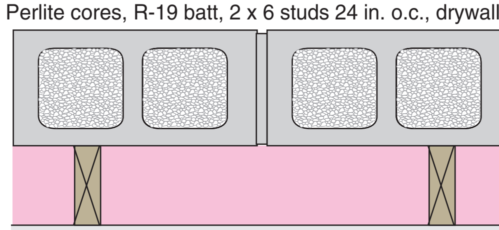
R_{eff} = 18.8 U_{eff} = 0.053

Concrete cores, R-19 batt, 2 x 6 studs 24 in. o.c., drywall



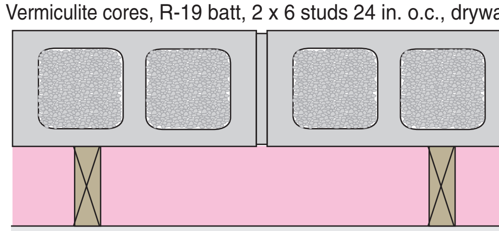
R_{eff} = 18.4 U_{eff} = 0.054

Perlite cores, R-19 batt, 2 x 6 studs 24 in. o.c., drywall



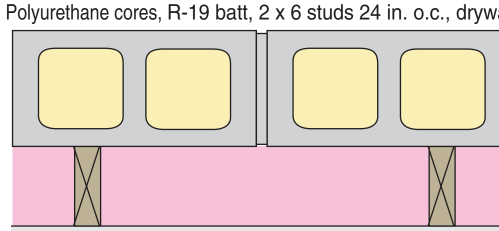
R_{eff} = 20.1 U_{eff} = 0.050

Vermiculite cores, R-19 batt, 2 x 6 studs 24 in. o.c., drywall



R_{eff} = 20.1 U_{eff} = 0.050

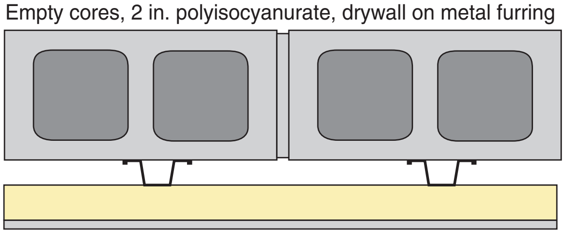
Polyurethane cores, R-19 batt, 2 x 6 studs 24 in. o.c., drywall



R_{eff} = 20.3 U_{eff} = 0.049

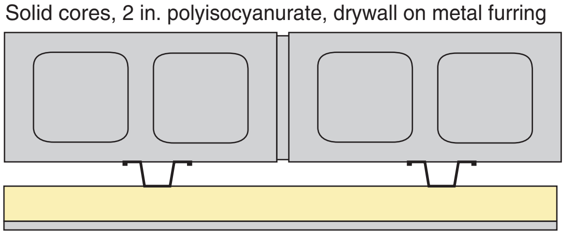
8 x 16 BLOCK,

Empty cores, 2 in. polyisocyanurate, drywall on metal furring



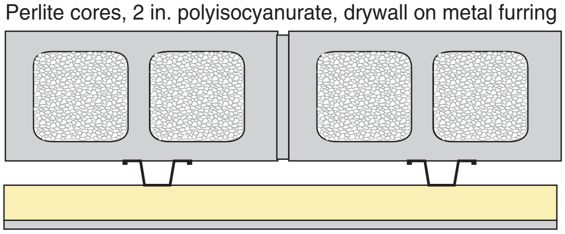
R_{eff} = 18.1 U_{eff} = 0.055

Solid cores, 2 in. polyisocyanurate, drywall on metal furring



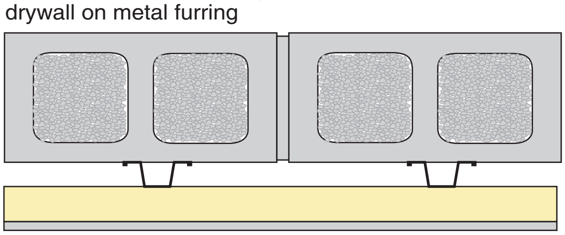
R_{eff} = 17.7 U_{eff} = 0.056

Perlite cores, 2 in. polyisocyanurate, drywall on metal furring



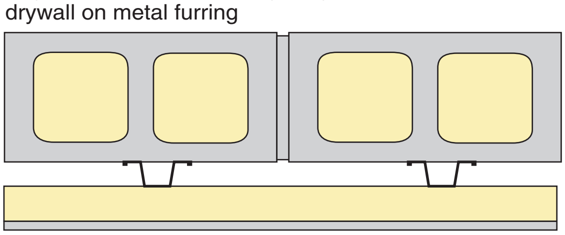
R_{eff} = 19.4 U_{eff} = 0.052

Vermiculite cores, 2 in. polyisocyanurate, drywall on metal furring



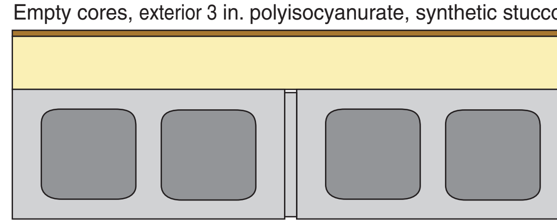
R_{eff} = 19.4 U_{eff} = 0.052

Polyurethane cores, 2 in. polyisocyanurate, drywall on metal furring



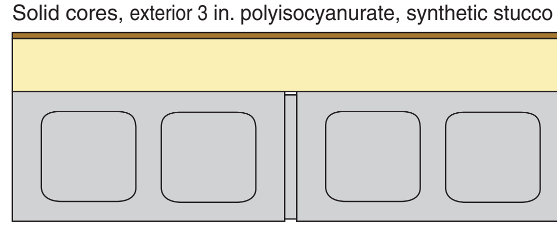
R_{eff} = 19.6 U_{eff} = 0.0511

Empty cores, exterior 3 in. polyisocyanurate, synthetic stucco



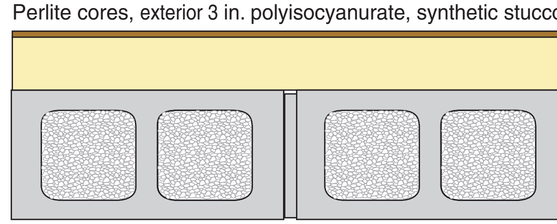
R_{eff} = 21.2 U_v = 0.047

Solid cores, exterior 3 in. polyisocyanurate, synthetic stucco



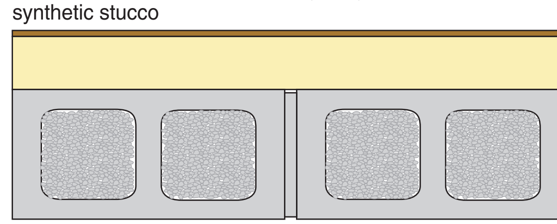
R_{eff} = 20.8 U_{eff} = 0.048

Perlite cores, exterior 3 in. polyisocyanurate, synthetic stucco



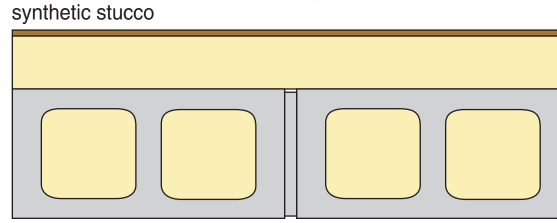
R_{eff} = 22.5 U_{eff} = 0.044

Vermiculite cores, exterior 3 in. polyisocyanurate, synthetic stucco



R_{eff} = 22.5 U_{eff} = 0.044

Polyurethane cores, exterior 3 in. polyisocyanurate, synthetic stucco

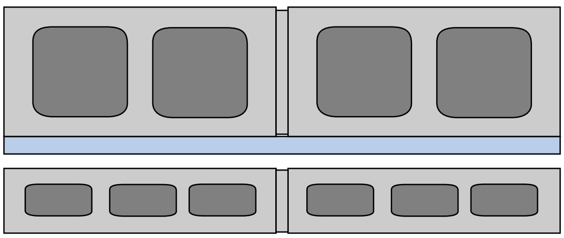


R_{eff} = 22.7 U_{eff} = 0.044

Concrete Masonry Cavity Assemblies

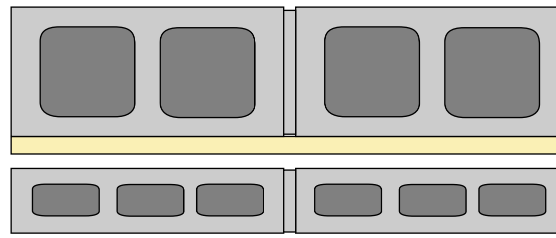
8 x 16 BLOCK + 4 x 16 VENEER, NO FINISH, 135 PCF

Empty cores, 1 in. extruded polystyrene



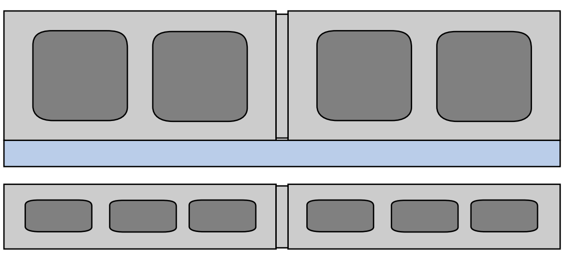
$R_{eff} = 8.3$ $U_{eff} = 0.120$

Empty cores, 1 in. foil-faced polyisocyanurate



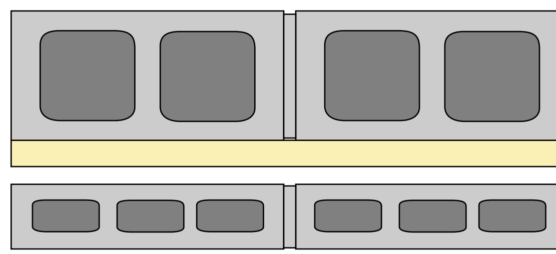
$R_{eff} = 11.8$ $U_{eff} = 0.085$

Empty cores, 1 1/2 in. extruded polystyrene



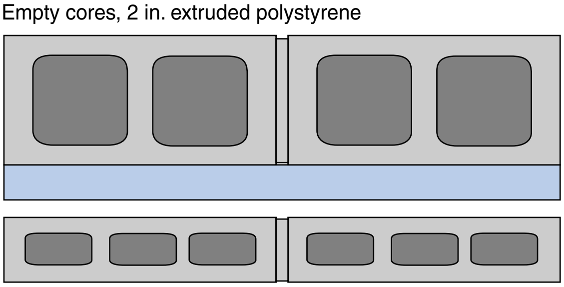
$R_{eff} = 10.8$ $U_{eff} = 0.093$

Empty cores, 1 1/2 in. foil-faced polyisocyanurate



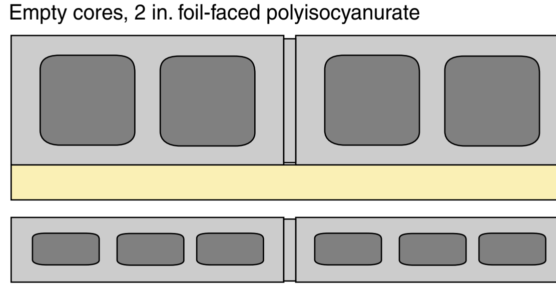
$R_{eff} = 15.6$ $U_{eff} = 0.064$

Empty cores, 2 in. extruded polystyrene



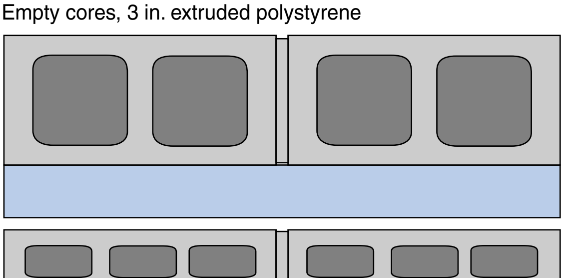
$R_{eff} = 13.3$ $U_{eff} = 0.075$

Empty cores, 2 in. foil-faced polyisocyanurate



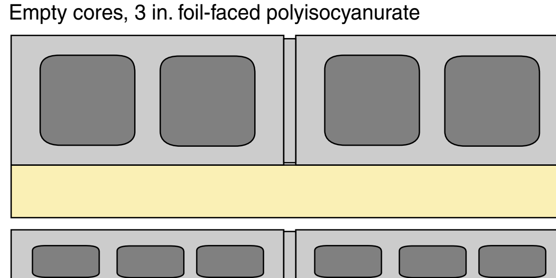
$R_{eff} = 19.5$ $U_{eff} = 0.051$

Empty cores, 3 in. extruded polystyrene



$R_{eff} = 18.3$ $U_{eff} = 0.055$

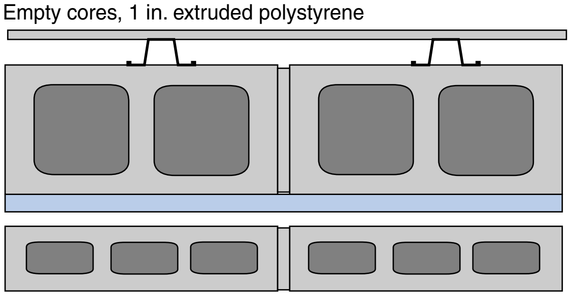
Empty cores, 3 in. foil-faced polyisocyanurate



$R_{eff} = 26.3$ $U_{eff} = 0.038$

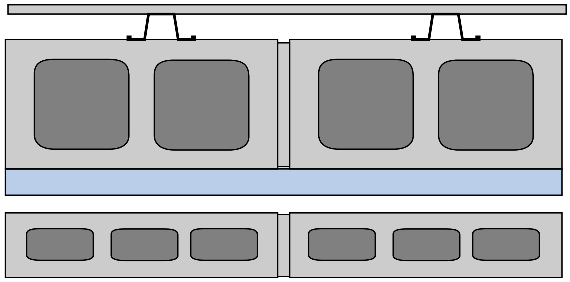
8 x 16 BLOCK, 4 x 16 VENEER, 1/2 in. DRYWALL ON METAL FURRING, 135 PCF

Empty cores, 1 in. extruded polystyrene



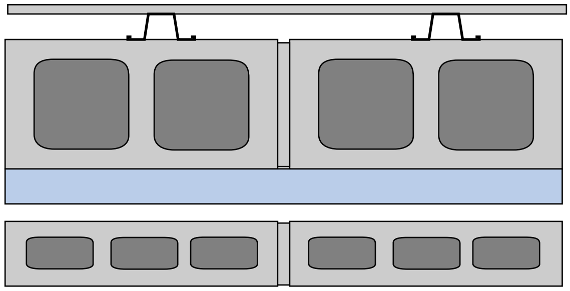
$R_{eff} = 9.7$ $U_{eff} = 0.103$

Empty cores, 1 1/2 in. extruded polystyrene



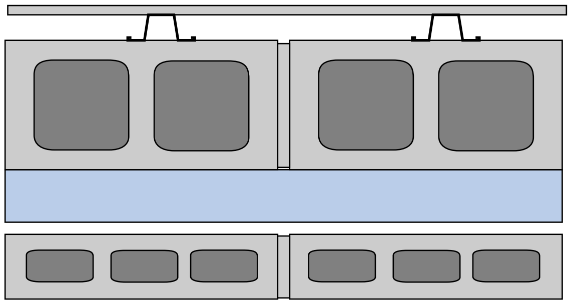
$R_{eff} = 12.2$ $U_{eff} = 0.082$

Empty cores, 2 in. extruded polystyrene



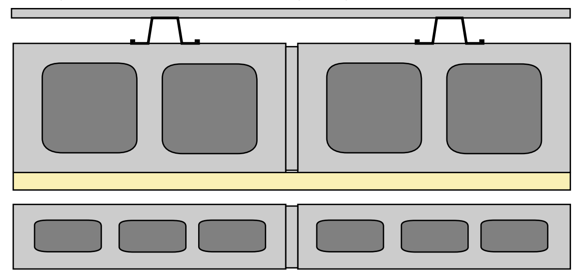
$R_{eff} = 14.7$ $U_{eff} = 0.068$

Empty cores, 3 in. extruded polystyrene



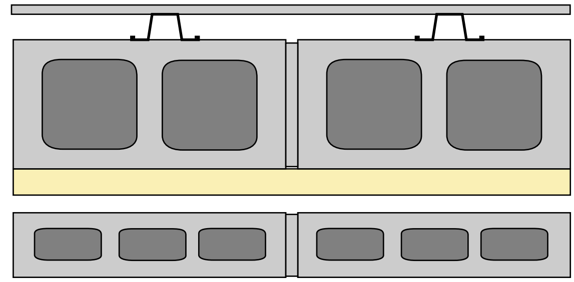
$R_{eff} = 19.7$ $U_{eff} = 0.051$

Empty cores, 1 in. foil-faced polyisocyanurate



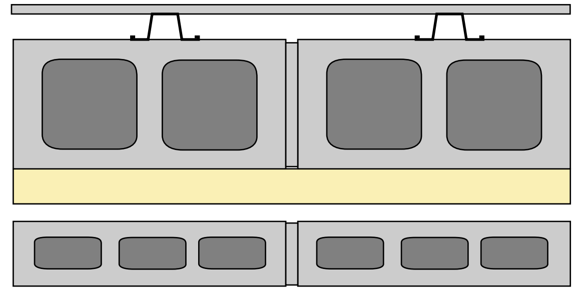
$R_{eff} = 13.2$ $U_{eff} = 0.076$

Empty cores, 1 1/2 in. foil-faced polyisocyanurate



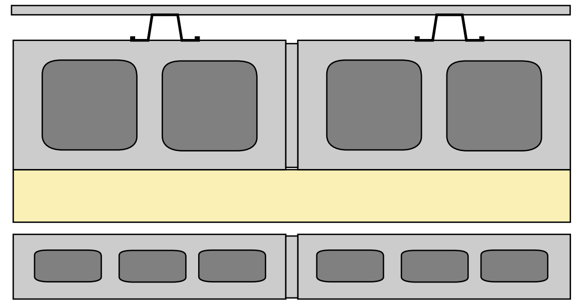
$R_{eff} = 17.0$ $U_{eff} = 0.059$

Empty cores, 2 in. foil-faced polyisocyanurate



$R_{eff} = 20.9$ $U_{eff} = 0.048$

Empty cores, 3 in. foil-faced polyisocyanurate

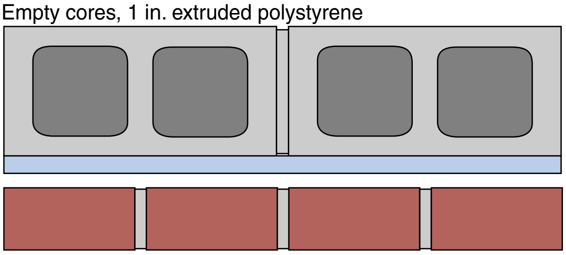


$R_{eff} = 27.7$ $U_{eff} = 0.036$

Concrete Masonry and Brick Assemblies

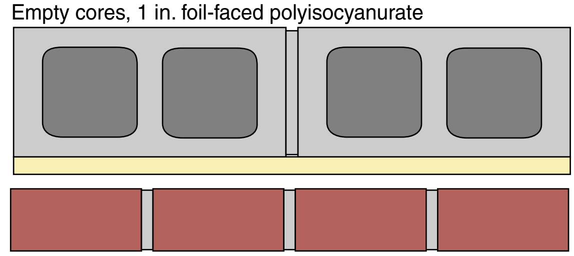
8 x 16 BLOCK + 4 x 16 BRICK VENEER, NO FINISH, 135 PCF

Empty cores, 1 in. extruded polystyrene



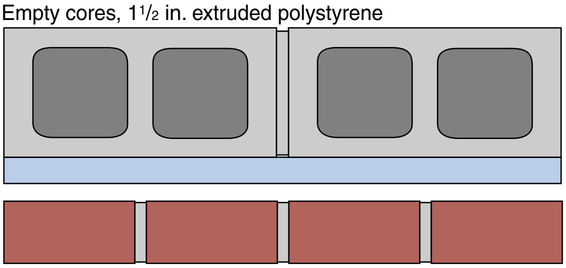
R_{eff} = 7.9 U_{eff} = 0.127

Empty cores, 1 in. foil-faced polyisocyanurate



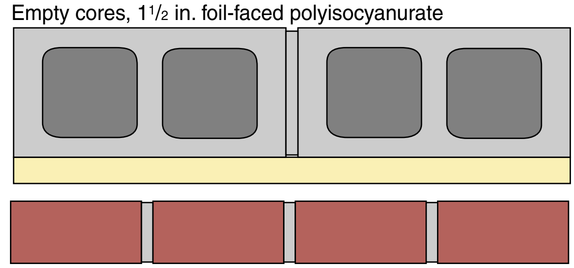
R_{eff} = 11.4 U_{eff} = 0.088

Empty cores, 1 1/2 in. extruded polystyrene



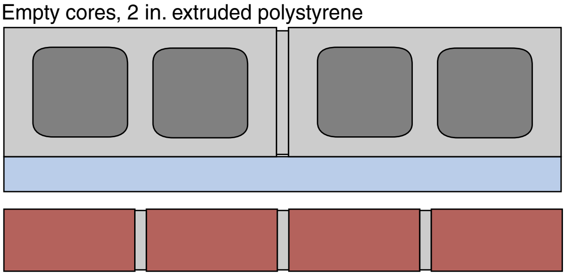
R_{eff} = 10.4 U_{eff} = 0.096

Empty cores, 1 1/2 in. foil-faced polyisocyanurate



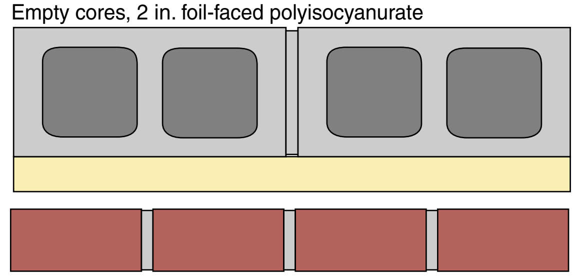
R_{eff} = 15.2 U_{eff} = 0.066

Empty cores, 2 in. extruded polystyrene



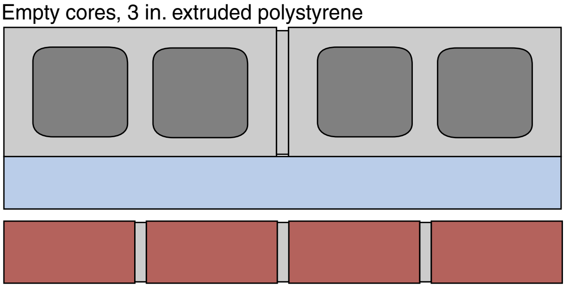
R_{eff} = 12.9 U_{eff} = 0.078

Empty cores, 2 in. foil-faced polyisocyanurate



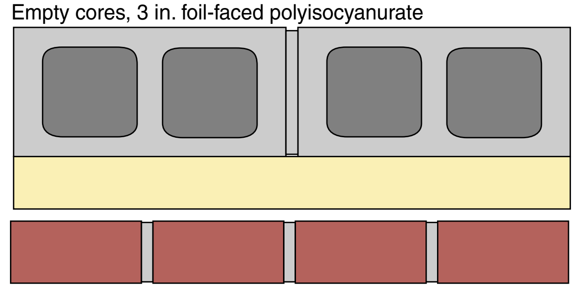
R_{eff} = 19.1 U_{eff} = 0.052

Empty cores, 3 in. extruded polystyrene



R_{eff} = 17.9 U_{eff} = 0.056

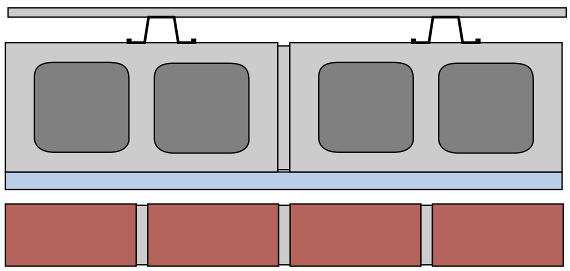
Empty cores, 3 in. foil-faced polyisocyanurate



R_{eff} = 25.9 U_{eff} = 0.039

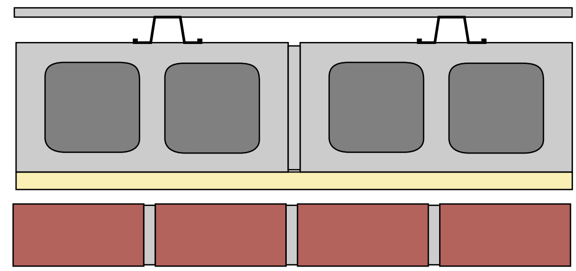
8 x 16 BLOCK, 4 x 16 BRICK VENEER, 1/2 in. DRYWALL ON METAL FURRING, 135 PCF

Empty cores, 1 in. extruded polystyrene



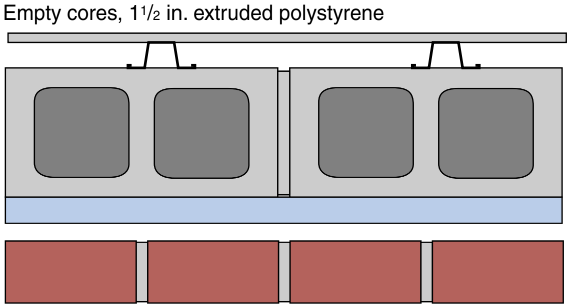
R_{eff} = 9.3 U_{eff} = 0.108

Empty cores, 1 in. foil-faced polyisocyanurate



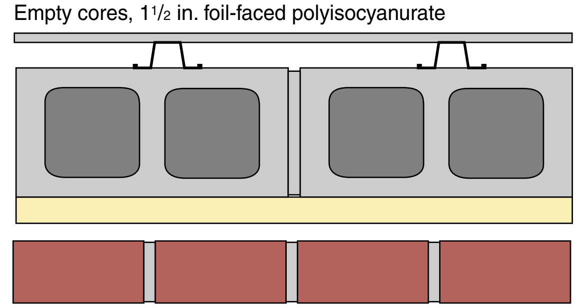
R_{eff} = 12.8 U_{eff} = 0.078

Empty cores, 1 1/2 in. extruded polystyrene



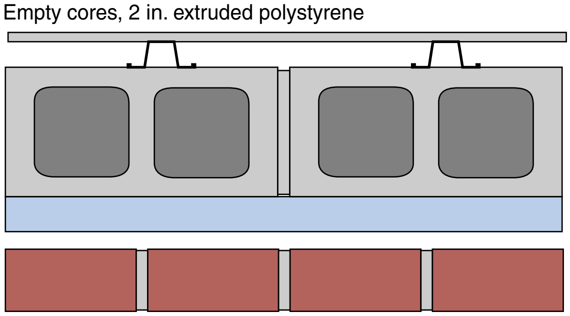
R_{eff} = 11.8 U_{eff} = 0.085

Empty cores, 1 1/2 in. foil-faced polyisocyanurate



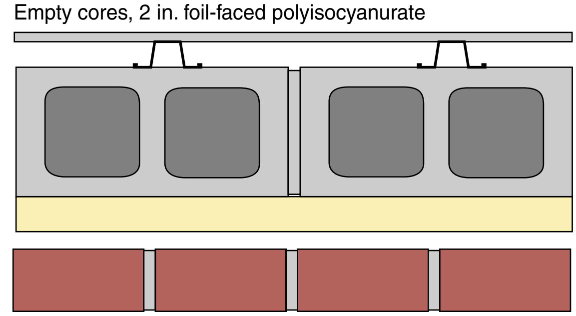
R_{eff} = 16.6 U_{eff} = 0.060

Empty cores, 2 in. extruded polystyrene



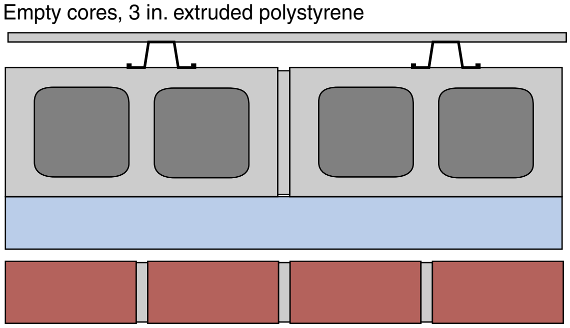
R_{eff} = 14.3 U_{eff} = 0.070

Empty cores, 2 in. foil-faced polyisocyanurate



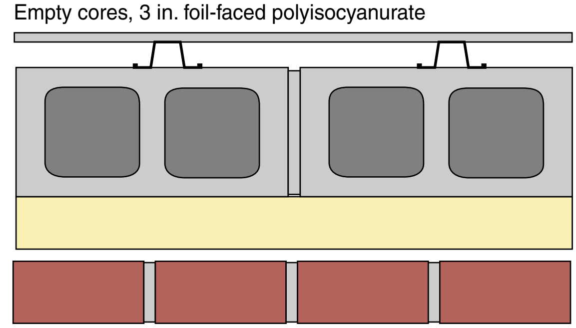
R_{eff} = 20.5 U_{eff} = 0.049

Empty cores, 3 in. extruded polystyrene



R_{eff} = 19.3 U_{eff} = 0.052

Empty cores, 3 in. foil-faced polyisocyanurate



R_{eff} = 27.3 U_{eff} = 0.037

14

Best Practice Insulating

How best to insulate? That is the number one question homeowners ask when considering investments to lower their heating and cooling bills. And that is the subject of this chapter.

To answer the question we need to begin at the beginning—*Where to Insulate: the Thermal Envelope*. The graphic illustration of a building's thermal envelope—the boundary between the outdoors and the interior conditioned spaces—identifies the surfaces we need to insulate: *attics and cathedral ceilings, walls, slab foundations, crawl spaces*, and *full basements*. Older basements sometimes pose special problems, so we include detailed drawings for *retrofitting full basements*.

For each surface we show a number of building science–approved options, as well as the fuel- and location-dependent recommended R-values.

Where to Insulate: The Thermal Envelope

In dealing with a building's heat loss and heat gain, building scientists employ a useful concept: the building's thermal envelope. The thermal envelope is the set of contiguous surfaces separating the conditioned (heated and/or cooled) interior of a building from the outdoors and the earth. Included surfaces are roofs, ceilings, exterior walls, foundation walls, floors, windows, and doors.

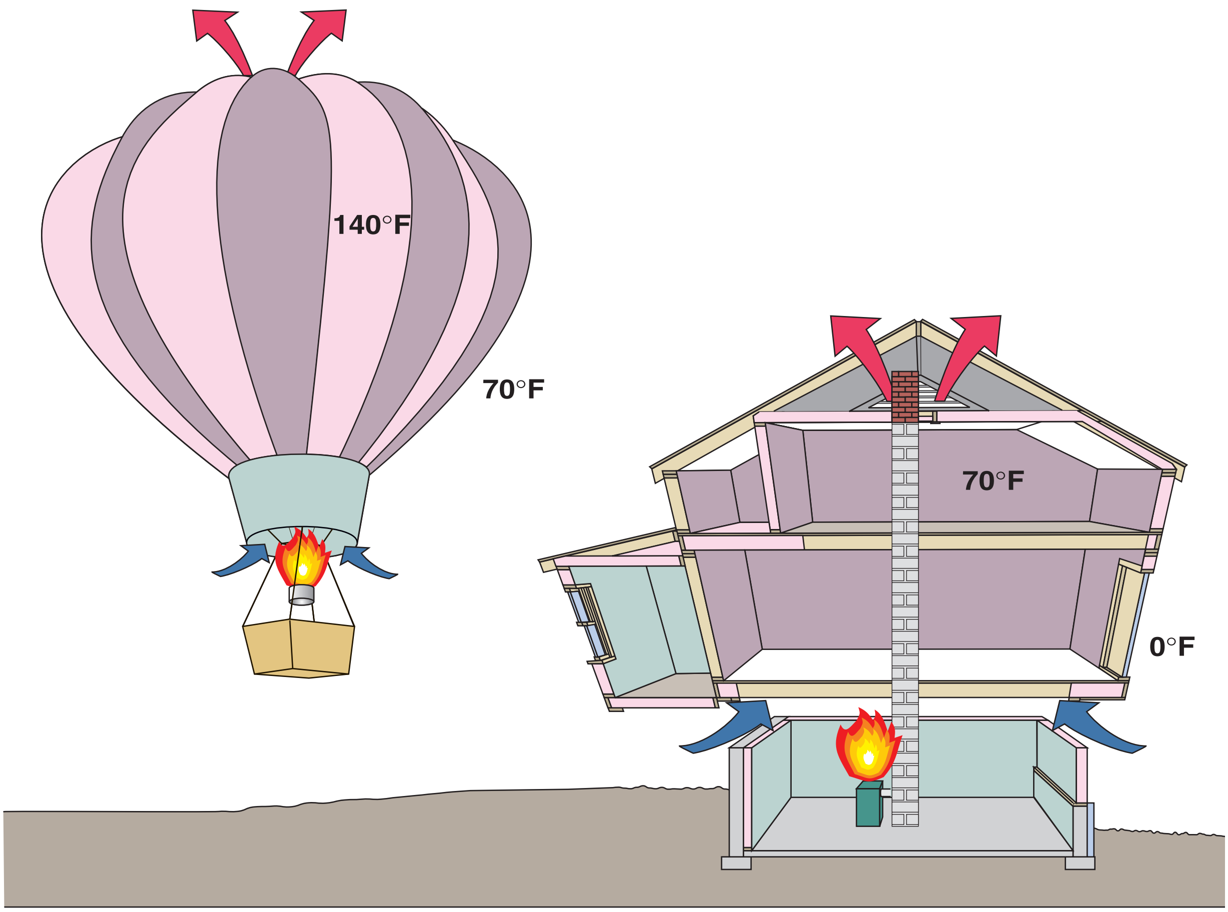
A useful analogy can be made between a cold-climate thermal envelope in winter and a hot air balloon. As shown in the illustration below, both contain a volume of warm air. Just as conduction through the fabric and airflow through the vent at the top of the balloon will allow hot air to escape, so will gaps in the thermal envelope.

To be maximally effective, every surface comprising the thermal envelope must be insulated to the R-value appropriate to the climate.

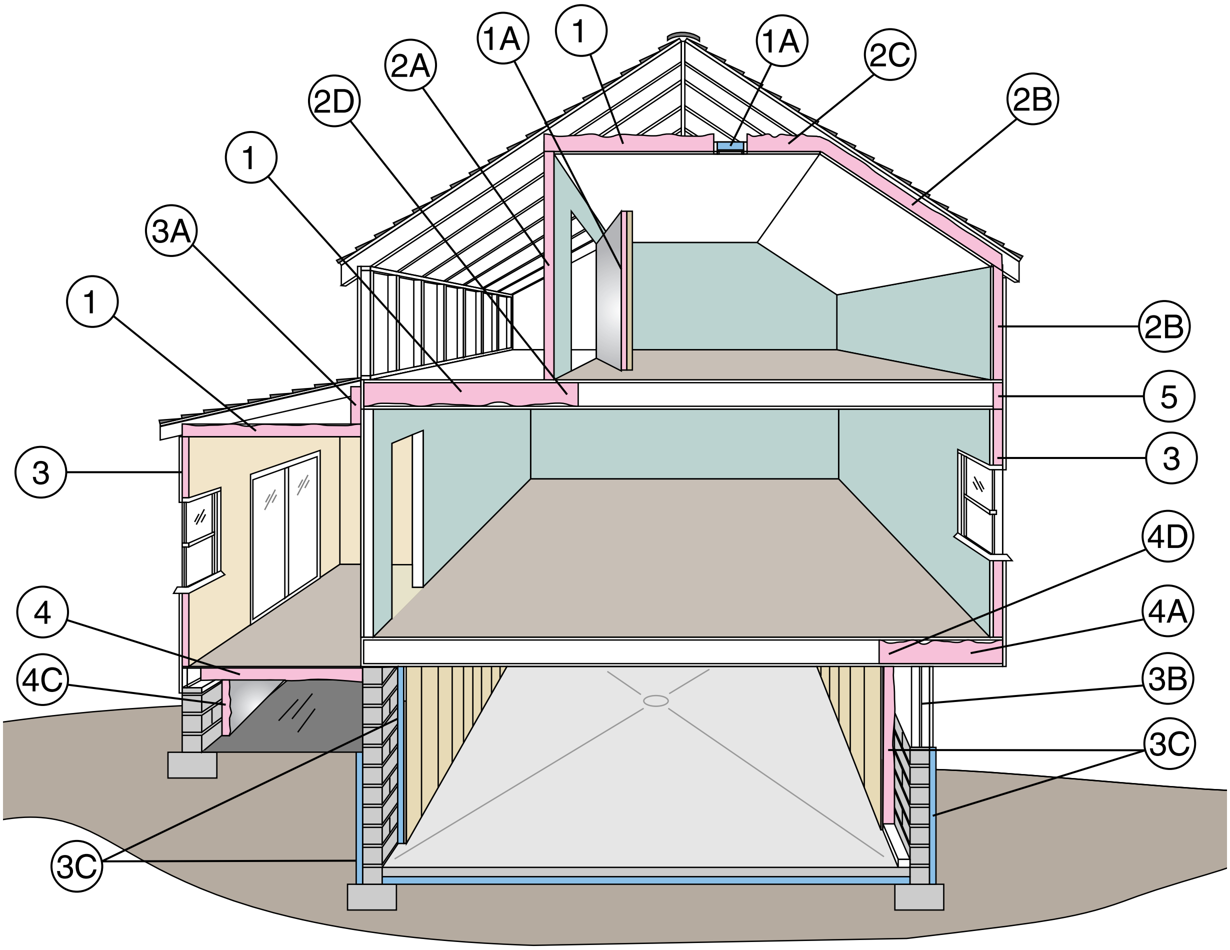
What is the appropriate R-value? The rational answer is the R-value that results in minimum life-cycle cost (LCC)—the sum of the costs of heating and cooling losses through the insulated surface plus the initial cost of installing the insulation.

The Oak Ridge National Lab's ZIP-Code Insulation Program, found at http://web.ornl.gov/sci/buildings/tools/zip/, lists the LCC-based recommended insulation levels for new and existing houses. The building surfaces included are identified in the thermal envelope illustration on the facing page.

Thermal Envelopes in Winter Are Like Hot Air Balloons



Where to Insulate



1. In unfinished attic spaces, insulate between and over floor joists to seal off living spaces below.
   1A. attic access door

2. In finished attic rooms with or without dormers, insulate:
   2A. between studs of knee walls
   2B. between studs and rafters of exterior walls and roof
   2C. ceilings with cold spaces above
   2D. extend insulation into joist space to reduce air flows

3. All exterior walls, including:
   3A. walls between living spaces and unheated garages, shed roofs, or storage areas
   3B. foundation walls above ground level
   3C. foundation walls in heated basements—full wall, either interior or exterior

4. Floors above unconditioned spaces, such as vented crawl spaces and unheated garages. Also insulate:
   4A. portion of floor cantilevered beyond exterior wall below
   4B. slab floors at grade level (not shown)
   4C. as an alternative to floor insulation, foundation walls of unvented crawl spaces
   4D. extend insulation into joist space to reduce air flows

5. Band joists.

Insulating Attics and Cathedral Ceilings

Four issues must be addressed when insulating attics and cathedral ceilings:

1. The insulation should have the R-value recommended in the tables on the facing page for the building location and energy sources.

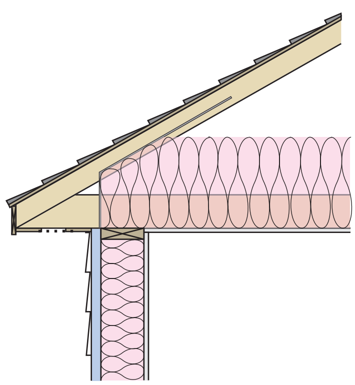
2. There should be no air leaks from the conditioned space below.

3. The type(s) of insulation and vapor barriers should be such that condensation does not occur within the attic or cathedral ceiling except in rare instances.

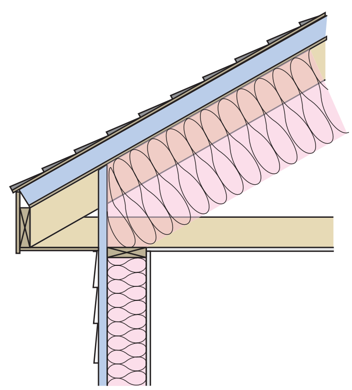
4. In areas of snow buildup (Zones 5 and above), the construction should be such that ice dams do not occur.

The six examples below and on pp. 432–434 provide a range of solutions satisfying all of the criteria.

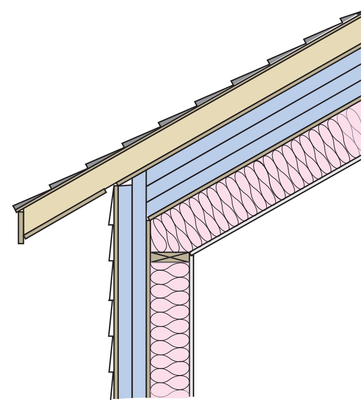
Attic and Cathedral Ceiling Insulation Configurations



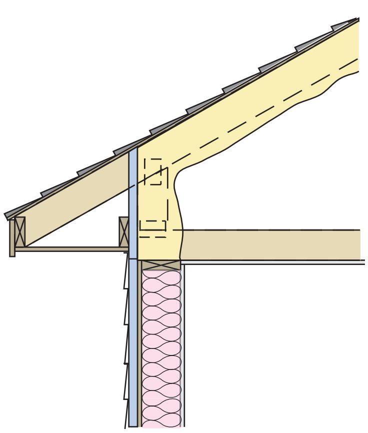
Vented attic with ceiling insulation



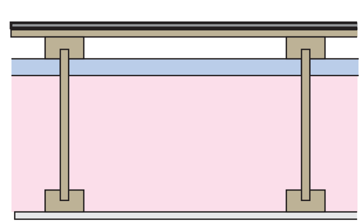
Unvented attic with roof insulation



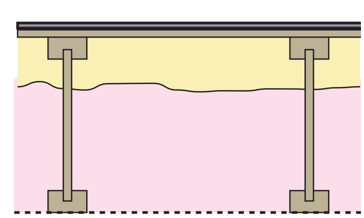
High R-value vented cathedral ceiling



Unvented attic with spray foam roof insulation



Vented cathedral ceiling with I-joist rafters



Unvented cathedral ceiling with I-joist rafters

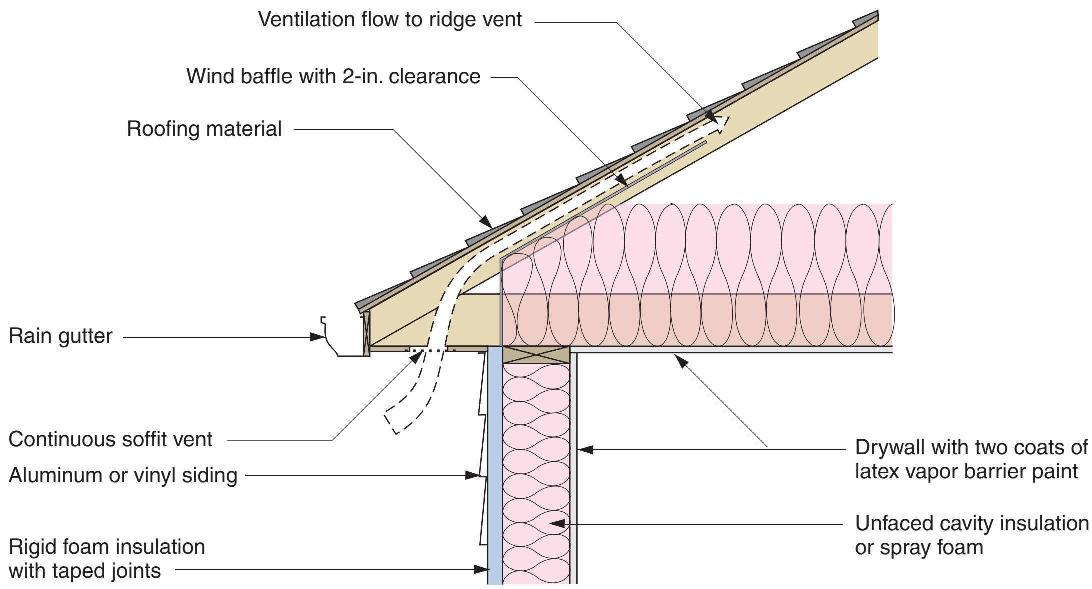
Recommended R-Values for Attic Floors

Location	Natural Gas Heat Electric AC	Heat Pump Heat Electric AC	Fuel Oil Heat Electric AC	Natural Gas Heat No AC	Fuel Oil Heat No AC
AZ, Phoenix	38	38	38	22	22
CA, Los Angeles	22	19	22	19	19
CO, Denver	49	38	38	49	38
DC, Washington	49	38	49	49	38
FL, Miami	38	22	38	11	0
GA, Atlanta	38	38	38	38	38
IL, Chicago	38	49	38	38	38
LA, Baton Rouge	38	38	38	38	22
ME, Portland	49	49	49	49	49
MA, Boston	49	49	38	49	38
MN, Duluth	49	49	49	49	49
MO, St Louis	49	38	38	49	38
NY, New York	38	49	38	38	38
TX, Dallas	38	38	38	38	22
VT, Burlington	49	49	49	49	49
WA, Seattle	38	38	38	38	38

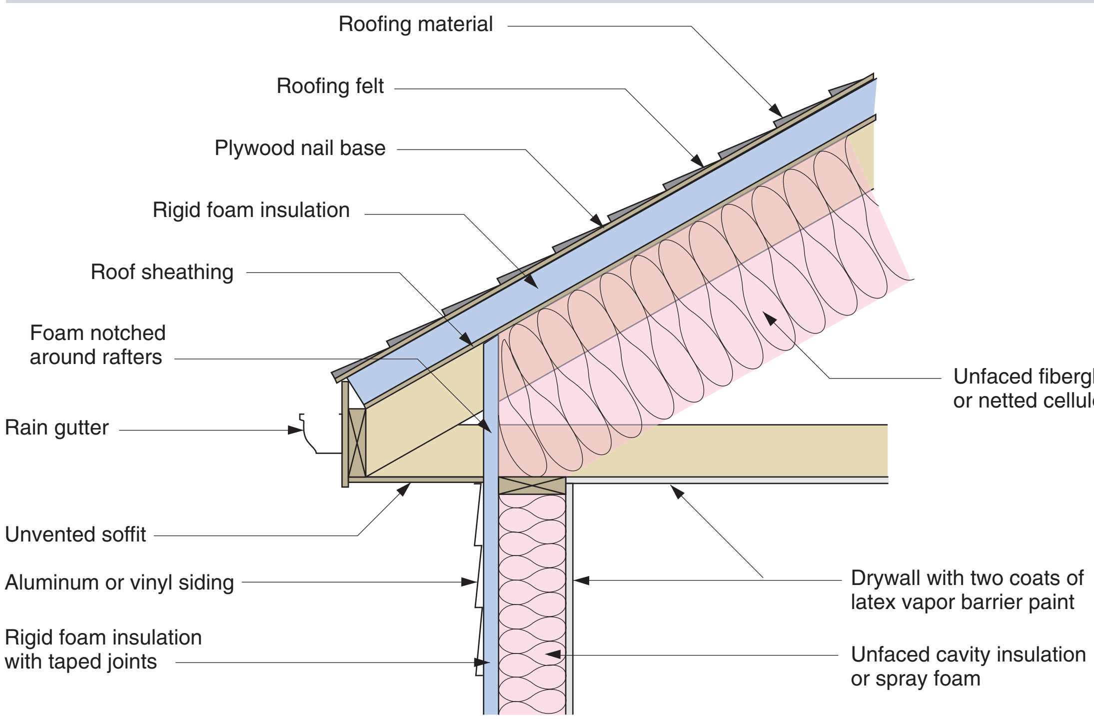
Recommended R-Values for Cathedral Ceilings

Location	Natural Gas Heat Electric AC	Heat Pump Heat Electric AC	Fuel Oil Heat Electric AC	Natural Gas Heat No AC	Fuel Oil Heat No AC
AZ, Phoenix	30	22	30	22	11
CA, Los Angeles	19	11	19	11	11
CO, Denver	38	38	38	38	38
DC, Washington	38	30	38	38	38
FL, Miami	22	22	22	11	0
GA, Atlanta	38	30	38	30	30
IL, Chicago	38	38	38	38	38
LA, Baton Rouge	30	22	22	22	19
ME, Portland	38	38	38	38	38
MA, Boston	38	38	38	38	30
MN, Duluth	38	38	38	38	38
MO, St Louis	38	30	38	38	38
NY, New York	38	38	30	38	30
TX, Dallas	38	30	30	22	22
VT, Burlington	38	38	38	38	38
WA, Seattle	38	22	38	38	38

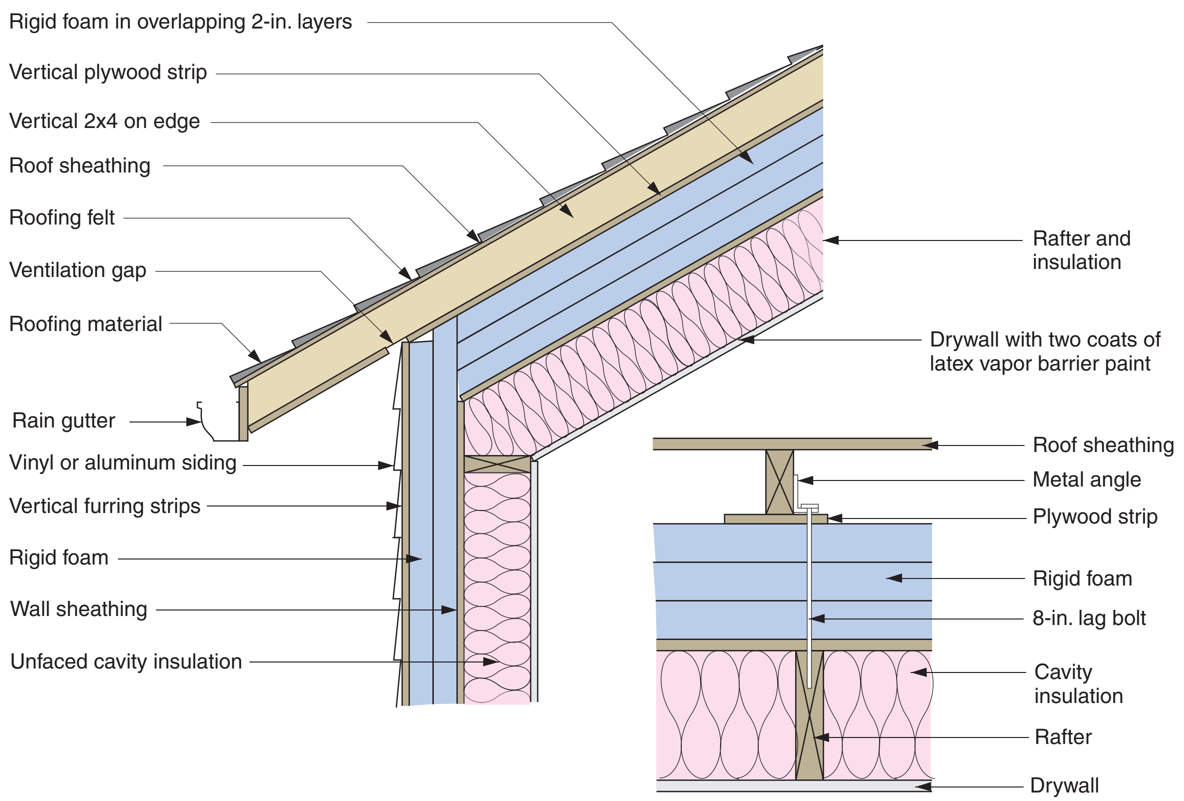
Vented Attic with Ceiling Insulation



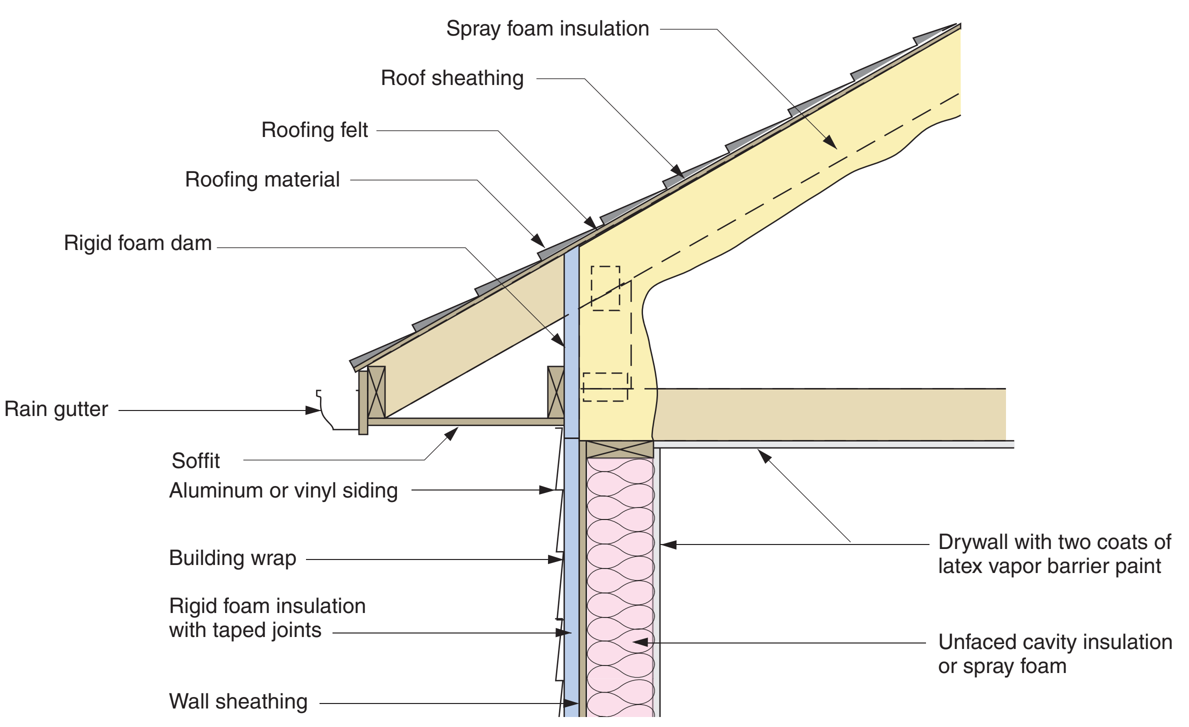
Unvented Attic with Roof Insulation



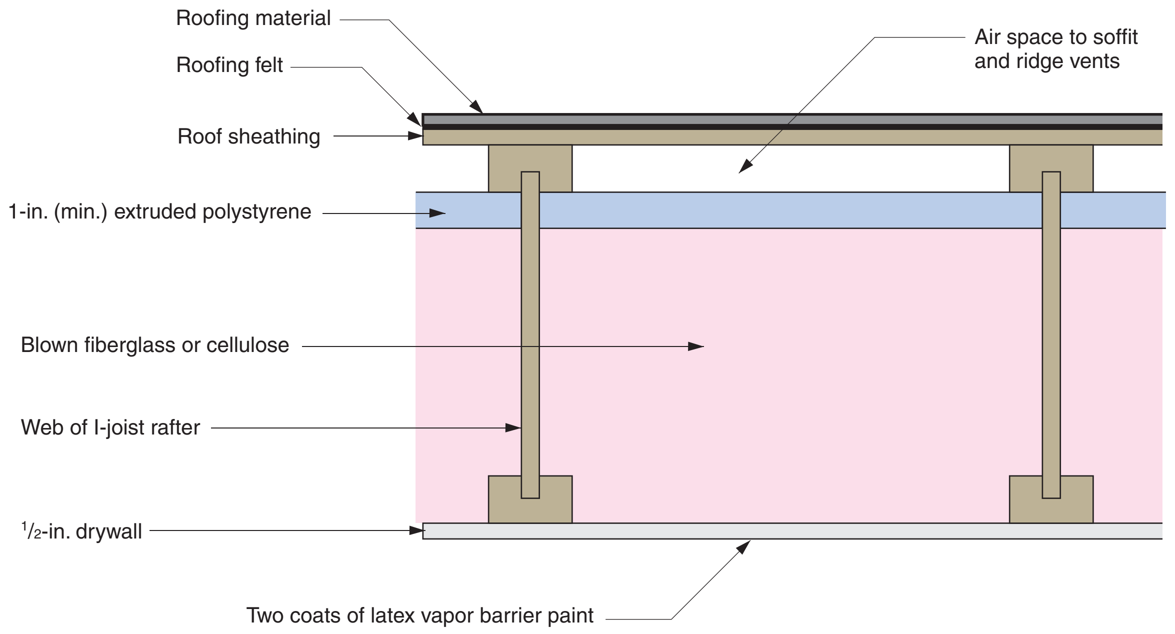
High R-Value Vented Cathedral Ceiling



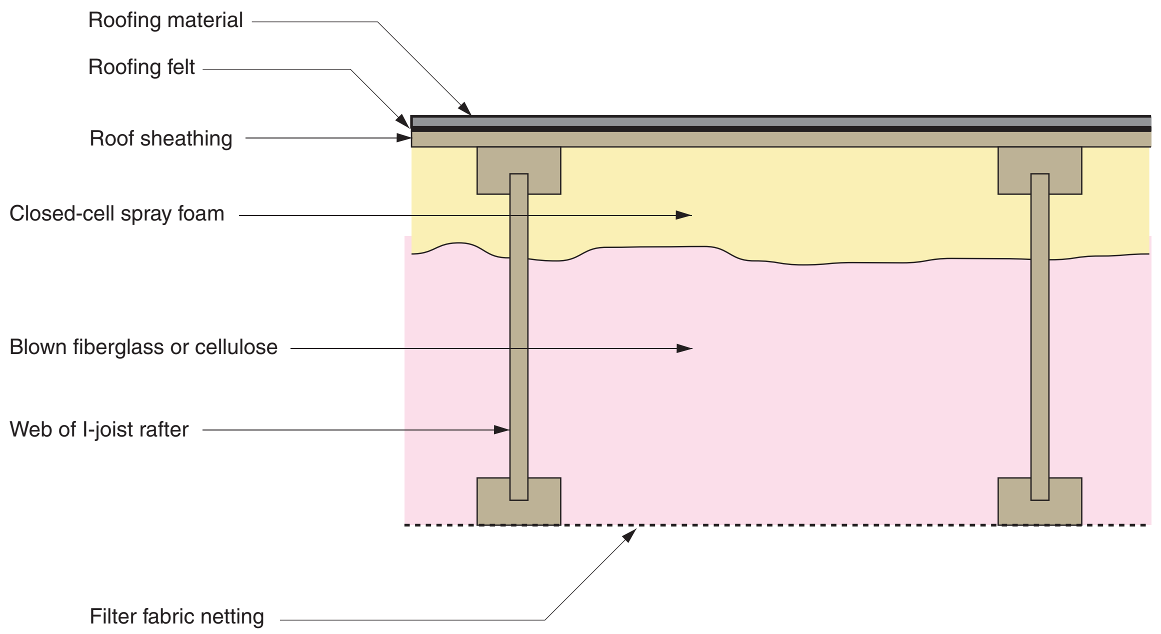
Unvented Attic with Spray Foam Roof Insulation



Vented Cathedral Ceiling with I-Joist Rafters



Unvented Cathedral Ceiling with I-Joist Rafters



Insulating Walls

Three criteria should be satisfied when building or retrofitting walls:

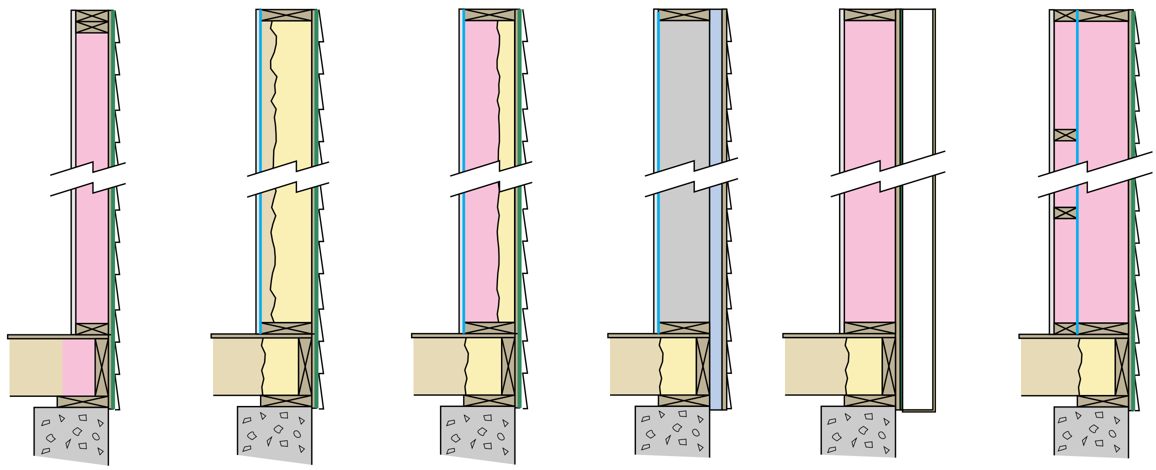
1. The insulation should have the INC-recommended R-value(s) listed in the tables on p. 436 appropriate to the building location and sources of heating and cooling.

2. There should be no through-wall air leaks.

3. The type(s) of insulation and vapor barriers should be such that condensation does not occur anywhere within the wall cavity or materials.

The twelve examples shown below and detailed on pp. 437–442 provide a wide range of possible solutions, from new construction to retrofit.

Wall Insulation Configurations



Conventional frame with fiber-filled cavities

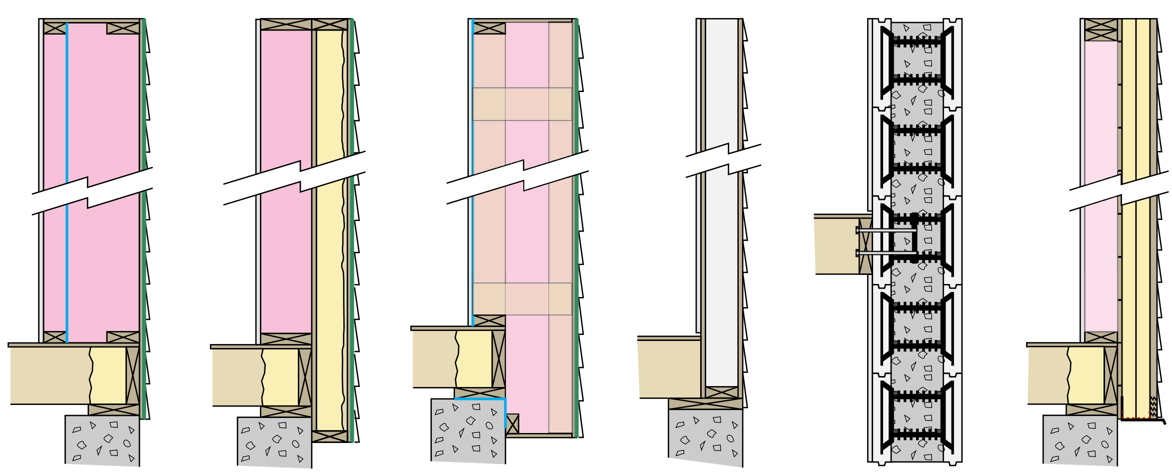
OVE frame with spray foam in cavities

OVE frame with spray foam & fiber in cavities

OVE frame with foam sheathing & cellulose in cavities

OVE frame with fiber-filled cavities & EIFS cladding

OVE frame with extra-thick fiber-filled cavities



Double-studded wall with fiber fill

OVE frame with fiber-filled cavities & exterior spray foam

Larsen truss with fiber fill

SIPs with EPS cores

Insulated concrete forms walls.

Conventional wall retrofitted with exterior polyisocyanurate foam

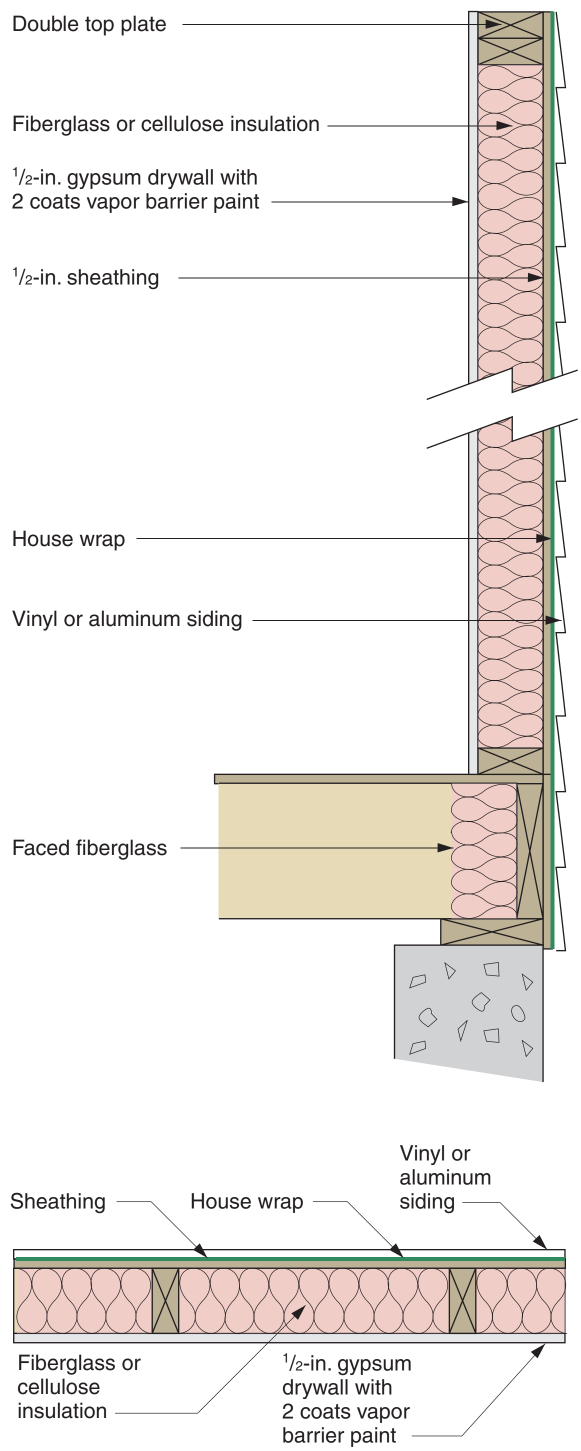
Recommended R-Values for Conventional Wall Sheathing/Cavity

Location	Natural Gas Heat Electric AC	Heat Pump Heat Electric AC	Fuel Oil Heat Electric AC	Natural Gas Heat No AC	Fuel Oil Heat No AC
AZ, Phoenix	0/13	0/11	0/13	0/11	0/11
CA, Los Angeles	0/11	0/11	0/11	0/11	0/11
CO, Denver	5/13	0/13	0/13	5/13	0/13
DC, Washington	5/13	0/13	0/13	5/13	0/13
FL, Miami	0/11	0/11	0/11	0/0	0/0
GA, Atlanta	0/13	0/13	0/13	0/13	0/13
IL, Chicago	0/13	5/13	0/13	0/13	0/13
LA, Baton Rouge	0/13	0/11	0/11	0/11	0/11
ME, Portland	7/13	7/13	5/13	7/13	5/13
MA, Boston	5/13	5/13	0/13	5/13	0/13
MN, Duluth	5/13	5/13	5/13	5/13	5/13
MO, St Louis	5/13	0/13	0/13	5/13	0/13
NY, New York	0/13	5/13	0/13	0/13	0/13
TX, Dallas	0/13	0/13	0/13	0/13	0/11
VT, Burlington	5/13	7/13	5/13	5/13	5/13
WA, Seattle	0/13	0/13	0/13	0/13	0/13

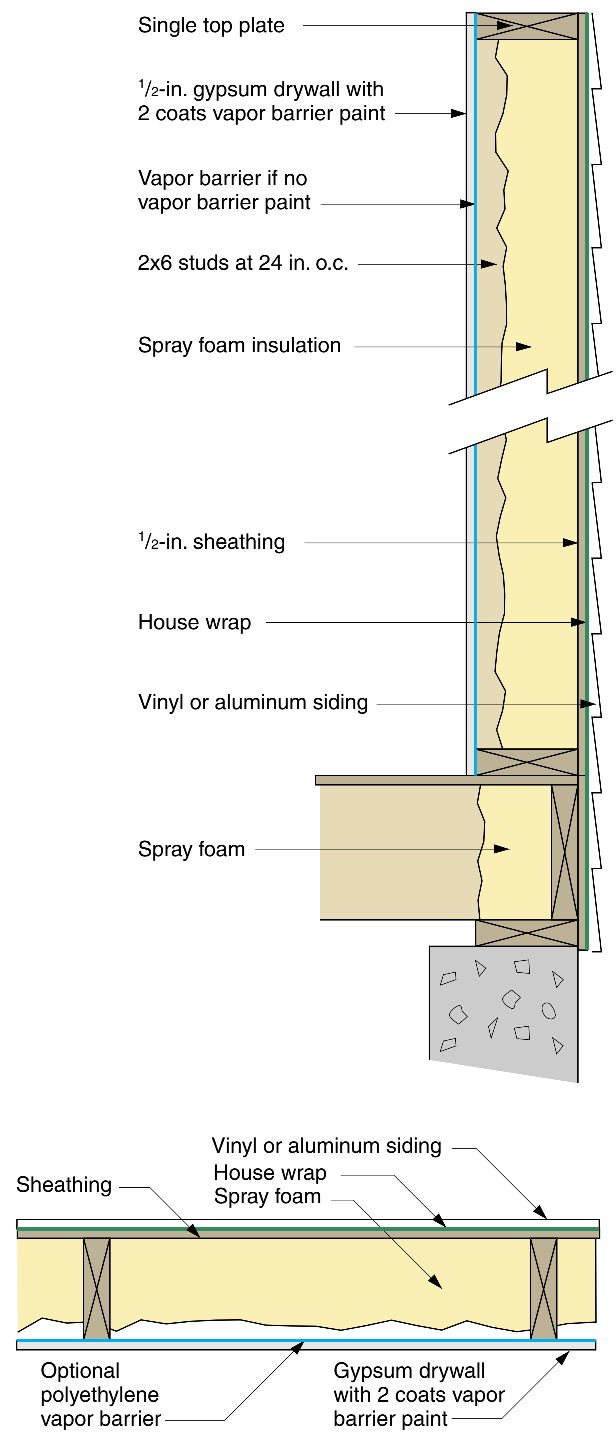
Recommended R-Values for OVE Wall Sheathing/Cavity

Location	Natural Gas Heat Electric AC	Heat Pump Heat Electric AC	Fuel Oil Heat Electric AC	Natural Gas Heat No AC	Fuel Oil Heat No AC
AZ, Phoenix	0/19	0/19	0/19	0/19	0/19
CA, Los Angeles	0/19	0/11	0/19	0/11	0/11
CO, Denver	0/19	0/19	0/19	0/19	0/19
DC, Washington	0/19	0/19	0/19	0/19	0/19
FL, Miami	0/19	0/11	0/19	0/0	0/0
GA, Atlanta	0/19	0/19	0/19	0/19	0/19
IL, Chicago	0/19	0/19	0/19	0/19	0/19
LA, Baton Rouge	0/19	0/19	0/19	0/19	0/19
ME, Portland	5/19	5/19	0/19	5/19	0/19
MA, Boston	0/19	0/19	0/19	0/19	0/19
MN, Duluth	0/19	5/19	0/19	0/19	0/19
MO, St Louis	0/19	0/19	0/19	0/19	0/19
NY, New York	0/19	0/19	0/19	0/19	0/19
TX, Dallas	0/19	0/19	0/19	0/19	0/19
VT, Burlington	5/19	5/21	0/21	5/19	0/21
WA, Seattle	0/19	0/19	0/19	0/19	0/19

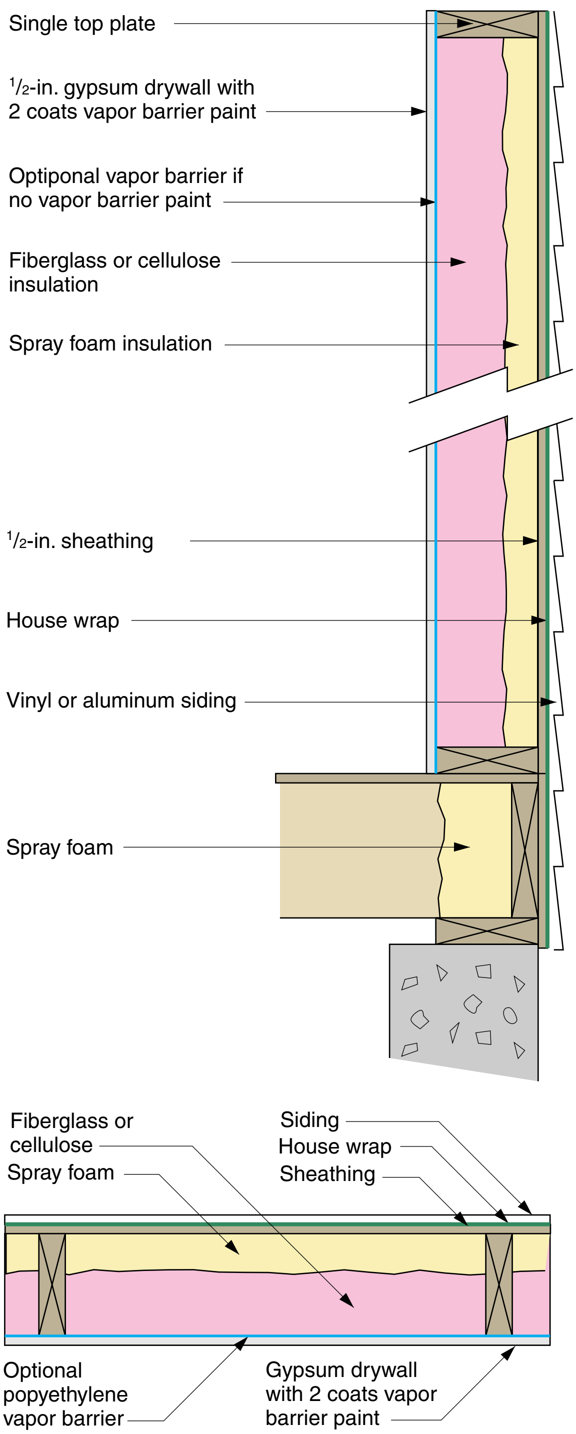
Conventional Frame with Fiber-Filled Cavities



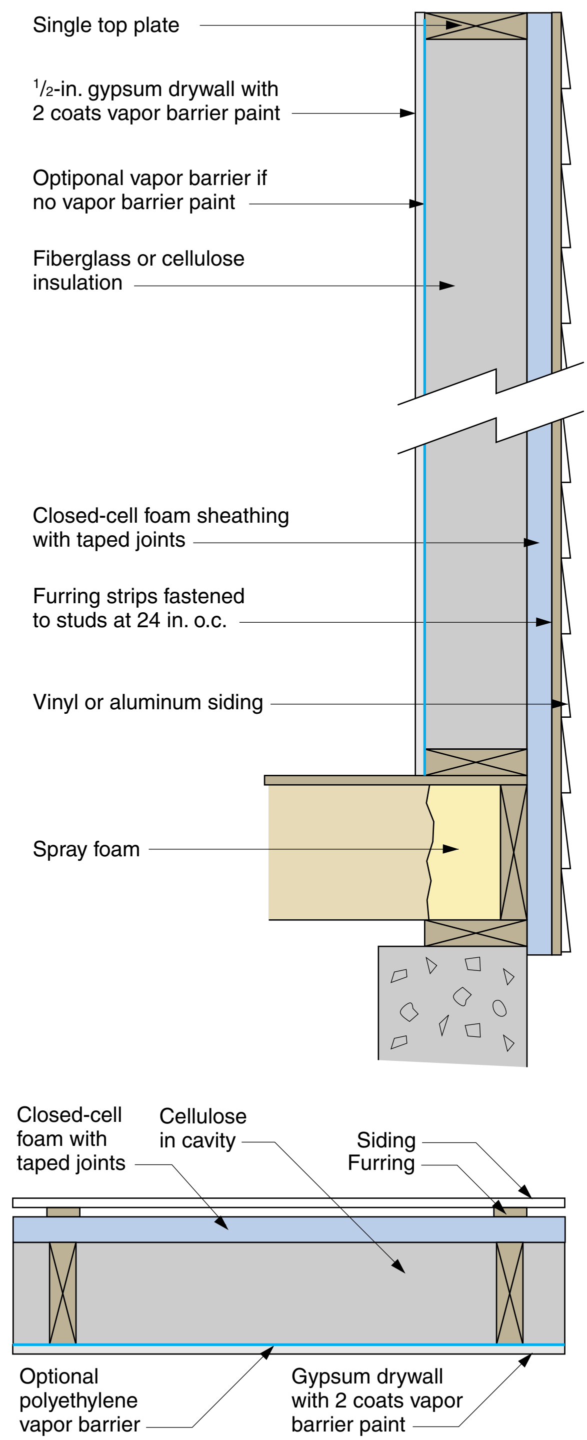
OVE Frame with Spray Foam in Cavities



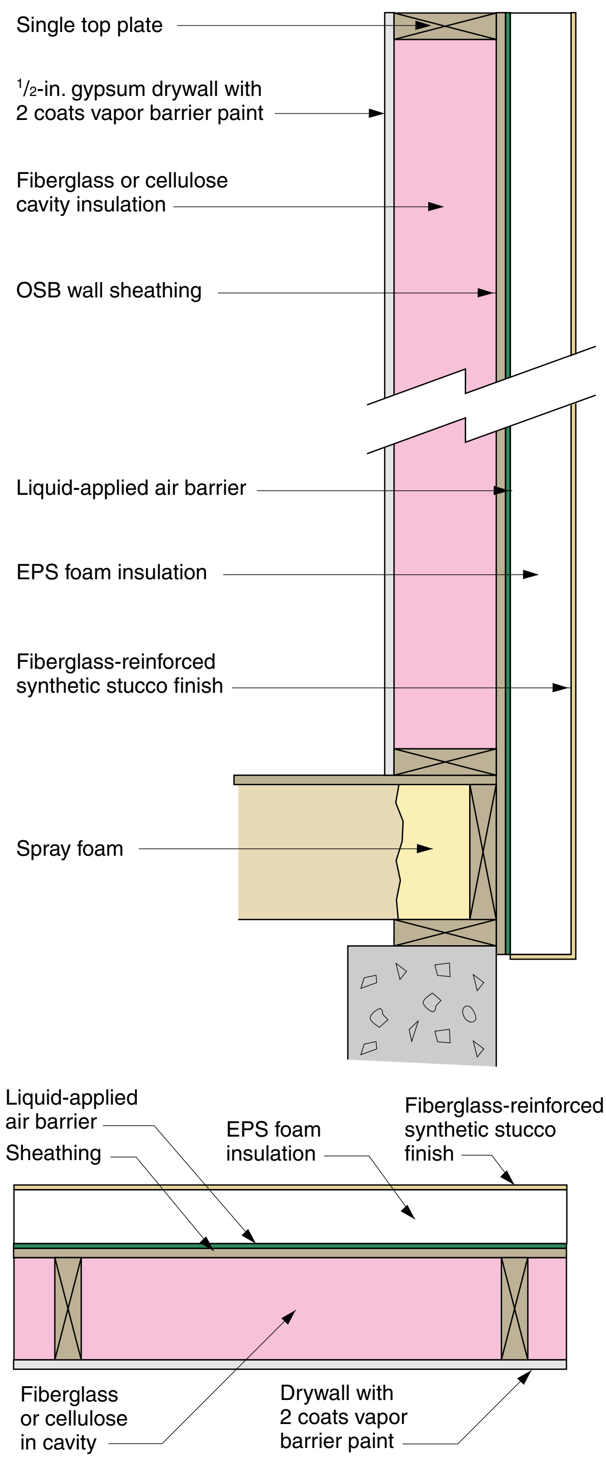
OVE Frame with Spray Foam and Fiber in Cavities



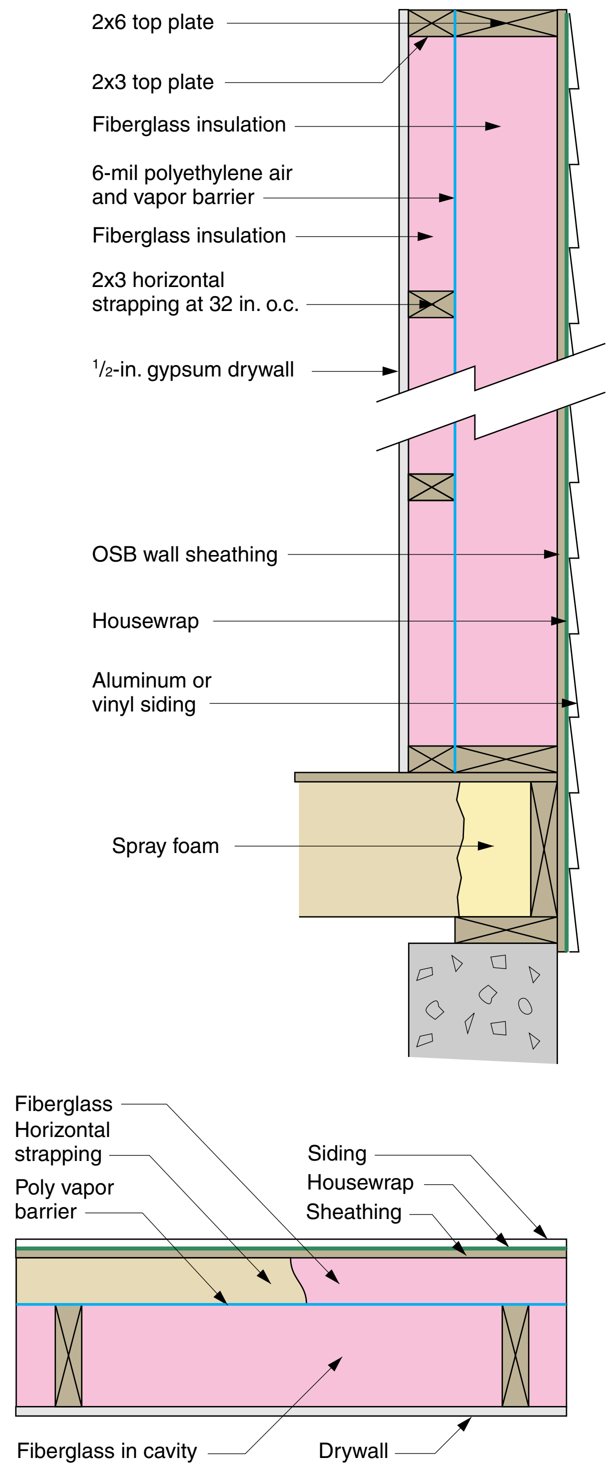
OVE Frame with Foam Sheathing and Cellulose in Cavities



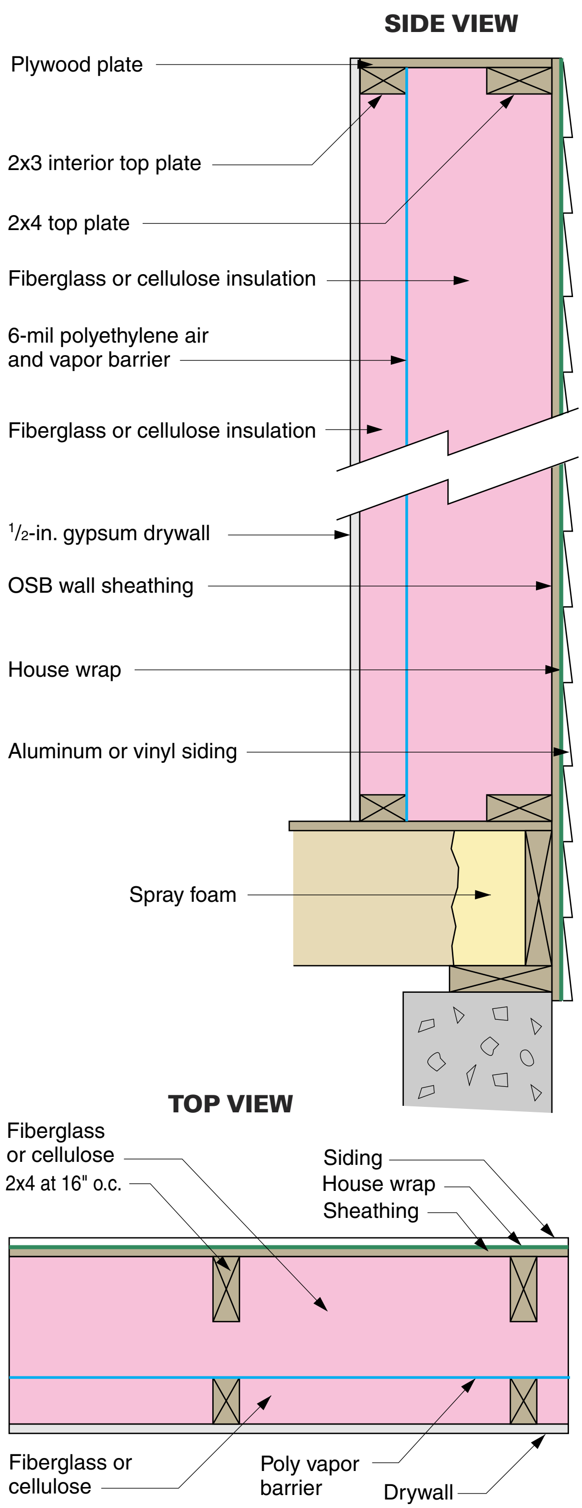
OVE Frame with Fiber-Filled Cavities and EIFS Cladding



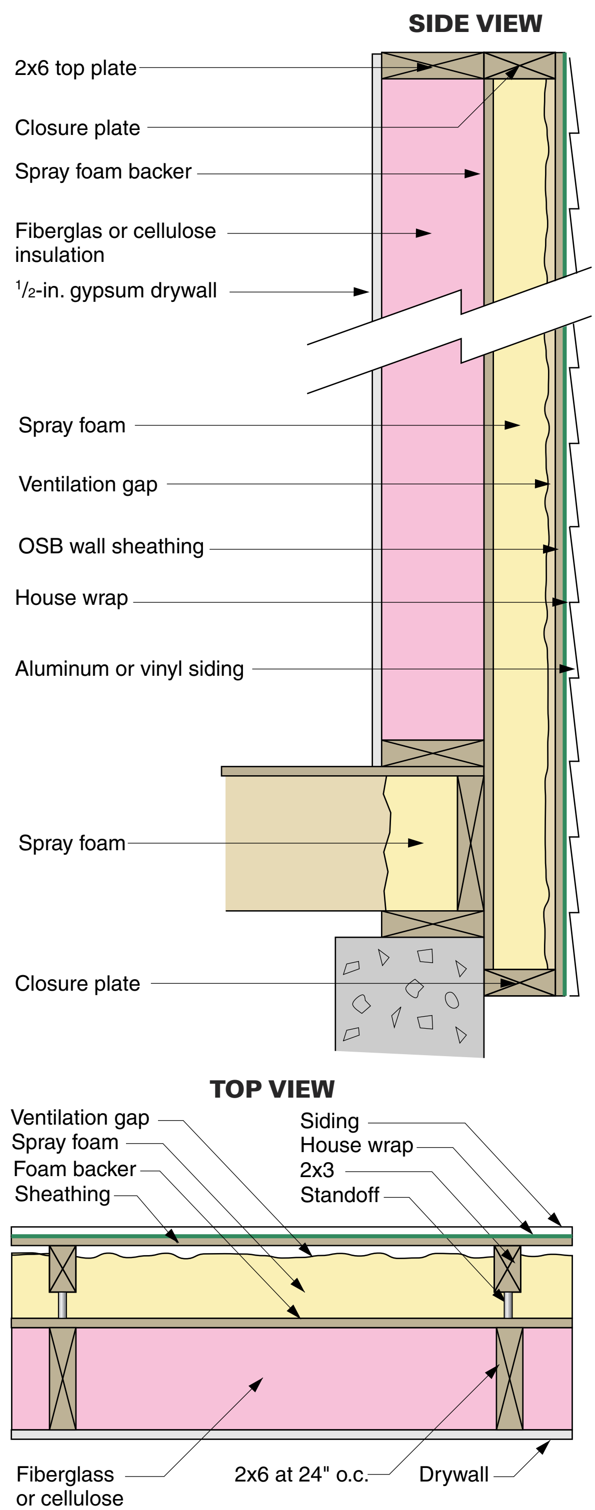
OVE Frame with Extra-Thick Fiber-Filled Cavities



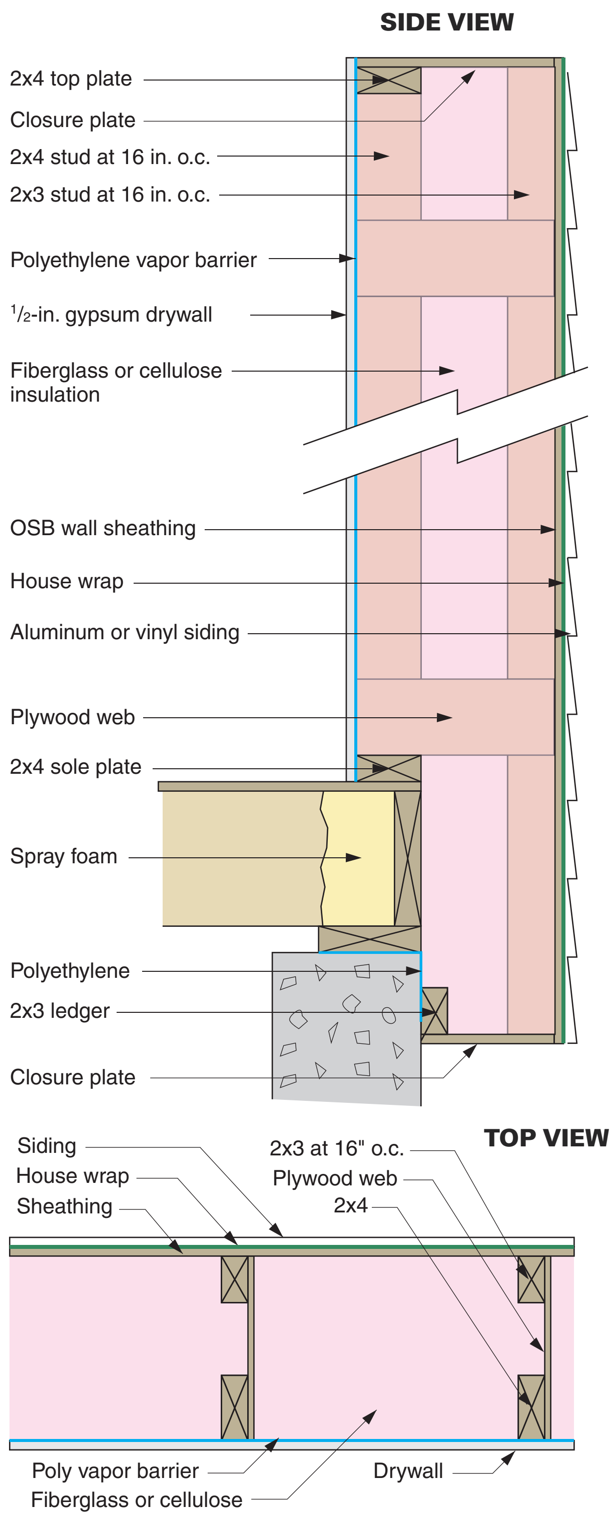
Double-Studded Wall with Fiber Fill



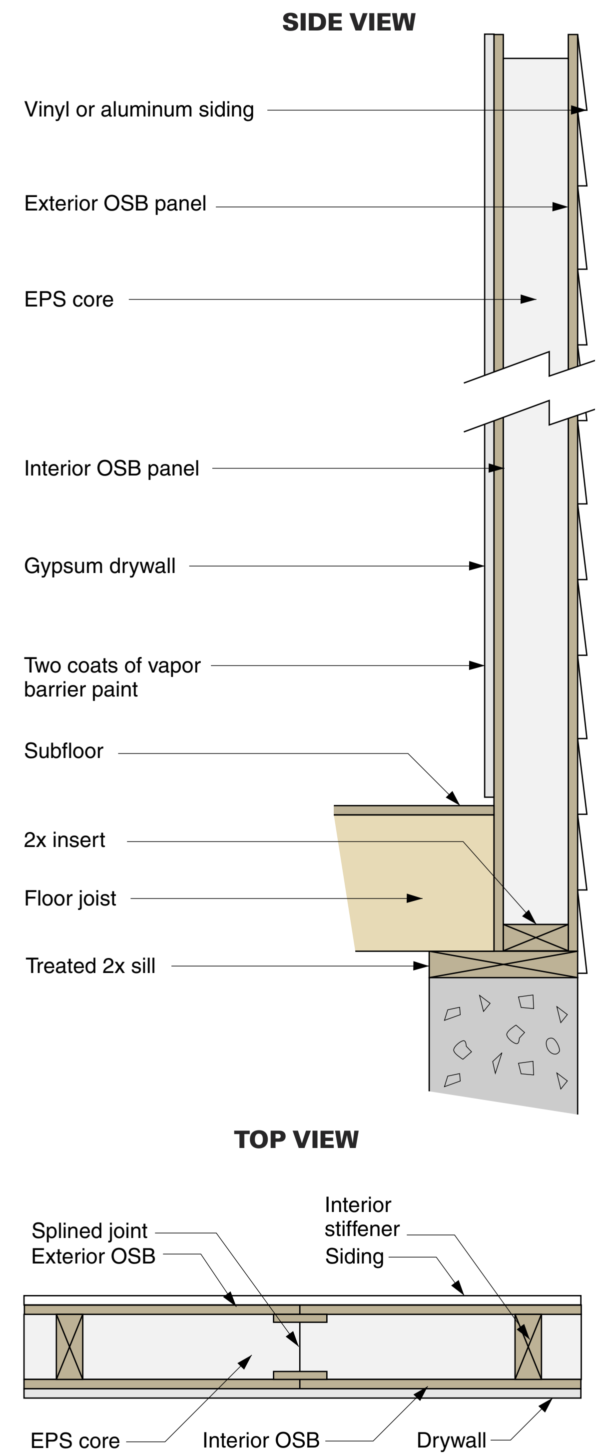
OVE Frame with Fiber-Filled Cavities and Exterior Spray Foam



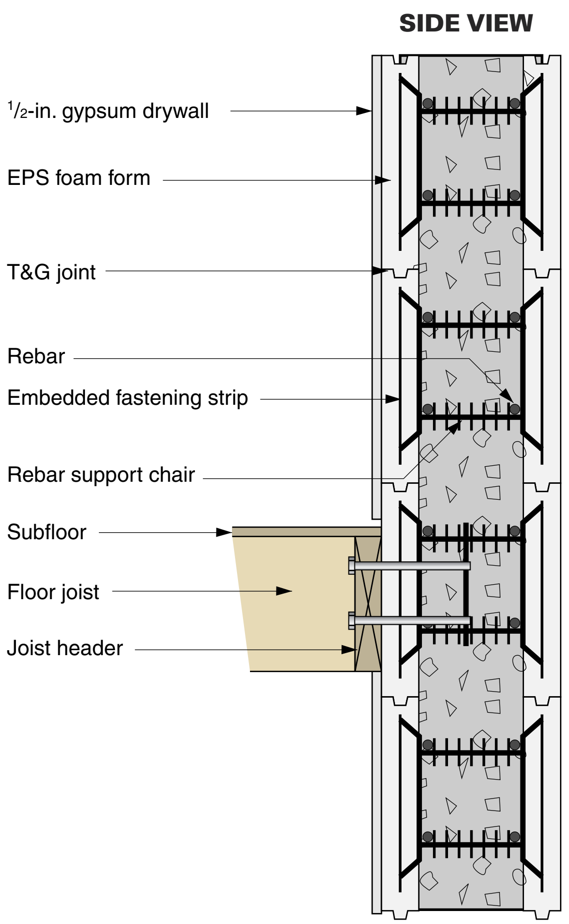
Larsen Truss with Fiber Fill

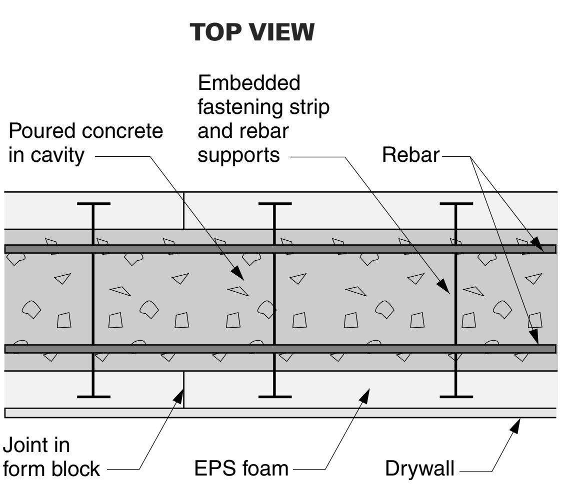


Structural Insulated Panels (SIPs) with EPS Cores

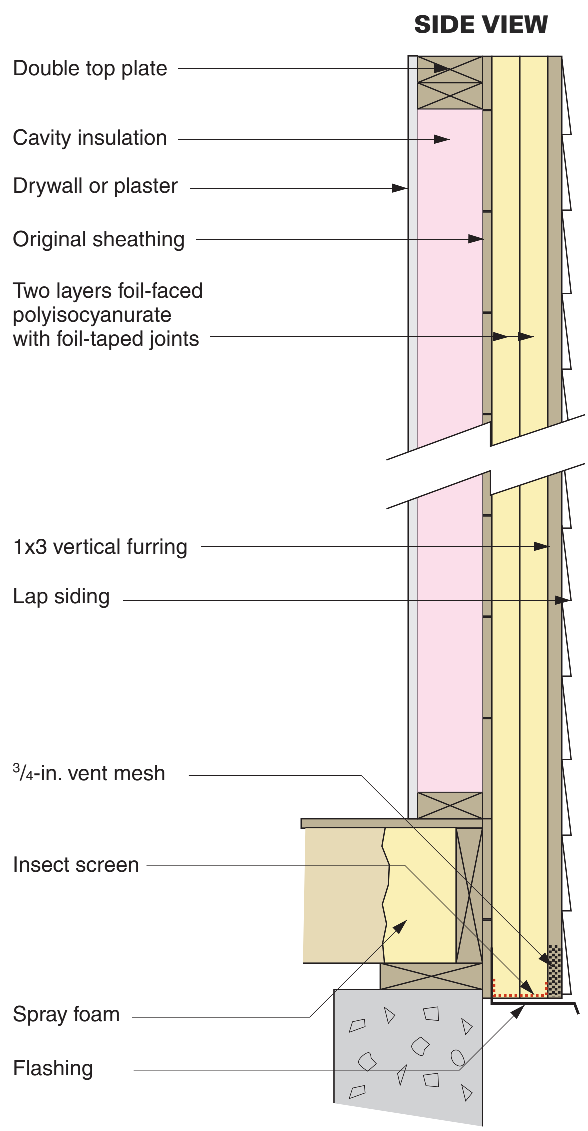


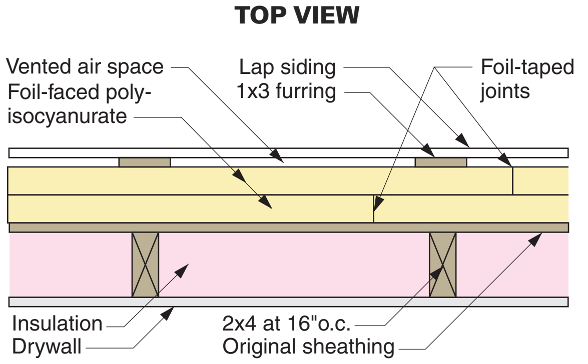
Insulated Concrete Form (ICF) Wall





Conventional Wall Retrofitted with Exterior Polyisocyanurate Foam





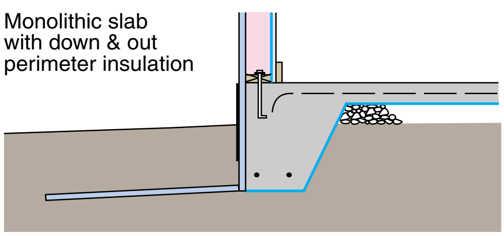
Insulating Slab Foundations

It was long believed that slabs lost little heat. After all, the earth itself is a source of heat, and the temperature of the soil at depth is roughly the same as the average annual air temperature for the location. Both of these facts are true, but what was overlooked is the short circuit to the outside through the thermally conductive perimeter of the slab.

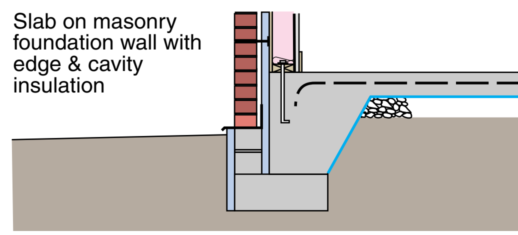
Below and on the following pages are eight approaches to preventing slab heat loss. All use closed-cell, waterproof extruded polystyrene with an R-value of 5 per in. thickness to retard heat flow, plus a continuous vapor retarder (usually polyethylene sheeting) to prevent incursion of radon gas and moisture from the soil below.

Slab-on-Grade Insulation Configurations

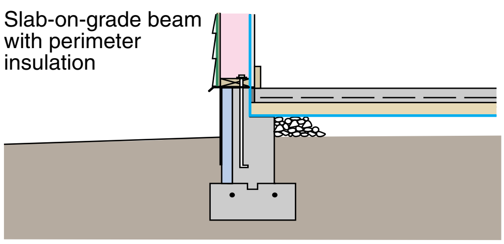
Monolithic slab with down & out perimeter insulation



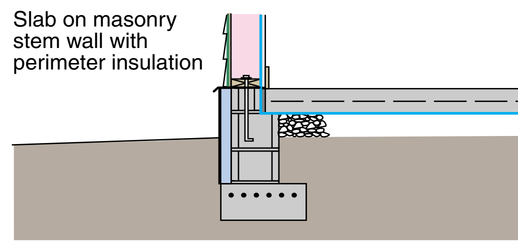
Slab on masonry foundation wall with edge & cavity insulation



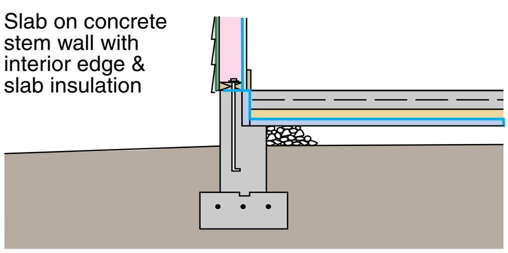
Slab-on-grade beam with perimeter insulation



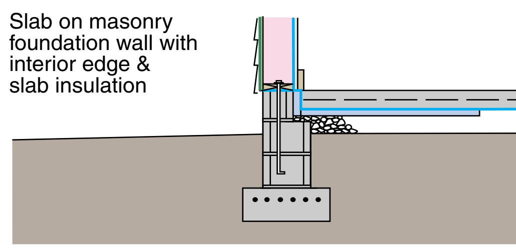
Slab on masonry stem wall with perimeter insulation



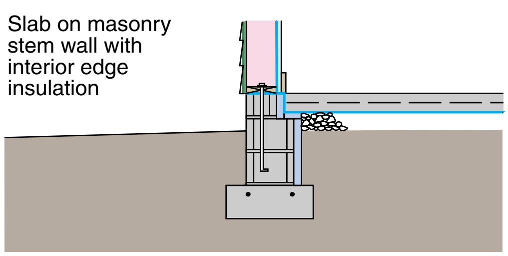
Slab on concrete stem wall with interior edge & slab insulation



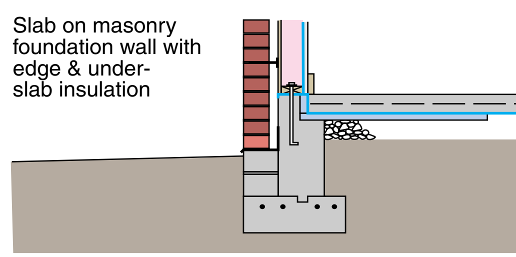
Slab on masonry foundation wall with interior edge & slab insulation



Slab on masonry stem wall with interior edge insulation



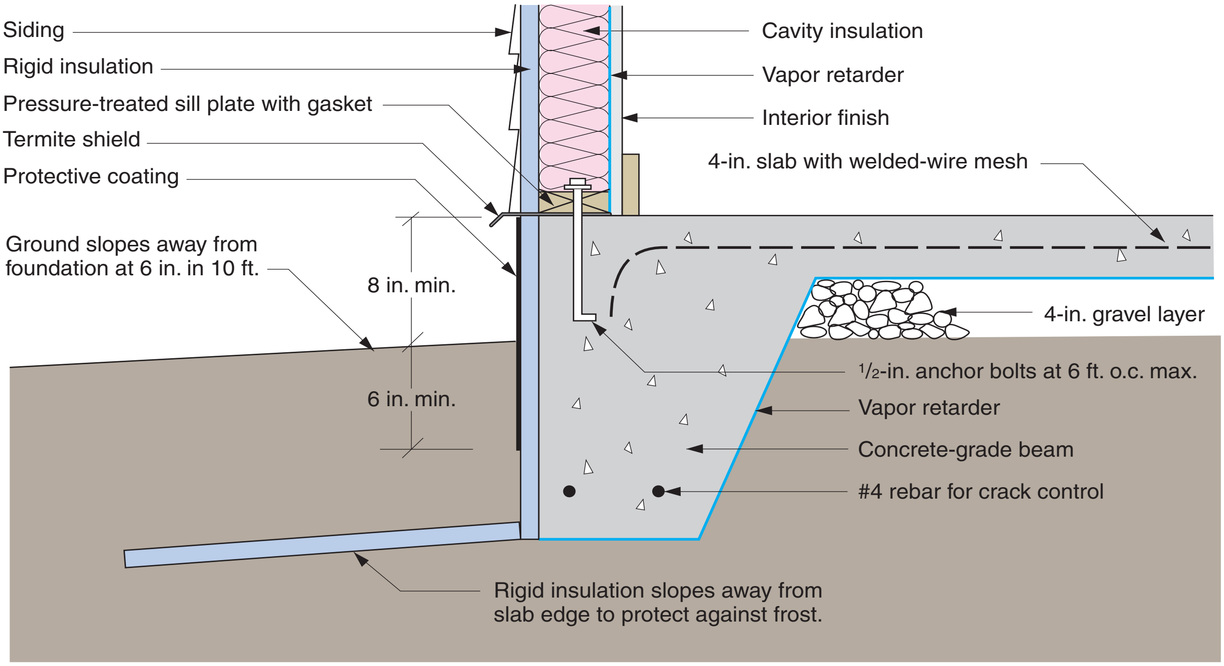
Slab on masonry foundation wall with edge & under-slab insulation



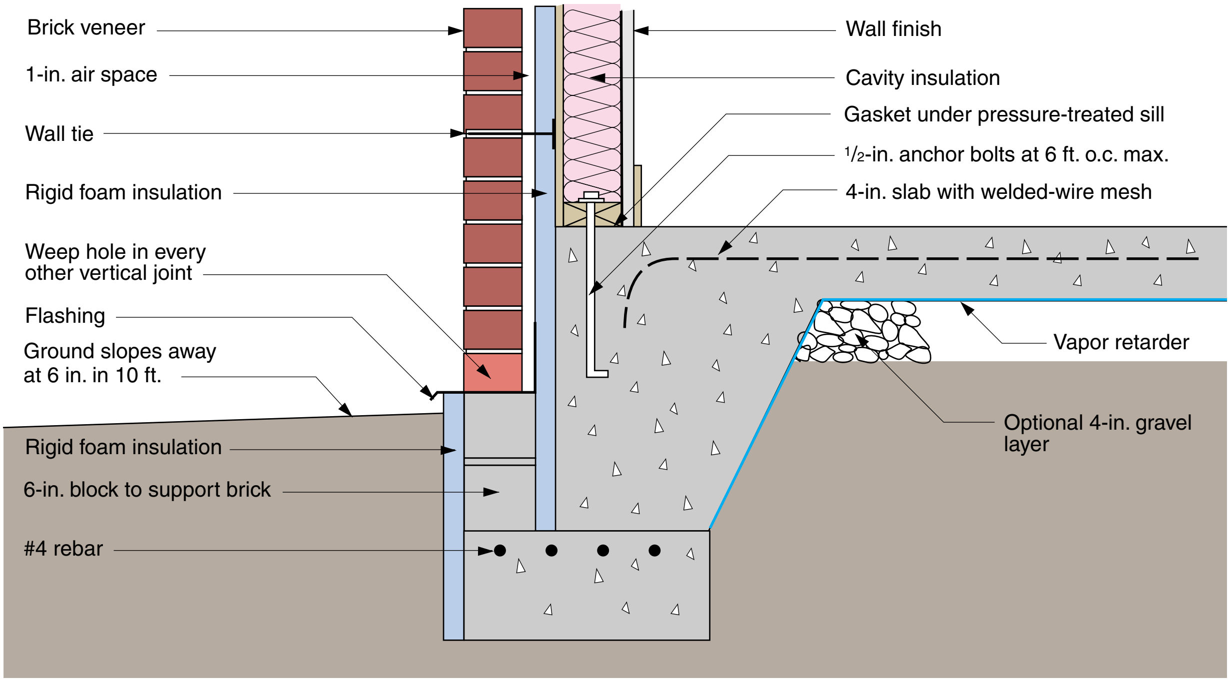
Recommended R-Values for Slab Edge Insulation

Location	Natural Gas Heat Electric AC	Heat Pump Heat Electric AC	Fuel Oil Heat Electric AC	Natural Gas Heat No AC	Fuel Oil Heat No AC
AZ, Phoenix	4	4	4	0	0
CA, Los Angeles	0	0	0	0	0
CO, Denver	8	8	8	8	8
DC, Washington	8	8	8	8	8
FL, Miami	4	0	4	0	0
GA, Atlanta	8	4	8	8	4
IL, Chicago	8	8	8	8	8
LA, Baton Rouge	4	4	4	0	0
ME, Portland	8	8	8	8	8
MA, Boston	8	8	8	8	8
MN, Duluth	8	8	8	8	8
MO, St Louis	8	8	8	8	8
NY, New York	8	8	8	8	8
TX, Dallas	8	4	4	4	0
VT, Burlington	8	8	8	8	8
WA, Seattle	8	4	8	8	8

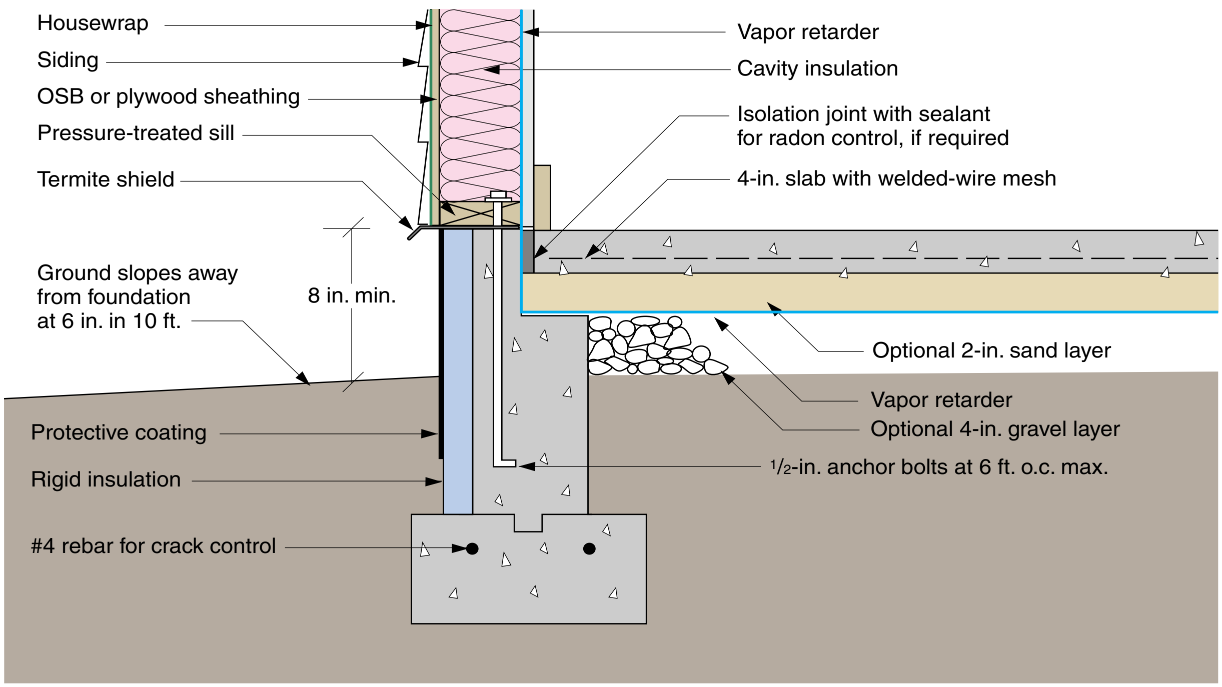
Monolithic Slab with Down-and-Out Perimeter Insulation



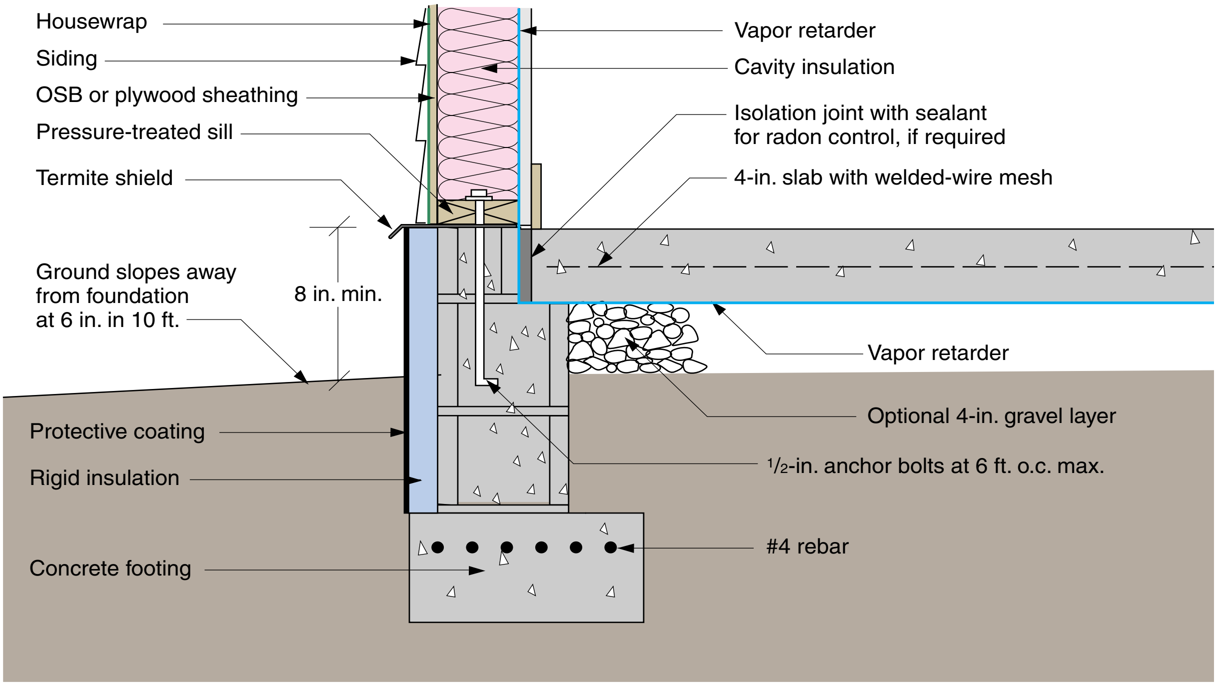
Slab on Masonry Foundation Wall with Edge and Cavity Insulation



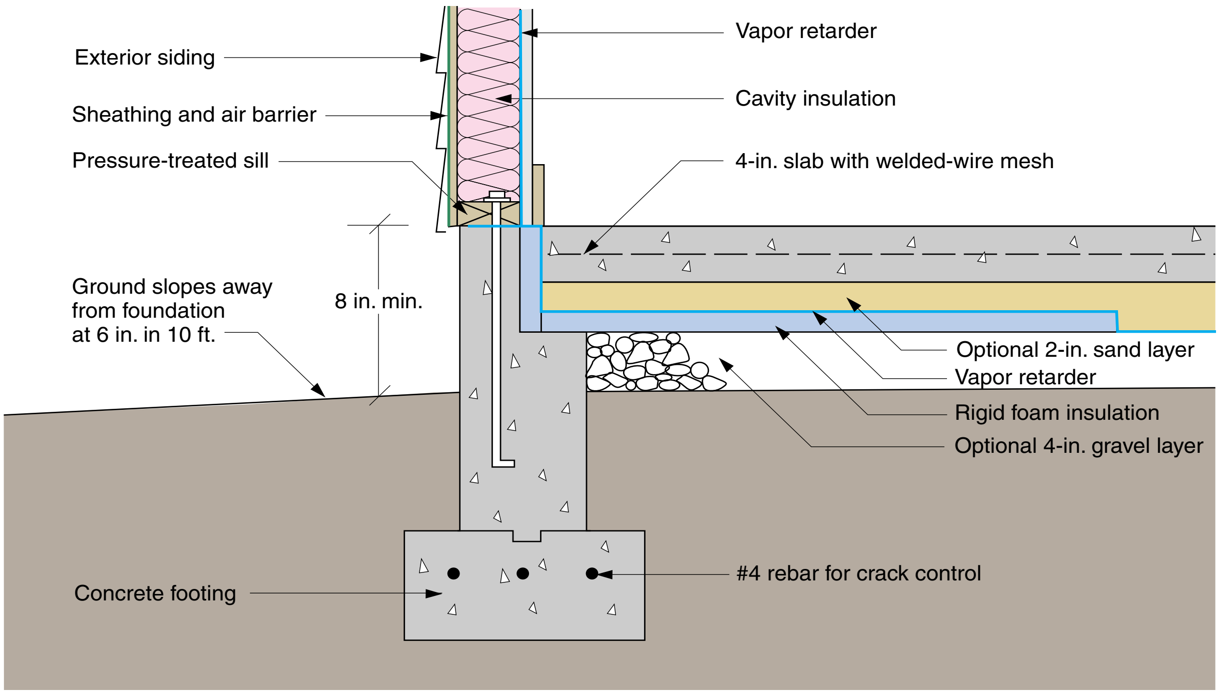
Slab-on-Grade Beam with Perimeter Insulation



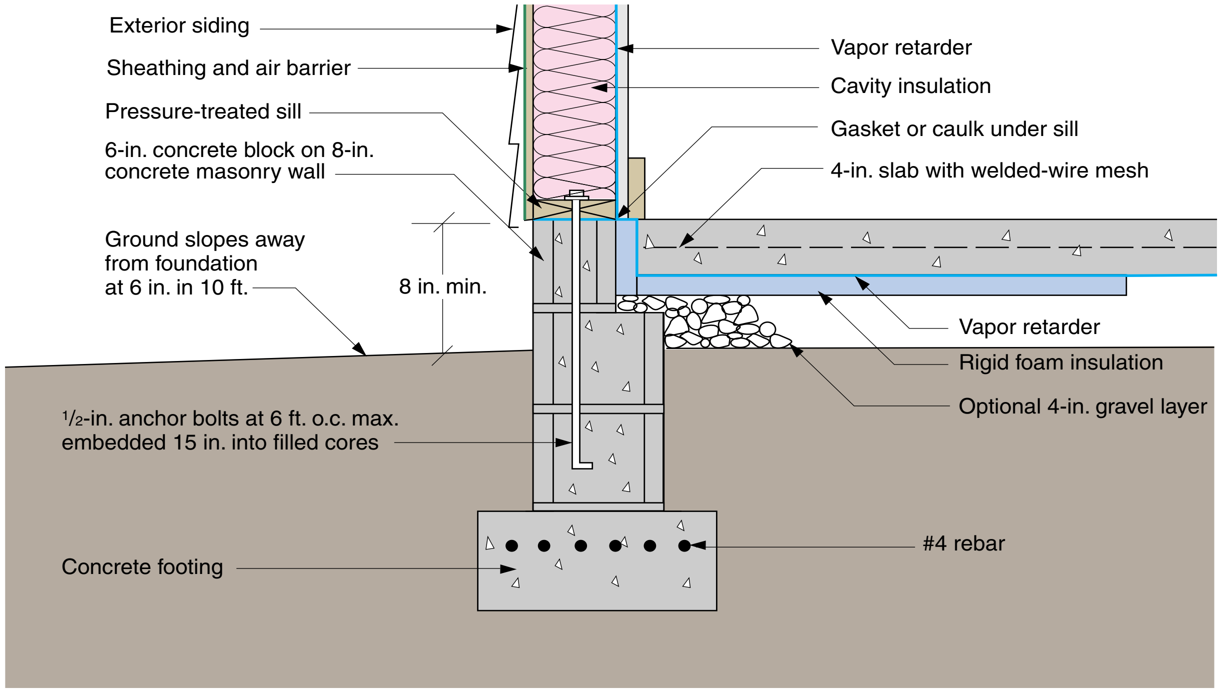
Slab on Masonry Stem Wall with Perimeter Insulation



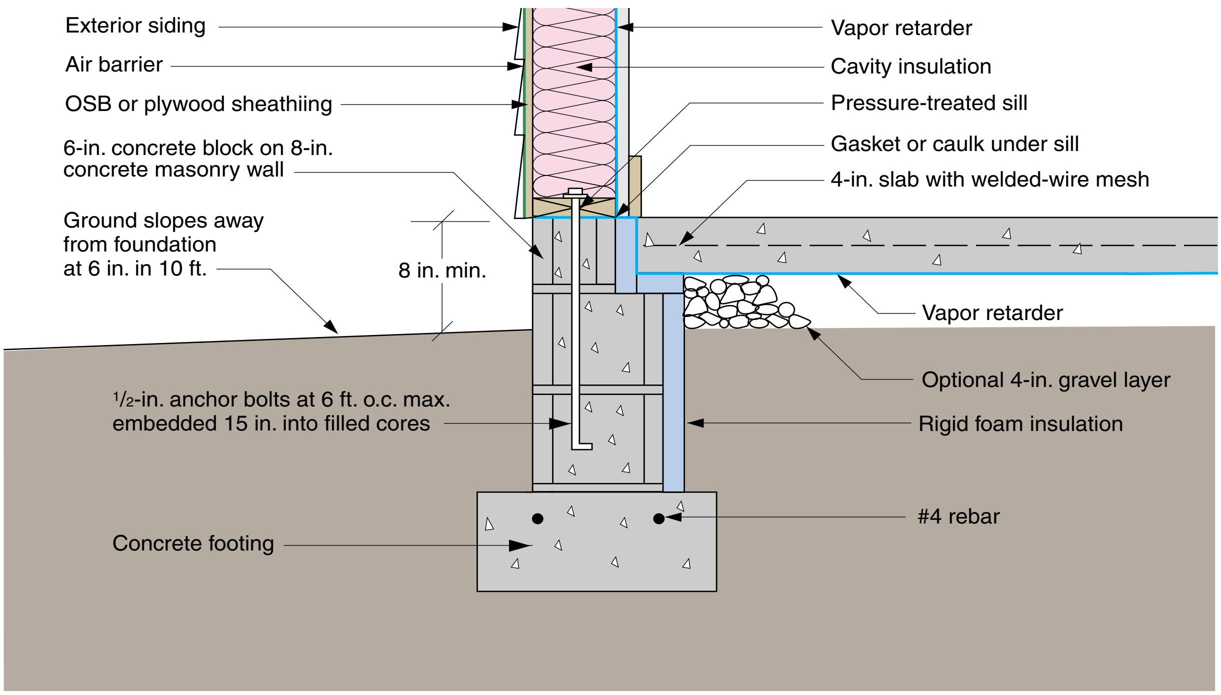
Slab on Concrete Stem Wall with Interior Edge and Slab Insulation



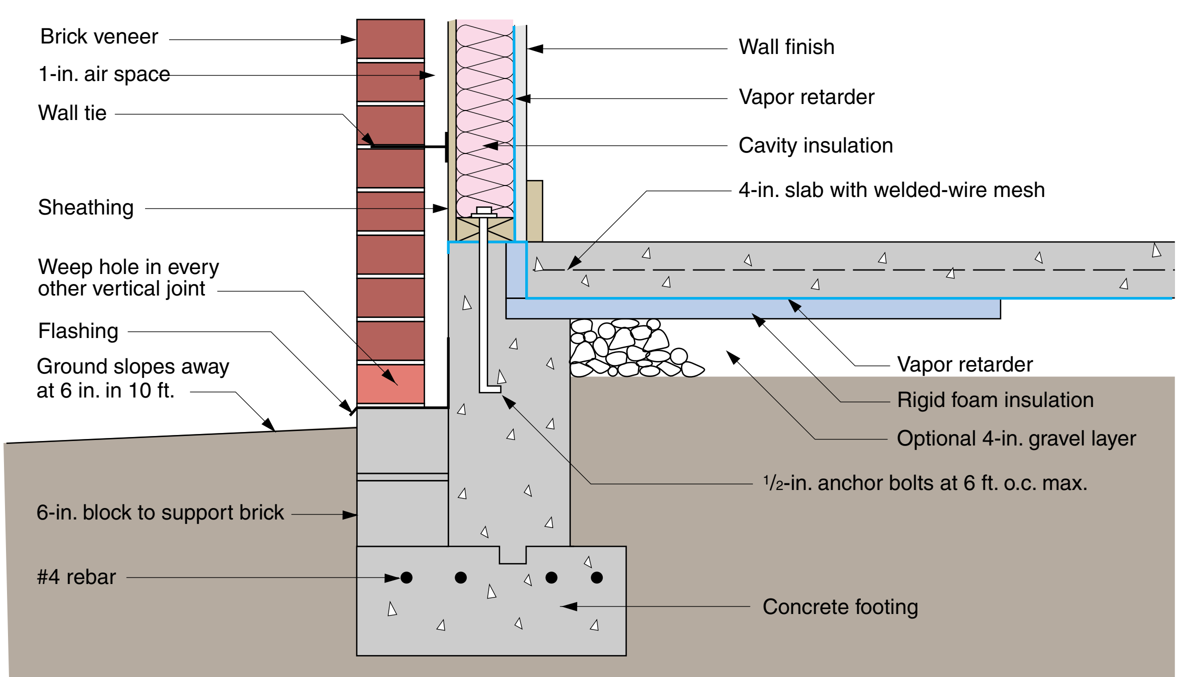
Slab on Masonry Foundation Wall with Interior Edge and Slab Insulation



Slab on Masonry Stem Wall with Interior Edge Insulation



Slab on Masonry Foundation Wall with Edge and Under-Slab Insulation

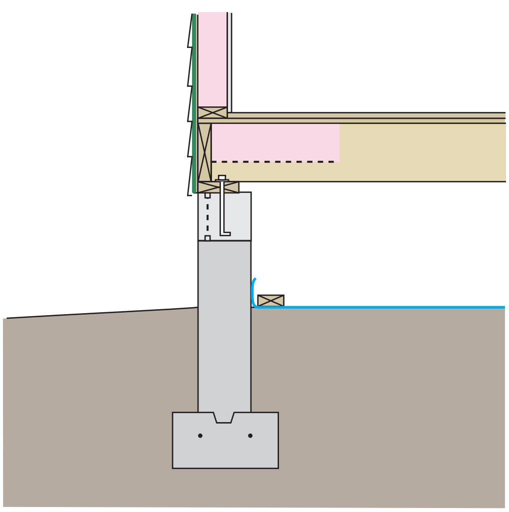


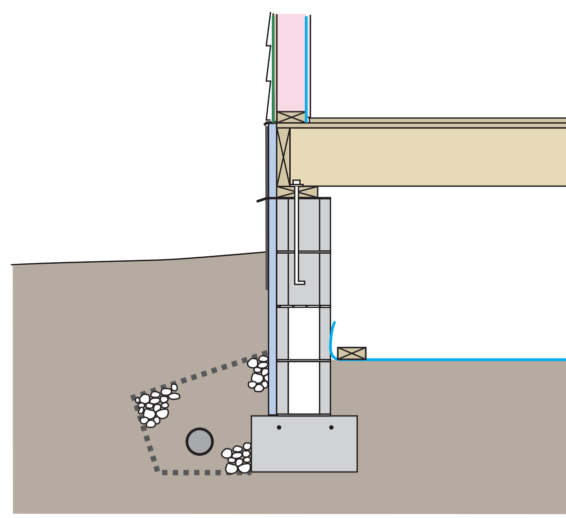
Insulating Crawl Spaces

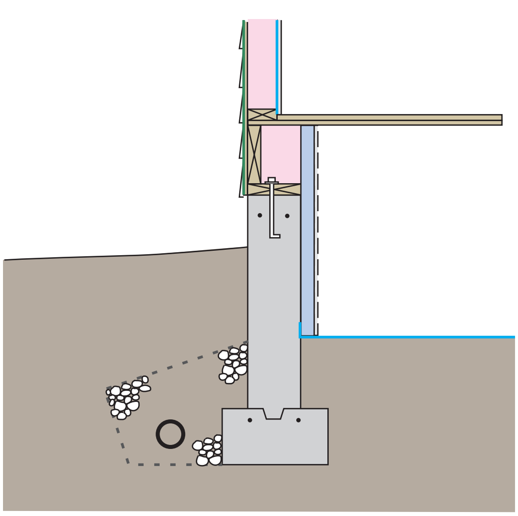
Many building codes require crawl spaces to be ventilated in order to remove moisture in the summer. Counter to intuition, however, warm humid summer air condenses moisture on the cooler building surfaces in the crawl space, leading to dry rot. It is now considered better to tightly seal the crawl space and install an effective moisture barrier over the soil.

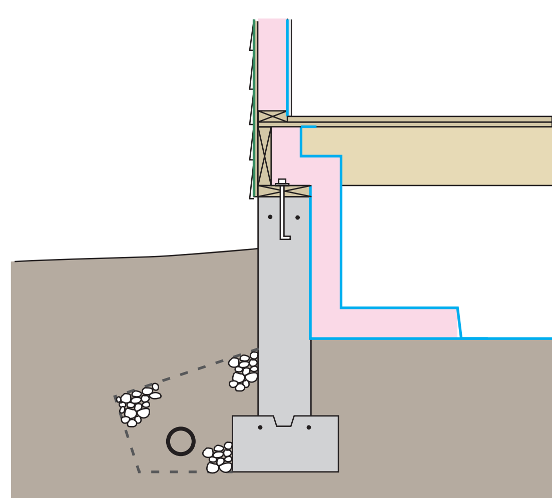
Furthermore, vented crawl spaces must be insulated at the floor above, leaving pipes exposed to freezing. Insulating the walls of an unvented crawl space places pipes and ducts inside the home's thermal envelope.

Crawl-Space Insulation Configurations


Vented crawl space
with floor insulation


Unvented crawl space with
exterior foam perimeter insulation


Unvented crawl space with
interior foam perimeter insulation


Unvented crawl space with
interior batt perimeter insulation

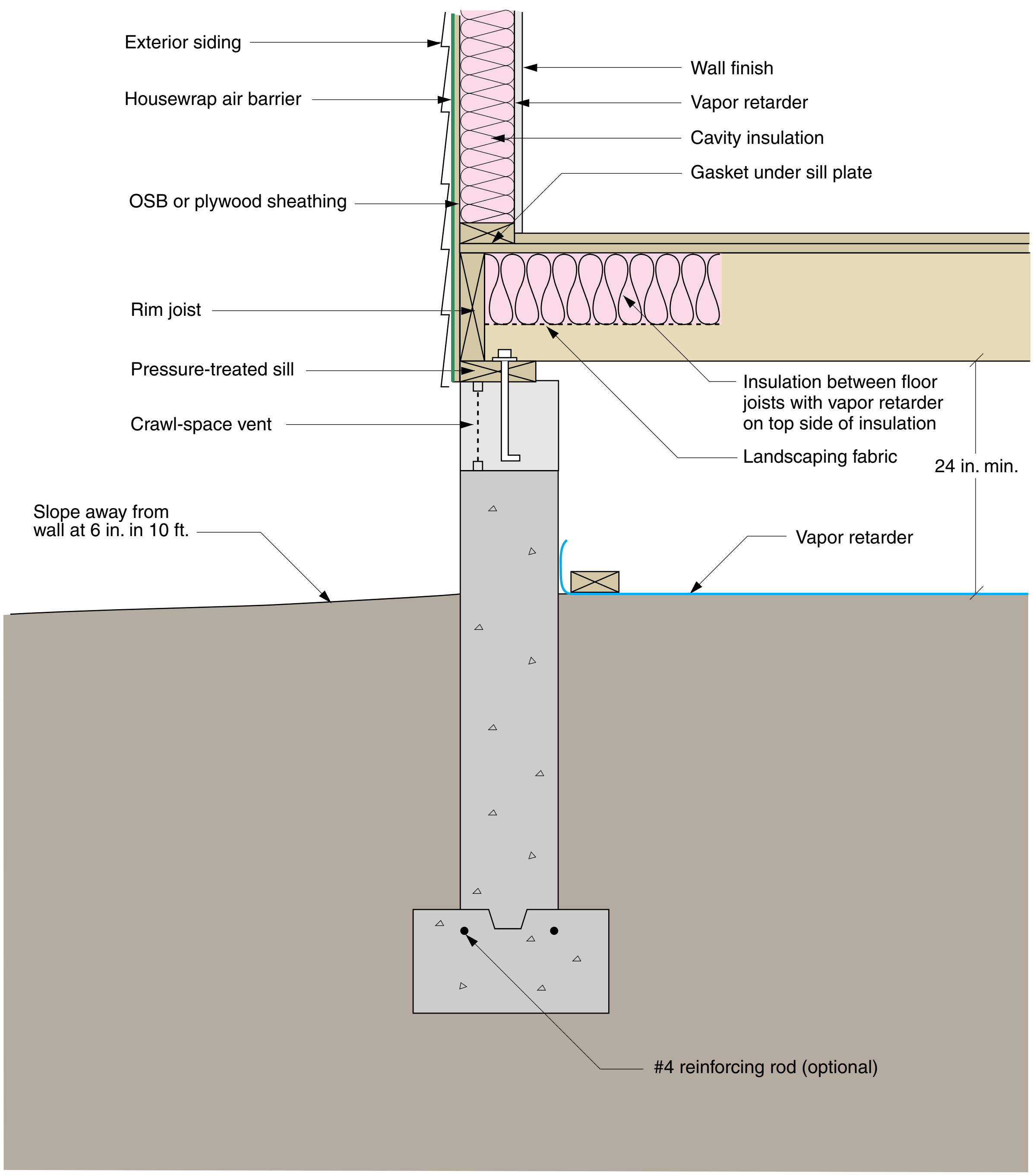
Recommended R-Values for Crawl-Space Ceilings

Location	Natural Gas Heat Electric AC	Heat Pump Heat Electric AC	Fuel Oil Heat Electric AC	Natural Gas Heat No AC	Fuel Oil Heat No AC
AZ, Phoenix	11	11	11	11	11
CA, Los Angeles	11	11	11	0	0
CO, Denver	25	25	25	25	25
DC, Washington	25	25	25	25	25
FL, Miami	11	11	11	0	0
GA, Atlanta	25	13	25	25	25
IL, Chicago	25	25	25	25	25
LA, Baton Rouge	13	11	11	13	11
ME, Portland	25	25	25	25	25
MA, Boston	25	25	25	25	25
MN, Duluth	25	25	25	25	25
MO, St Louis	25	25	25	25	25
NY, New York	25	25	25	25	25
TX, Dallas	13	13	13	13	13
VT, Burlington	25	25	25	25	25
WA, Seattle	25	13	25	25	25

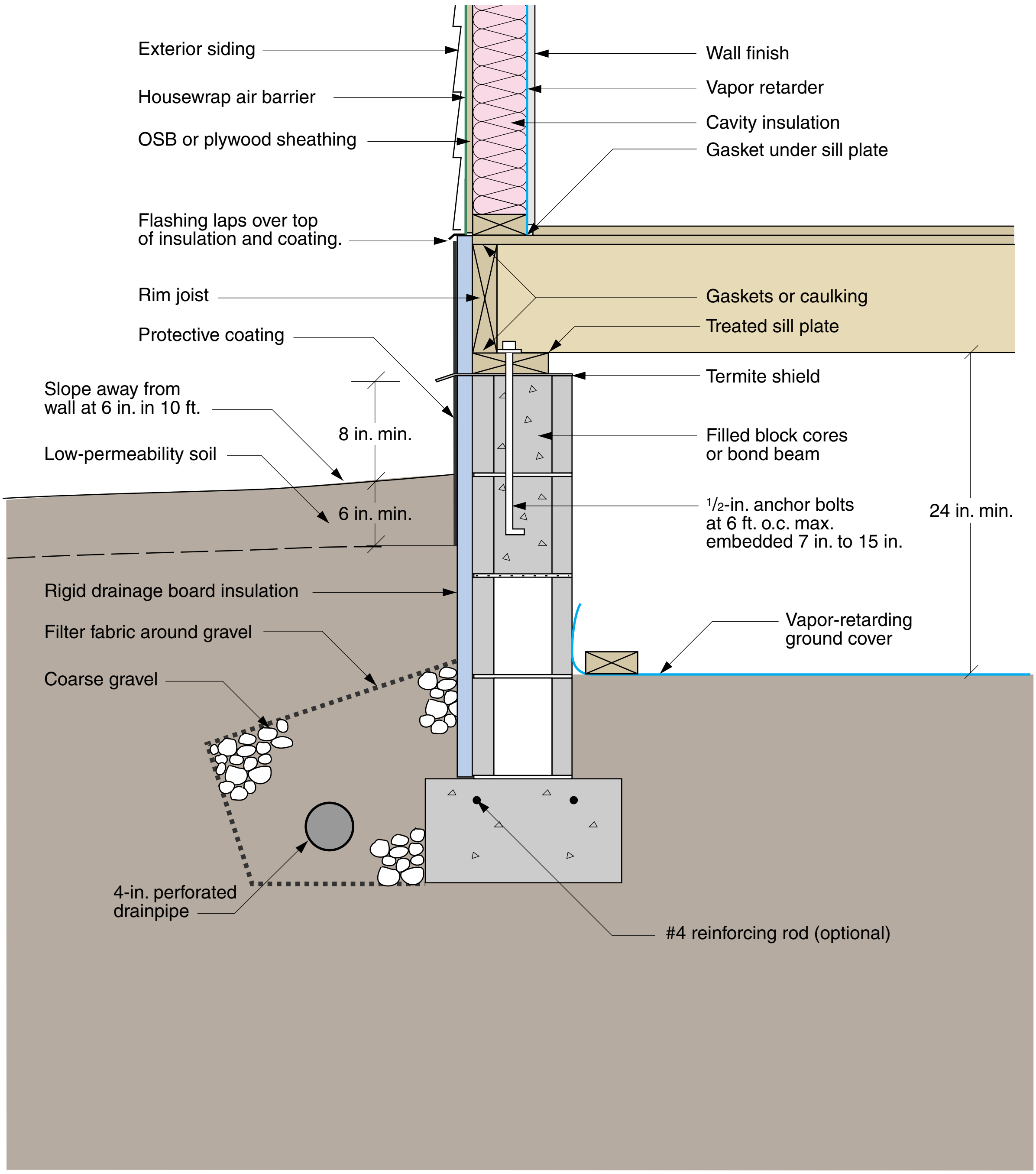
Recommended R-Values for Crawl-Space Walls

Location	Natural Gas Heat Electric AC	Heat Pump Heat Electric AC	Fuel Oil Heat Electric AC	Natural Gas Heat No AC	Fuel Oil Heat No AC
AZ, Phoenix	13	11	13	11	11
CA, Los Angeles	11	11	11	11	11
CO, Denver	19	19	19	19	19
DC, Washington	19	19	19	19	19
FL, Miami	11	11	11	11	0
GA, Atlanta	19	13	19	19	19
IL, Chicago	19	19	19	19	19
LA, Baton Rouge	13	11	11	13	11
ME, Portland	19	19	19	19	19
MA, Boston	19	19	19	19	19
MN, Duluth	19	19	19	19	19
MO, St Louis	19	19	19	19	19
NY, New York	19	19	19	19	19
TX, Dallas	19	13	13	13	13
VT, Burlington	19	19	19	19	19
WA, Seattle	19	13	19	19	19

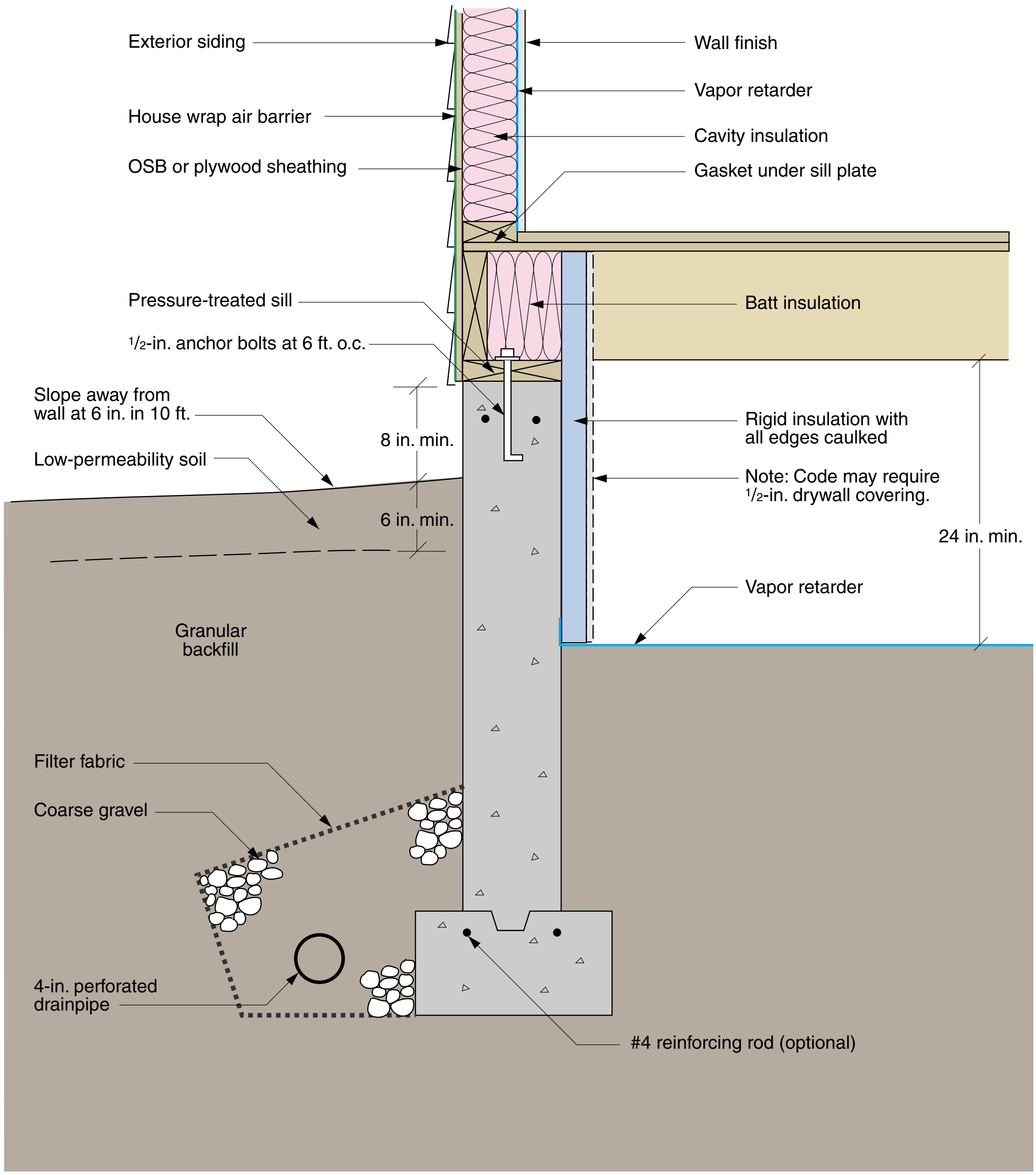
Vented Crawl Space with Floor Insulation



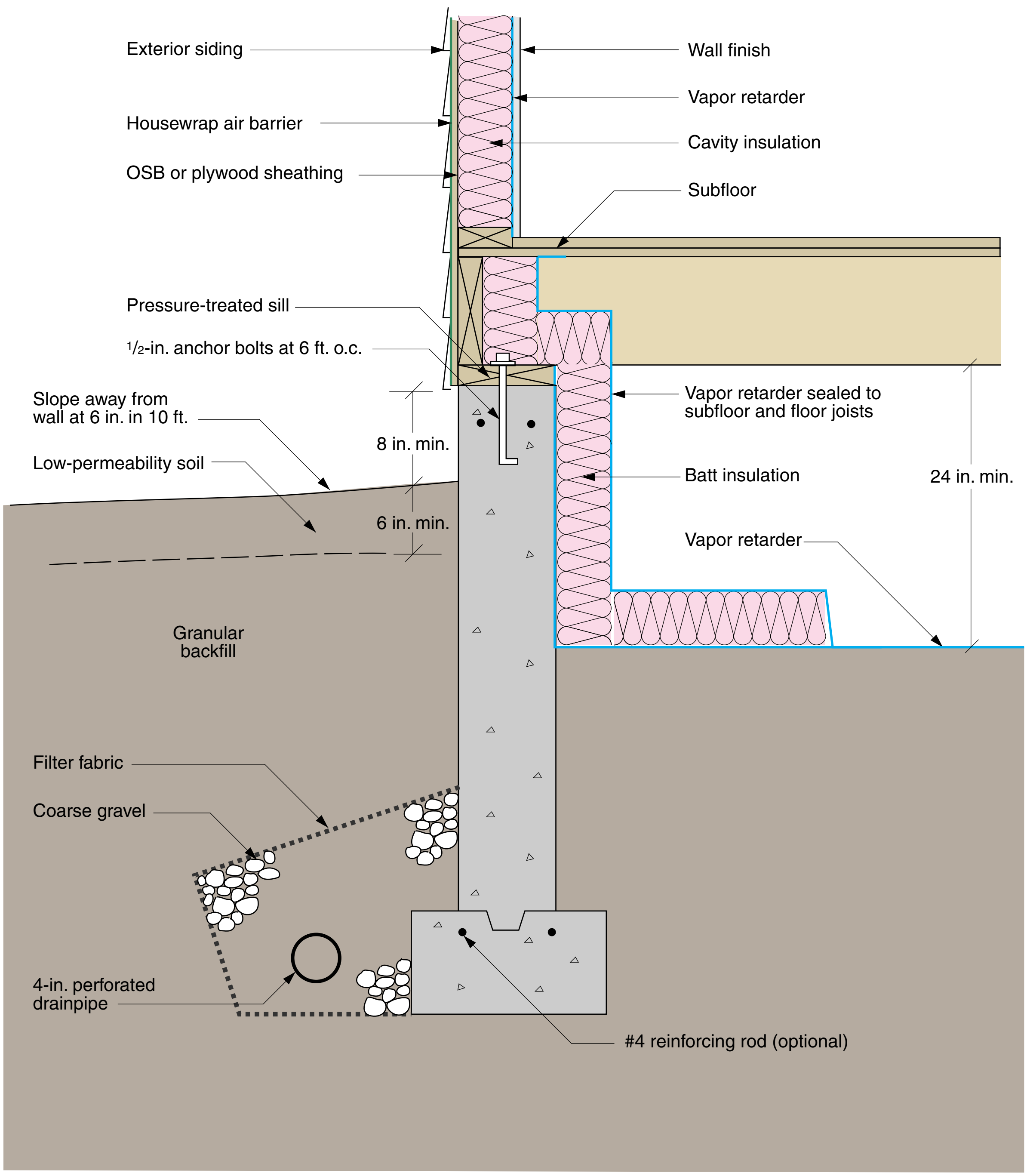
Unvented Crawl Space with Exterior Foam Perimeter Insulation



Unvented Crawl Space with Interior Foam Perimeter Insulation



Unvented Crawl Space with Interior Batt Perimeter Insulation



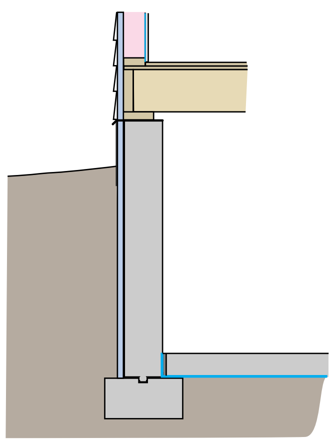
Insulating Full Basements

Full basements are popular in cold climates because they provide spaces for wiring, plumbing, heating equipment, and storage. It is easy to believe that they lose little heat because the surrounding earth serves as a thermal mass, while the house above provides a steady source of heat. It is now known that the basement walls of a building, otherwise insulated to current standards, account for up to 25% of total heat loss.

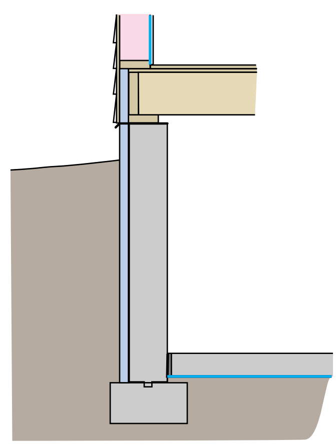
The IRC recommends basement wall (or floor above) insulation in all climate zones, as shown in the tables on p. 456.

The following six pages detail basement wall and floor insulation alternatives for new construction. Following these six, we detail four approaches to retrofitting insulation to existing homes.

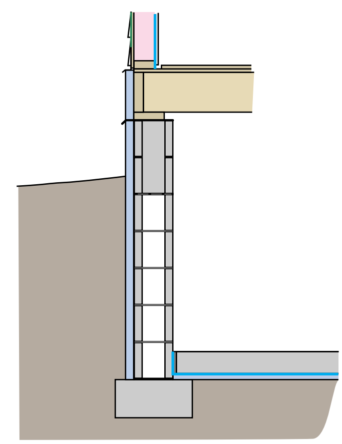
Basement Insulation Configurations



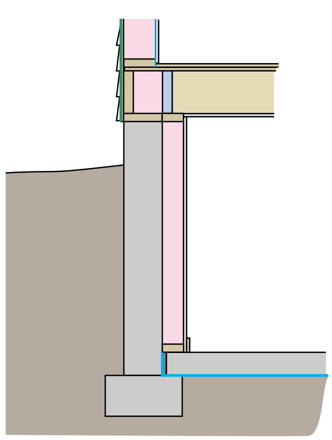
Continuous rigid foam
wall and foundation sheathing



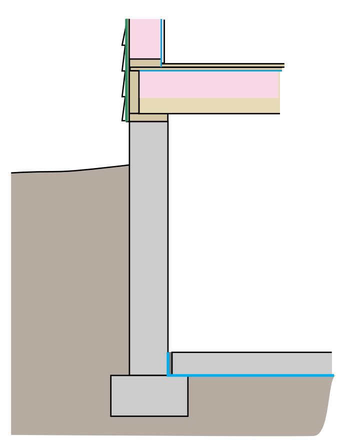
Full-height exterior foam
and cantilevered wall framing



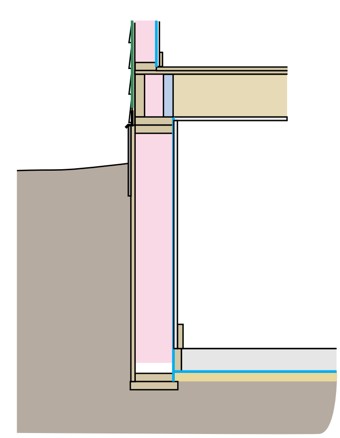
Full-height exterior foam
extended over rim joist



Interior framed wall
with batt insulation



Unconditioned basement
with floor insulation



All-weather wood foundation
with batt insulation

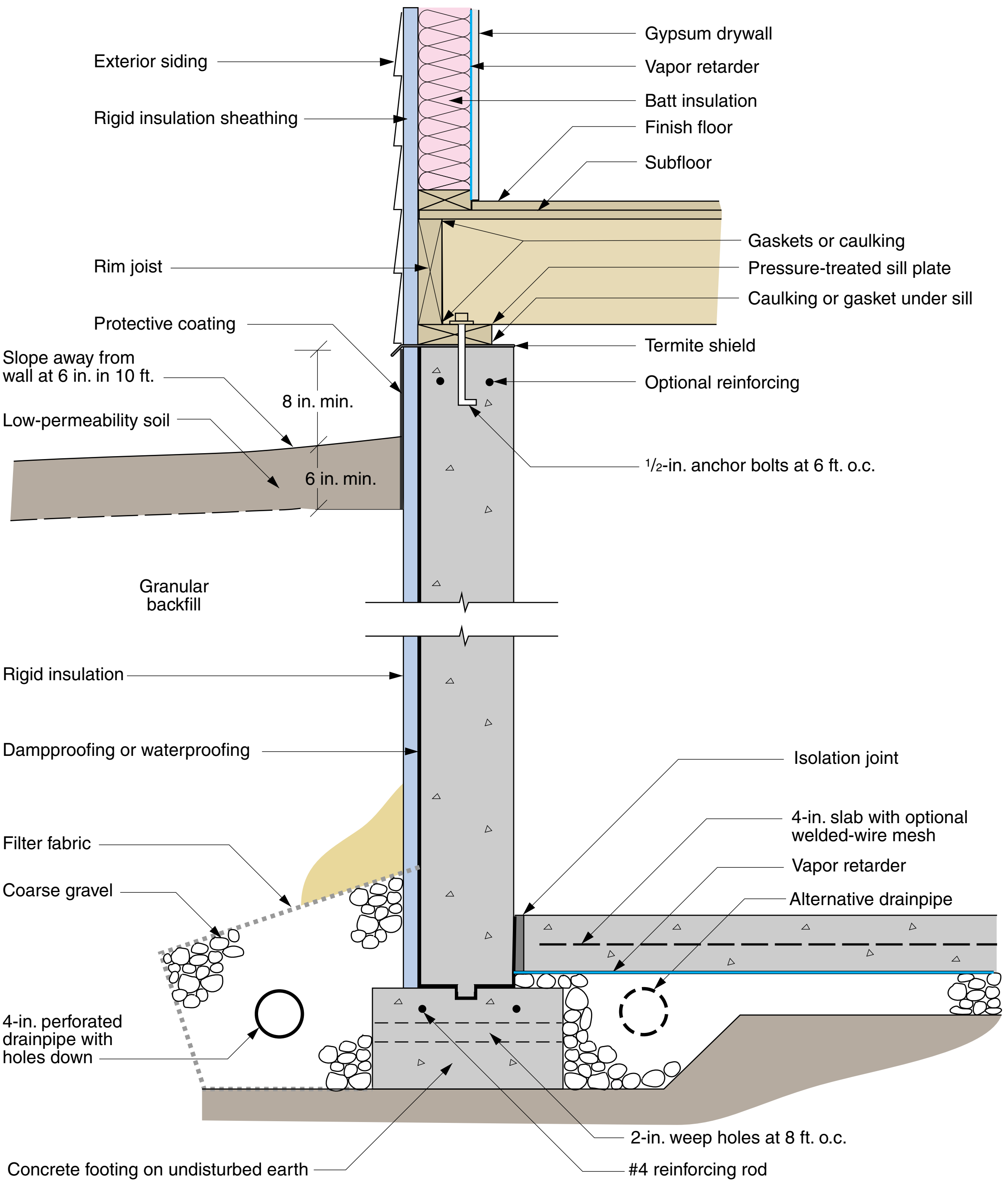
Recommended R-Values for Basement Wall Exteriors

Location	Natural Gas Heat Electric AC	Heat Pump Heat Electric AC	Fuel Oil Heat Electric AC	Natural Gas Heat No AC	Fuel Oil Heat No AC
AZ, Phoenix	4	4	4	4	4
CA, Los Angeles	4	0	4	4	0
CO, Denver	10	8	8	10	8
DC, Washington	10	5	8	10	8
FL, Miami	0	0	0	0	0
GA, Atlanta	5	5	5	5	5
IL, Chicago	8	8	8	8	8
LA, Baton Rouge	4	4	4	4	4
ME, Portland	15	15	12	15	12
MA, Boston	12	10	8	10	8
MN, Duluth	15	15	12	15	12
MO, St Louis	10	5	8	10	8
NY, New York	8	8	5	8	5
TX, Dallas	5	5	4	5	4
VT, Burlington	15	15	15	15	15
WA, Seattle	8	4	8	8	8

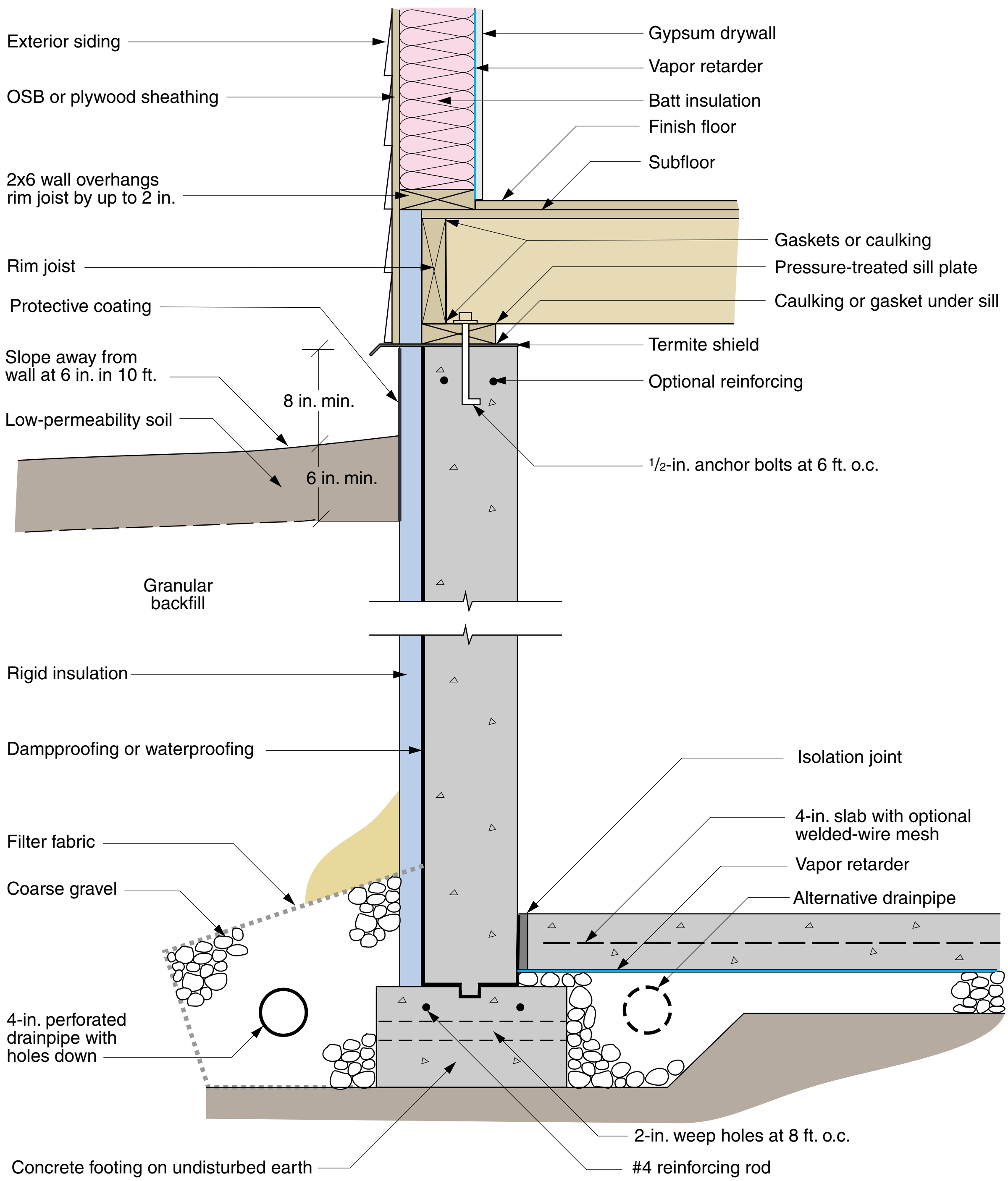
Recommended R-Values for Basement Wall Interiors

Location	Natural Gas Heat Electric AC	Heat Pump Heat Electric AC	Fuel Oil Heat Electric AC	Natural Gas Heat No AC	Fuel Oil Heat No AC
AZ, Phoenix	11	11	11	11	11
CA, Los Angeles	11	11	11	11	11
CO, Denver	11	11	11	11	11
DC, Washington	11	11	11	11	11
FL, Miami	0	0	0	0	0
GA, Atlanta	11	11	11	11	11
IL, Chicago	11	11	11	11	11
LA, Baton Rouge	11	11	11	11	11
ME, Portland	13	13	11	13	11
MA, Boston	11	11	11	11	11
MN, Duluth	11	11	11	11	11
MO, St Louis	11	11	11	11	11
NY, New York	11	11	11	11	11
TX, Dallas	11	11	11	11	11
VT, Burlington	13	19	11	13	11
WA, Seattle	11	11	11	11	11

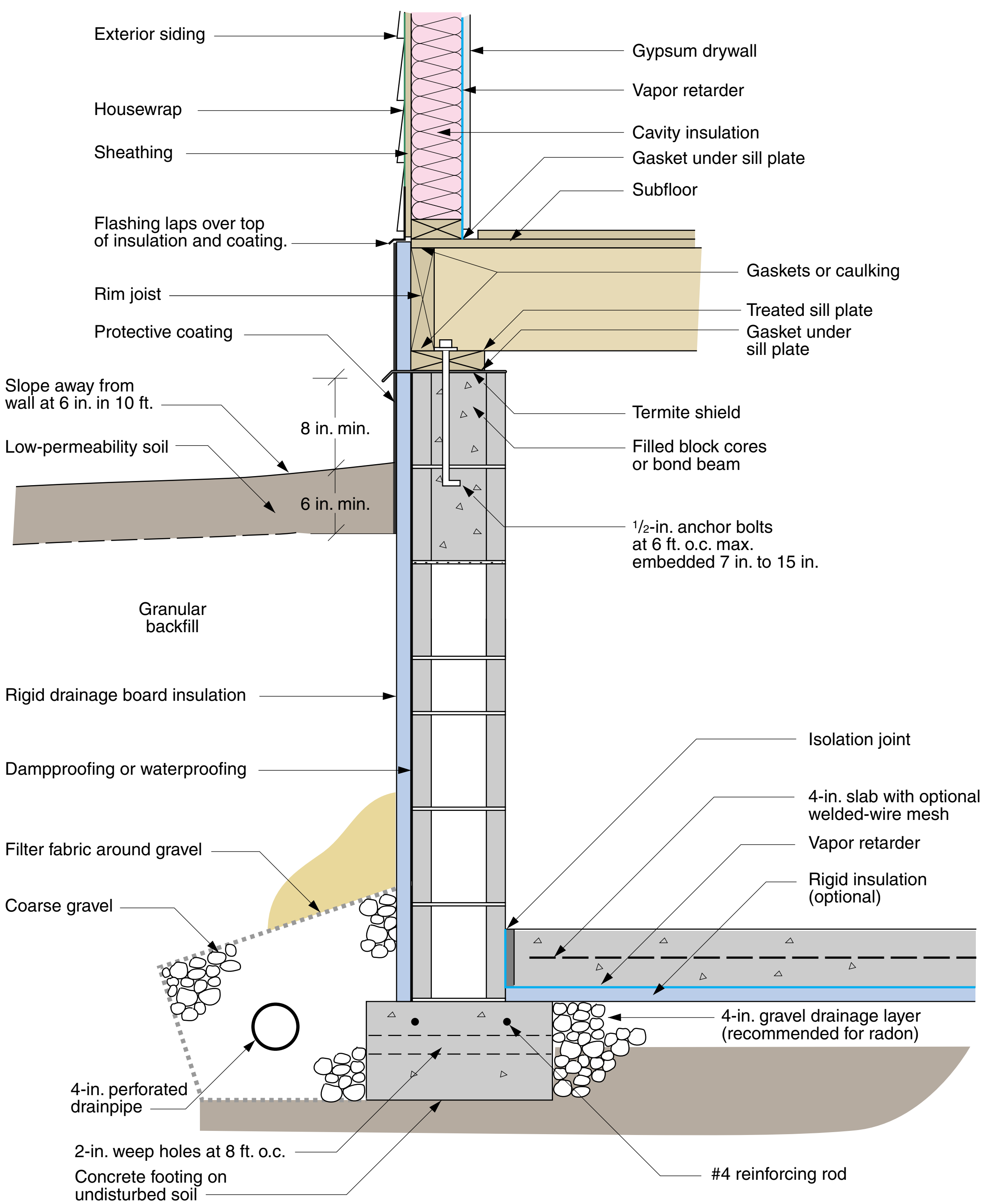
Continuous Rigid Foam Wall and Foundation Sheathing



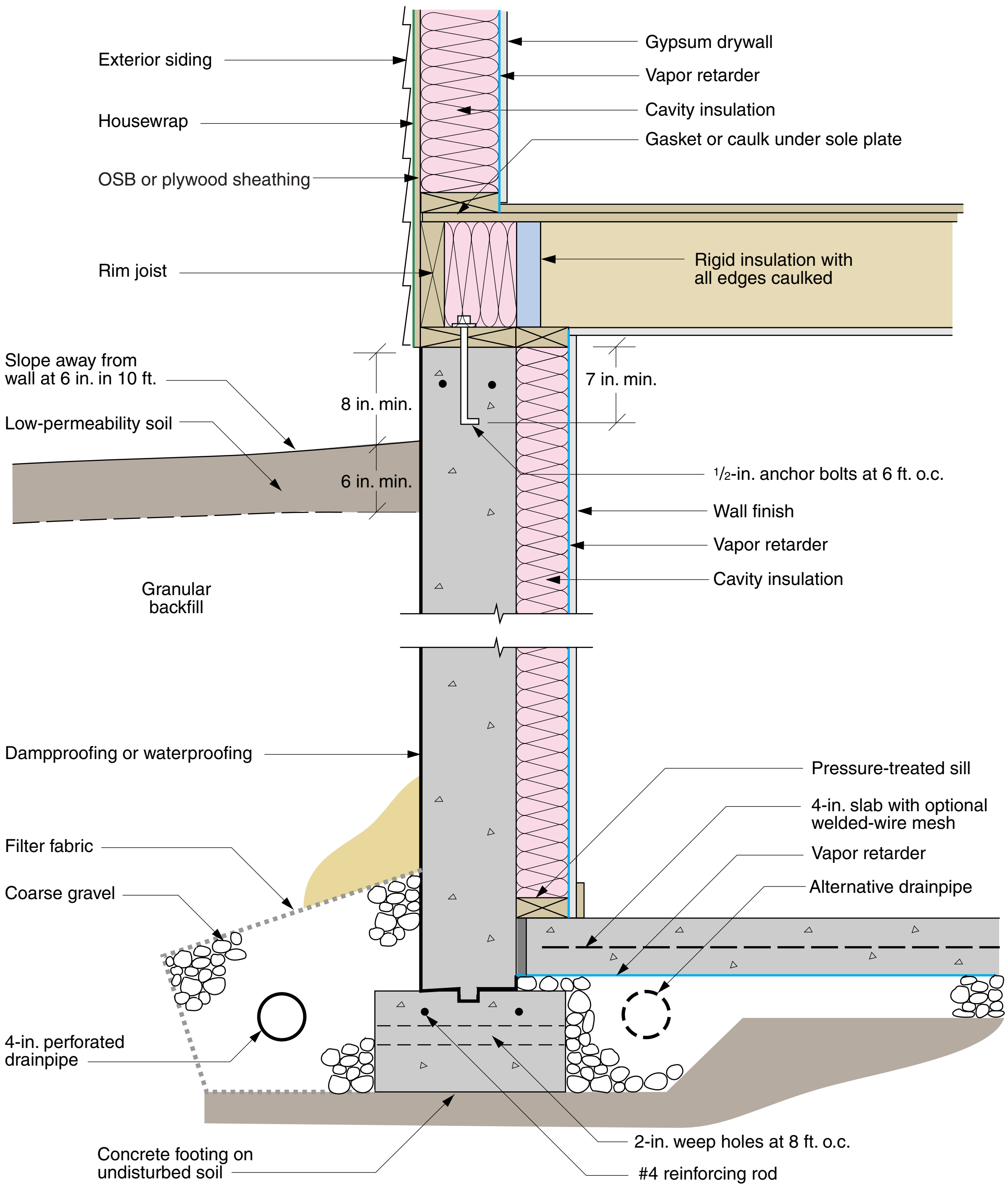
Full-Height Exterior Foam and Cantilevered Wall Framing



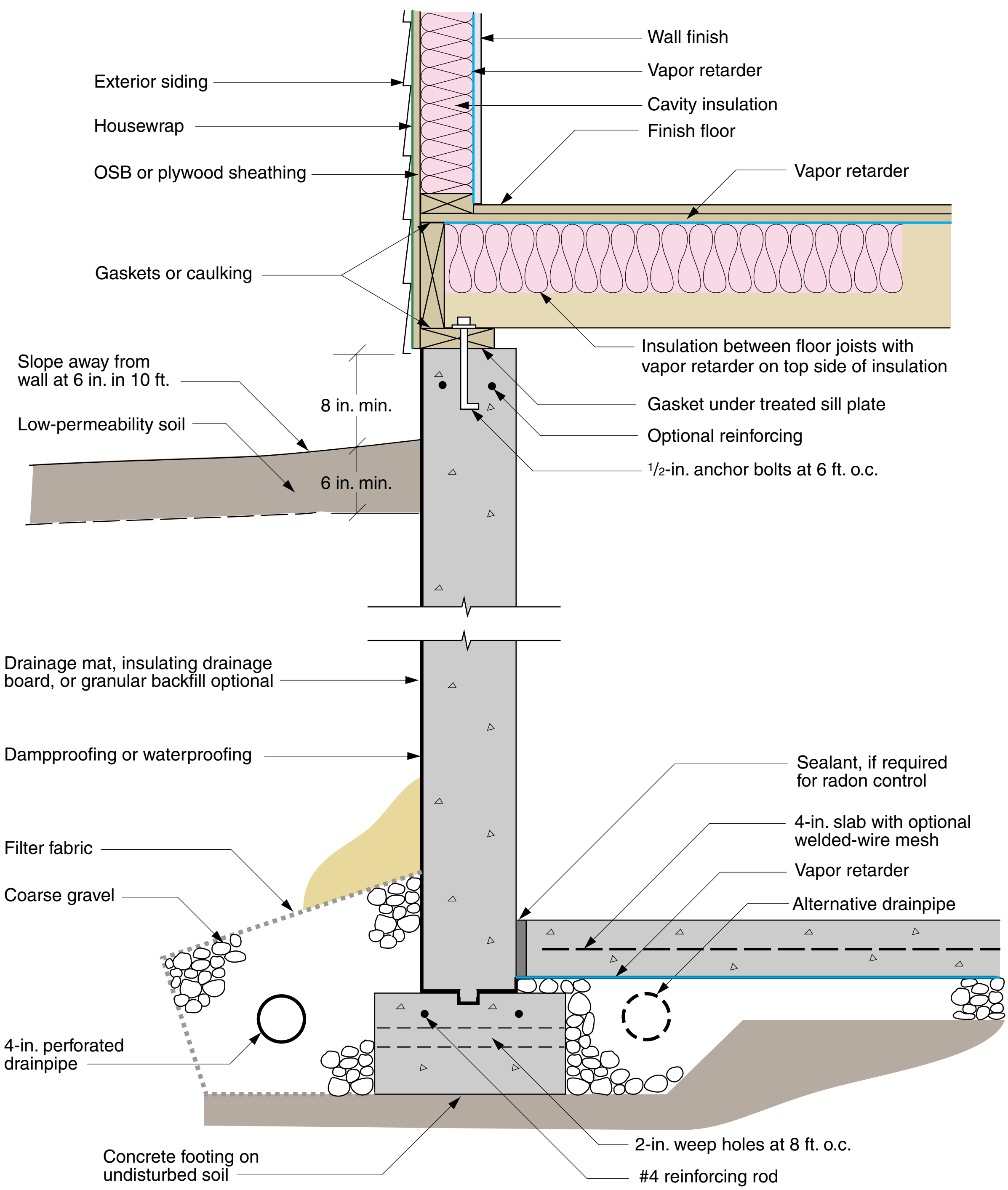
Full-Height Exterior Foam Extended over Rim Joist



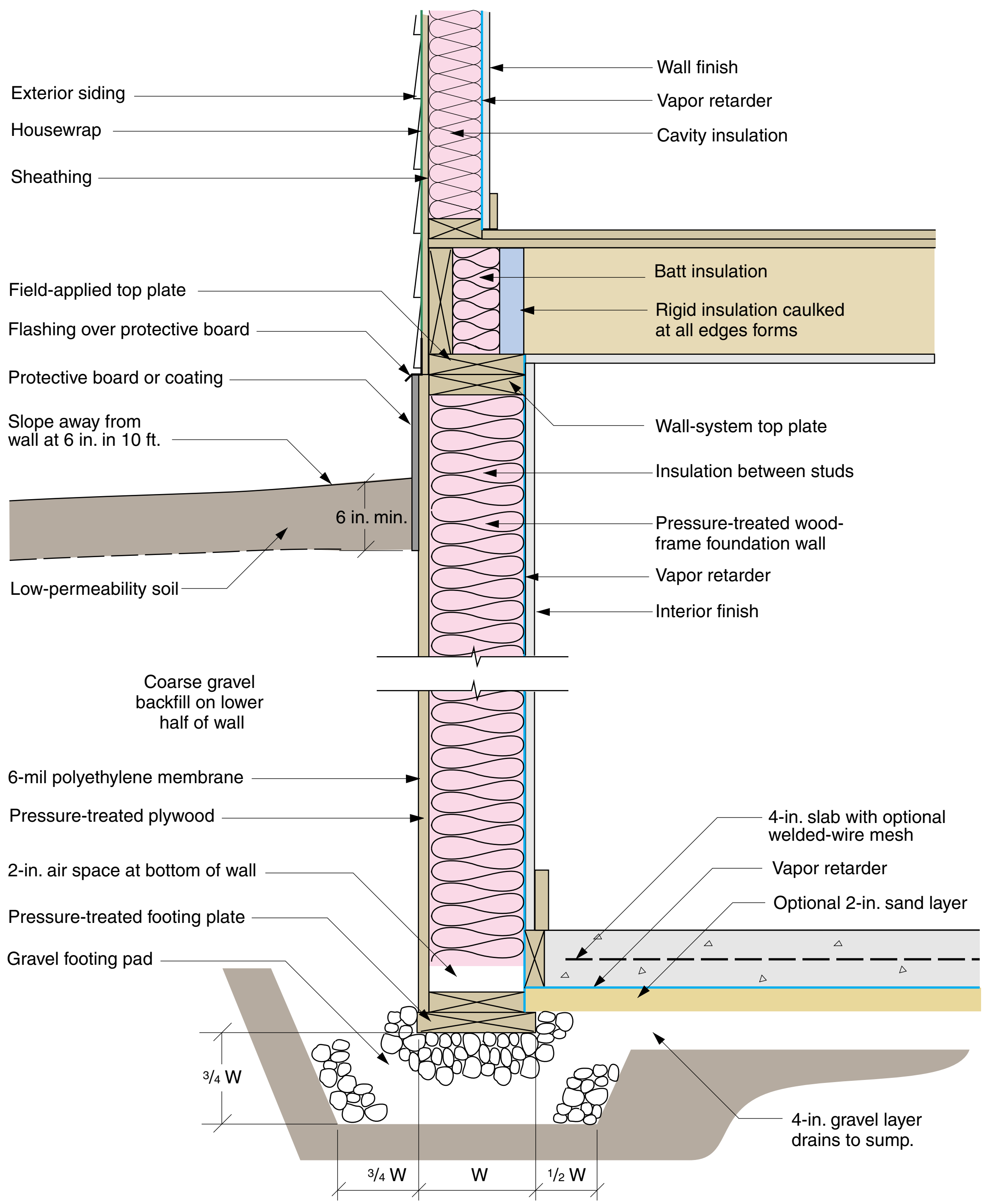
Interior Framed Wall with Batt Insulation



Unconditioned Basement with Floor Insulation



All-Weather Wood Foundation with Batt Insulation

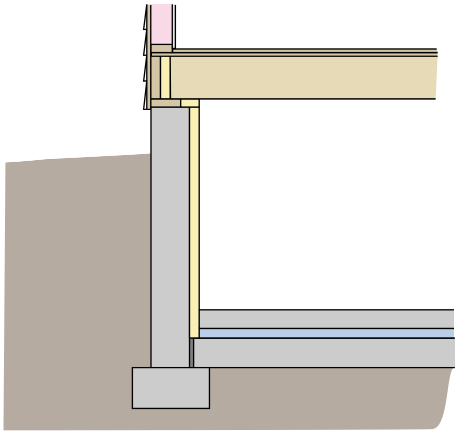


Retrofitting Full Basements

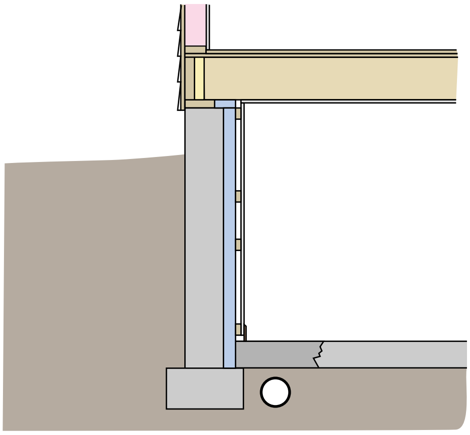
If an existing full basement had been constructed correctly, it would have a perimeter drain and be dry. Unfortunately, this is often not the case. Here, we offer four alternatives for both reducing heat loss and creating a drier basement space. The first is appropriate where the existing slab is broken and/or uneven. The second and third solve a flooding problem at the same time as creating a more useful space below ground. The fourth minimizes three problems: air leakage, heat loss, and summer humidity.

Alternatives 2 through 4 also offer the chance to install wiring if you decide to turn the basement into habitable space.

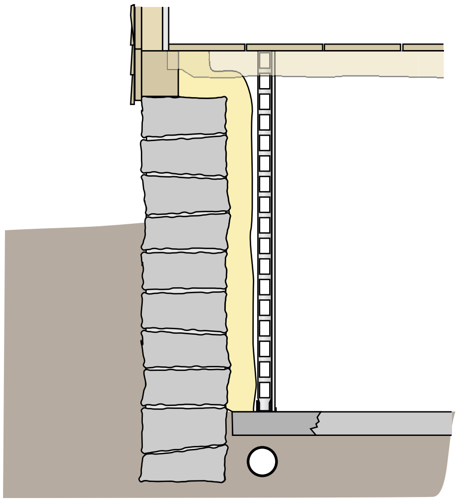
Basement Retrofit Configurations



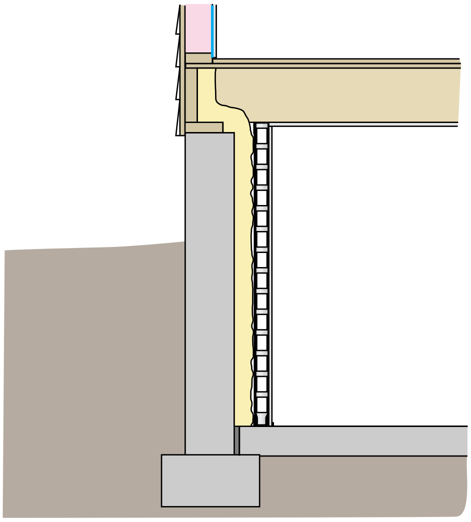
Basement retrofit with foam wall and floor insulation



Wet basement retrofit with foam and interior drainage

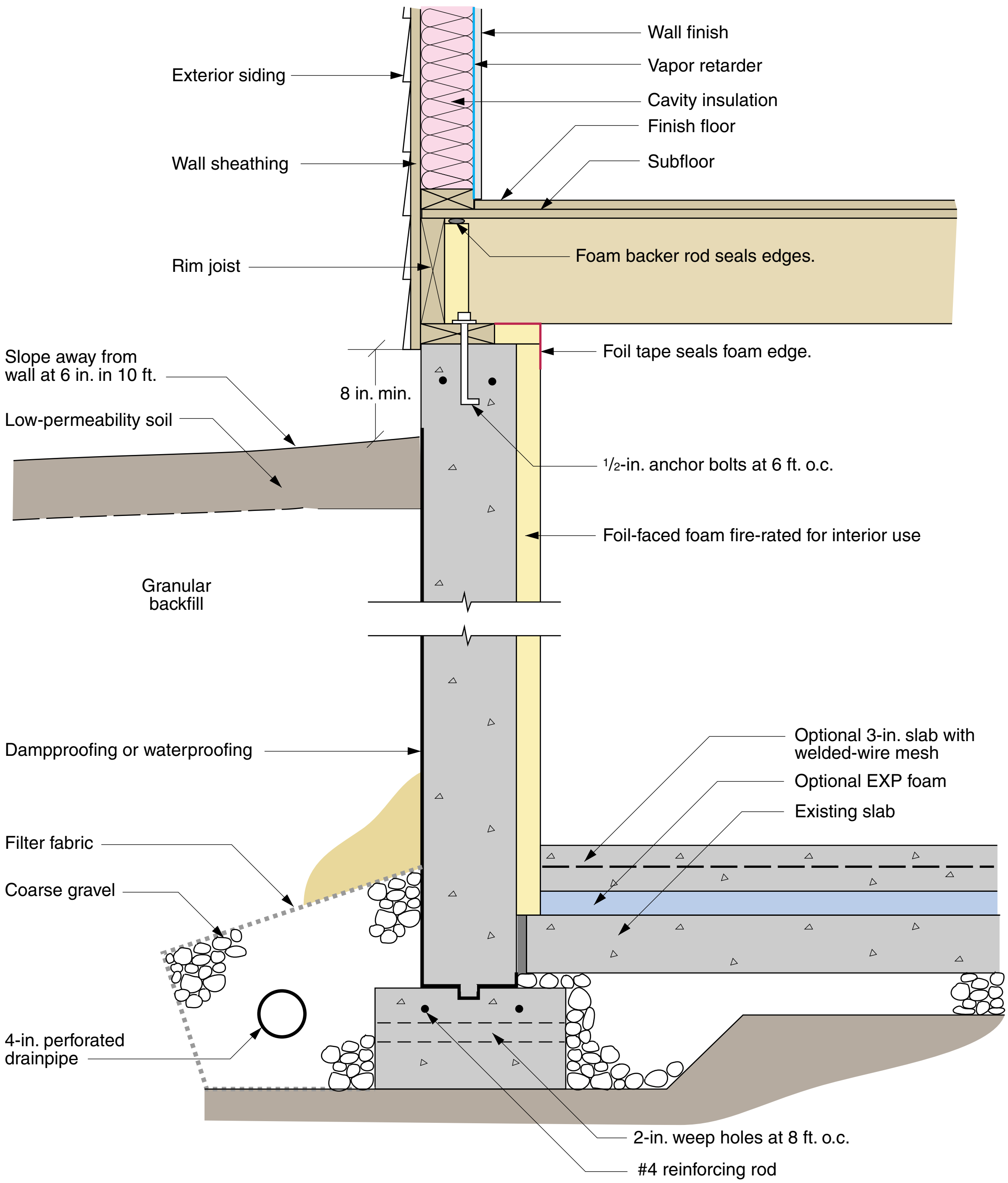


Rubble wall retrofit with spray foam, finished wall, and interior drainage

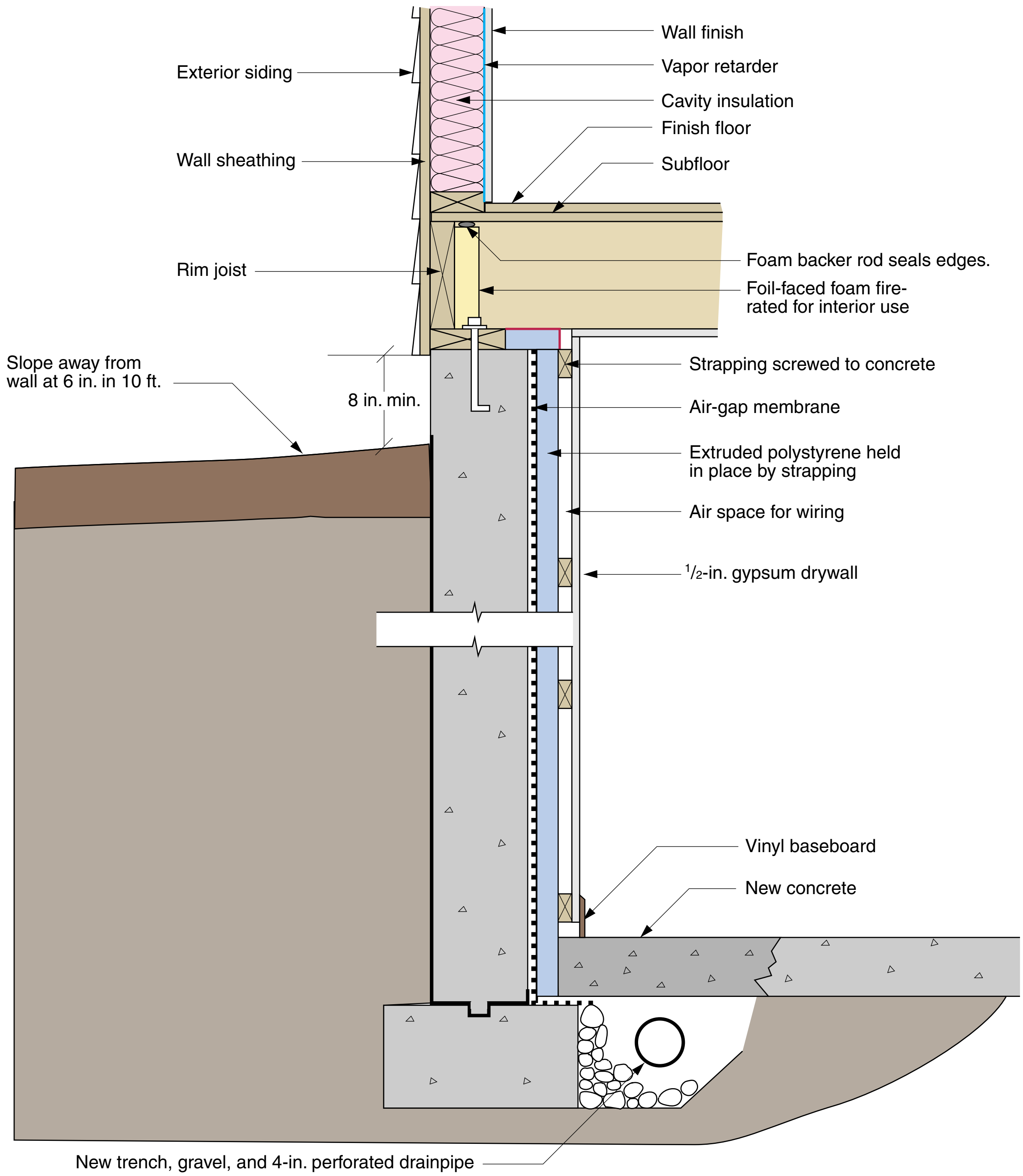


Concrete wall retrofit with interior spray foam and finished wall

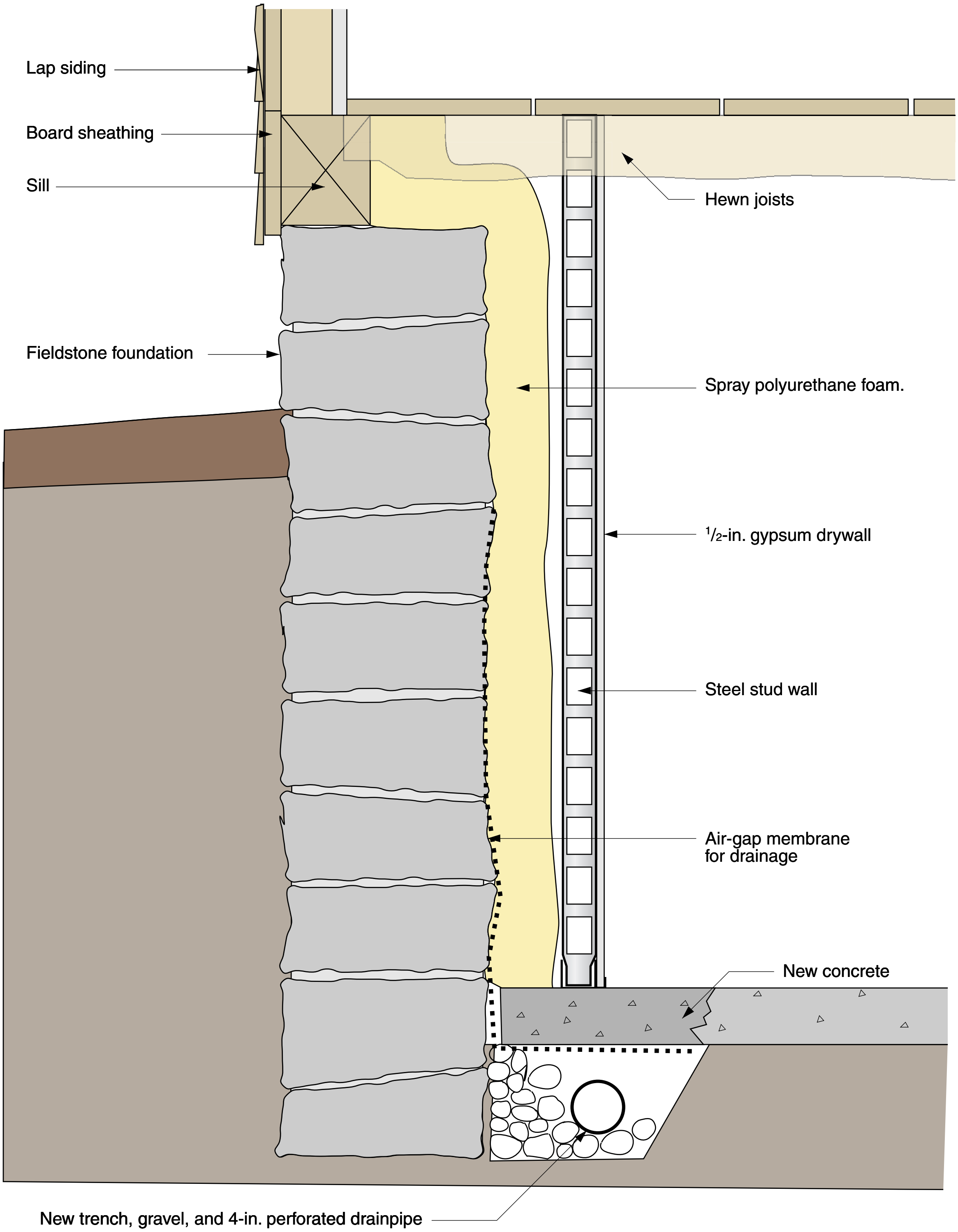
Basement Retrofit with Foam Wall and Floor Insulation



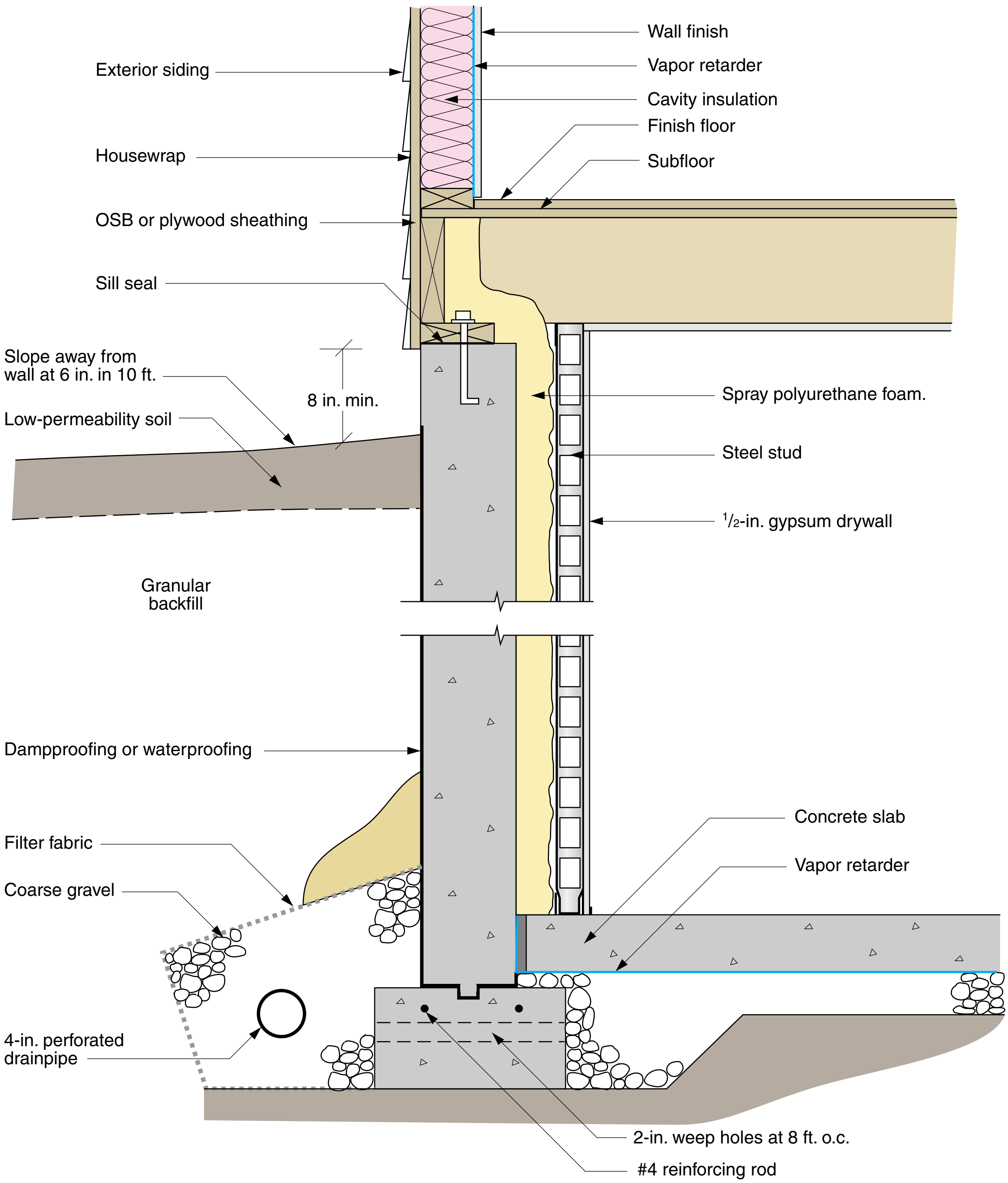
Wet Basement Retrofit with Foam and Interior Drainage



Rubble Wall Retrofit with Spray Foam, Finished Wall, and Interior Drainage



Concrete Wall Retrofit with Interior Spray Foam and Finished Wall



15

Air-Sealing Existing Buildings

Infiltration–the uncontrolled exchange of interior and exterior air in a building–is the largest component of energy loss in older structures. Fortunately, the techniques for air-sealing existing buildings are now well established.

Using a graphic *field guide to air leak*s, we uncover and attack the problem areas from top to bottom: *attic air leaks, basement air leaks, interior air leaks, and exterior air leaks.*

A Field Guide to Air Leaks

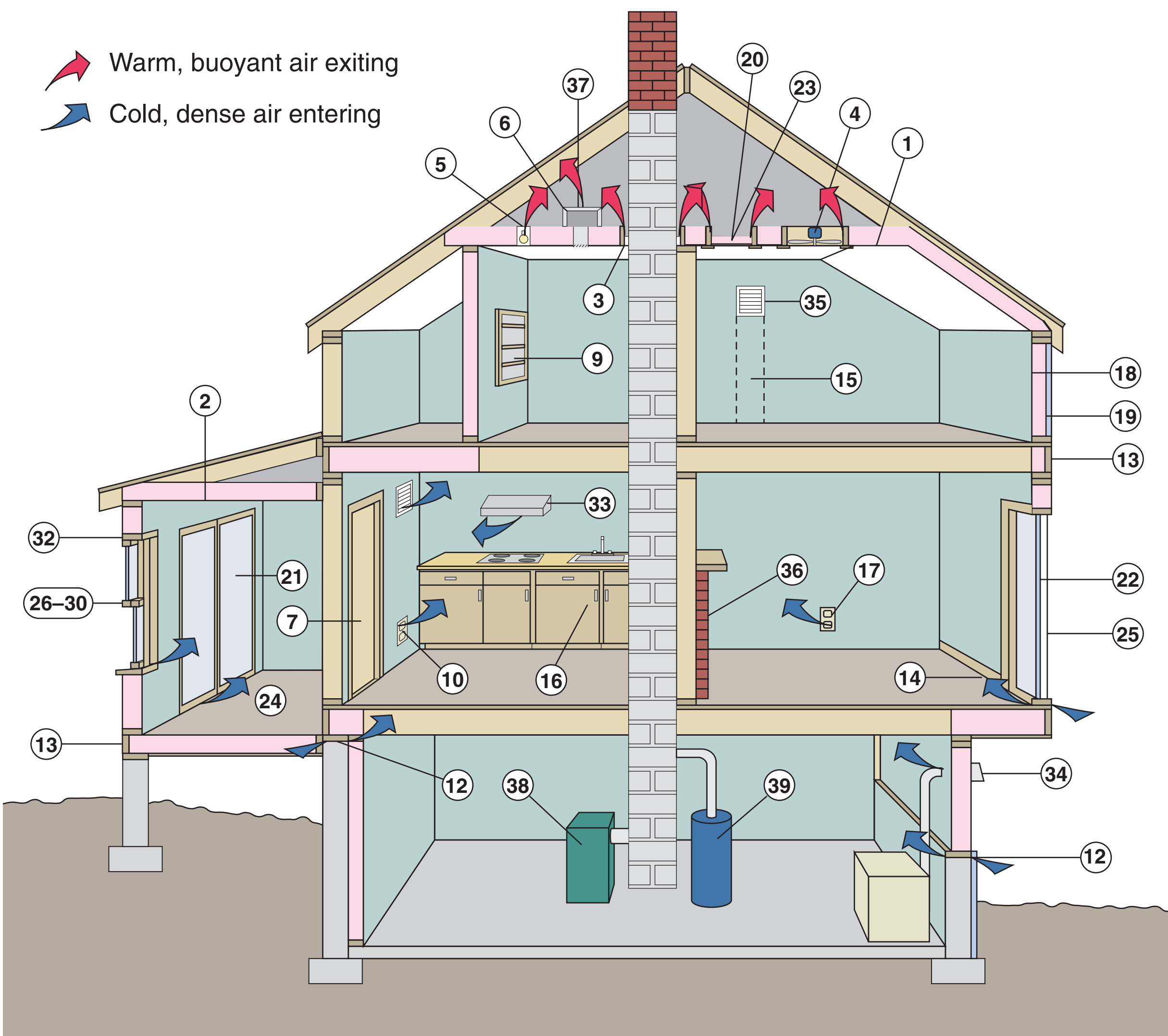
Below is a similar home to the one we saw on p. 429. The previous illustration was simplified, but now we are looking at a real house with real imperfections. The 39 identified air leaks are listed in the table on the facing page with their average measured areas.

Most homes have a vented clothes dryer (Leak #34). Is the damper on yours stuck open? If so, the table shows it is equivalent to a 4-sq.-in. hole.

Does your home have a masonry chimney (Leak #3)? If so, the fire code-required 2-in. gap between it and the ceiling framing surrounding it is equivalent to a hole in the ceiling of 12 sq. in.

The total area of air leaks in the average home is an incredible 288 sq. in. You read that right, 2 sq. ft. That is effectively the same as leaving a window sash open about a foot all winter long!

Thirty-Nine Common Air Leaks in a Home's Thermal Envelope



Equivalent Sizes of Typical Air Leaks

Air Leak	Area, sq. in.
Ceiling	
1. General, per 100 sq. ft	0.05
2. Dropped ceiling, per 100 sq. ft, no poly vapor barrier	78
With poly vapor retarder	8
3. Framing around chimney	12
Sealed off	1
4. Whole-house fan, louvers closed	8
Covered with weatherstripped box	0.6
5. Ceiling fixture, surface or sealed, recessed	0.3
Recessed, not air-tight	4
6. Pipe or duct through ceiling	1
Caulked at ceiling	0.2
Interior Walls	
7. Pocket door	5
8. Pipe or HVAC duct in wall cavity (not shown)	2
9. Recessed cabinet	0.8
10. Electrical switch or receptacle	0.2
With foam cover plate gasket	0.03
Exterior Walls	
11. General, per 100 sq. ft. (not shown)	0.8
12. Sill on masonry foundation	65
Caulked	13
13. Box sill	65
Caulked	13
14. Floor/wall joint	27
Caulked	7
15. HVAC duct in wall	9
16. Pipe in wall	2
17. Electrical switch or receptacle	0.2
With foam cover plate gasket	0.05
18. Polyethylene vapor retarder (deduct for)	-30
19. Extruded polystyrene sheathing (deduct for)	-15
Doors	
20. Attic fold down	17
Weatherstripped	8
Insulated and weatherstripped cover	2

Air Leak	Area, sq. in.
21. Patio sliding	16
22. Entrance	8
Weatherstripped	6
Magnetic seal	4
23. Attic hatch	6
Weatherstripped	3
24. Air-lock entry (deduct for)	-4
25. Storm door (deduct for)	-3
Windows (All Weatherstripped)	
26. Double-hung	0.8
27. Horizontal slider	0.6
28. Awning	0.2
29. Casement	0.2
30. Fixed	0.2
Door and Window Frames	
31. Masonry wall (not shown)	2
Caulked	0.4
32. Wood wall	0.6
Caulked	0.1
Vents	
33. Range hood, damper open	9
Damper closed	2
34. Clothes dryer, damper open	4
Damper closed	1
35. Bathroom, damper open	3
Damper closed	1
36. Fireplace, damper open	54
Average damper closed	9
Stove insert with cover plate	2
Heat and Hot Water	
37. Ducts in unheated space	56
Joints caulked and taped	28
38. Furnace, with retention head burner	12
With stack damper	12
With retention head and stack damper	9
39. Gas/oil boiler or water heater	8

Source: *Cataloguing Air Leakage Components in Houses*, Princeton University Center for Energy and Environmental Studies, 1984

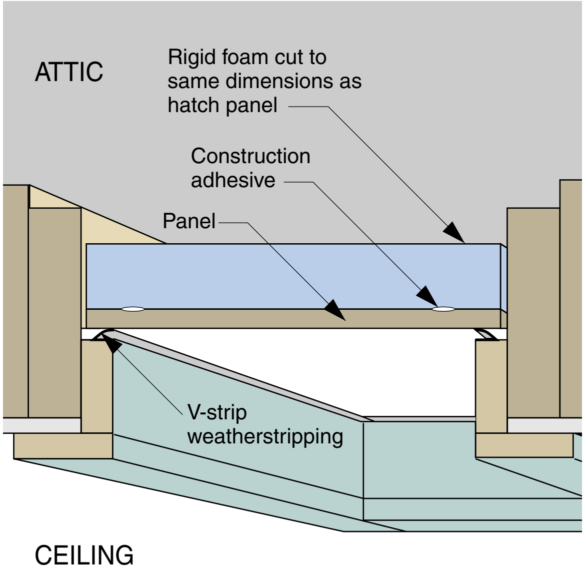
Attic Air Leaks

Attic Access Panel

Did you realize that the little access panel in the ceiling is an exterior door? If you define an exterior door as one that separates the inside from the outside, then the panel is one because your attic is (or should be) ventilated and at outdoor temperature.

Cut a piece of rigid foam the exact size of the lift-out hatch panel and fasten it to the panel's attic side with either construction adhesive, long roofing nails, or long drywall screws.

Apply either V-strip or sponge rubber weatherstripping to the top of the scuttle casing, as shown in the illustration at right. What you have just done will pay for itself in just a few months, and it will last a lifetime.



Pull-Down Stairs

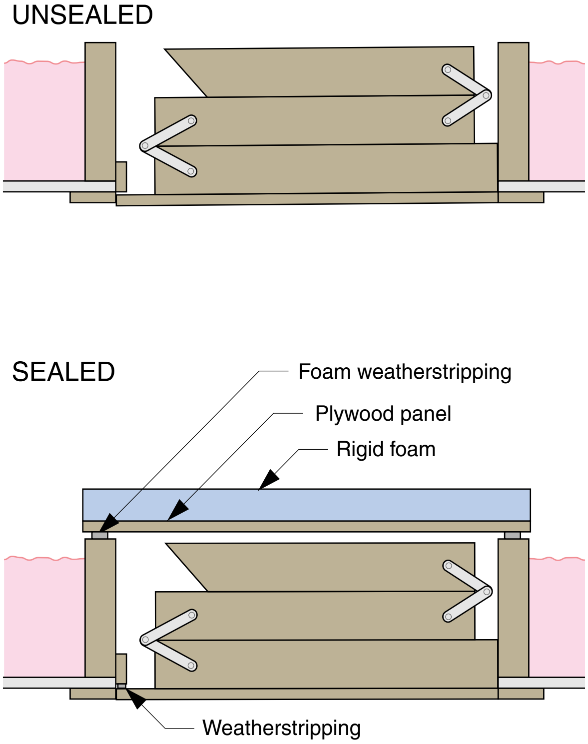
Many homes have attic pull-down stairs instead of a hatch hole. These are large and notoriously leaky. You can purchase a kit for insulating and sealing the stair opening, or you can make your own, as shown.

To make your own, simply cut a panel of ½-in. plywood and a matching panel of rigid foam to fit over the ceiling framing surrounding the fold-down stairs.

Attach the foam to the plywood with construction adhesive or long drywall screws.

If the depth of the framing box is insufficient to contain the folded stairs, build up the surrounding framing with ripped 2×4 stock to the required height. Apply foam weatherstripping to the top edge of the framed box.

According to the air-leak field guide on pp. 470–471, you have just plugged a hole to the outside of 15 sq. in.

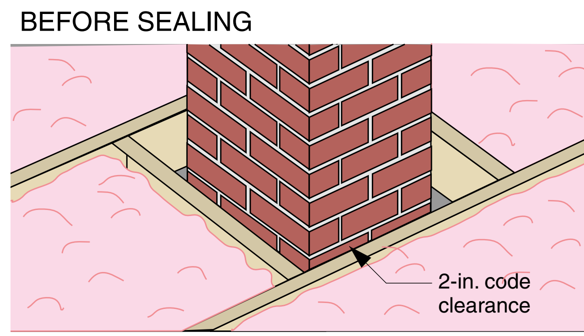


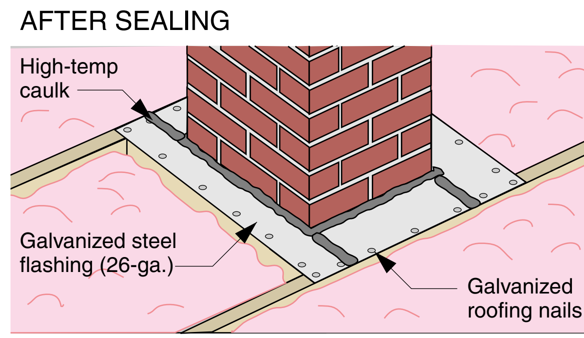
Masonry Chimney Surround

Fire codes require a 2-in. clearance between masonry chimneys and combustible materials, including the floor and ceiling framing surrounding the chimney. Most often interior chimneys are enclosed within wood-framed walls. What you will discover if you look down around a chimney passing through the attic is a hollow passage connecting the basement and the attic. If it is winter, you will also feel a strong draft of warm air flowing up into the attic—a heat loss disaster!

The solution is to nail four strips of 26-ga. galvanized roof flashing to the joists boxing in the chimney. Butt the metal strips up against the masonry and seal the joints with high-temperature caulk (available at most home centers).

What about stuffing the gap with unfaced fiberglass? Don't do it. The resin binding the glass fibers is flammable.

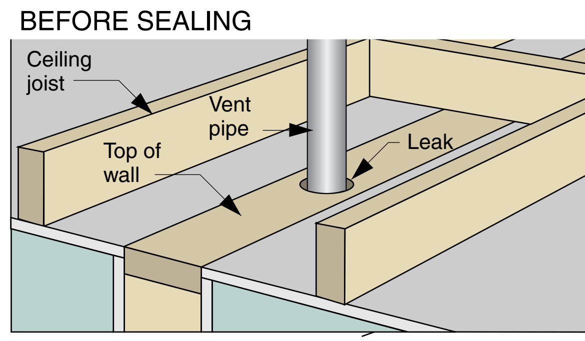


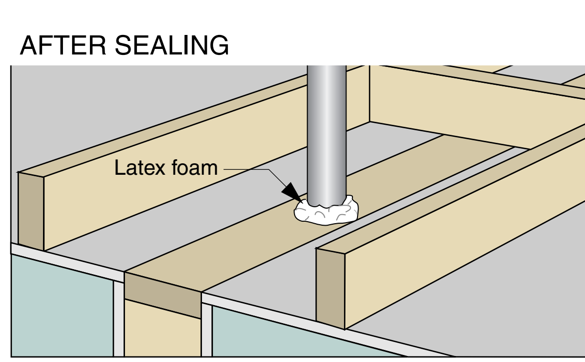


Vent Pipes

Plumbers are rarely finish carpenters. When they cut holes for pipes in wall framing they are interested in only one thing: a loose fit. Therefore, when you find a vent pipe passing through the attic, you will generally find it coming through an oversized hole in the top plate of an interior wall. Worse yet, you may find it passing between a pair of interior walls with the space between the walls unsealed.

In the first case, the solution is to fill the space around the pipe with a generous application of latex foam. In the second case, seal the space between the two walls with strips of 6-in. or 8-in. metal flashing. Unlike the case of the chimney space, this flashing may be aluminum, which is easily cut with ordinary scissors or a utility knife.



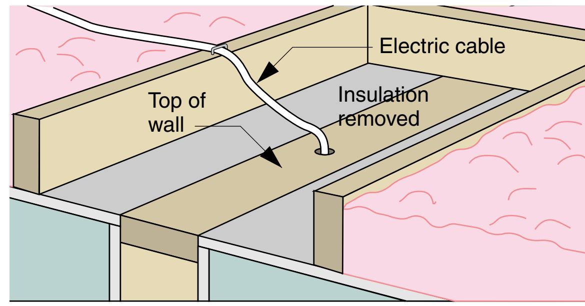


Wiring Ceiling Penetrations

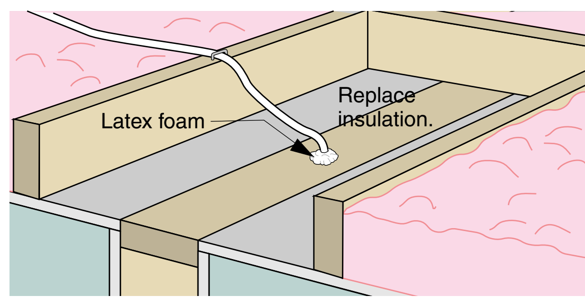
If you find an electrical cable running across the floor of the attic, it probably connects a switch in an interior wall to a ceiling light fixture. The cable will enter the attic through an oversized hole drilled through the top plate of a wall below.

To seal the oversized hole, remove the insulation (if any) covering the area, and fill around the hole with latex foam. Then replace the insulation.

BEFORE SEALING



AFTER SEALING

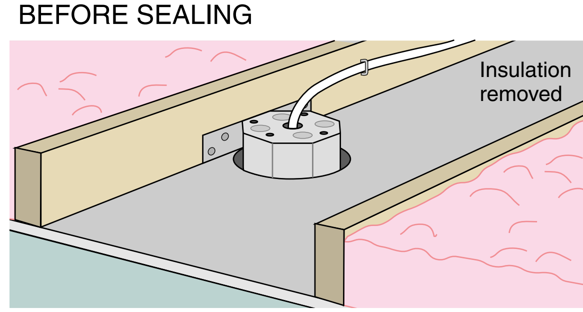


Ceiling Light Fixtures

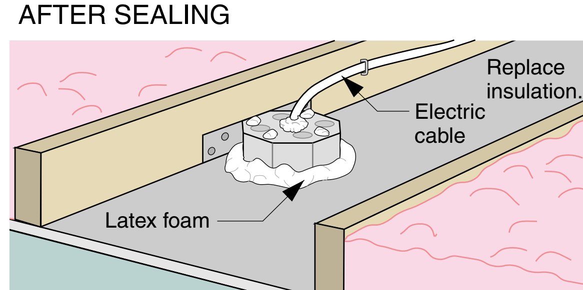
By the electrical code, all wiring connections must be made within electrical boxes. Where there is a ceiling fixture, you will find an electrical box. This is usually a round or octagonal metal can fastened to a joist. Whoever designed these boxes didn't have energy conservation in mind. They are full of holes and are surrounded by an oversized hole in the ceiling. Fill all holes and gaps with latex foam.

If the box is the size of a large cylindrical coffee can and is attached to another box to one side, it is housing a recessed light. The code says there must be a 3-in. clearance between it and insulation. Unfortunately, there are only two effective solutions: (1) disconnect the fixture and seal the opening at ceiling level with a plastic sheet, or (2) replace the fixture with an expensive IC (Insulation Contact) fixture.

BEFORE SEALING



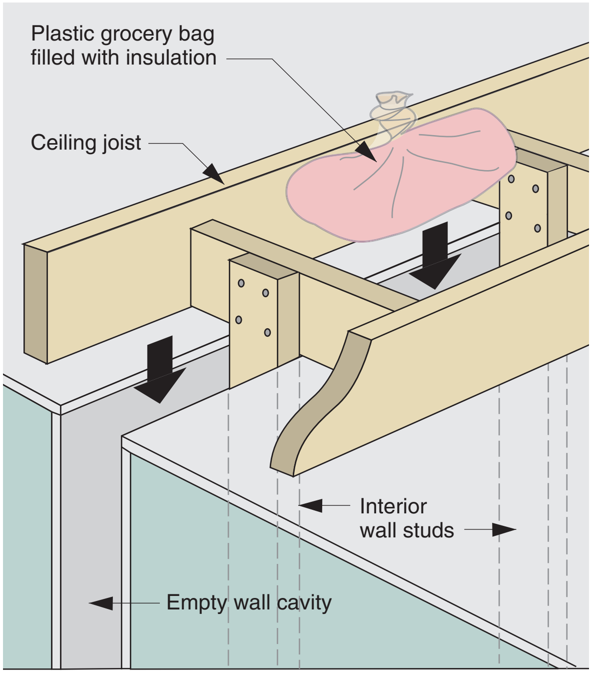
AFTER SEALING



Open Interior Walls

If your house was built prior to about 1950, chances are good that it was framed in the older "balloon frame" style. Rather than constructing interior walls with top and bottom plates connecting the tops and bottoms of studs and raising the wall into place, the interior walls were built in place with the tops of the studs nailed to ceiling joists or blocking installed between ceiling joists. This type of construction leaves the stud cavities on the top floor open to the attic. Of course, these act as miniature chimneys venting warm air into the attic.

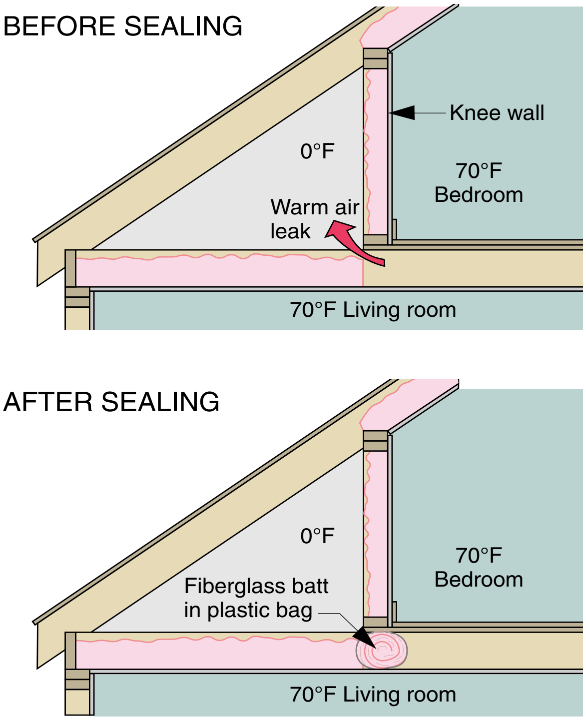
Using your floor plan, locate the tops of the interior walls in the attic and remove any covering insulation. Fill plastic grocery bags with pieces of unfaced fiberglass batt, seal the bags by tying the bag handles together, and stuff the bags into the tops of the stud cavities. The compressed fiberglass will serve to fill the cavity, and the plastic will stop air flow.



Knee Walls

If your house has top-floor rooms with knee walls (short walls with crawl spaces behind them), the sloping ceilings, knee walls, and floors of the crawl spaces are all probably insulated with fiberglass or rockwool batts. Since the floor under the room was inaccessible at the time of insulating, it was left uninsulated. Although that was standard practice when the house was built, we now realize air between the joists in the floor is warmed from above and below and flows out into the uninsulated and vented crawl space. Essentially, the crawl space, if properly vented to the outside, is part of the outdoors.

The solution, again, is filling plastic grocery bags with unfaced fiberglass batt, sealing the bags by tying the bag handles together, and stuffing the bags between the joists under the floor. The bags will stop the warm air escaping into the unheated crawl space.



Basement Air Leaks

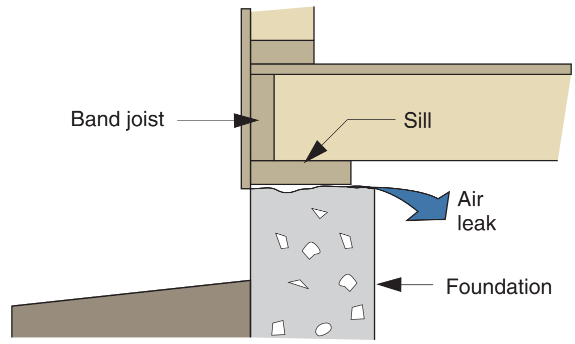
Foundation and Sill

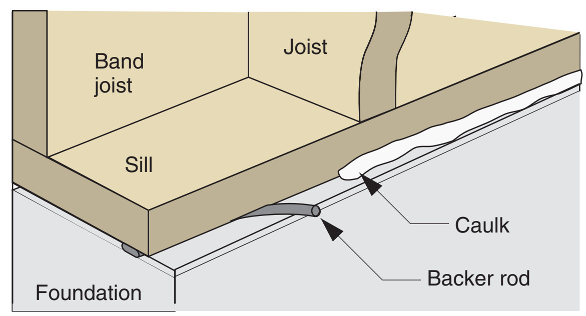
Unlike lumber, concrete can be neither planed nor sanded, and it is difficult to smooth when poured between foundation forms. As a result, the tops of foundation walls can be rather rough and uneven. To prevent air leaks between the top of the foundation and the wood sill, contractors now install strips of "sill sealer"—thin strips of closed-cell foam—under the sill.

Unless your home was built recently, it doesn't have this feature. At best, it may have an ineffective and leaky strip of unfaced fiberglass.

The solution is stuffing foam backer rod into the joint with a putty knife wherever possible, followed by cleaning the wood and concrete of dust and caulking the joint.

Backer rod is used to back up the caulk used to seal joints in concrete block construction. It can be found at most stores that sell masonry construction supplies.

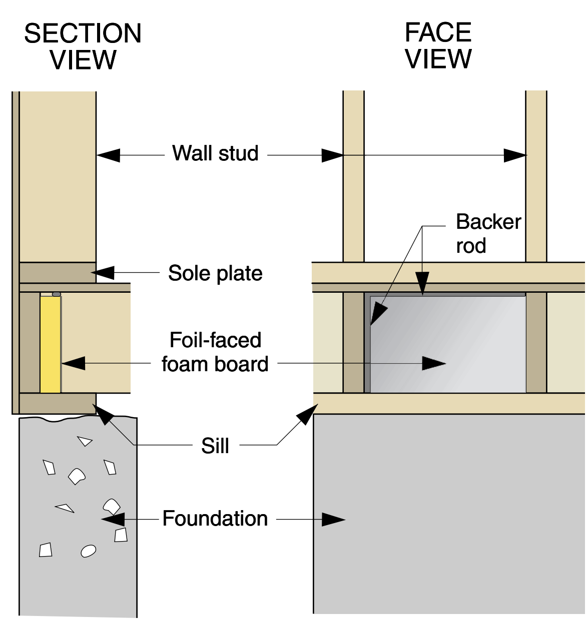




Rim Joist

The building sill (Field Guide Item #12) is not the only problem in the basement. The assemblage of wood framing (Item #13, the "box sill") immediately above the building sill also accounts for a surprising 65 sq. in. of leakage area. In addition, as you can see from the section view in the illustration at right, the rim joist offers little in the way of R-value. Fortunately, we can solve both problems with one application.

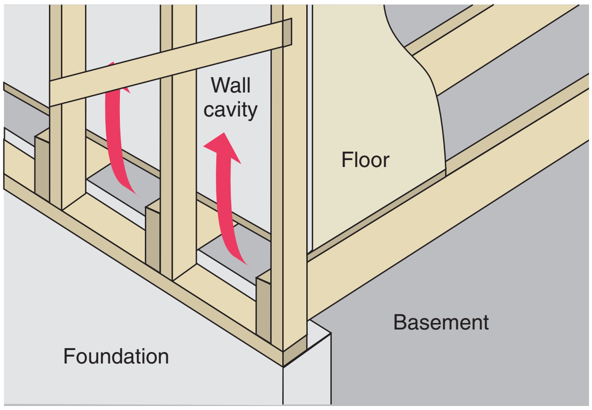
The solution is to cut Thermax HD foil-faced rigid foam panels ⅛ in. shorter and narrower than the rectangular space between the joists and wedge them hard up against the rim joists. Stuffing ¼-in. foam backer rod into the side and top gaps will hold the panels in place and seal against moisture and air leaks. Facing the foil side into the basement should satisfy local fire code regulations.

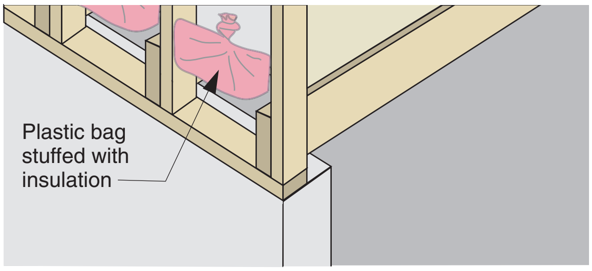


Balloon-Frame Wall Cavities

If your home was built before 1950, chances are it has a balloon frame. The name derives from the fact that the walls are framed with long studs extending unbroken from sill to rafters. Balloon framing was replaced by modern platform framing, due partly to the unavailability of long studs (up to 24 ft.) but also to the ease with which fire could spread from basement to attic through the tall flue-like wall cavities. Unfortunately these wall cavities act like so many chimney flues, allowing warm air to escape from the basement into the cold, ventilated attic.

From a stepladder in the basement, reach over the sill and up into the outside wall. If you can reach beyond floor level, you have a balloon frame. If so, fill plastic grocery bags with fiberglass batt, tie the handles together, and stuff the bags up into the stud spaces from below. The bags will stop the air flow.



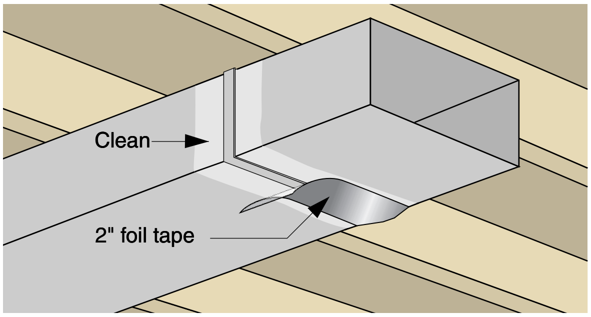


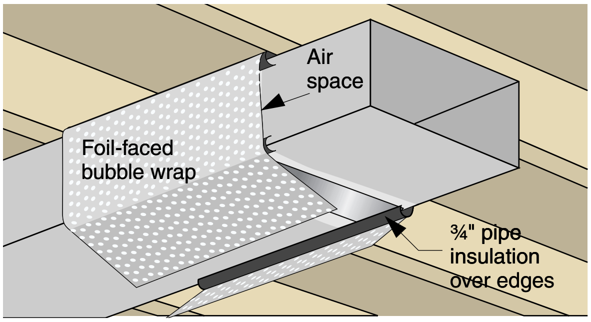
Ducts in Unconditioned Spaces

Wherever a duct runs outside of your home's thermal envelope (in the attic, crawl space, unheated garage, etc.), any air leak is also an energy loss.

Where you can reach a duct, sealing its seams is quite simple. First, clean the seam or joint with glass cleaner and paper towels, then tape the seam with 2-in.-wide UL-181-approved foil tape. Why not duct tape? Because fabric-based duct tape deteriorates quickly when heated, whereas foil-faced tape will last for many years.

While you are at it, insulate the ducts. Purchase R-8 fiberglass "duct wrap" or wrap foil-faced bubble wrap around the ducts, using pieces of slit foam pipe insulation at the edges to create insulating ¾-in. air spaces. Tape the joints between the wraps with clear packing tape, available at any office supply store.





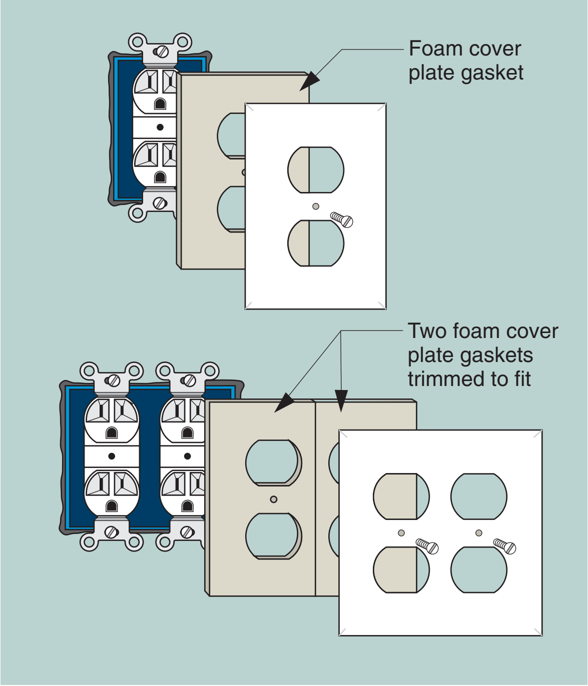
Interior Air Leaks

Receptacles and Switches

According to the air-leak field guide on pp. 470–471, a receptacle or switch plate equates to 0.2 sq. in. of leak. That's a pretty small hole, so why bother? Do you have any idea how many receptacles your home has? The average new home contains 80 receptacles, and 80 × 0.2 sq. in. = 16 sq. in.

Sealing the leaks could not be simpler. Hardware stores and home centers sell packages of foam gaskets to be installed under the cover plates, Simply remove the cover plate screw(s) and plate, fit the foam gasket over the receptacle or switch, and replace the plate. Where there are multiple receptacles or switches, trim additional gaskets to fit without overlapping.

Make sure you or your screwdriver doesn't contact anything inside the box. Those are live wires back there. To play it safe, turn off the circuit breaker serving the circuit you are working on.

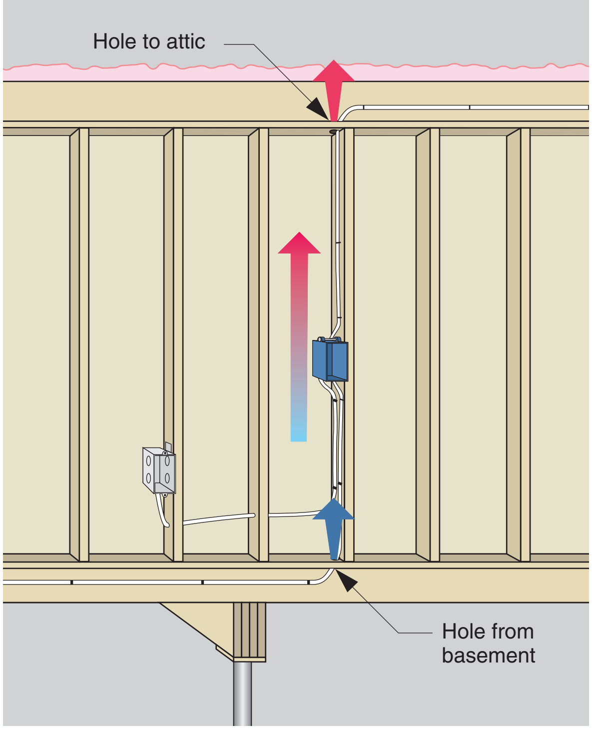


Interior-Wall Electrical Boxes

OK, you have gasketed all of the receptacles and switches located on the outside walls. Why do the same for those located on interior walls? After all, those are all inside the thermal envelope, so a leak is not a loss, right?

Wrong, or at least not necessarily. Study the illustration at right. Suppose you are Mickey Mouse®, living in the basement, and you wish to visit Minnie Mouse®, residing in the attic. You find an electrical cable disappearing up through the basement ceiling. Following it through the oversized hole you find it runs up inside a wall to a switch box. Another wire exits the top of the switch box and disappears into the top plate of the wall.

You follow the wire again, and, voila! you are in the attic. The moral of the story: you never know where those wires will end up.

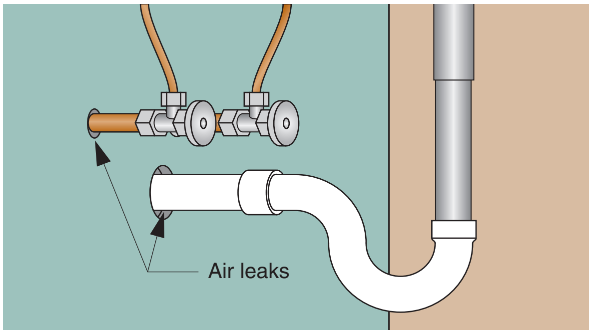


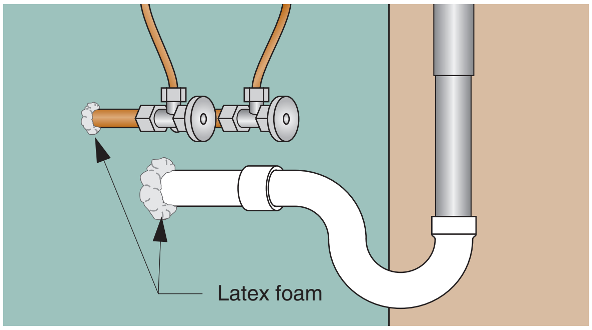
Pipes through Walls

As with wires in walls, without x-ray vision we have no idea where supply and drain pipes lead. We do know, however, that they ultimately run downhill to the basement. We also know that they are somehow vented through the roof. Those shiny little rings (escutcheons) plumbers place over the pipes where they disappear into a wall or floor? Those are to conceal the oversized hole the plumber drilled.

Where are these pipes found? Almost always beneath kitchen and bath sinks. Look inside the kitchen sink cabinet and inside all bathroom vanities.

Sealing a leak couldn't be simpler. If there is an escutcheon, slide it back or remove it, then fill the gap between pipe and wall or floor with easily cleaned up latex foam, and replace the escutcheon.

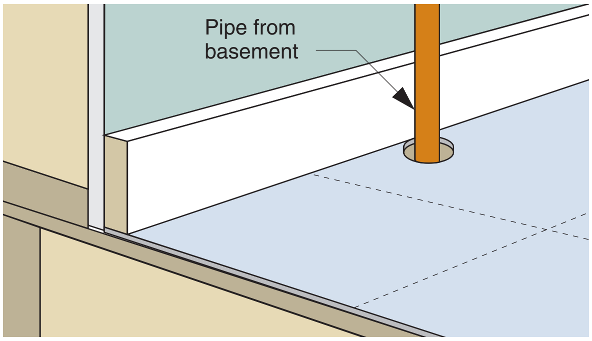


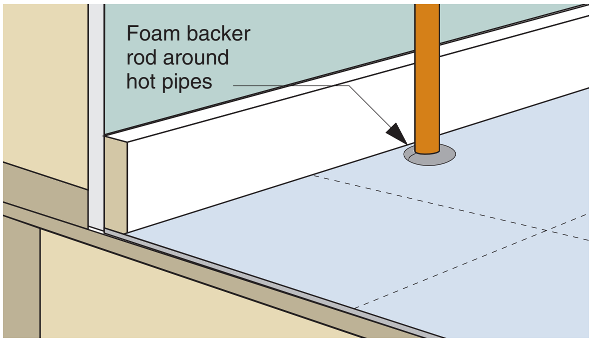


Pipes through Floors

Hot water baseboards and radiators are served by pipes from the basement. In very old houses, running water was added later, and the hot and cold supply pipes will be found exposed in the corner of a room or hiding in a closet. Regardless of when they were installed, the holes through which they run are oversized, creating large air leaks.

Here, relative motion is more likely, and the pipes serving baseboards and radiators are likely to become very hot. Latex foam is friable and breaks down with high heat. Therefore, seal the leaks by wrapping short lengths of foam backer rod around the pipes and stuffing them down into the hole. If you can't find backer rod, cut inch-long sections of foam pipe insulation, place it over the pipe, and force it down into the gap.

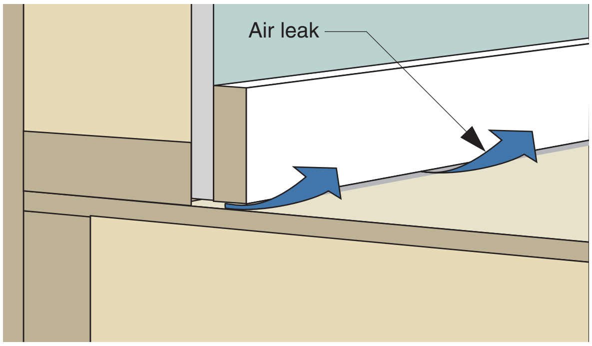


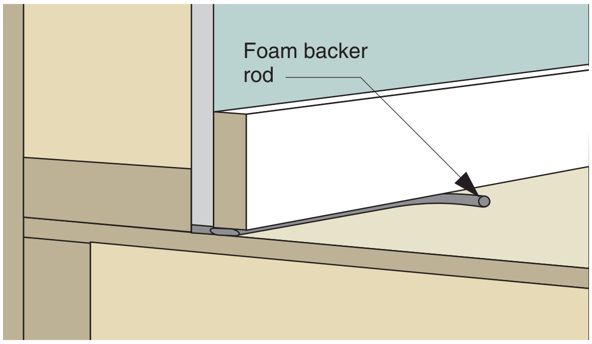


Exterior-Wall Baseboards

Wood shrinks when it dries. Framing and finish lumber dries after a house is occupied, resulting in myriad small cracks and joints in and between the walls and floors. Picture a 1⁄16-in. crack between the baseboard and floor. For a typical 24-ft. by 40-ft. house with two floors (1,920 sq. ft. of floor area), the length of baseboard along the outside walls is 256 ft. or 3,072 in. The area of the 1⁄16-in. gap would be 3,072 in. × 1⁄16 in. = 192 sq. in. You can see that the effective leakage area of 27 sq. in. listed in the Field Guide on pp. 470–471 might actually be conservative.

Caulking 256 ft. of baseboard would be, at the least, messy. A better solution is stuffing ¼-in.-diameter foam backer rod (it is compressible) into the cracks with a putty knife wherever possible. Don't worry about the putty knife damaging the foam. It will be out of sight but still effective.



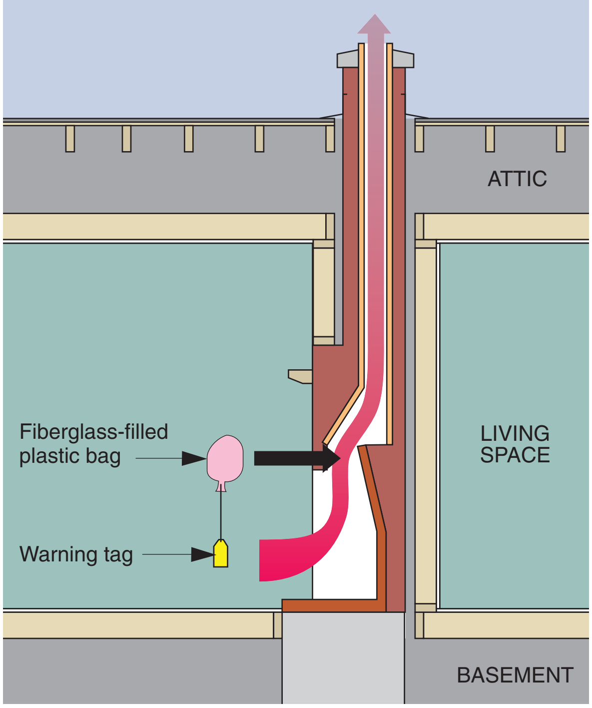


Fireplaces

Fireplaces work because hot air rises. Unfortunately, this "stack effect" continues all winter, even in the absence of a fire. The Field Guide indicates 54 sq. in. of leakage with the fireplace damper open. Is your damper open? Does your fireplace even have a damper?

To determine the status of your fireplace and damper it is not necessary to lie with your head in the fireplace. Just activate the flash on your digital camera, reach in, point the camera up, and take a picture. The photo will clearly show the condition of both the damper and the chimney flue.

Unless the damper closes tightly, open it up and stuff the fireplace throat with fiberglass-filled plastic grocery bags. To avoid an unpleasant surprise the next time someone builds a fire, hang a conspicuous warning tag down into the fireplace opening!



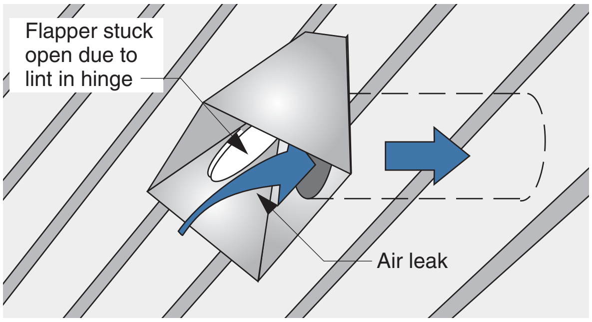
Exterior Air Leaks

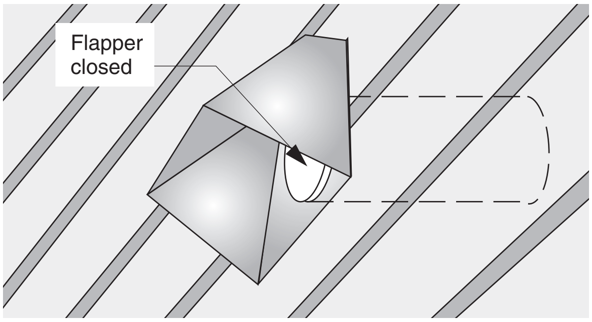
Clothes Dryer Vents

Do you wonder why the inside of your clothes dryer is as cold as a refrigerator in winter? The lint filter in the dryer catches most, but not all, of the tiny lint fibers in the exhaust. When the humid, lint-carrying exhaust air hits the vent housing outdoors, some of the moisture condenses and deposits lint on the housing, the flap, and the tiny springs whose purpose is to keep the flap closed. After six months the lint buildup is so great that the flap is jammed open permanently.

The solution is to clean the housing and springs with an old toothbrush until the flapper operates easily. Post a reminder note on the dryer to clean the flapper after Labor Day every year. If you notice the dryer suddenly becoming frigid, it's time to get out the old toothbrush again!

Why not just vent the dryer into the basement? Don't do it—unless you like mold!

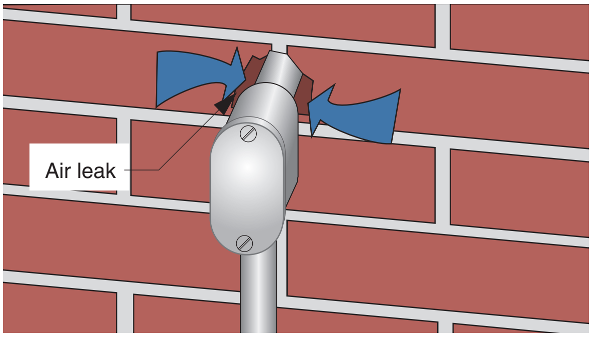


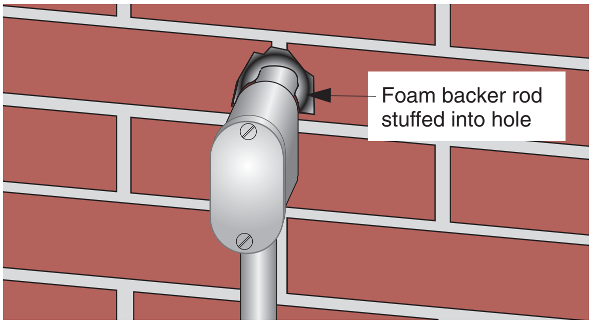


Wiring Penetrations

Especially when electrical wiring, telephone service, or television cable is added to a home, the hole the installer drills in the foundation or wall is likely to be larger than required in order to make pulling the cable through easier. This is especially true when the hole is drilled in brick or concrete.

Latex foam turns to powder when exposed to sunlight, and polyurethane is "blobby" and turns an unsightly yellow. A better solution is to stuff the gap between cable and wall with foam backer rod. If the hole is really big, fill it with backer rod to within ¼-in. of the surface, then fill the remaining space with acrylic latex or silicone caulk.





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Floors, Walls, and Ceilings

Floors, walls, and ceilings are the surfaces we live with. It's important to select the best material and to install it properly to achieve long-term performance.

This chapter starts at the bottom. *Hardwood flooring* is a hallmark of a quality home. You can buy unfinished or prefinished hardwood flooring in three styles: strip, plank, and parquet. This section shows you interesting parquet patterns, how to estimate coverage, and how to install wood flooring over concrete or wood subfloor. A new kid on the block, *floating engineered wood flooring*, promises to replace most of the classic wood flooring products.

Resilient flooring is the most common choice for wet floors in the kitchen and bath. The other choice for wet areas is *ceramic tile*. Using proper *tile-setting materials* ensures long-lasting applications. Our tables of *standard tile sizes* and comprehensive illustration of common *tile patterns* allows preplanning of room layouts.

Installing *gypsum wallboard* is one of the most popular of all homeowner projects. In this section you'll find the variety of wallboards, how to estimate all of the materials needed to finish a room, and techniques from a professional manual.

A section on solid *wood paneling* shows the patterns commonly available, how to estimate quantities, and installation.

Suspended ceilings are inexpensive solutions for hiding basement pipes and wire, or lowering high ceilings. Provided are step-by-step procedures for installing this engineered system.

Our nearly complete collection of standard *wood moldings*, along with suggestions for *built-up wood moldings*, will help you create a truly finished interior.

Hardwood Flooring

Hardwood flooring is available in three styles: strip, plank, and parquet.

Strip Flooring

Strip flooring is tongue-and-grooved on all four edges, making for a very secure installation without visible nails. Lengths vary by grade. The table below shows the standard cross-sectional sizes (thickness × width) and the board feet to order to cover a specified floor area. The table assumes a 5% cutting-waste factor.

Plank Flooring

Plank flooring is the same as strip flooring, except widths range from 3 to 8 inches. Because of its greater width, plank flooring is subject to more swelling and shrinkage with change in humidity. Standard planks should be installed with a gap the thickness of a putty knife. Laminated plank is also available in three-ply construction. Since plank flooring is sold by the square footage of its face dimensions, simply multiply the floor area by 1.05 to allow for waste.

Estimating Hardwood Strip Flooring (board feet, assuming 5% waste)

Floor Area, square feet	Cross-Sectional Size, inches						
	3/4 × 1 1/2	3/4 × 2 1/4	3/4 × 3 1/4	1/2 × 1 1/2	1/2 × 2	3/8 × 1 1/2	3/8 × 2
5	8	7	6	7	7	7	7
10	16	14	13	14	13	14	13
20	31	28	26	28	26	28	26
30	47	42	39	42	39	42	39
40	62	55	52	55	52	55	52
50	78	69	65	69	65	69	65
60	93	83	77	83	78	83	78
70	109	97	90	97	91	97	91
80	124	111	103	111	104	111	104
90	140	125	116	125	117	125	117
100	155	138	129	138	130	138	130
200	310	277	258	277	260	277	260
300	465	415	387	415	390	415	390
400	620	553	516	553	520	553	520
500	775	691	645	691	650	691	650

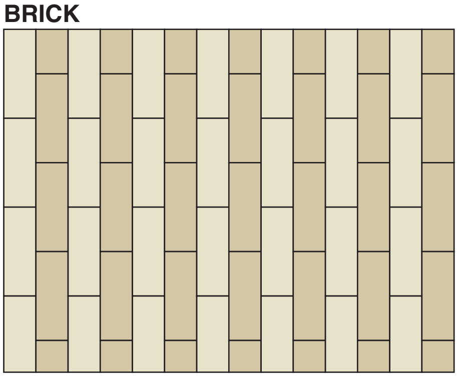
Parquet Flooring

Parquet flooring consists of either slats (precisely milled short strips) or blocks (strips preassembled into square units). Slats are usually square edged. Blocks may be square edged or, more commonly, tongue-and-grooved on all four sides. Most blocks are $^{5}/_{16}$-inch thick.

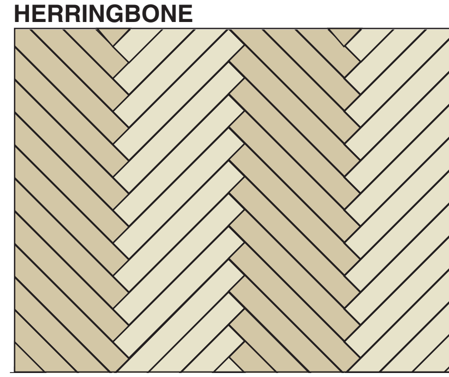
Face dimensions vary with manufacturer but are usually 6×6, 8×8, 9×9, 10×10, or 12×12 inches. The illustration below shows a few of the dozens of parquet patterns that can be either purchased as blocks or assembled from strips.

Parquet Patterns

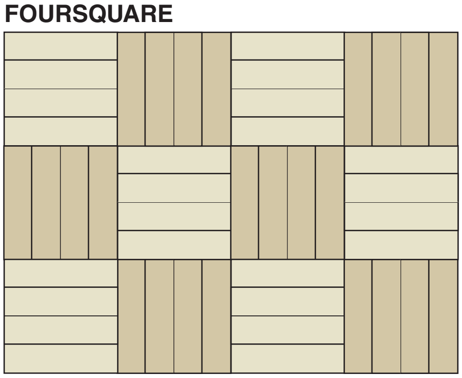
BRICK



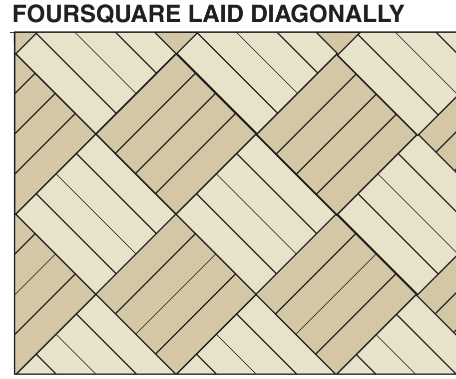
HERRINGBONE



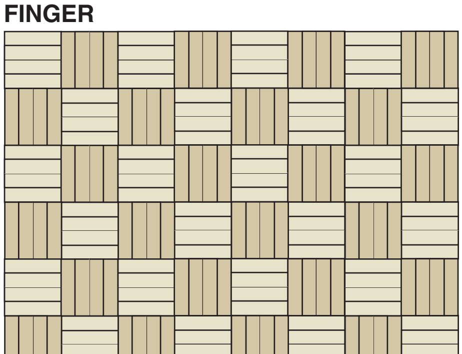
FOURSQUARE



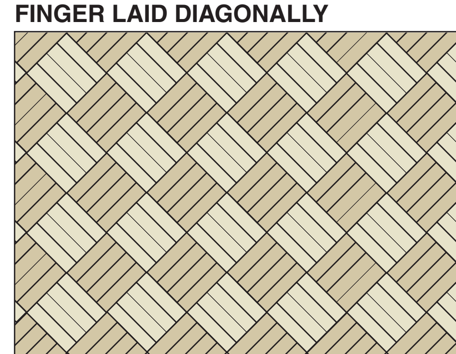
FOURSQUARE LAID DIAGONALLY



FINGER



FINGER LAID DIAGONALLY



Strip Flooring Installation

Solid wood flooring is subject to dimensional change when its moisture content changes. Make sure the flooring never gets wet, is stored in a dry location, and is allowed to equilibrate for at least five days at the installation site.

When flooring is installed over a concrete slab with plywood subfloor (top illustration at right), the slab must be dry and must not be located below grade. Tape a 1-square-foot piece of clear polyethylene to the slab for 24 hours; if no condensation appears, the slab is dry.

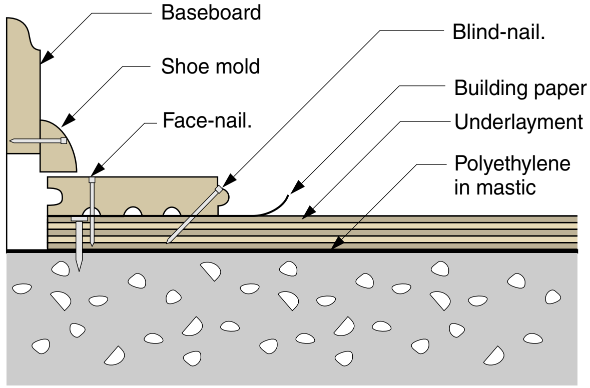
Apply cold cut-back asphalt mastic with a fine-tooth, 100-square-foot-per-gallon trowel. After it dries $1^1/_2$ hours minimum, unroll 6-mil polyethylene over the entire area with 6-inch overlaps. Walk on the entire surface to make sure the mastic makes contact. (Small bubbles may be punctured.)

Nail $^3/_4$-inch sheathing or underlayment-grade plywood to the slab, leaving $^3/_4$-inch spaces at walls and $^1/_4$ inch between panels. Nail or cement finish flooring to the plywood per manufacturer's instructions.

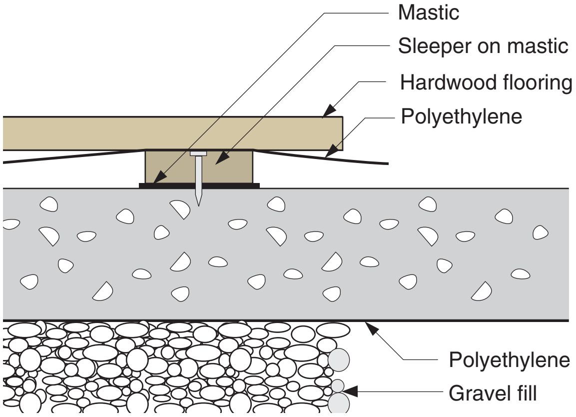
Strip flooring may also be installed over a slab and wood sleepers. Lay pressure-treated 18- to 48-inch random-cut 2×4 sleepers 12 inches on-center in asphalt mastic (enough for 100% contact). Stagger and overlap the sleepers at least 4 inches. Leave $^3/_4$ inch at walls. Cover with polyethylene, lapping joints at sleepers.

With conventional wood joist construction over a basement or crawl space, either outside cross ventilation must be provided or the crawl space must be unvented and supplied with conditioned air (see pp. 452-455). In either case, the crawl-space earth must be covered with polyethylene. The subfloor should be either $^5/_8$-inch or thicker performance-rated exterior or underlayment plywood or $^3/_4$-inch square-edge, group I dense softwood boards laid diagonally on joists with $^1/_4$-inch spaces. Plywood must be laid with the face veneer across joists.

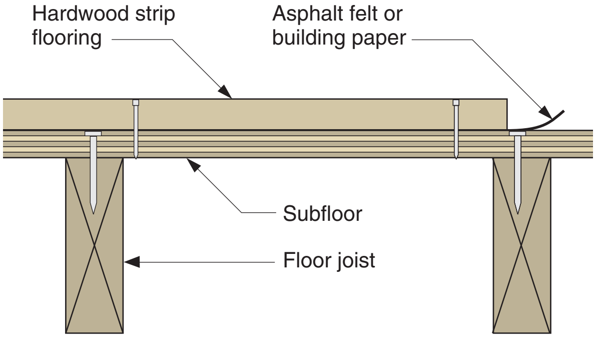
Slab with Plywood Subfloor



Slab with Wood Sleepers



Over Crawl Space



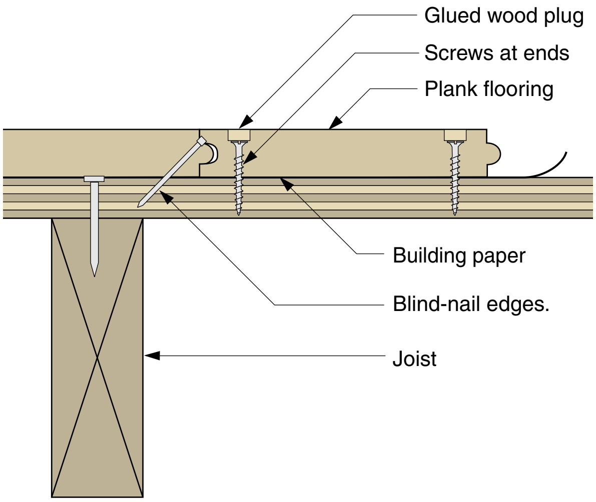
Plank Flooring Installation

Sealing the backs of planks >4 inches wide is recommended to minimize cupping with moisture changes.

Random-width planks are installed in the same way as strip flooring, except for a combination of edge nails and countersunk and plugged face screws, as shown in the illustration at right. The general practice is to blind-nail through the tongue as with conventional strip flooring. Pairs of flat-head or drywall screws at the ends of the planks hold the ends securely and are aesthetically pleasing. The countersunk screws are then covered with wood plugs glued into the holes.

Use 1-inch screws for flooring laid over $^3/_4$-inch plywood on a slab. Use 1- to $1^1/_4$-inch screws for planks over screeds or wood joists. Some manufacturers recommend leaving an expansion crack the thickness of a putty knife. between planks.

Fasteners for Plank Flooring



Nailing Schedule

Flooring	Fasteners	Spacing
¾″ THICK T&G		
$1^1/_2$″, $2^1/_4$″, $3^1/_4$″ strip	2″ barbed flooring cleat 7d or 8d flooring nail 7d or 8d casing nail 2″ 15-ga. staples with $^1/_2$″ crowns	8″–12″
4″–8″ plank	2″ barbed flooring cleat 7d or 8d flooring nail 2″ 15-ga. staples with $^1/_2$″ crowns	8″
½″ THICK T&G		
$1^1/_2$″, 2″ wide	$1^1/_2$″ barbed flooring cleat 5d screw Cut steel or wire casing nail	10″
⅜″ THICK T&G		
$1^1/_2$″, 2″ wide	$1^1/_4$″ barbed flooring cleat 4d bright wire casing nail	8″
5/16″ THICK SQUARE EDGE		
$1^1/_2$″, 2″ wide	1″ 15 ga. fully barbed flooring brad	2 nails every 7″
$1^1/_3$″ wide	1″ 15 ga. barbed flooring brad	1 nail every 5″ on alternate sides

1. T&G flooring blind-nailed on tongue edge.
2. Face nailing required on starting and ending strips.
3. Hard species may require predrilling to avoid splits.
4. Always follow manufacturer's specific fastening instructions.

Floating Engineered Wood Flooring

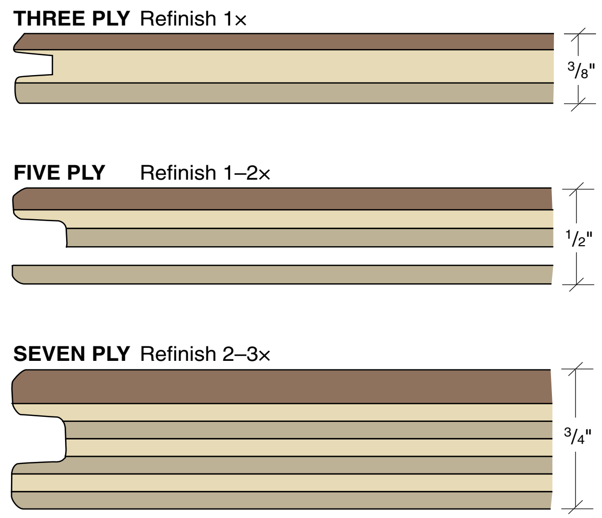
Engineered wood products—plywood and oriented strand board—have nearly totally replaced boards as sheathings. The same transformation is taking place with hardwood flooring. Long considered the gold standard in flooring, hardwood strip and parquet flooring is beautiful and durable but suffers swelling and shrinkage with moisture changes. Laminating a quality hardwood surface veneer to a plywood base yields a moisture-impervious flooring with the beauty of hardwood. In addition, its thick (up to five coats) factory-applied finish is far more durable than any finish you can apply on site.

Its single drawback depends on the level of abuse: sand, foot traffic, children, and dogs. The relatively thin top veneer can be refinished but a few times (see illustration at right). You get what you pay for. If your floor gets hard use, spend the extra money up front to avoid total replacement down the road.

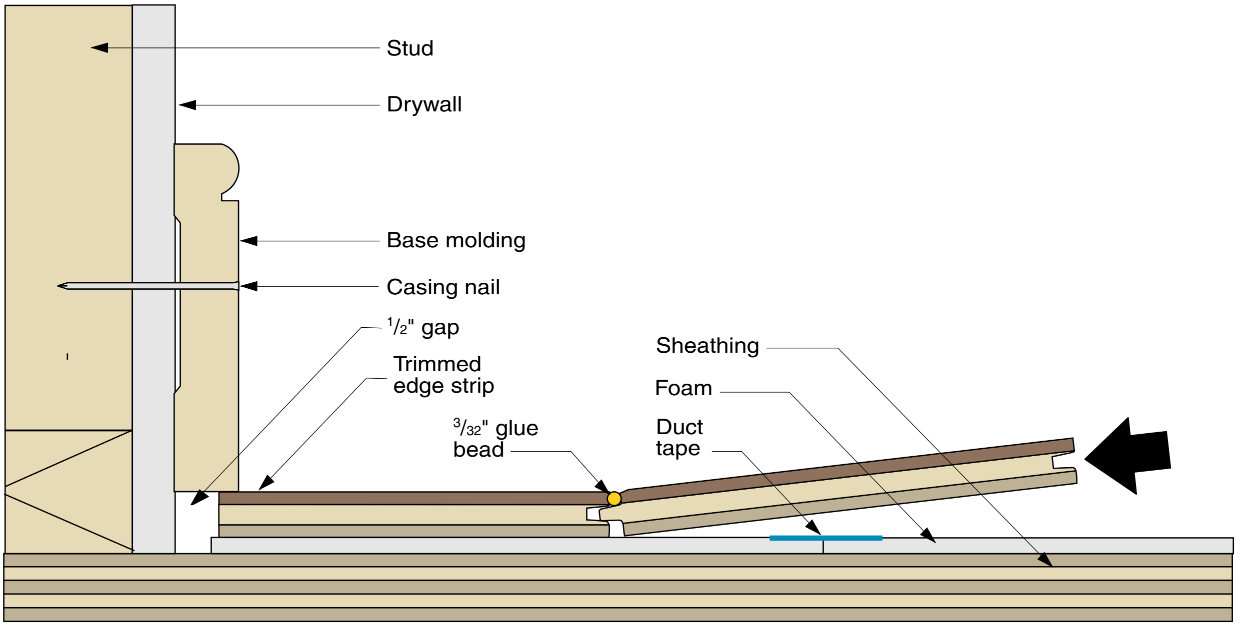
The Floating Floor

Dimensional stability, uniform structure, interlocking joints, and glued edges result in a room-sized assemblage that behaves like a single oversized panel. Installed over a water- and vapor-resistant foam-plastic underlayment, the unattached flooring literally floats over any type of underlayment or existing floor. An additional benefit of the foam underlayment and total absence of rigid fastening to the sheathing and framing below is sound isolation.

Floating Flooring Installation



Floating Flooring Installation Details



Resilient Flooring

Resilient Flooring

No-wax cushion vinyl has eliminated all competition in the resilient-flooring market. Available as 12-foot-wide rolls and as 9×9- and 12×12-inch tiles, cushion vinyl consists of a shiny (no-wax) clear vinyl coating, colored vinyl substrate, high-density vinyl foam, and a felt back. The roll material may be loose-laid, with double-sided tape or joint adhesive only at seams, or it may be fully glued down. Tiles are meant to be glued down. Some are self-sticking; others are applied over vinyl adhesive.

The primary measure of quality and longevity is the thickness of the clear no-wax wear layer. When the wear layer is worn through, the flooring has to be replaced or periodically treated with a vinyl dressing or wax.

All resilient flooring must be applied over a solid, smooth base. If the base is not smooth, the reflective vinyl will appear wavy. If the base is not solid (plywood with a missing knot, for example), women's heels or other heavily loaded objects may punch through.

The table at right describes adequate bases for resilient flooring. However, plywood is recommended as the best underlayment by most resilient flooring manufacturers.

Plywood Underlayment

Underlayment grades of plywood have a solid, sanded surface and solid inner plies for resistance to indentation and punctures from concentrated loads. APA underlayment-rated plywood is also dimensionally stable and eliminates swelling, buckling, and humps around nails. Where floors may be subject to moisture, use panels with an Exterior exposure rating. Ordinary sanded plywood grades such as A-C or B-C Exterior, and C-D Plugged Exposure 1 plywood are not adequate substitutes for Underlayment grade, since they do not ensure equivalent resistance to indentation or puncture.

The thickness of plywood underlayment required over uneven floors depends on floor roughness and expected loads: usually a minimum thickness of $^{11}/_{32}$-inch, although $^{1}/_{4}$-inch is acceptable for underlayment over smooth subfloors, especially in remodeling work. Thicker plywood underlayment, which is stiffer and more dimensionally stable, is recommended for large floor areas where sidelighting across long expanses of flooring tends to highlight any floor surface irregularities.

Plywood underlayment also provides a smooth surface for installation of adhered carpet flooring.

Concentrated loads from wheel traffic may cause deterioration of the plywood underlayment face beneath resilient floor covering. For such applications, smooth, tempered hardboard underlayment may be more appropriate.

Bases for Resilient Flooring

Existing Floor	Cover or Repairs
Plywood subfloor, not rated as underlayment	Hardboard or plywood underlayment
Plywood rated as underlayment	None needed
OSB rated as underlayment	None needed
Single-layer board subfloor	Plywood underlayment, $^{5}/_{8}$″ minimum
Subfloor plus finish floor of strips less than 3″ wide	Replace damaged strips; renail loose spots; sand smooth
Subfloor plus finish floor of strips more than 3″ wide	Hardboard or plywood underlayment
Concrete	None needed, but clean thoroughly by degreasing and wire brushing

Ceramic Tile

Tile Varieties

The word *tile* generally means any hard-wearing material used to cover floors, walls, and roofs. In building we are most interested in six categories of tile intended to cover floors and walls

Glazed Wall Tile is intended for decorative interior applications. The most popular size is 4 1/2 by 4 1/2 inches, but many other rectangular, hexagonal, and octagonal sizes are available.

Mosaic Tile is premounted and spaced on a fabric backing. All mosaics come with 1/16-inch joints.

Paver Tile is formed by compressing clay dust. Most pavers are rectangular, but hexagons and Spanish patterns are also available.

Floor Tile (Porcelain) is made of highly refined clay and fired at extreme temperatures, resulting in a floor surface that wears well and is water- and frost-resistant.

Quarry Tile is an extremely hard, wear-resistant, unglazed, moderately priced tile that is ideal for floors.

Natural Stone, usually cut to standard sizes, is also used as a flooring tile. Granite, marble, and slate are the most popular, with the granite and marble usually polished to a mirror finish.

Floor Tile Ratings

Floor tiles, unlike wall tiles, are subject to wear and freezing, and must not be slippery under foot. The most important ratings to consider are:

Coefficient of Friction (ASTM C 1028) tells how slippery the tile is when dry and when wet. It is thus vital when trying to avoid slip and fall injuries. The American Disabilities Act (ADA) requires ratings of ≥0.6 for level floors and ≥0.8 for ramps.

Water Absorption (ASTM C 373) tells the maximum amount of water the tile can absorb as a percentage by weight. It is important if exposed to freeze-thaw cycles. *Non-vitreous* absorbs >7% water, *semi-vitreous* absorbs 3%-7% water, *vitreous* absorbs 0.5%-3% water, and *impervious* absorbs <0.5% water.

Abrasive Hardness (ASTM C 501) measures the resistance to abrasion of the tile surface. The higher the number, the harder the tiles surface:

1. walls only
2. low-traffic residential
3. residential and medium interior commercial
4. heavy interior commercial
5. extra-heavy interior or exterior commercial

Modular Ceramic Tile Sizes

Type	Thickness	Shape	Dimensions, inches
Glazed Wall	5/16	Rectangular	3×6, 4 1/4×4 1/4, 6×4 1/4, 6×6, 6×8, 8×10
Mosaic	1/4	Rectangular	1×1, 1×2, 2×2
	1/4	Hexagonal	1×1, 2×2
Paver	3/8	Rectangular	4×4, 4×8, 6×6
	1/2	Rectangular	4×4, 4×8, 6×6
Floor	3/8	Rectangular	6×6, 6×12, 12×12, 13×13, 16×16
Quarry	1/2	Rectangular	3×3, 3×6, 4×4, 4×8, 6×6, 8×8
	3/4	Rectangular	4×8, 6×6

Tile-Setting Materials

Cement Backerboard

Other than concrete, the best base for setting tiles is cement backerboard, a fiberglass-reinforced cement panel that is rigid and water-resistant. It comes in panel sizes of 3×5 feet, 4×4 feet, and 4×8 feet and thicknesses of $^1/_4$ and $^1/_2$ inches.

Fasten the backerboard in place using $1^1/_4$-inch ($1^1/_2$-inch for $^1/_2$-inch board) No. 8-18 × $^3/_8$-inch galvanized, waferhead, self-countersinking screws.

Mortars and Adhesives

A wide variety of materials is available for setting tiles. The choice of material depends on the application (wet or dry, freezing or not) and the skill level of the tile setter.

Organic mastics are used exclusively for wall tiles up to 6 by 6 inches that are not subject to loads. They are convenient in that they are supplied premixed in a can.

Thin-set mortars consist of premixed sand and portland cement. A latex additive improves bonding, water resistance, and flexibility. The latex version is recommended over all wood substrates.

Grout

Grout (for filling the joints between tiles) may be identical to the tile-setting material, except that organic mastic may be used only for setting tile. More commonly the grout is of finer consistency and contains dye to match or complement the color(s) of the tile. Latex grout, like latex-additive mortar, improves flexibility and water resistance.

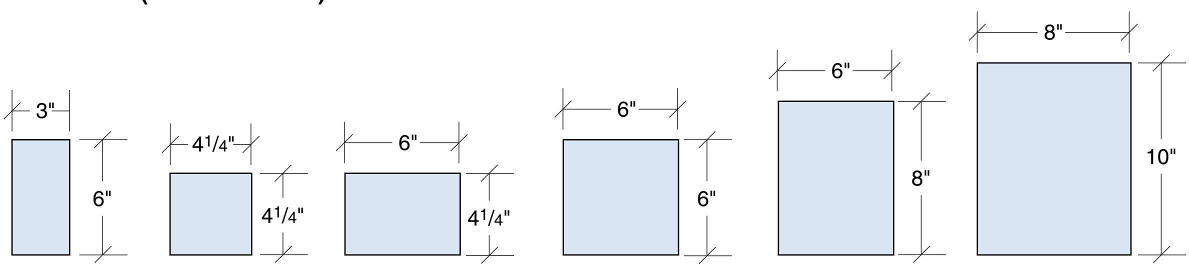
Tile-Setting Materials

Material	Form	Bed, inches	Advantages	Disadvantages
Organic adhesive	Ready-set mastic	$^1/_{16}$	Easy application Low cost Flexible bond	Interior only Immersion resistance
Epoxy mortar	2 or 3 parts mixed on site	$^1/_{16}$–$^1/_8$	Excellent resistance to water and chemicals Very strong bond	Limited working time Difficult application
Thin-set mortar	Dry mix of portland cement, sand, and latex	$^1/_4$	Immersion resistance Freeze resistance	Must be kept moist for 3 days before grouting
Portland cement mortar	Portland cement, sand, and water mixed on site	$^3/_4$ (walls) $1^1/_4$ (floors)	Allowance for slight leveling of uneven surfaces	Presoaking of tiles required; metal lath reinforcement recommended

Standard Tile Sizes

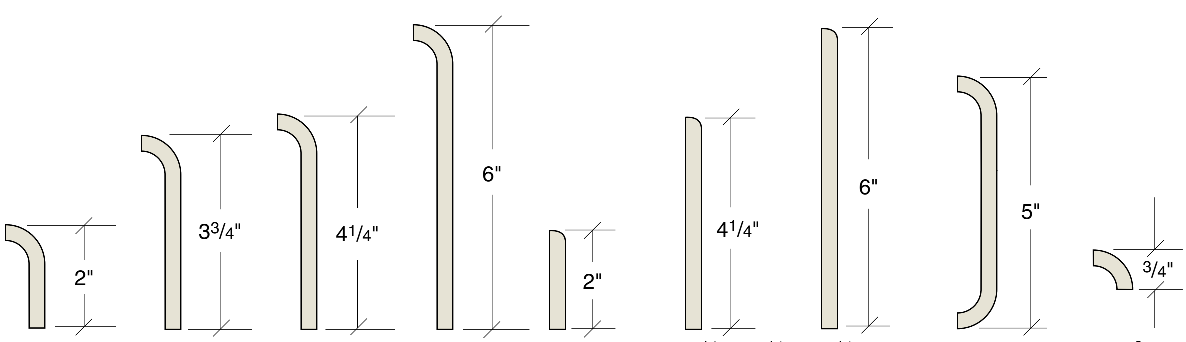
Wall Tile

FIELD TILE (thickness 5/16")

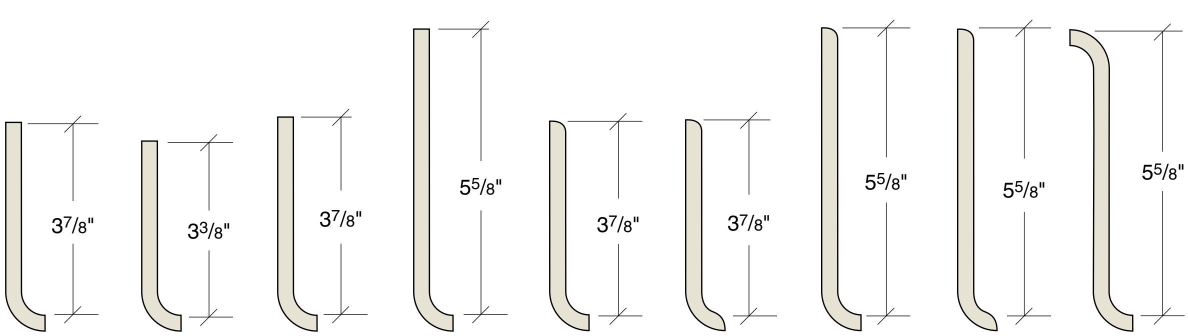


3" x 6" field | 4 1/4" x 4 1/4" field | 6" x 4 1/4" field | 6" x 6" field | 6" x 8" field | 8" x 10" field

TRIM SECTIONS (thickness 5/16")



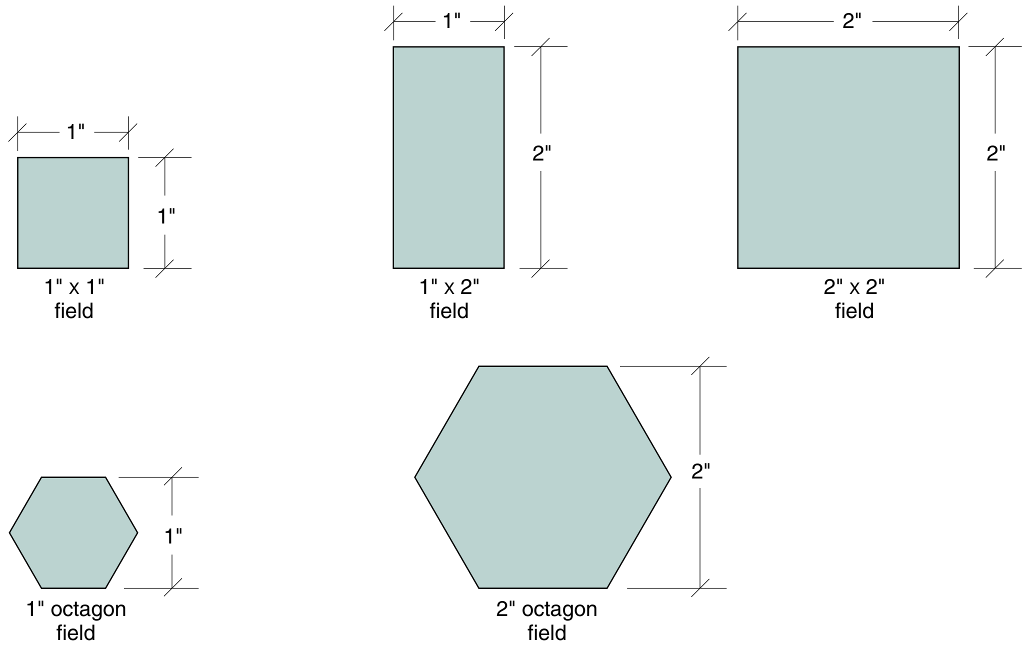
6" x 2" bullnose | 6" x 3 3/4" bullnose | 6" x 4 1/4" bullnose | 4 1/4" x 6" 6" x 6" bullnose | 6" x 2" surface bullnose | 4 1/4" x 4 1/4" 4 1/4" x 6" surface bullnose | 4 1/4" x 6" surface bullnose | 6" x 5" curb | 6" x 3/4" bead



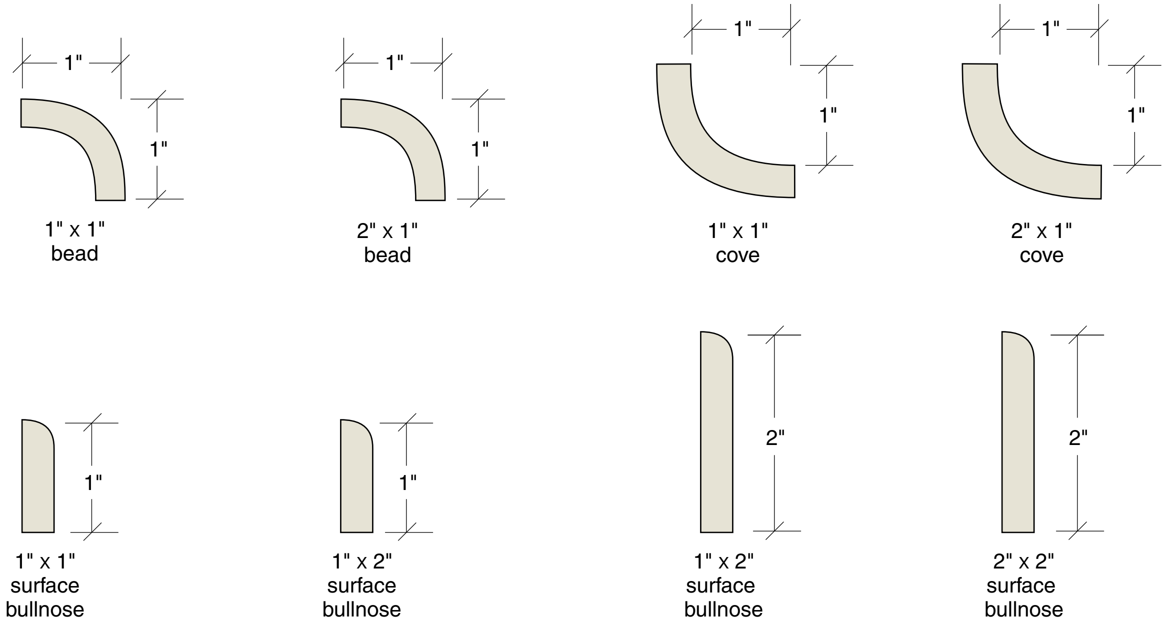
4 1/4" x 3 7/8" cove | 6" x 3 3/8" cove | 6" x 3 7/8" cove | 4 1/4" x 5 5/8" 6" x 5 5/8" cove | 6" x 3 7/8" base | 6" x 3 7/8" base | 6" x 5 5/8" base | 6" x 5 5/8" base | 6" x 5 5/8" base

Mosaic Tile

FIELD TILE (thickness 1/4")

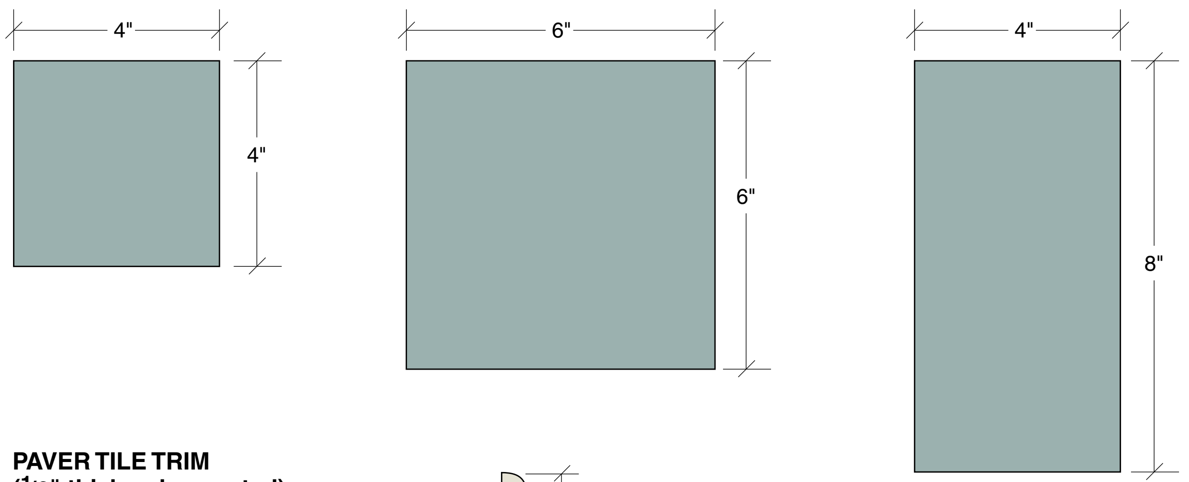


TRIM SECTIONS (thickness 1/4")

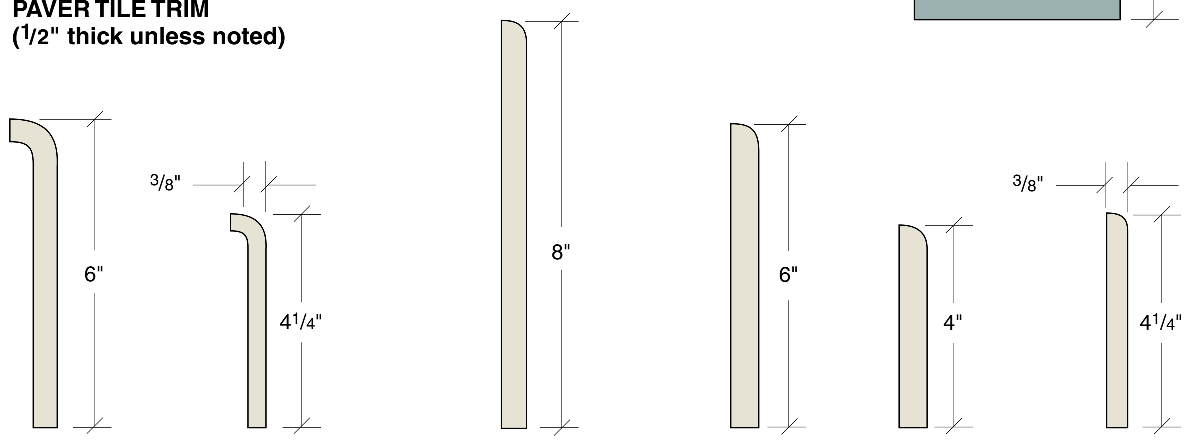


Paver Tile

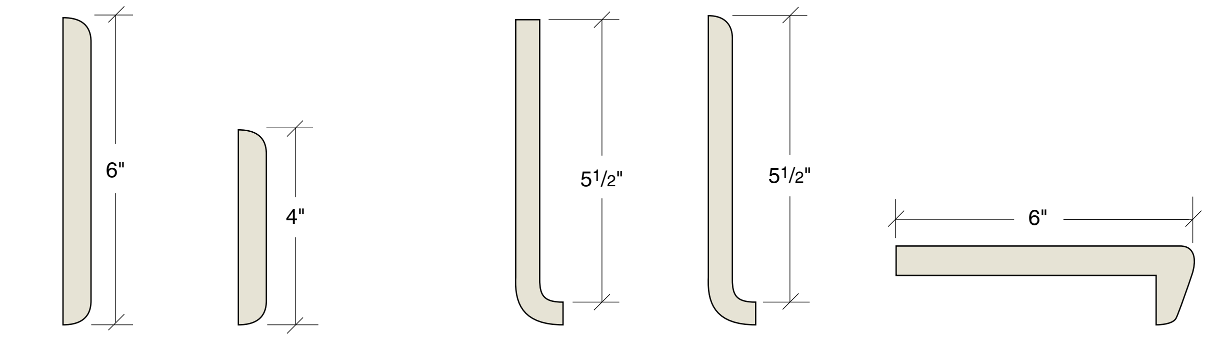
PAVER FIELD TILE
(both 1/2" and 3/8" thick)



PAVER TILE TRIM
(1/2" thick unless noted)



6" x 6" bullnose | 4 1/4" x 4 1/4" bullnose | 4" x 8" surface bullnose | 6" x 6" surface bullnose | 8" x 4" surface bullnose | 4 1/4" x 4 1/4" surface bullnose

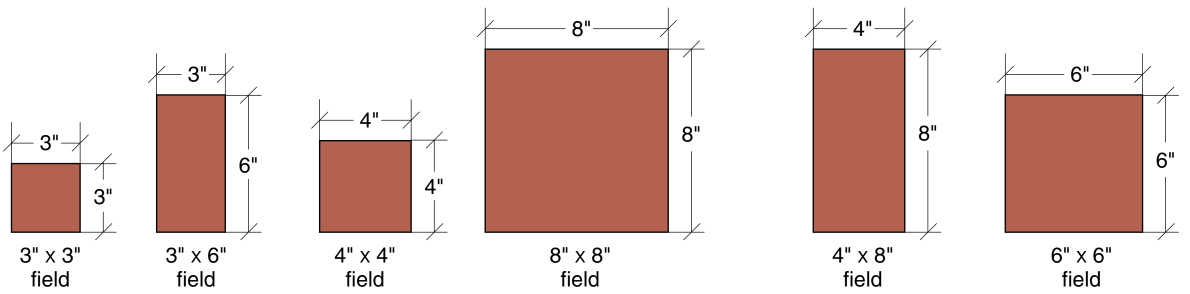


6" x 6" double bullnose | 8" x 4" double bullnose | 6" x 5 1/2" cove | 6" x 5 1/2" cove base | 6" x 6" window sill or step nosing

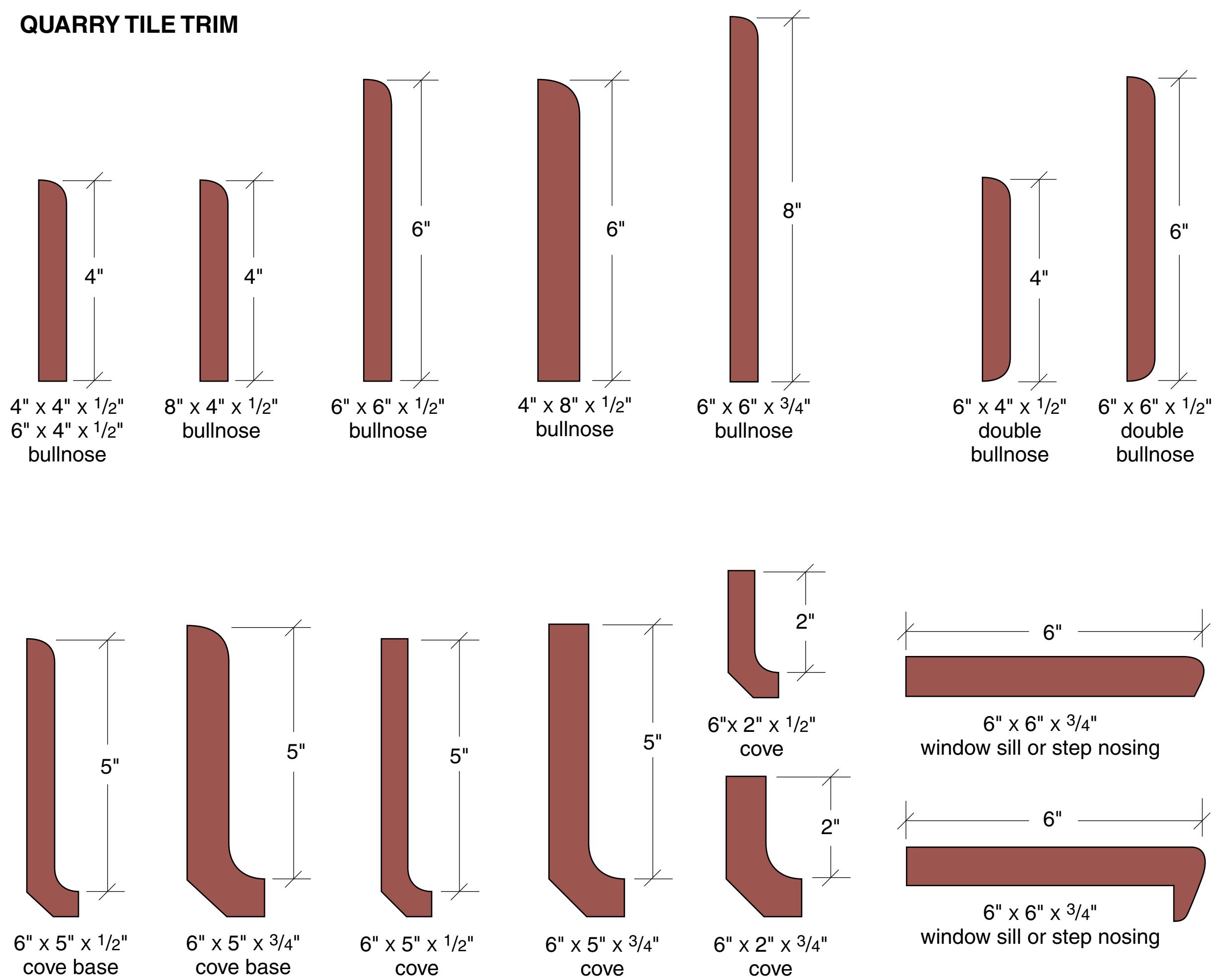
Quarry Tile

FIELD TILES (thickness 1/2")

FIELD TILES (thickness 1/2" & 3/4")

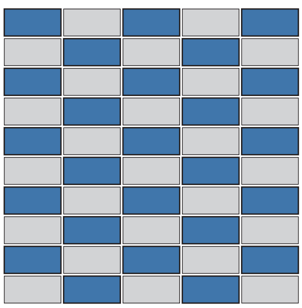


QUARRY TILE TRIM

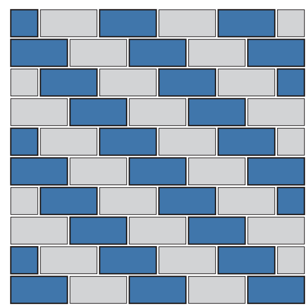


Tile Patterns

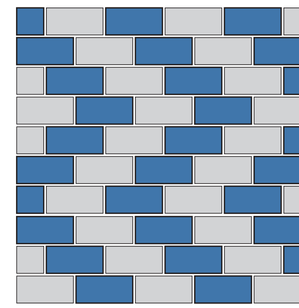
Tile Patterns



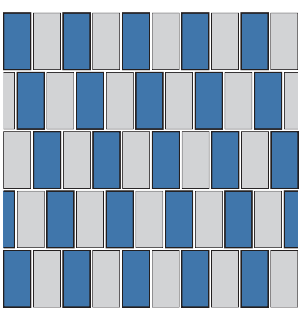
Dark rectangle 50%
Light rectangle 50%



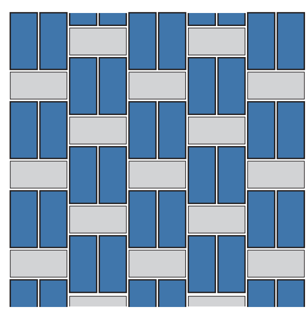
Dark rectangle 50%
Light rectangle 50%



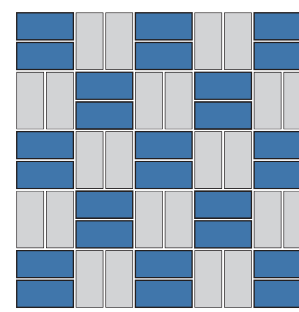
Dark rectangle 50%
Light rectangle 50%



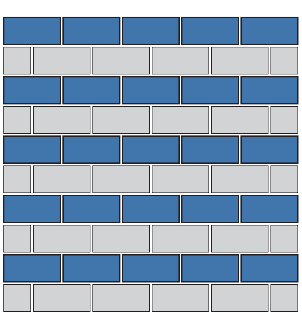
Dark rectangle 50%
Light rectangle 50%



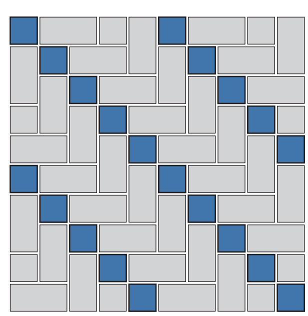
Dark rectangle 67%
Light rectangle 33%



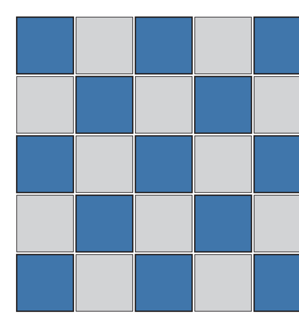
Dark rectangle 50%
Light rectangle 50%



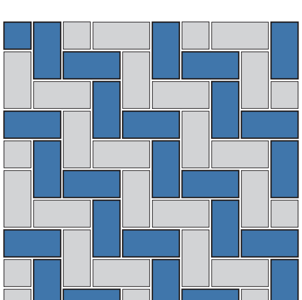
Dark rectangle 50%
Light rectangle 50%



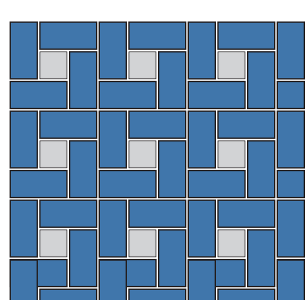
Dark square 20%
Light rectangle 80%



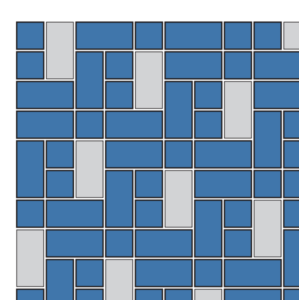
Dark square 50%
Light square 50%



Dark rectangle 50%
Light rectangle 50%

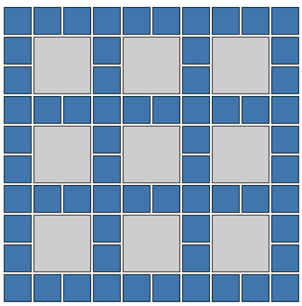


Dark rectangle 89%
Light square 11%

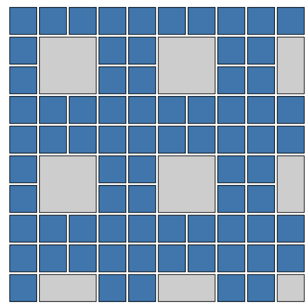


Dark rectangle 58% Square 25%
Light rectangle 17%

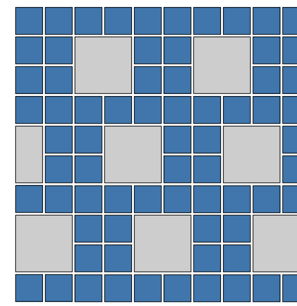
Tile Patterns—*Continued*



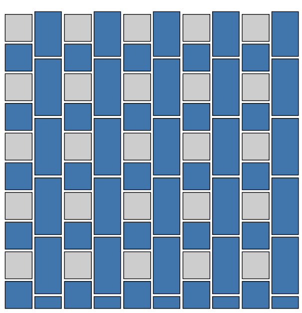
Dark square 56%
Light square 44%



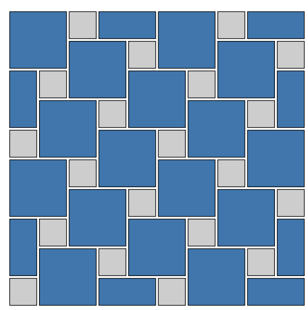
Dark square 75%
Light square 25%



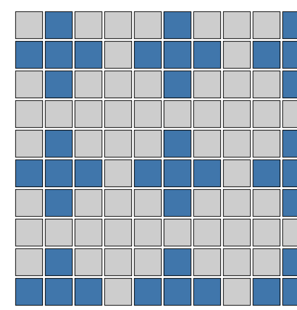
Dark square 67%
Light square 33%



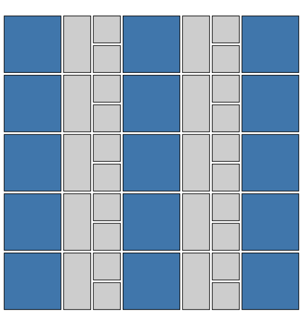
Dark square 25% Dark rectangle 50%
Light square 25%



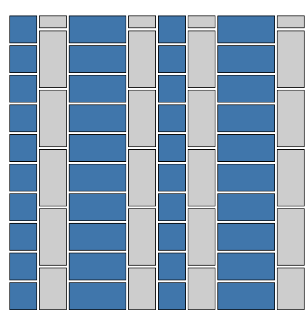
Dark square 80%
Light square 20%



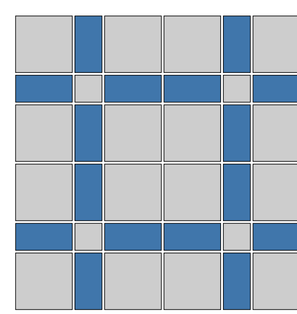
Dark square 31%
Light square 69%



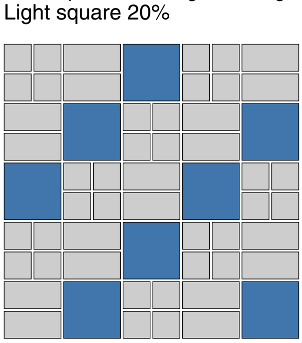
Dark square 60% Light rectangle 20%
Light square 20%



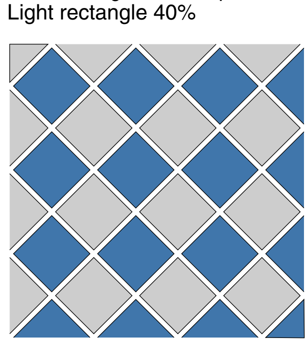
Dark rectangle 40% Square 20%
Light rectangle 40%



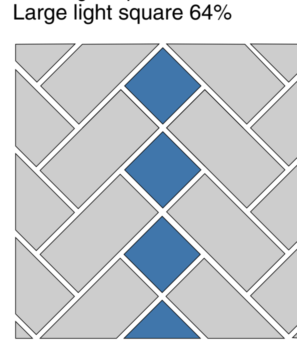
Small light square 4% Dark rectangle 32%
Large light square 64%



Small light square 32% Light rectangle 36%
Large dark square 32%



Dark square 50%
Light square 50%



Dark square 20%
Light rectangle 80%

Gypsum Wallboard

Gypsum Wallboard Types

Gypsum wallboard, due to its low cost, ease of application, ease of finishing, and superior fire and acoustic properties, is the most common wall material. The table below shows the readily available types and sizes of gypsum wallboard and their applications.

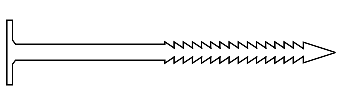
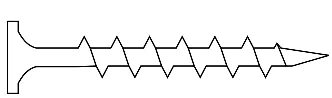
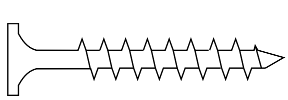
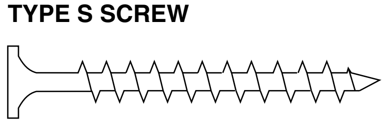
Gypsum Drywall Products

Type	Application	Edge Types	Thicknesses, inches	Lengths, feet
Regular	Usual wall and ceiling applications in dry locations where special fire rating not required	Tapered, square, rounded	¼ ⅜ ½ ⅝	6, 8, 10, 12
Foil-backed	Same as regular, but with aluminum foil back face suitable as vapor barrier	Tapered, rounded, square	⅜ ½ ⅝	6, 8, 10, 12, 14, 16
Water-resistant (type W)	Moist areas such as bathrooms; as base for ceramic tile	Tapered	½ ⅝	8, 11, 12
Fire-rated (type X)	Walls and ceilings with increased fire rating	Tapered, rounded, square	½ ⅝	6, 8, 10, 12, 14, 16

Fasteners

Various specialized fasteners have been developed specifically for gypsum drywall (see the table below). The appropriate type depends not on the type of drywall, but on the type of substrate being fastened to. The drywall screw has proven so technically superior in wood-to-wood applications, as well, that it is now available in lengths to 4 inches.

Fasteners for Gypsum Wallboard

Type	Common Length	Application	Base Penetration
 RING-SHANK NAIL	1¼″	Single layer of wallboard to wood framing or furring	¾″
 TYPE W SCREW	1¼″	Single layer of wallboard to wood framing or furring	⅝″
 TYPE S SCREW	1″	Single layer of wallboard to sheet metal suds and furring	⅜″
 TYPE G SCREW	1⅝″	Wallboard to gypsum wallboard or wood framing	½″

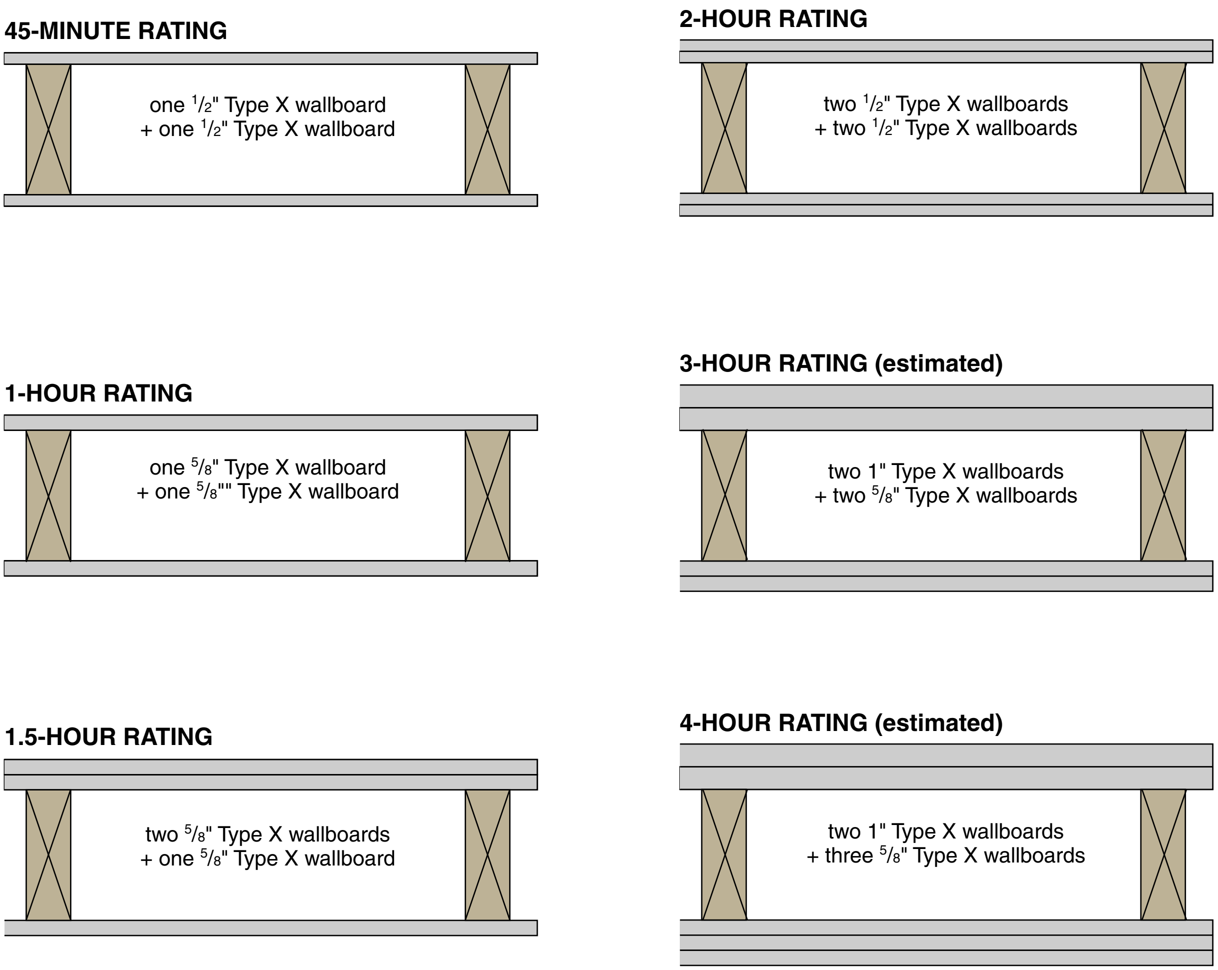
Achieving Fire Ratings

Walls with 45-minute and 1-hour fire ratings are often required in residential construction. For example, the International Residential Code requires a 1-hour rating for the wall that separates a dwelling from an attached garage and, unless that wall extends to the roof, a 45-minute rating for the garage ceiling.

Commercial buildings may require even greater fire ratings. Gypsum drywall is ideally suited to fire-rated construction because the material of which it is formed contains chemically bound water in the ratio of 1 quart to 10 pounds of drywall. The temperature of the drywall and the framing that it protects cannot rise much above 212°F until all of the water has been converted to steam and driven off.

The illustration below shows drywall constructions that achieve fire ratings ranging from 1 to 4 hours. The framing material can be either wood or steel.

Fire-Rated Constructions

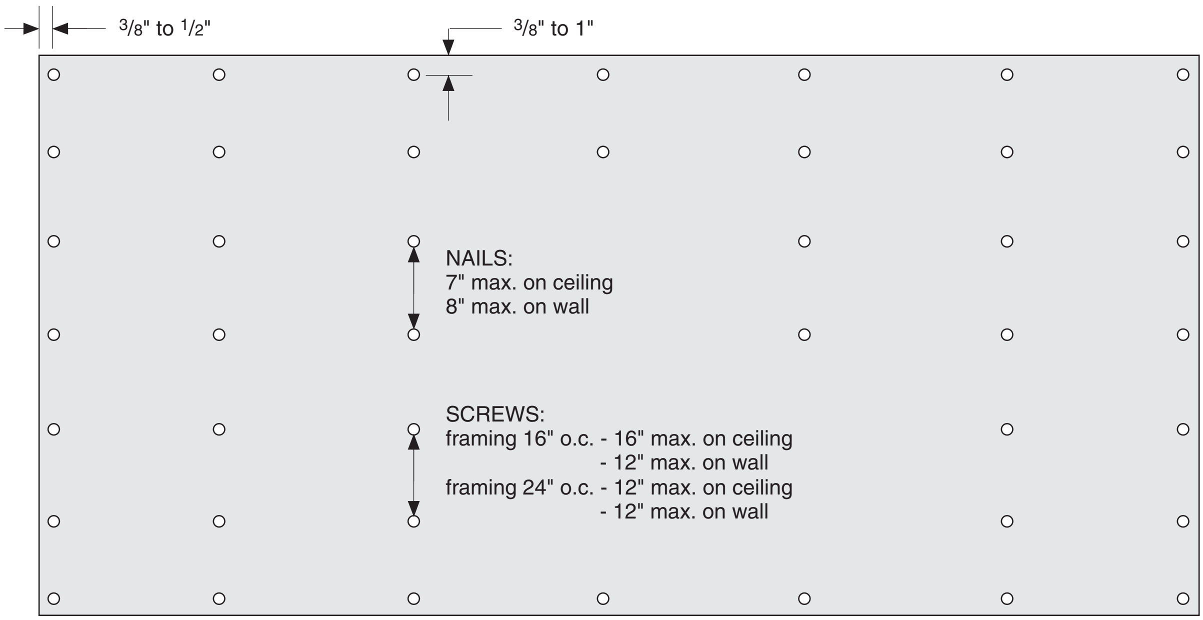


Fastening Schedule

The illustration below shows the maximum recommended fastener spacing. Select fastener lengths as shown at right for adequate framing penetration:

- ring-shank nails — 3/4 inch into wood
- type W screws — 5/8 inch into wood
- type S screws — 3/8 inch into metal
- type G screws — 1/2 inch into gypsum

Gypsum Drywall Fastener Spacing

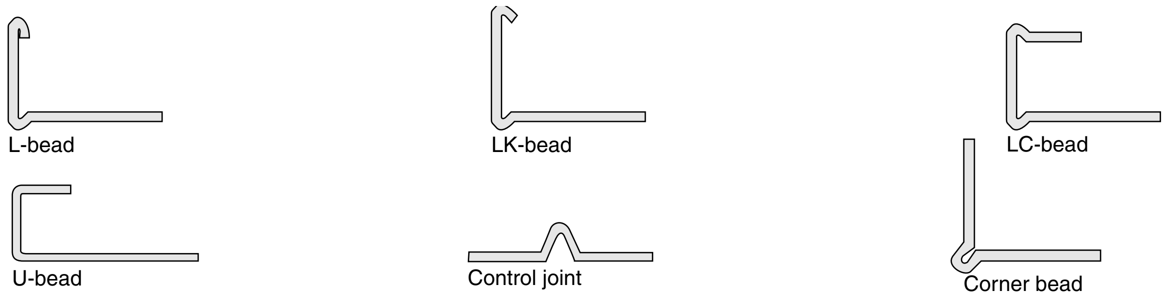


Metal Trim Accessories

The illustration below shows a variety of metal trim accessories designed to protect exposed drywall edges from mechanical damage and produce a neat finish with minimal effort or skill.

The trim is of lightweight perforated steel, which cuts easily with tin snips. The best results on corner and L-beads are obtained when the trim is bedded and nailed into joint compound, then finished in the same way as paper tape.

Metal Drywall Trim Accessories



Floating Corner Techniques

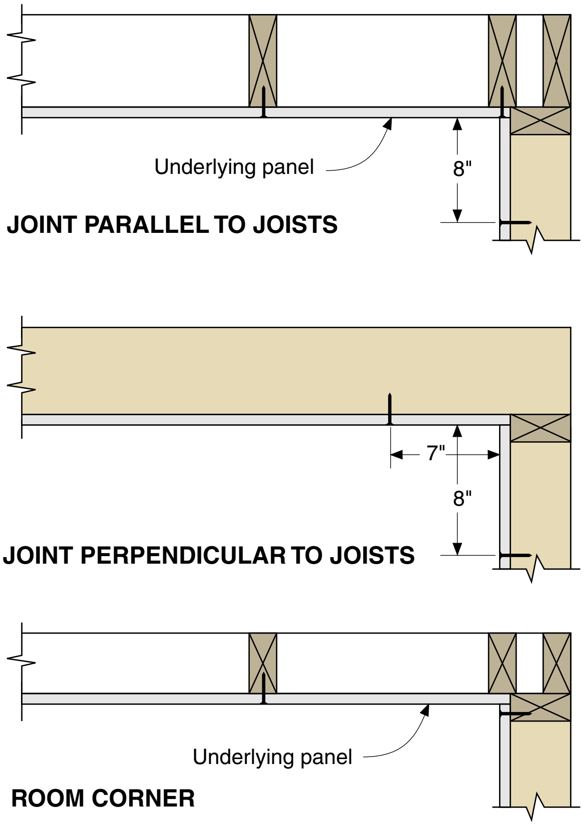
The cracking of ceiling/wall joints and room corners is minimized by a technique known as “floating.” Drywall is always applied to the ceiling first, then the wall panels are shoved up tightly beneath.

Where the ceiling/wall joint runs parallel to the ceiling framing (see the illustration at top right), the ceiling panel is nailed or screwed at its edge, and the wall panel is not.

Where the ceiling/wall joint is perpendicular to the ceiling framing (see the illustration at middle right), neither edge is fastened.

At room corner joints (see the illustration at bottom right), the edge of the underlying, or first-applied, sheet floats.

Gypsum Drywall Fastener Spacing

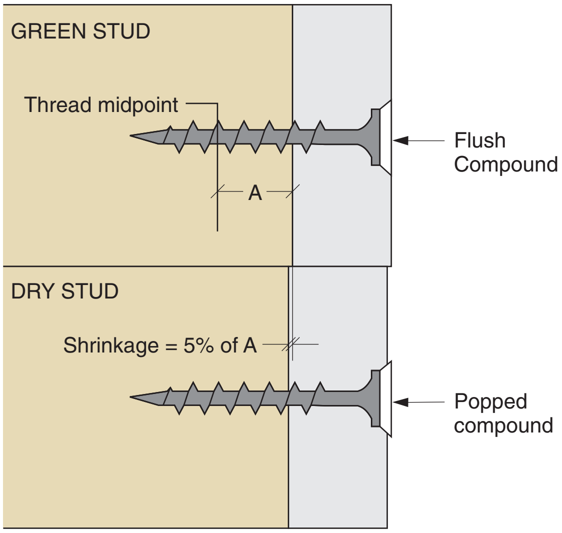


Fastener Pops

Fastener pops are most often the result of high-moisture-content framing drying and shrinking after drywalling. As shown in the illustration at right, the midpoint of the engaged threads of the fastener remain in place while the dimension between the midpoint and the framing edge shrinks by as much as 5%. If the drywall follows the framing (it usually does), the compound covering the fastener head pops out.

Delay repairing pops until the end of the heating season when the framing is finished shrinking. Press the gypsum board into firm contact with the framing, then drive the popped fasteners to just below the surface of the drywall. Remove loose material and fill the depressions with low-shrinkage spackling compound.

Why Drywall Fasteners “Pop”



Estimating Drywall Materials

The illustration at right and table below allow simple estimation of the materials required to finish walls and ceilings:

1. Measure the room's length, L, width, W, and height, H, in feet.

2. Calculate ceiling area: $A_c = L \times W$.

3. Calculate wall area: $A_w = 2(L \times H) + 2(W \times H)$.

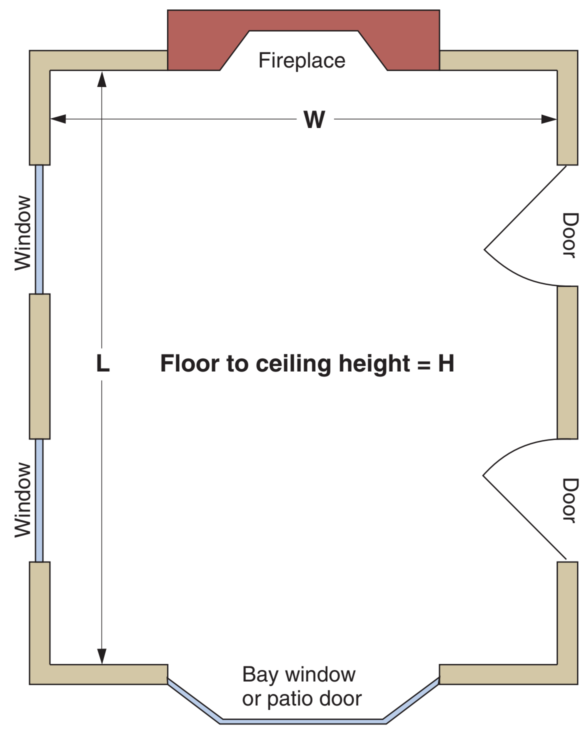
4. Total ceiling and wall areas: $A_t = A_c + A_w$.

5. Calculate net area, A_n, by deducting from A_t for each of the items below:

- windows, 8 square feet
- doors, 11 square feet
- fireplace, 16 square feet
- patio door or bay window, 22 square feet

6. Using A_n, find the required quantities of drywall, tape, joint compound, and screws or nails in the table below.

Room Dimensions for Estimating



Estimating Drywall Materials

Area, A_n, sq. ft	4 × 8	Wallboard Size 4 × 10	4 × 12	Joint Compound, lb	Joint Tape, ft	Drywall Nails	Drywall Screws
100	4	3	3	14	35	168	90
200	7	5	5	28	70	294	150
300	10	8	7	42	105	420	240
400	13	10	9	56	140	546	300
500	16	13	11	70	175	672	390
600	19	15	13	84	210	798	456
700	22	18	15	98	245	924	528
800	25	20	17	112	280	1,050	600
900	29	23	19	126	315	1,218	696
1,000	32	25	21	140	350	1,344	768
2,000	63	50	42	280	700	2,646	1,512
3,000	94	75	63	420	1050	3,948	2,256
4,000	125	100	84	560	1400	5,250	3,000

Joint Taping

Joints between sheets of gypsum drywall are taped and covered with joint compound. Tapered-edge boards have the two longer edges tapered to facilitate the process. Drywall should be applied either horizontally or vertically, in the manner that minimizes the number of square-edge joints, which require a much wider application of compound.

1. Fill the tapered area with compound, using a 6-inch trowel. Apply reinforcing tape, and press the tape firmly into the compound. Remove excess compound.

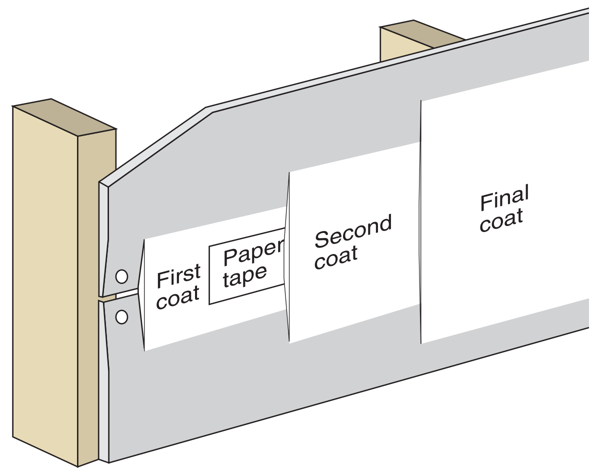
2. After the compound has dried completely, apply a second coat 8 inches wide, at square-edge joints, 12 to 16 inches wide.

3. After the second coat has dried, lightly sand or wipe with a damp sponge to remove any ridges or bumps. Apply a 12-inch-wide final coat. Lightly sand before painting.

4. Apply 2 inches of compound to both sides of inside corners. Fold the tape and press into the corner. Remove excess compound, leaving just enough under the tape for adhesion. Apply a finish coat to one side of the corner. Allow to dry, then apply a finish coat to the other side of the corner. After the finish coat is dry, lightly sand and prime.

5. Install metal cornerbead over outside corners. Apply compound over the cornerbead 4 inches wide, then 6 inches wide, then 10 inches wide on either side of the corner, allowing each layer to first dry. After the finish coat is dry, lightly sand and prime.

Gypsum Drywall Taping



Estimated Drying Time for Taped Joints

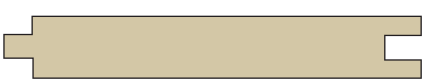
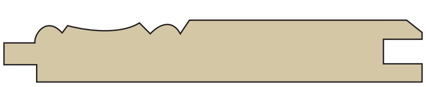
Relative Humidity	Temperature, °F 32	40	50	60	70	80	100
0%	38 hours	28 hours	19 hours	13 hours	9 hours	6 hours	3 hours
20%	48 hours	34 hours	23 hours	16 hours	11 hours	8 hours	4 hours
30%	2.2 days	39 hours	26 hours	18 hours	12 hours	9 hours	5 hours
40%	2.5 days	44 hours	29 hours	20 hours	14 hours	10 hours	5 hours
50%	3 days	2 days	36 hours	24 hours	17 hours	12 hours	6 hours
60%	3.5 days	2.5 days	42 hours	29 hours	20 hours	14 hours	8 hours
70%	4.5 days	3.5 days	2.2 days	38 hours	26 hours	19 hours	10 hours
80%	7 days	4.5 days	3.2 days	2.2 days	38 hours	27 hours	14 hours
90%	13 days	9 days	6 days	4.5 days	3 days	2 days	26 hours
98%	53 days	37 days	26 days	18 days	12 days	9 days	5 days

Wood Paneling

Nothing beats the warmth of genuine wood paneling, whether it be of irreplaceable old walnut, wide old-growth clear pine, or inexpensive knotty pine. The table below, from the Western Wood Products Association, provides area factors to help estimate the number of board feet required to cover walls:

1. Calculate the gross area by multiplying ceiling height by room perimeter, in feet.
2. Deduct the areas of windows, doors, and other non-paneled areas to get net area.
3. Multiply net area by the appropriate area factor in the table, and add 10% for waste.

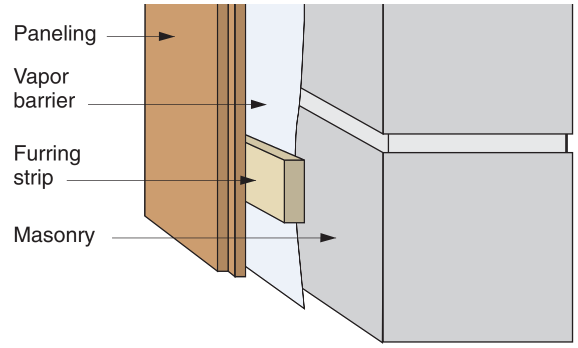
Wood Paneling Coverage

Paneling Style	Nominal Size, in.	Width Total, in.	Width Face, in.	Area Factor
 SQUARE-EDGE BOARD	1×4	3 1/2	3 1/2	1.14
	1×6	5 1/2	5 1/2	1.09
	1×8	7 1/4	7 1/4	1.10
	1×10	9 1/4	9 1/4	1.08
	1×12	11 1/4	11 1/4	1.07
 TONGUE & GROOVE	1×4	3 3/8	3 1/8	1.28
	1×6	5 3/8	5 1/8	1.17
	1×8	7 1/8	6 7/8	1.16
	1×10	9 1/8	8 7/8	1.13
	1×12	11 1/8	10 7/8	1.10
 PROFILE PATTERN (various)	1×6	5 7/16	5 1/16	1.19
	1×8	7 1/8	6 3/4	1.19
	1×10	9 1/8	8 3/4	1.14
	1×12	11 1/8	10 3/4	1.12
 V-JOINT RUSTIC	1×6	5 3/8	5	1.20
	1×8	7 1/8	6 3/4	1.19
	1×10	9 1/8	8 3/4	1.14
	1×12	11 1/8	10 3/4	1.12
 CHANNEL RUSTIC	1×6	5 3/8	4 7/8	1.23
	1×8	7 1/8	6 5/8	1.21
	1×10	9 1/8	8 5/8	1.16
	1×12	11 1/8	10 5/8	1.13

Paneling over Masonry

Over a masonry wall (see the illustration at right), 1×4 strapping should be fastened with either masonry nails or construction adhesive 36 inches on-center maximum. If the masonry wall is below grade, first apply a 6-mil vapor barrier, stapling it to the sill plate. Then install 1×4 furring, 36 inches on-center maximum, with masonry nails. An alternative is to install a stud wall and then wire and insulate between the studs before paneling.

Paneling Over Masonry



Trim

If the paneling has relief, baseboards will look better installed flush than installed over the paneling. Flush baseboards may be installed over furring strips, as in the illustration at right, or over 2×4 blocking between the studs. There should be sufficient blocking to catch not only the baseboard, but the bottom of the paneling as well.

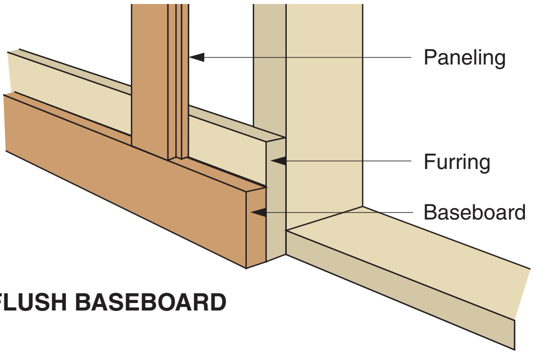
The second and third illustrations at right apply to either door or window trim.

If the paneling is applied directly to the existing wall surface, simply remove the existing door and window trim and replace them with square-edge strips of the same thickness and species as the paneling.

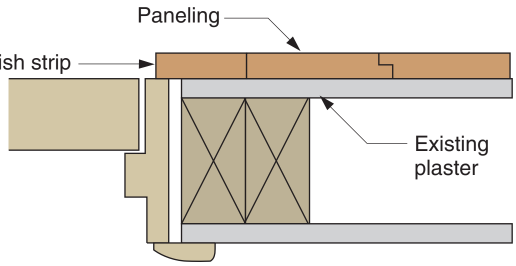
If the paneling is furred out, use jamb extenders to bring the jambs out to the finish wall surface and apply casing over the joint.

Electrical switch and receptacle boxes can be left in place with convenient extension collars, available from electrical suppliers and larger hardware stores.

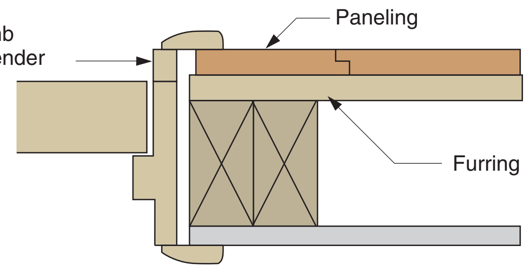
Trim Details



FLUSH BASEBOARD



PANELING OVER EXISTING PLASTER



PANELING OVER FURRING

Suspended Ceilings

A suspended ceiling is a simple and inexpensive way to achieve a level ceiling beneath an existing ceiling or roof, whether flat or not. A strong point is the convenience of "dropping in" fluorescent fixtures at any point. A weakness is a commercial look, not appropriate to residences except in utilitarian rooms such as laundries, game rooms, or workshops.

Installation

Install a suspended ceiling as follows:

1. Plot the dimensions of the room on a large piece of 8×8-inch graph paper. Let each square represent either 3 or 6 inches. On the plot, draw a 2×4-foot grid so that the spaces next to the perimeter are symmetric and as large as possible (see the illustration on the facing page).

2. If the original ceiling is flat and level, measure down to the level of the new ceiling (allowing 6 inches minimum for recessed light fixtures), and snap a chalk line around the perimeter of the room. If the ceiling is not level, establish a level perimeter with a line level. Double-check the level by running the line level around the perimeter in the opposite direction and comparing results. If the difference exceeds 1/4 inch, split the differences between the two lines.

3. Fasten sections of wall angle with the bottom flanges at the level of the chalk line. Nail them into studs if possible. Don't be shy about poking holes in the wall to find stud locations—as long as the holes are above the suspended-ceiling level where they will be out of sight.

4. Stretch strings along the positions of the main tees. Use a plumb bob or level to mark the locations where the string intersects the ceiling joists overhead. Again, don't be afraid to poke holes to find the joist locations: They'll never be seen.

5. Cut suspension wires 12 inches longer than the distance between the old ceiling or ceiling joists and the wall angle, and fasten a wire at each marked intersection. After fastening, make a right-angle bend in the wire at the level of the stretched string.

6. Determine, from the layout sketch, the distance from the wall to the first intersection with a cross tee (1 foot 6 inches in the layout example on the facing page). Measure this distance from the end of a main tee, and select the slot just beyond. From the slot, measure back toward the original end, and mark. Cut the main tee 1/8 inch shorter than the mark, which allows for the thickness of the wall angle.

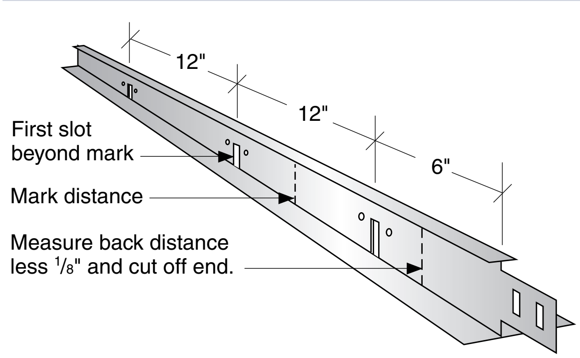
7. Install all of the main tees, repeating step 6 each time. Main tees are 12 feet long, but splice fittings are available if required.

8. Install the cross tees by snapping the end tongues into the main tee slots. Cross tees at the perimeter will have to be cut to fit.

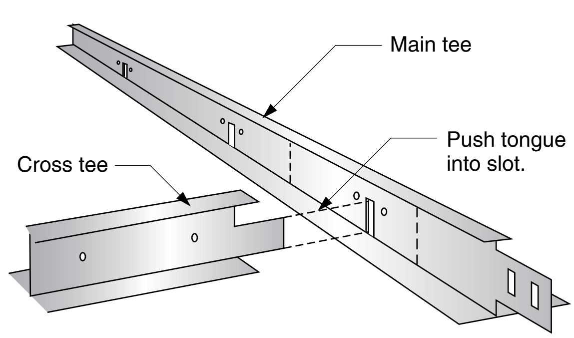
9. Install the wiring for any recessed light fixtures.

10. Install the ceiling panels, cutting perimeter panels as necessary with a utility knife and straightedge.

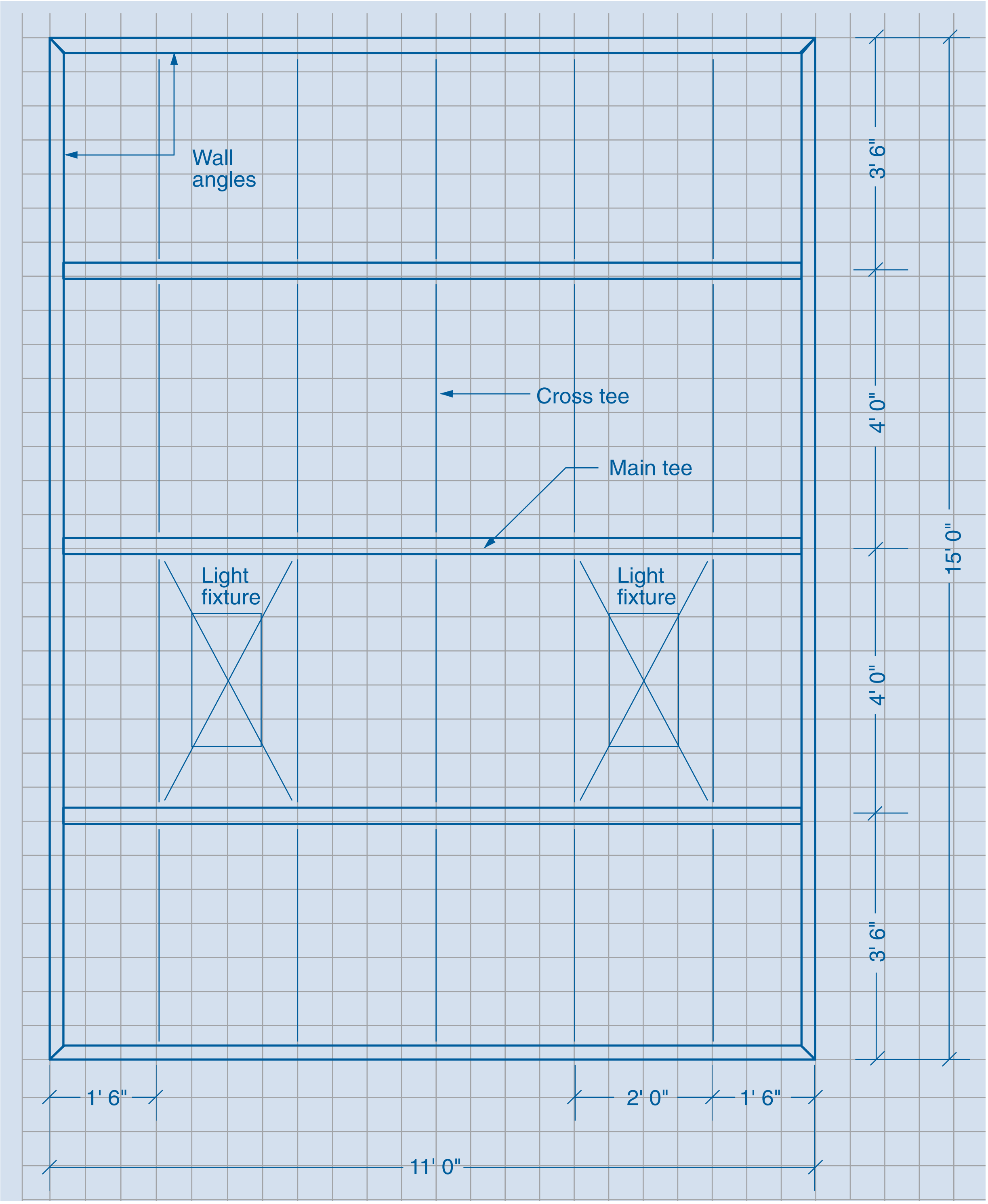
Cutting a Main Tee



Installing Cross Tees



Laying Out a Suspended Ceiling Grid



Wood Moldings

Wood moldings are strips of wood milled with flat or curved surfaces continuous over their lengths. The name *molding* derives from the fact that they are so perfectly smooth, they appear to be molded of plaster. The purposes of moldings include decoration (such as edging for paneling), protection (such as chair rails), and concealment (such as base and cove moldings).

Crown, Bed, and Cove Moldings are milled from thin stock but installed at an angle at the wall/ceiling intersection, allowing the molding to be wide yet follow irregularities in the wall and ceiling.

Quarter-Rounds are designed to both cover and reinforce the joint between paneling and a frame.

Base Shoes are used alone or on top of regular board stock to cover the wall/floor joint and to protect the base of the wall.

Astragals cover panel joints and sometimes simply add decorative relief.

Screen Moldings are used to fasten and cover the edges of screening material in door and window frames.

Casings frame windows and doors and cover the joint between the door or window frame and the plaster or drywall finish. They are hollow on the back side in order to still lie flat despite possible cupping.

Brick Moldings provide casings for doors and windows in masonry walls.

Drip Caps are designed to shed water over doors and windows but have been mostly replaced by metal flashings.

Stops are used on both door and window frames to constrain the motion of the door or sash.

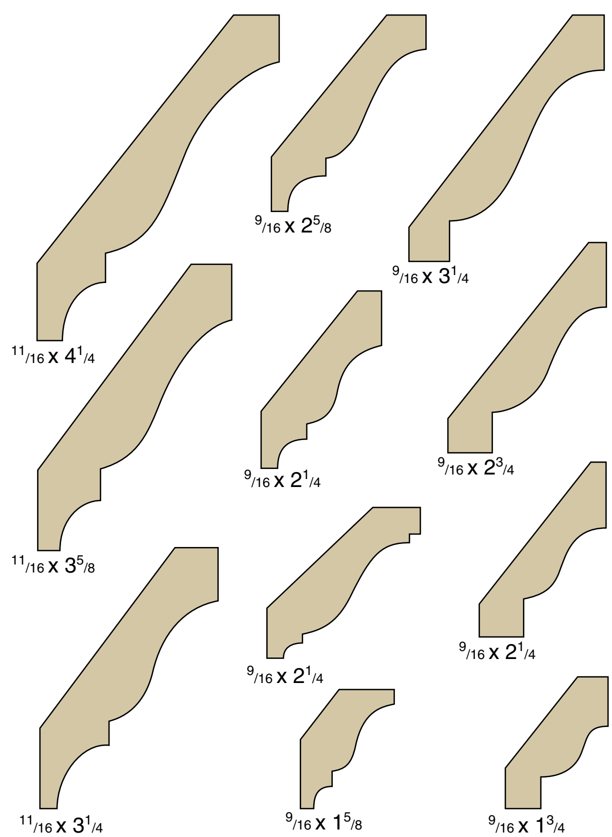
Panel Strips and **Mullion Casings** are used to join large sections of paneling or to join several window units together.

The most common species of wood used in moldings is ponderosa pine. Other species used in significant quantities are alder, poplar, cherry, maple, mahogany, red oak, sugar pine, fir, larch, cedar, and hemlock. Clear wood in long lengths is increasingly more expensive, so manufacturers have turned to finger jointing to eliminate defects. As large, clear-wood moldings become more expensive, manufacturers now offer the most popular moldings in medium density fiberboard (MDF), polystyrene foam, and polyurethane foam.

The Moulding & Millwork Producers Association (MMPA) promulgates standard molding patterns. The illustrations that follow contain *scale* sections of the most popular patterns of the WM Series. Regional millwork distributors generally offer selections of these patterns, customized to local demand.

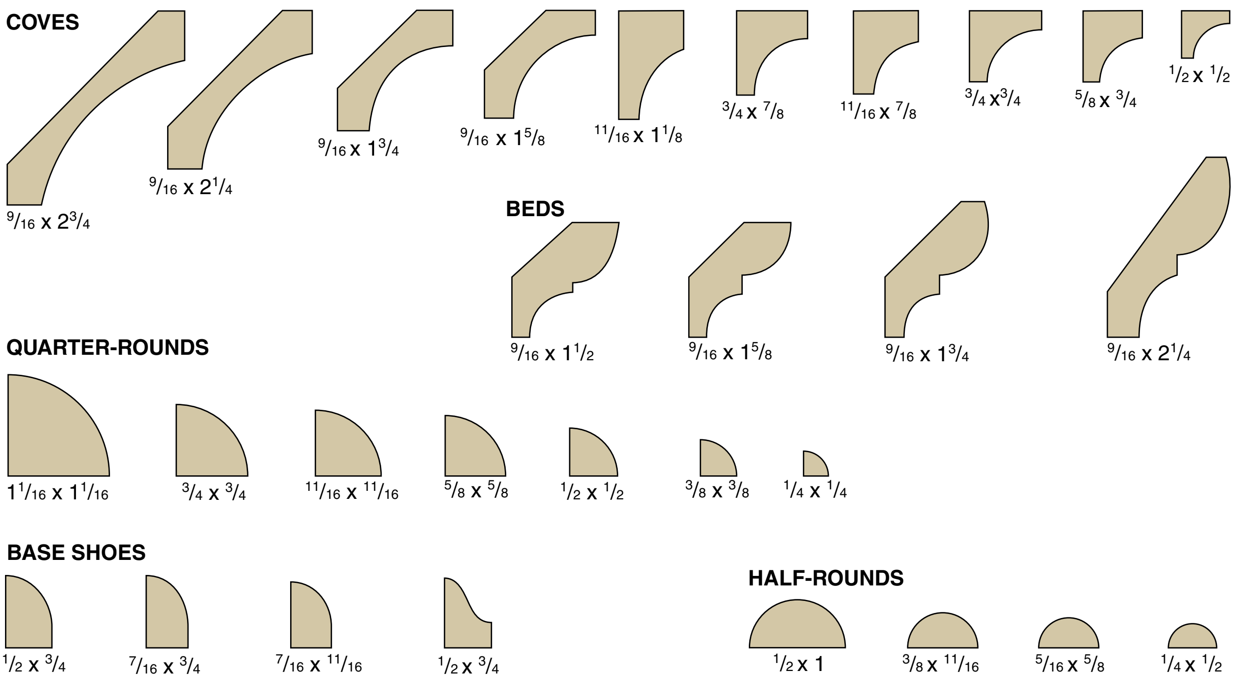
Standard moldings may be combined to create a nearly infinite number of custom moldings. Examples of what might easily be created on-site are shown on p. 512.

Crown Moldings (half scale)



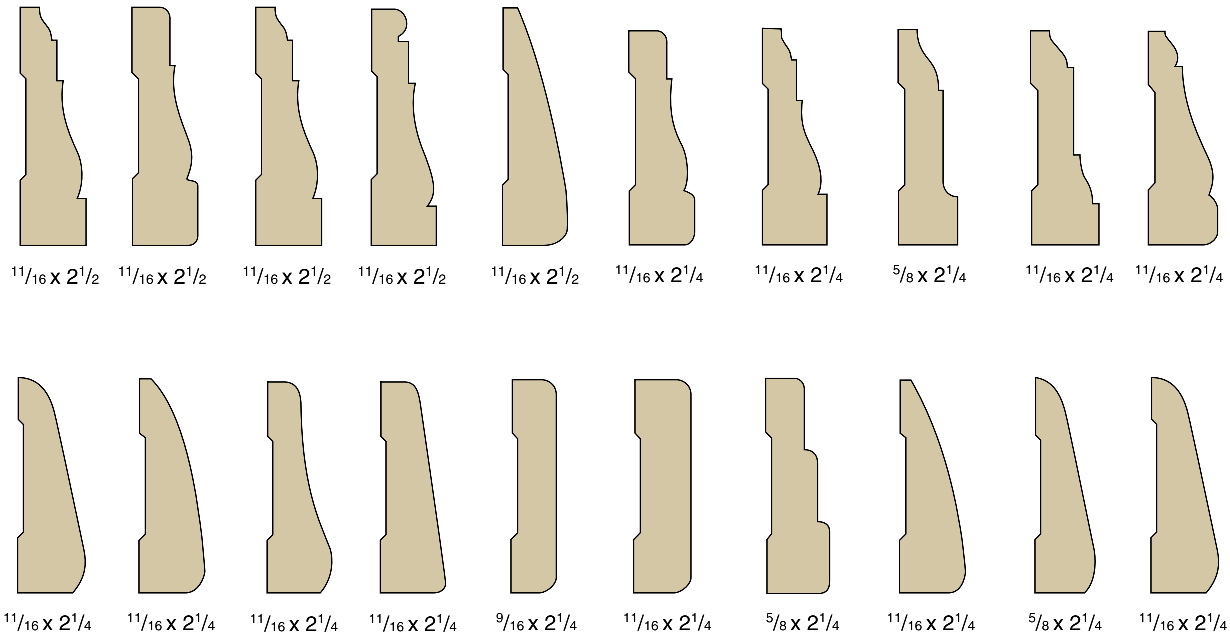
*Measurements are in inches

Coves, Beds, Quarter-Rounds, Half-Rounds, and Base Shoes (half scale)



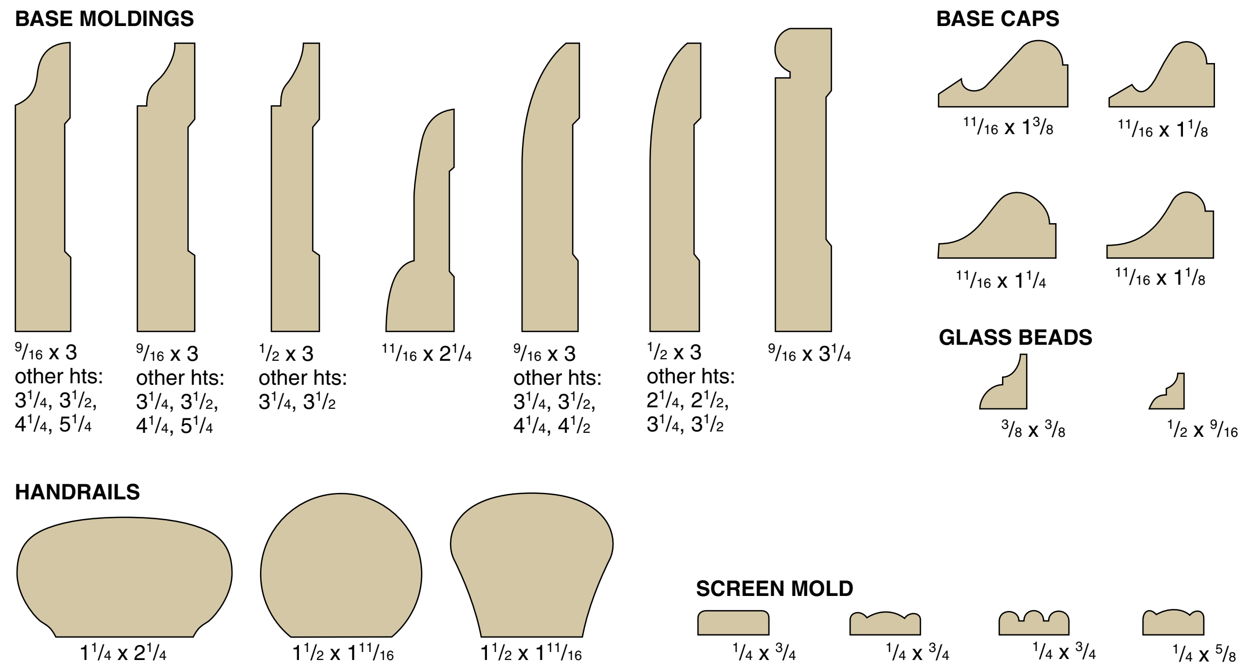
*Measurements are in inches

Casings (half scale)



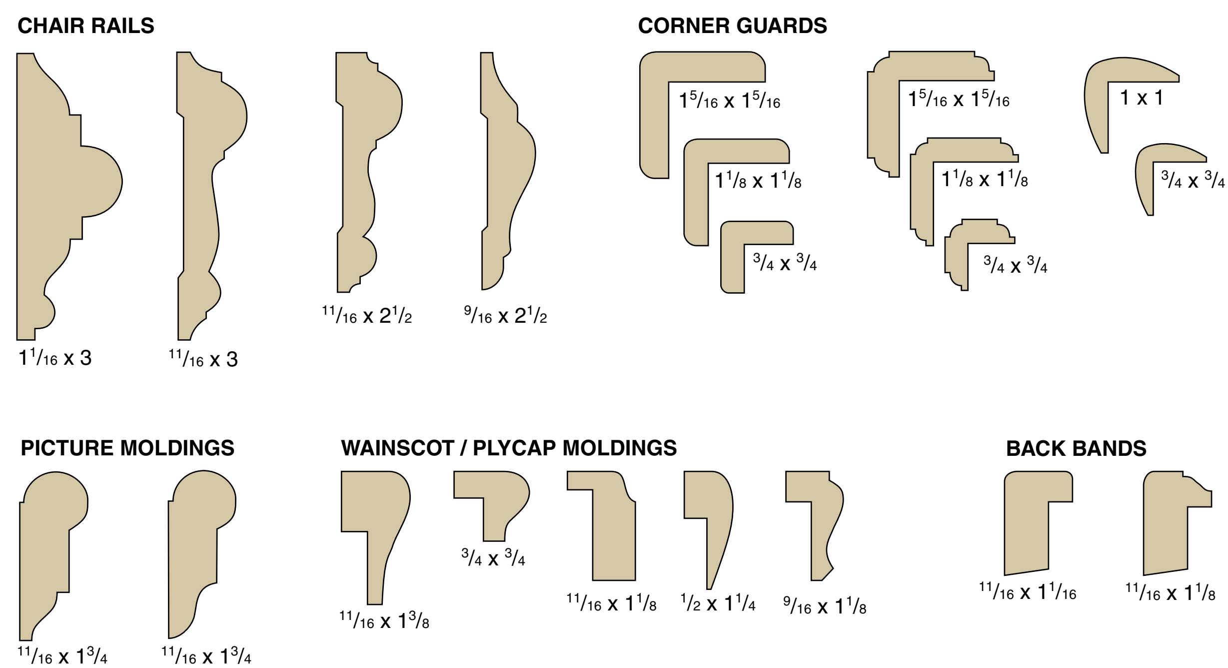
*Measurements are in inches

Base Moldings, Base Caps, Screen Molds, Glass Beads, and Hand Rails (half scale)



*Measurements are in inches

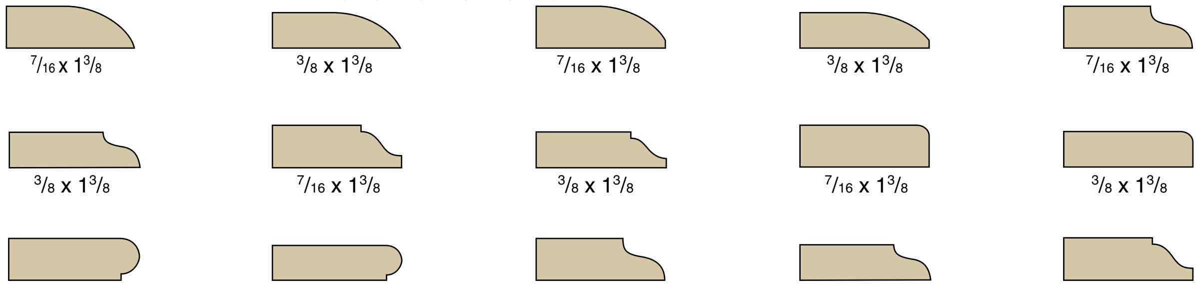
Chair Rails, Corner Guards, Picture Molding, Back Bands, and Wainscoting/Plycaps



*Measurements are in inches

Stops, Battens, and Shingle/Panel Moldings (half scale)

STOPS Note additional widths: 3/4, 7/8, 1 1/8, 1 1/4, 1 5/8, 1 3/4, 2 1/4

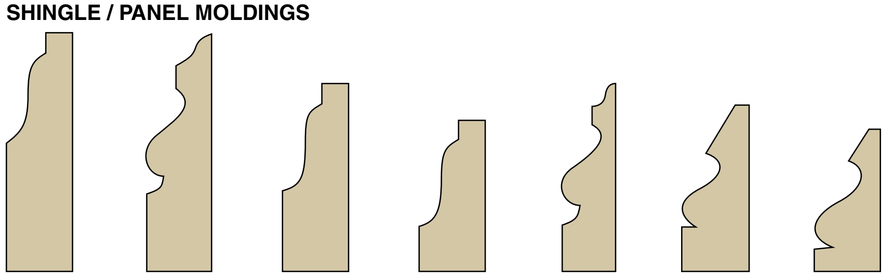


7/16 x 1 3/8 | 3/8 x 1 3/8 | 7/16 x 1 3/8 | 3/8 x 1 3/8 | 7/16 x 1 3/8

3/8 x 1 3/8 | 7/16 x 1 3/8 | 3/8 x 1 3/8 | 7/16 x 1 3/8 | 3/8 x 1 3/8

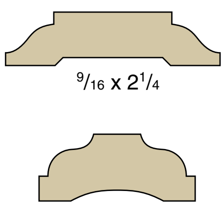
7/16 x specified widths | 3/8 x specified widths | 7/16 x 1 3/8 | 3/8 x 1 3/8 | 7/16 x 1 3/8

SHINGLE / PANEL MOLDINGS



11/16 x 2 1/2 | 11/16 x 2 1/2 | 11/16 x 2 | 11/16 x 1 5/8 | 9/16 x 2 | 11/16 x 1 3/4 | 11/16 x 1 1/2

BATTENS



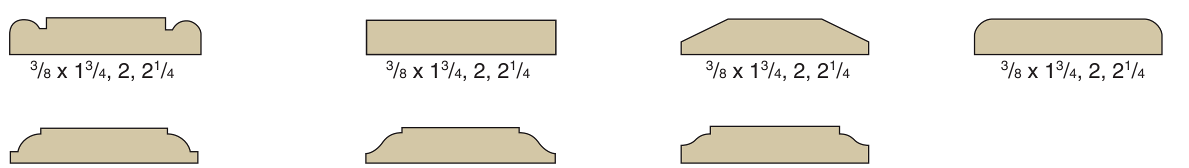
9/16 x 2 1/4

11/16 x 1 5/8

*Measurements are in inches

Panel Strip/Mullion Casings, Rabbeted Stools, Astragals, and Panel Moldings

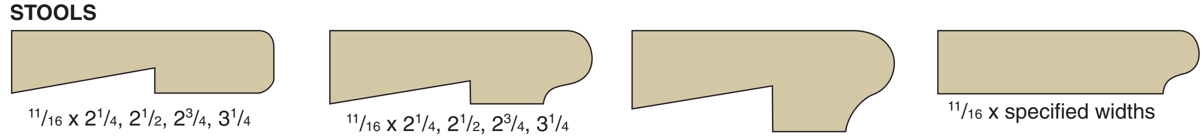
PANEL STRIPS/MULLION CASINGS



3/8 x 1 3/4, 2, 2 1/4 | 3/8 x 1 3/4, 2, 2 1/4 | 3/8 x 1 3/4, 2, 2 1/4 | 3/8 x 1 3/4, 2, 2 1/4

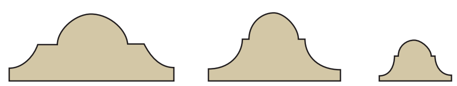
3/8 x 1 3/4, 2, 2 1/4 | 3/8 x 1 3/4, 2, 2 1/4 | 3/8 x 1 3/4, 2, 2 1/4

STOOLS



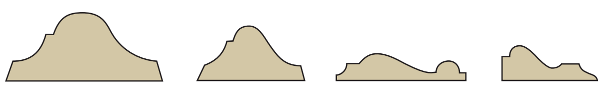
11/16 x 2 1/4, 2 1/2, 2 3/4, 3 1/4 | 11/16 x 2 1/4, 2 1/2, 2 3/4, 3 1/4 | 1 1/16 x 2 3/4, 3 1/4, 3 5/8 | 11/16 x specified widths

FLAT AGALS



11/16 x 1 3/4 | 11/16 x 1 3/8 | 7/16 x 3/4

PANEL MOLDINGS

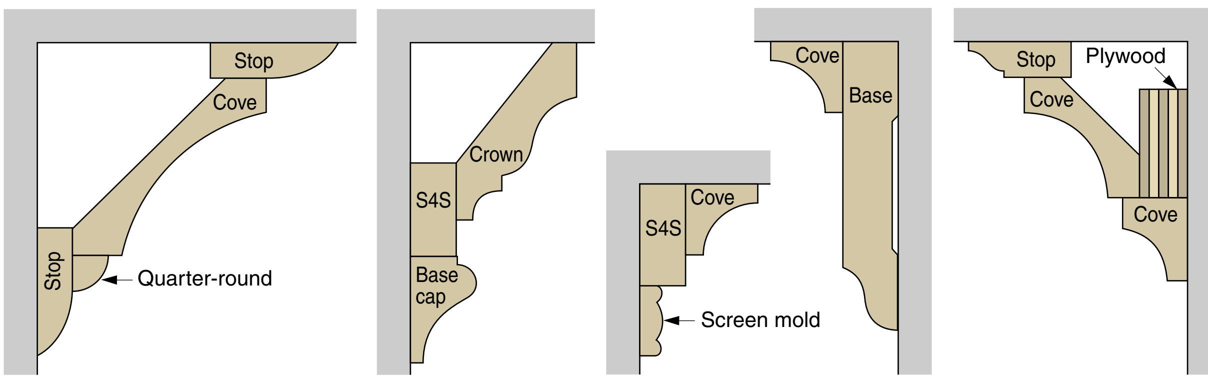


11/16 x 1 5/8 | 9/16 x 1 1/8 | 9/32 x 1 3/8 | 3/8 x 1

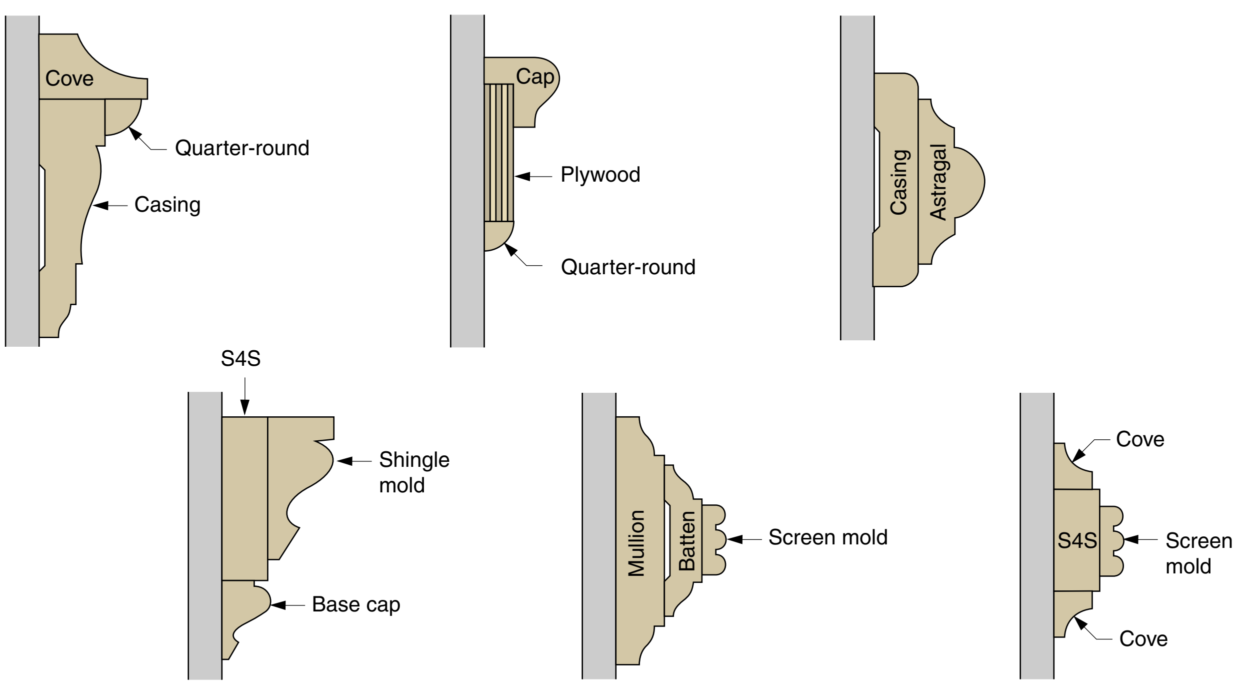
*Measurements are in inches

Wood Moldings

Built-Up Crown Moldings (half scale)



Built-Up Chair Rails (half scale)



17

Storage

Homes today, if anything, have too many rooms and too much space. But regardless of floor area, they never seem to have enough storage for the acquisitive families that occupy them. Instead of building a storage barn or even a new home, we'll show you how you can increase the effectiveness of the space that you already have.

We start with *bath cabinetry*. In the old days, with pedestal-mounted sinks, about the only storage in the bathroom was the medicine cabinet. Replace that old sink with one or more lavatories in a multidrawer vanity.

One of the most popular remodels is the kitchen. Today's kitchens are as much about fashion as utility. If you feel a kitchen remodel coming up, get to your local home center to check out the vast array of options in *kitchen cabinetry*. We offer here a generic catalog of the cabinets you will find.

If you feel your present home is bulging at the seams and impossibly cluttered, go to a boat show for inspiration. Yacht designers, particularly those of sailboats, have developed the art of *finding more storage* to the ultimate. We offer a field guide to the possibilities you may discover in your non-floating home.

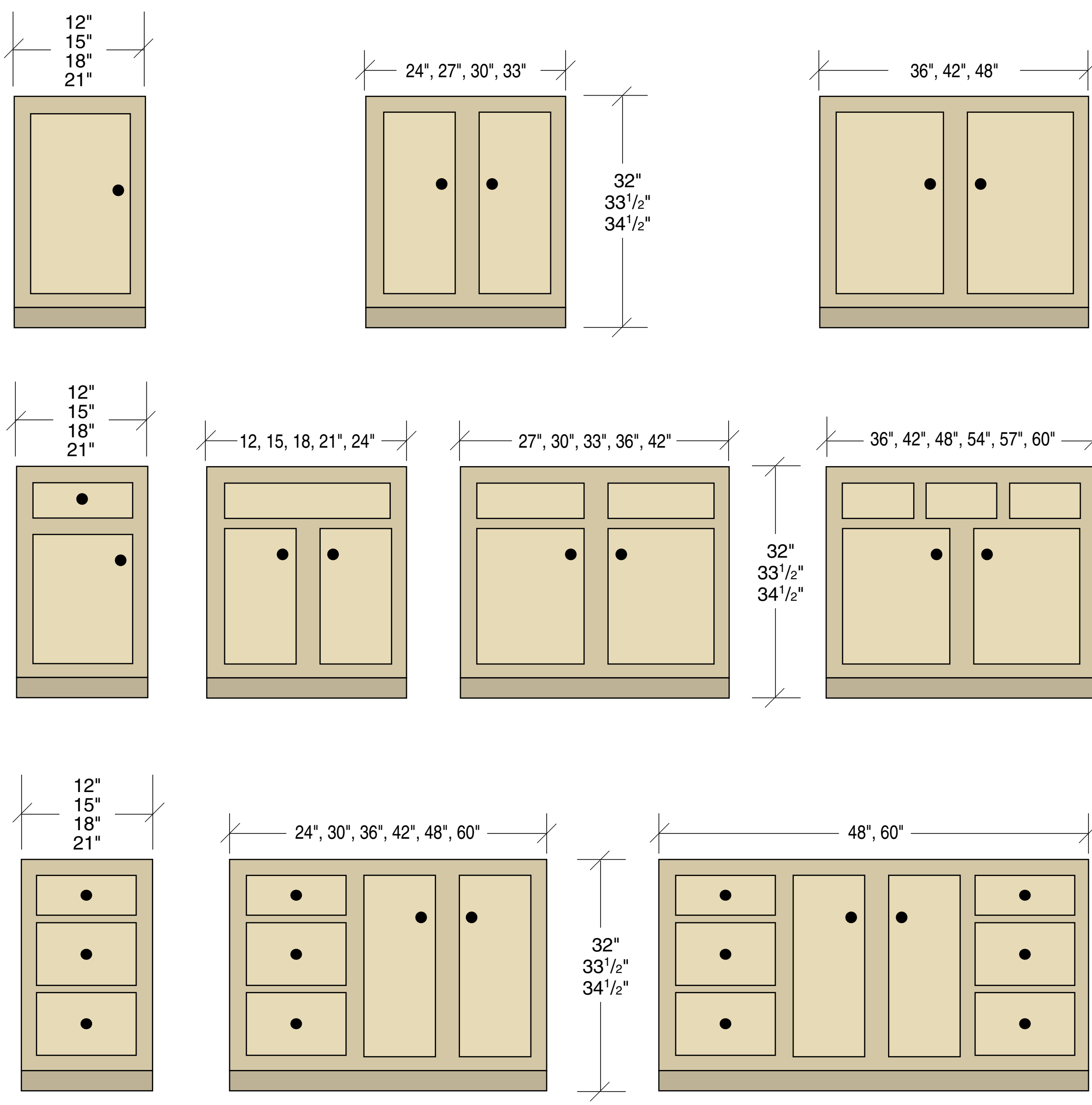
The most common, least expensive form of storage is plain *shelving*. We offer solutions to the two most common questions: how to support the shelves, and what distances they can span without sagging.

Bath Cabinetry

Most cabinet manufacturers offer comprehensive lines of both bath and kitchen cabinets. Some offer both lines in the standard kitchen-cabinet height (without countertop) of 34½ inches so that cabinet types can be combined. Most, however, offer bath cabinets (vanities) with heights of either 32 or 33½ inches.

Most manufacturers also offer vanities with depths (front to back of frame) of both 18 and 21 inches. When combining vanity modules and when ordering vanity tops, double-check the vanity depths.

Typical Modular Bath Cabinetry



Kitchen Cabinetry

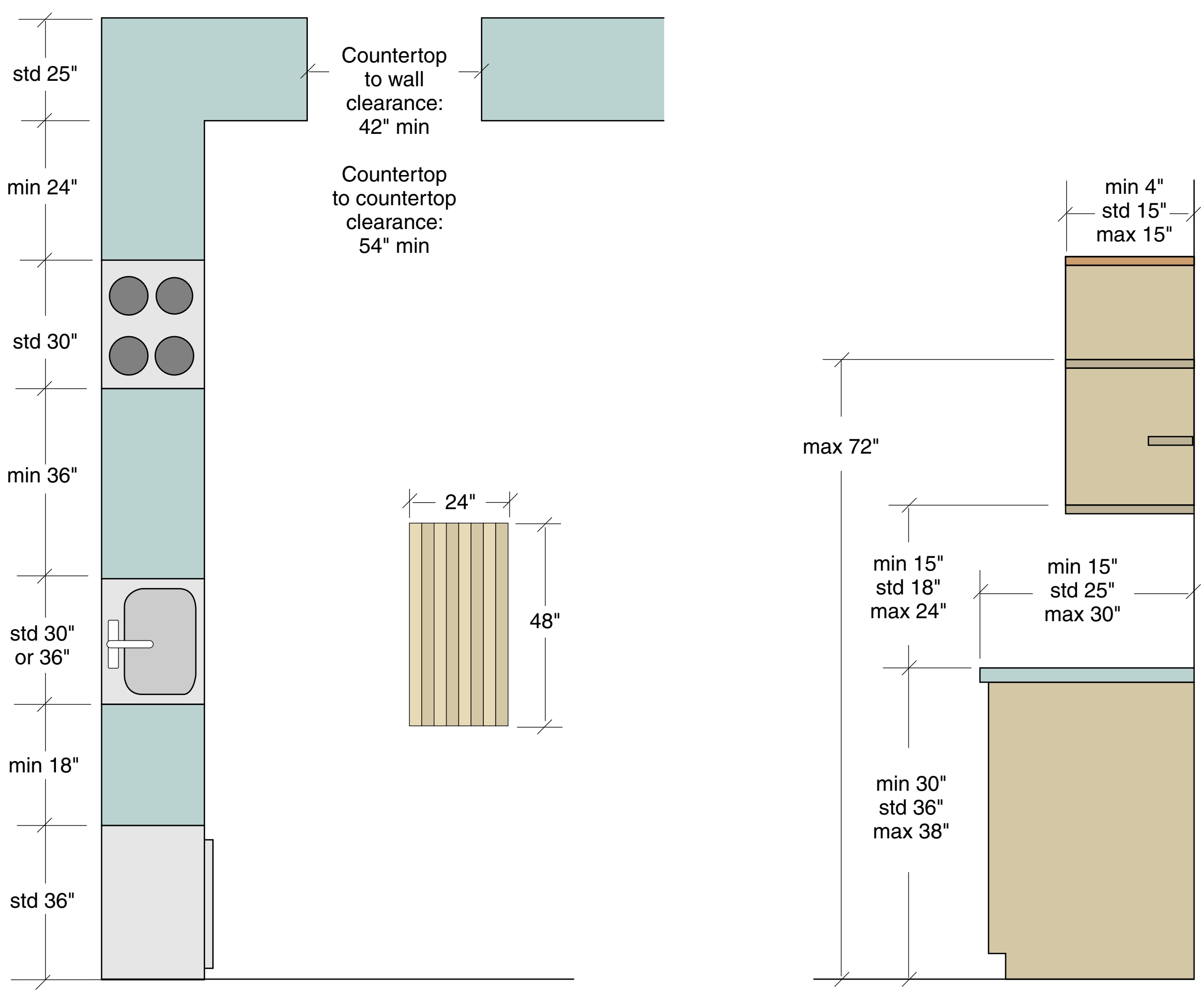
Unless you special-order or build your own, chances are your cabinetry will be of standard dimensions. The only choice open to you is the height of the wall cabinets above the counter.

Low wall cabinets make wall shelving more accessible. On the other hand, if you plan to hang a microwave oven and a cookbook shelf under the wall cabinets, you will need greater height for a useful counter surface.

The countertop frontages shown here are the minimum. Cooks who use lots of pots and pans or who entertain a lot will appreciate 36 inches to the left of the sink and a separate 24- by 48-inch work surface, such as the island shown.

Recessed counter surfaces on inside corners do not count toward either frontage or surface area.

Recommended Kitchen Cabinetry Dimensions



Kitchen Cabinetry—*Continued*

Standard modular kitchen cabinets are available in a wide range of styles and prices.

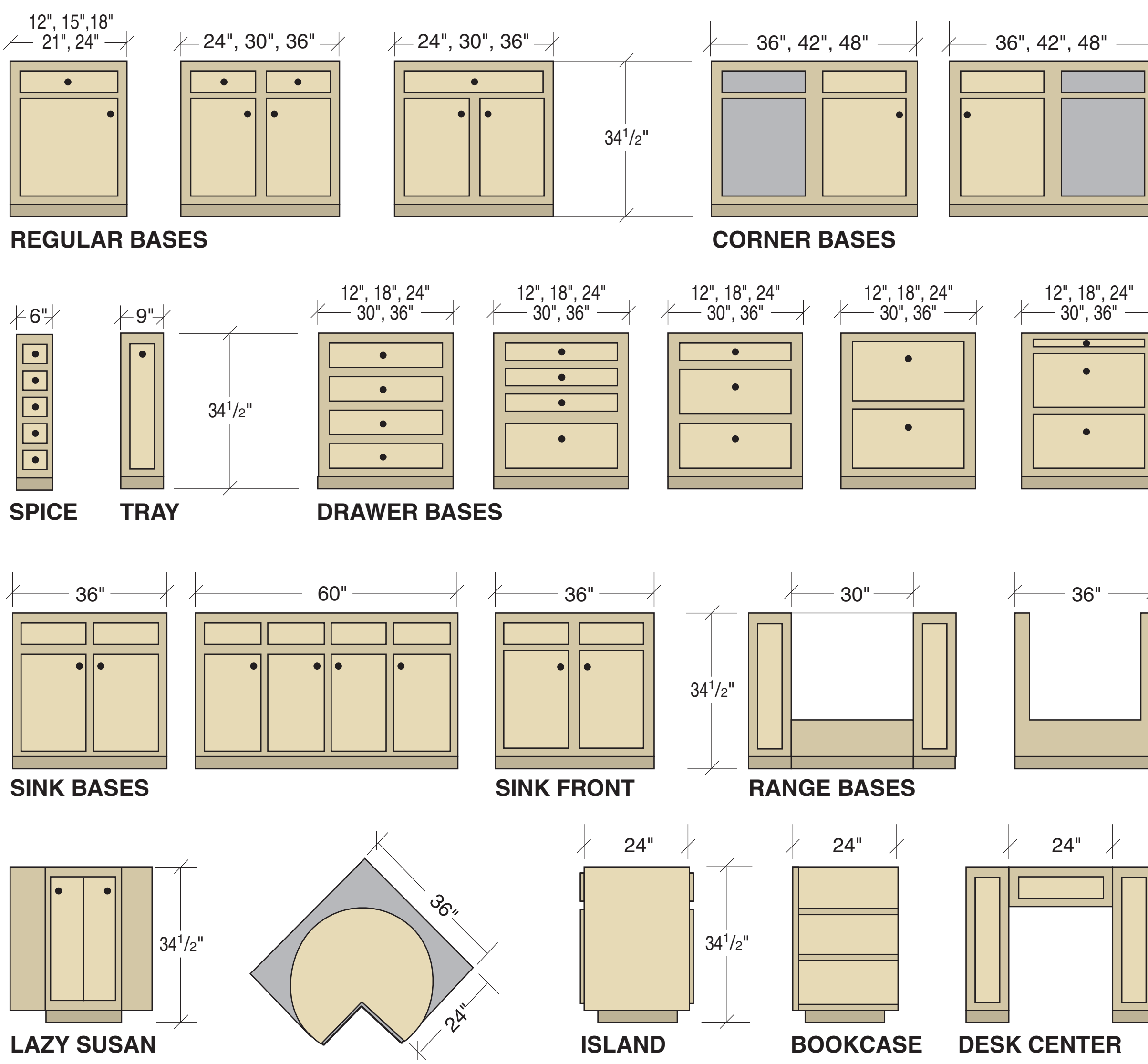
Standard base cabinet height is 34½ inches, assuming a 1½-inch countertop and 36-inch counter surface height. Cabinet height can be raised or lowered by adding to or removing from the kick space.

Ideal counter height is considered to be the bottom of a bent elbow less 3 inches, but modifying counter heights should be taken seriously because it decreases the home's resale value.

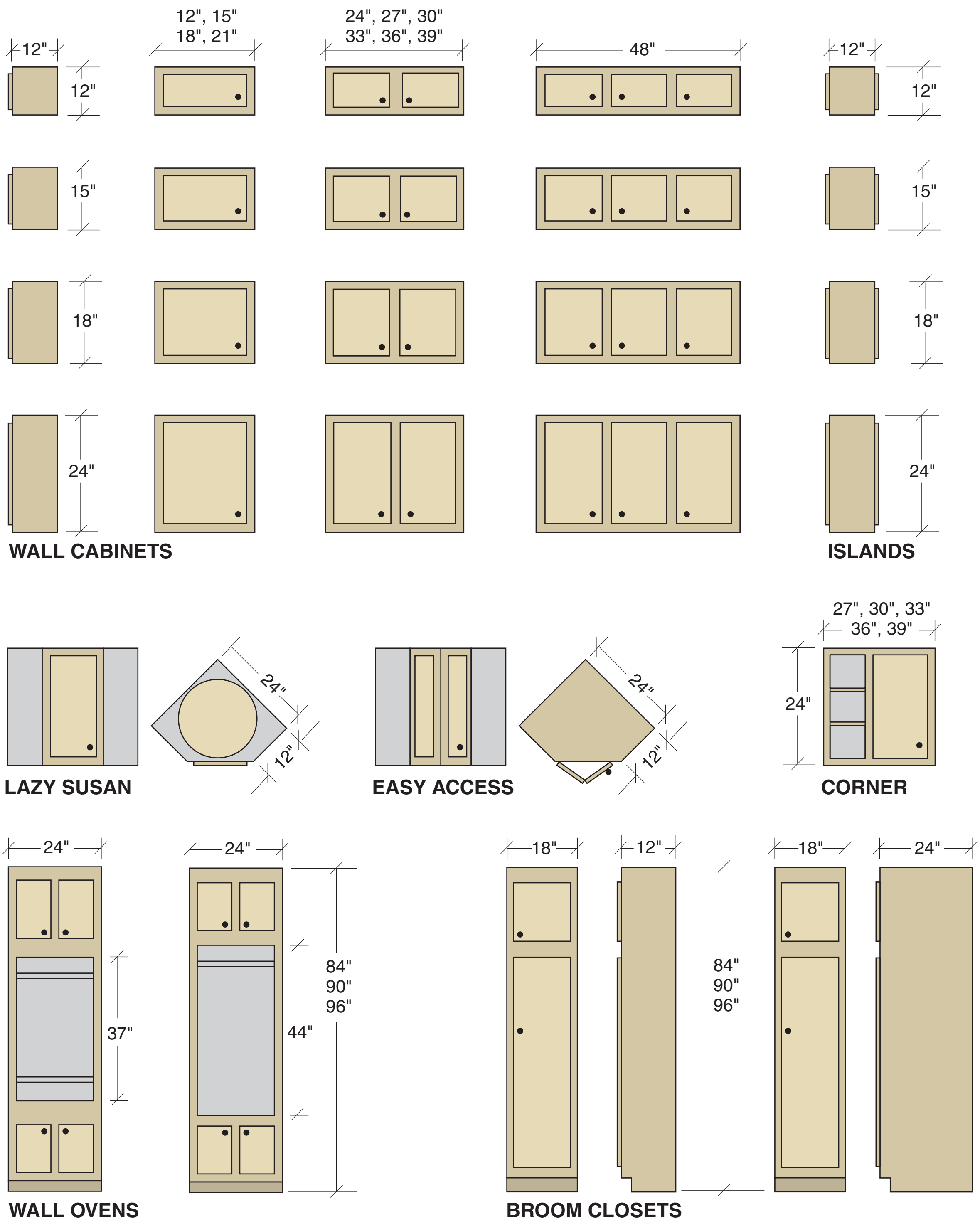
Cabinet widths range from 9 to 36 inches in 3-inch increments, and 36 to 48 inches in 6-inch increments. Exact fit is made by trimming standard 3- and 6-inch filler strips.

Typical modular kitchen cabinets are shown below and on the facing page.

Typical Modular Kitchen Base Cabinets



Typical Modular Kitchen Wall Cabinets



Finding More Storage

The single most common complaint about houses is lack of storage space. Of course, just as "nature abhors a vacuum," so do our possessions rapidly fill all available space. Short of holding an annual garage sale, however, we can increase, or at least improve, the built-in storage capacities of our homes. The illustration on the facing page points to storage possibilities you may have overlooked:

1. The space behind a knee wall is perfect for either built-in bookshelves or (as shown) drawers. Note that to preserve the home's thermal envelope, the insulation must be between the rafters.

2. Heated or unheated, attics offer huge unused storage spaces. If the insulation is between the rafters, install a plywood or OSB floor. If the insulation is between the joists, suspend a platform from the rafters.

3. The spaces under most beds store nothing more than shoes and dust bunnies. Placing the mattress on a platform allows for pull-out drawers that are perfect for storage of sheets and blankets.

4. Dual-lavatory vanities often contain enough undercounter space for a half-dozen drawers. If that is not enough, add a hanging wall cabinet to any blank wall in a large bathroom.

5. Walk-in closets are a must for both him and her. Extra depth can be used for storage shelves, as well as one or two closet poles.

6. You can never have too much cabinet space in a kitchen. Utilize every inch of wall space for both undercounter and wall cabinets.

7. A room between an attached garage and the kitchen can serve double duty as both a mud room and a pantry. Pantries are especially useful because their open shelving allows one to see the contents at a glance.

8. A linen closet can often be tucked into a leftover nook or cranny. It doesn't have to be very large to store the linens for the average home.

9. An entrance closet solves the problem of where to hang guest overcoats and umbrellas. Find a place close to the entrance door so that wet and muddy apparel doesn't penetrate too far into your home.

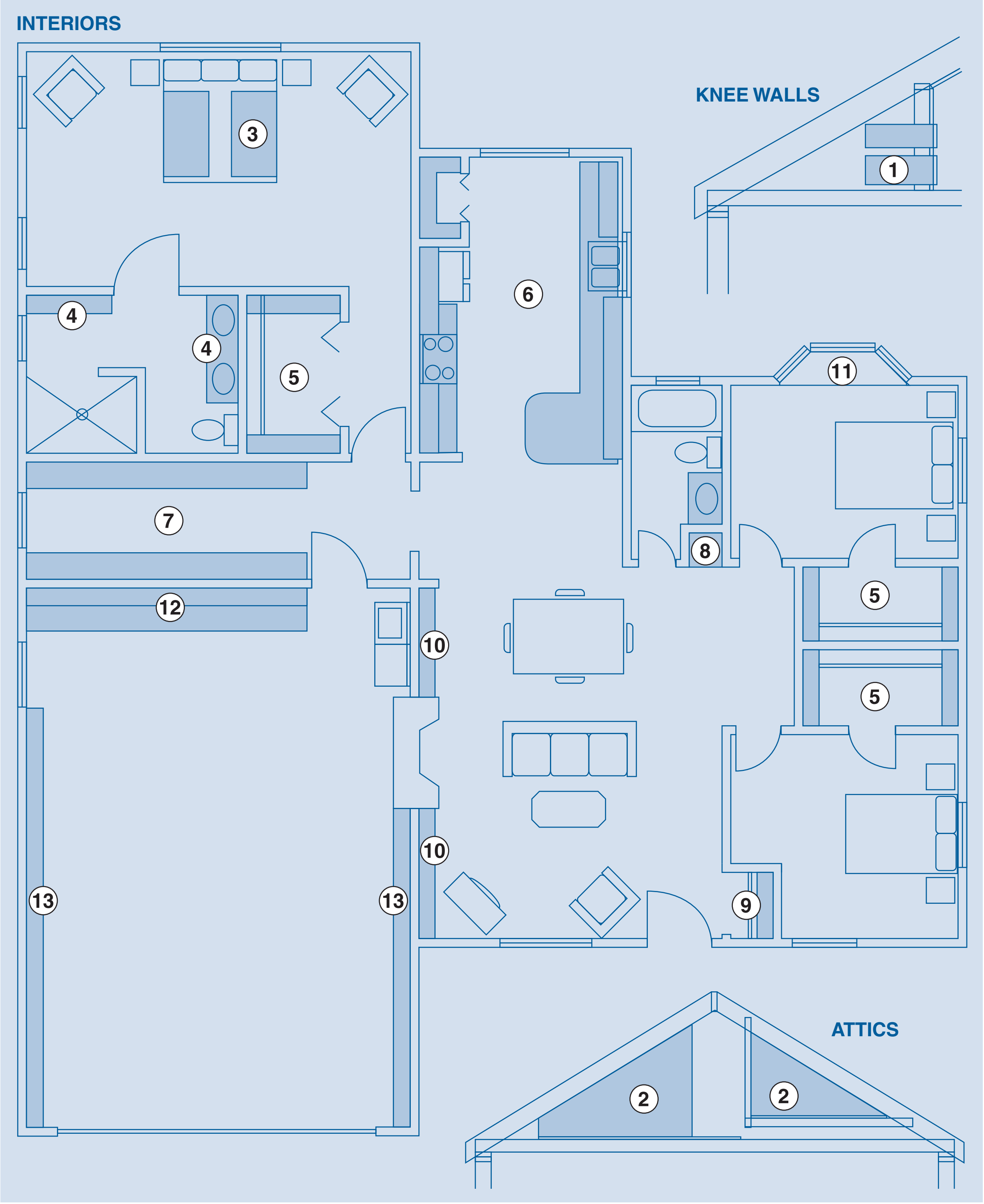
10. Walls on either or both sides of a fireplace are the perfect places for built-in shelves and bookcases. Use them for a sound system, family photos, and interesting objets d'art, as well as your prized collection of books.

11. A window bay is a perfect place for a window seat, whether for you or the family cat. Hinge the seat, and you will have a perfect place to store games and toys for the grandchildren.

12. Garages offer a wealth of storage opportunities. A space beyond the automobiles at the end may be perfect for a built-in workshop. Placing the workbench on top of kitchen base cabinets provides drawers for storage of tools and supplies. Use kitchen wall cabinets for storage of paints, stains, adhesives, and chemicals. Install pegboard, or plywood with screws and nails, on the wall beneath the cabinets for hanging tools.

13. A wide garage may provide space along one side for wall racks to hold bicycles, canoes, kayaks, etc. The walls of even the narrowest garage can be used to hang garden tools.

Finding More Storage Space



Shelving

No residence or office ever has enough shelving, whether for books, DVDs, clothes, or items for display.

For fixed shelving, carefully consider the heights of the items to be shelved. Book heights, for example, range from 8 inches for small paperbacks to 16 inches or more for oversize coffee-table editions. Use the tables below and at right to calculate the spacing of your shelves. Better yet, sort your items by size, and use the actual maximum dimensions. Remember, however, that the height is the clear distance between shelves, not the on-center spacing. If you are very careful, you may just squeeze in an extra shelf.

The tables on the facing page show the maximum clear spans of shelving limited by deflection (sag) of 1/240 of the shelf length (1 inch in 240 inches, ½ inch in 120 inches, 1⁄10 inch in 24 inches, etc.) for a range of uniformly distributed shelf loads.

To use one of the tables, weigh on a bathroom scale a typical load you plan to place on a running foot of shelf. If the shelf is 12 inches deep, that is the load in psf (pounds per square foot) of the first column. If the shelf is 6 inches deep, the psf is doubled.

Find the nearest psf in the first column, then run across the table to find the allowable shelf spans for the listed shelving materials and thicknesses.

The deflection ratio of 1/240 is quite conservative. For a more saggy ratio of 1/180, you can increase shelf loads by one-third. If the shelving has a back panel, the listed spans may be doubled by fastening the back edges of the shelves.

Heights of Shelved Objects

Item	Typical Height, in.
Audio cassette	5
Book, hardback	11
Book, oversized hardback	15
Book, paperback	8
Book, oversized paperback	16
CDs and DVDs	5
Slide carousel	10
Video tape	8

Dimensions of Closet Storage Items

Item	Dimensions, in.
LINEN (LENGTH × WIDTH × HEIGHT)	
Bath mat	9 × 10 × 3
Bath towel	13 × 14 × 2
Blanket	22 × 27 × 4
Dish towel	10 × 16 × 1
Fitted sheet	11 ×18 × 2
Flat sheet	14 × 15 × 2
Hand towel	6 × 10 × 1
Pillowcase	7 × 15 × 1
MEN'S CLOTHING (HANGING HEIGHT)	
Pants, folded	22 × 27
Pants, unfolded	11 × 18
Shirt	22 × 27
Suit	22 × 27
Tie	11 × 18
Topcoat	22 × 27
WOMEN'S CLOTHING (HANGING HEIGHT)	
Blouse	22 × 27
Coat	11 × 18
Dress, long	22 × 27
Dress, regular	22 × 27
Robe	11 × 18
Skirt	22 × 27
Suit	22 × 27
ACCESSORIES (HANGING HEIGHT)	
Garment bag	22 × 27
Shoe bag	11 × 18
Umbrella	22 × 27
CLEANING EQUIPMENT (WIDTH × HEIGHT)	
Broom, push	22 × 27
Broom, regular	11 × 18
Carpet sweeper	22 × 27
Floor polisher	22 × 27
Scrub bucket	11 × 18
Vacuum, canister	22 × 27
Vacuum, upright	11 × 18

Maximum Shelf Span, Shelves Freely Supported at Ends[1,4]

	Maximum Allowable Span (in.)[2,3]											
	Particleboard			Medium Density Fiberboard			AC Plywood		E. White Pine		Red Oak	
Load, psf	1/2″	5/8″	3/4″	1/2″	5/8″	3/4″	5/8″	3/4″	3/4″	1″	3/4″	1″
10	23	31	37	25	32	38	31	38	55	74	63	84
15	20	27	32	22	28	33	27	33	48	67	54	73
20	18	22	27	20	25	30	24	30	44	61	49	66
25	17	21	25	19	23	28	23	28	41	57	46	62
30	16	20	23	18	22	26	21	26	38	53	43	58
35	15	19	22	17	21	25	20	25	36	51	41	55
40	15	18	21	16	20	24	19	24	35	49	39	53
45	14	18	21	16	19	23	18	23	33	47	38	51
50	13	17	20	15	19	22	18	22	32	45	36	48

[1] Shelf ends not fastened in any way.

[2] Maximum span limited by deflection of 1/240 (deflection = length between supports divided by 240).

[3] Assumed Moduli of Elasticity: Particleboard = 0.32×10^6, Medium Density Fiberboard = 0.35×10^6, AC Plywood = 0.33×10^6, Eastern White Pine = 1.1×10^6, Red Oak = 1.6×10^6.

[4] Shelves may extend up to 6″ beyond end supports.

Maximum Shelf Span, Shelves Supported at Ends and Midpoint[1,4]

	Maximum Allowable Span (in.)[2,3]											
	Particleboard			Medium Density Fiberboard			AC Plywood		White Pine		Red Oak	
Load, psf	1/2″	5/8″	3/4″	1/2″	5/8″	3/4″	5/8″	3/4″	3/4″	1″	3/4″	1″
10	30	38	45	34	39	46	37	46	67	90	77	102
15	25	32	39	29	34	40	33	40	58	82	66	89
20	22	27	33	27	33	36	29	36	53	74	60	80
25	19	24	29	25	31	34	28	34	50	69	56	75
30	18	22	27	23	29	32	25	31	46	64	52	70
35	16	20	24	22	28	31	24	30	44	62	50	67
40	15	19	23	21	26	30	23	29	42	60	47	64
45	14	18	22	21	25	28	22	28	40	57	46	62
50	13	17	20	20	25	27	22	27	39	55	44	58

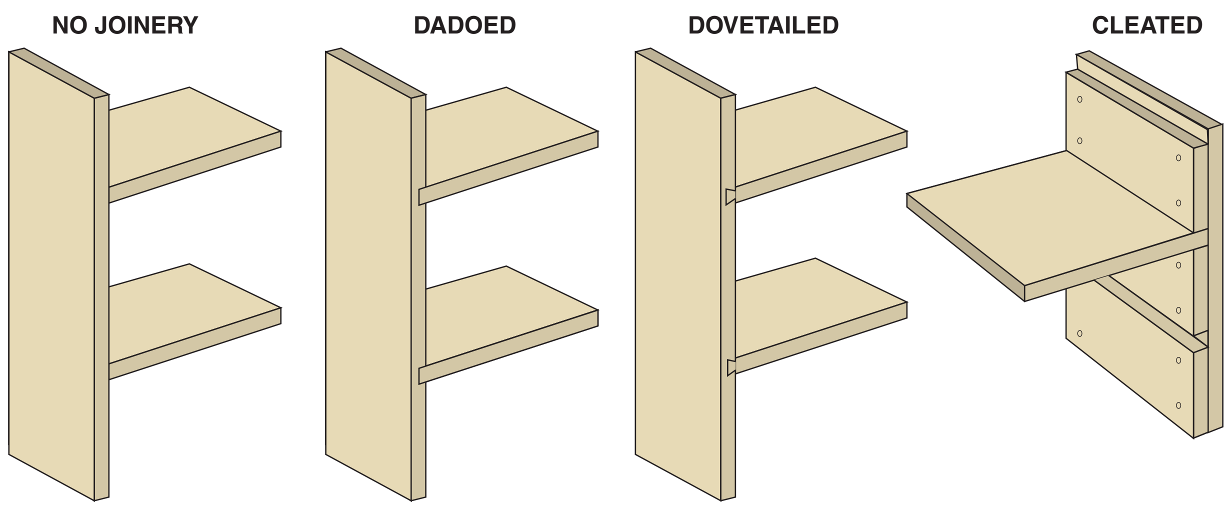
[1] Shelves freely supported at ends and at midpoint. Span refers to distance between an end and the midpoint, not the total shelf length.

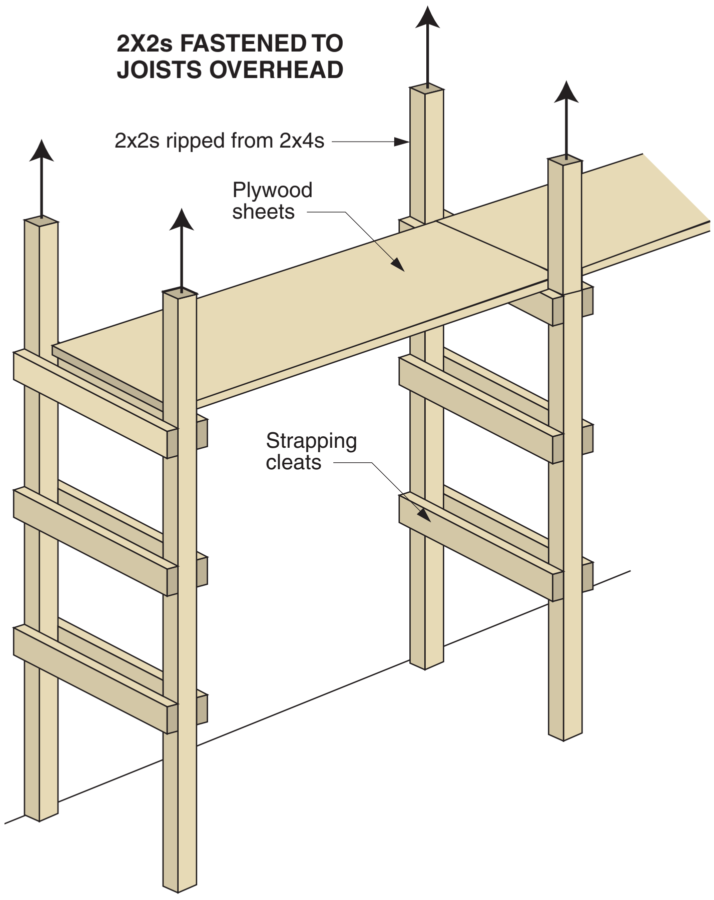
[2] Maximum span limited by deflection of 1/240 (deflection = length between supports divided by 240).

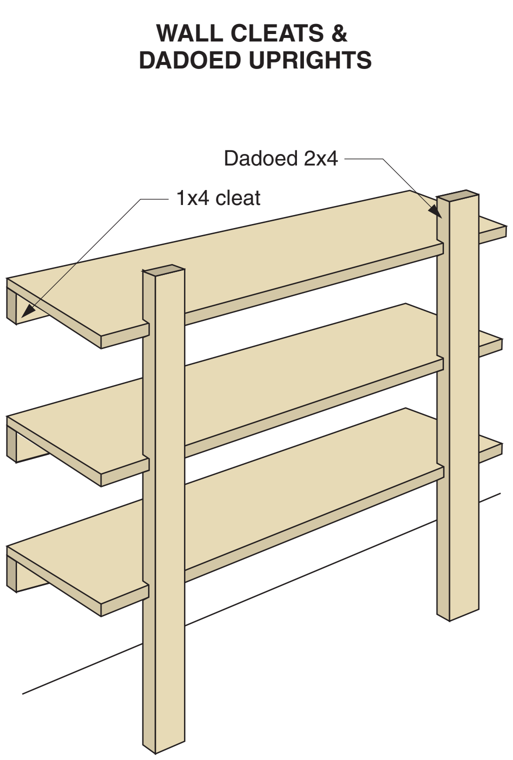
[3] Assumed Moduli of Elasticity: Particleboard = 0.32×10^6, Medium Density Fiberboard = 0.35×10^6, AC Plywood = 0.33×10^6, Eastern White Pine = 1.1×10^6, Red Oak = 1.6×10^6.

[4] Shelves may extend up to 6″ beyond end supports.

Fixed Shelving

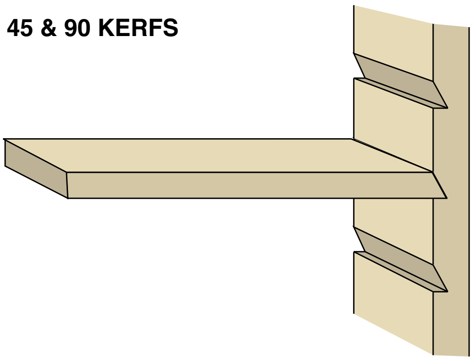




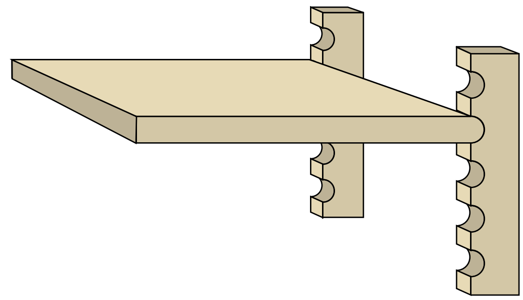


Adjustable Shelving

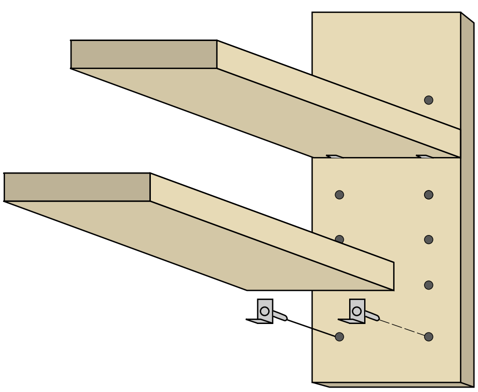
45 & 90 KERFS



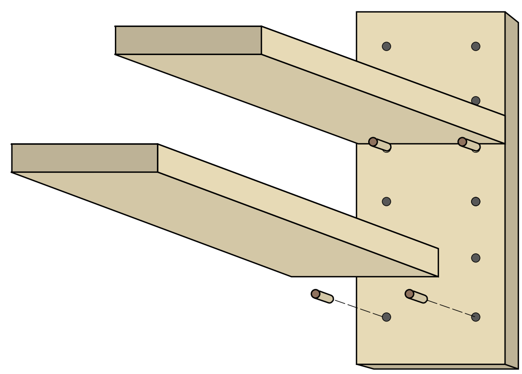
SPLIT 2X4 WITH 7/8" HOLES



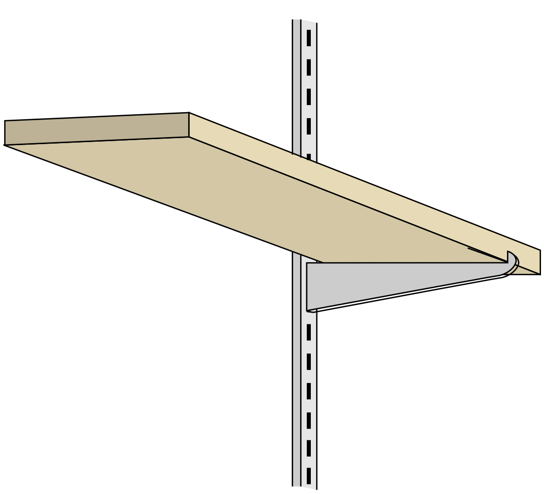
SHELF SUPPORTS



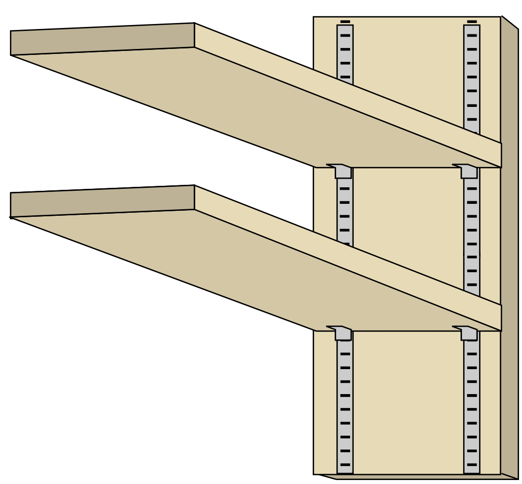
DOWELS



STANDARD & BRACKETS



PILASTERS & CLIPS



18

Heating

Americans have learned that energy supplies can no longer be taken for granted. No longer is the heating system a neglected, mysterious object in the nether regions of our homes that we try not to think about. Winter comfort requires that we have the right type of heating system, properly sized to the *building heat load*.

This chapter begins with a simple form for calculating heat loads, both for the coldest day of winter and for the entire winter.

Next, you'll learn how various *heat sources* (burners) and *distribution systems* work and the pros and cons of each.

Most of us have considered switching fuels at some time. Some of us supplement our main heating systems with wood stoves. *Fuels and efficiencies* gives you a simple method for comparing the cost per delivered Btu of all fuels and a chart that shows the percentage fuel savings from installing a more efficient system.

Fireplaces are notoriously inefficient, but if you are going to have a fireplace, you need to built it right. We show *fireplace construction* details that work.

For others, a wood stove is a more practical alternative to the fireplace. *Wood stove installation* and *Stovepipe installation* show the fire code requirements for stove and stovepipe clearances. Also shown is how to vent a wood stove into an existing fireplace.

If you don't already have a sound and safe masonry flue, the section on *metal prefabricated chimneys* will be helpful, showing every detail of six typical installations.

Finally, we provide you with a checklist so you can *meet the code (IRC)* requirements relating to heating.

Building Heat Loads

In designing a building and its equipment, we are interested in two types of heat load (rate of heat loss):

Design Heat Load This is the rate at which heat is lost from the building in British thermal units (Btu) per hour on that coldest night when the outside temperature is at the design minimum temperature (DMT) for the location. The number is used to size the heating system.

Annual Heat Load This is the annual heat load, the total heat loss in Btu over the entire heating season. The quantity can be used to estimate the annual heating bill in dollars.

Use the work sheet on the facing page to estimate both of these loads for your home. A completed example work sheet follows on p. 529.

Work Sheet Instructions

Line 1. Use line 1 if you have an unheated attic. Find the R-value in Chapter 13, or use a value of 3.0 if the attic is totally uninsulated.

Line 2. Use line 2 if the ceiling is also the underside of the roof. Get the R-value from Chapter 13, or use 3.0 if the roof is uninsulated.

Line(s) 3. Get the wall R-values from Chapter 13, or use 4.0 if the wall is uninsulated. If there are different wall constructions, use a different line for each type. Subtract window and door areas from each wall section.

Line(s) 4. The area of most exterior doors is 20 square feet. Use an R-value of 2.0 for solid wood doors, 3.0 for a wood door plus storm door, and 6.0 for an insulated door.

Line(s) 5. Window area is the area of the sash, not just the glazing. A window's R-value is simply 1/U, where U is the window's U-value. Find your windows' U-values from the very complete table of tested U-values on p. 293.

Line 6. Use this line if your home, or a portion of it, sits on piers or over a ventilated crawl space. Get the floor R-values from Chapter 13, or use 5.0 if the floor is uninsulated.

Line 7. Use this line if your home sits on a concrete slab. Use an R-value of 20 if the slab is uninsulated. To that, add the R-value of any added insulation.

Line 8. Use this line if your home has a basement. Use an R-value of 5.0 if the foundation is uninsulated. Add the insulation R-value (from Chapter 13) if the walls are insulated.

Line 9. For air changes per hour, use 1.5 for an older drafty house, 0.75 for a typical 10- to 30-year-old house, 0.50 for an average new house, and 0.25 for a new "green" or "energy-efficient" house. Heated volume is 8× the heated floor area.

Line 10. Add up all of the numbers appearing in the right-hand column above this line.

Line 11. First enter the sum from line 10. Next enter 65 minus the design minimum temperature ($DMT_{97.5\%}$) from the map on p. 42 or the table on p. 295. Multiply the entries and enter the result in the right column. Your heating contractor can use this result to properly size your heating system.

Line 12. Enter the sum from line 10. Next find heating degree-days, base 65°F, (HDD_{65}) from either the map on p. 42 or the table of climate data on p. 295. Multiply the entries. The result is the total annual heat loss.

To estimate the amount of fuel used, divide this number by 100,000 for gallons of oil; 70,000 per hundred cubic feet of gas; 3,410 for kilowatt-hours (kWhr) of electric-resistance heat; and 6,830 for an electric heat pump. (You will see how to adjust for other heating system efficiencies on p. 540.)

HDD_{65} is used with the assumption that the house requires heat when the daily average outdoor temperature drops below 65°F. If your house generates a lot of internal heat, or retains internal heat gains well, the heat may not come on until the outdoor temperature drops to 55°F, for example. In that case, use HDD_{55} from the table.

Work Sheet for Heat Loads

Surface	Area, sq ft	÷	R-value	=	Result
1. Ceiling under attic #1	______	÷	______	=	______
Ceiling under attic #2	______	÷	______	=	______
2. Cathedral ceiling or roof#1	______	÷	______	=	______
Cathedral ceiling or roof#2	______	÷	______	=	______
3. Exterior wall #1	______	÷	______	=	______
Exterior wall #2	______	÷	______	=	______
Exterior wall #3	______	÷	______	=	______
Exterior wall #4	______	÷	______	=	______
Exterior wall #5	______	÷	______	=	______
Exterior wall #6	______	÷	______	=	______
4. Exterior door #1	______	÷	______	=	______
Exterior door #2	______	÷	______	=	______
Exterior door #3	______	÷	______	=	______
5. Window type #1	______	÷	______	=	______
Window type #2	______	÷	______	=	______
Window type #3	______	÷	______	=	______
Window type #4	______	÷	______	=	______
6. Floor over crawl space	______	÷	______	=	______
7. Slab on-grade	______	÷	______	=	______
8. Foundation wall	______	÷	______	=	______
9. Air changes per hour ______	× 0.018 × heated volume in cu. ft.		______	=	______
10. Sum of results of all lines above				=	______
11. **Design heat load**: Line 10 ______	× ______		(65°F - DMT)	=	______ Btu/hour
12. **Annual heat load**: Line 10 ______	× 24 × ______		HDD_{65}	=	______ Btu/year

Building Heat Loads—*Continued*

The facing page contains an example work sheet showing the calculations for design heat load and annual heat load for the small house in Boston, MA, shown below.

The house is deliberately kept simple in order to clarify the calculations. Many homes will have more than one type of exterior wall, foundation, or window, and they will require multiple entries for these items.

Line 1. The ceiling measures 30 × 40 feet, so its area is 1,200 square feet. Chapter 13 gives an R-value of 35.5 for its two R-19 batts.

Line 3. After the areas of windows and doors are deducted, the remaining area of exterior wall is 996 square feet. The 2×6 wall with R-19 batts has an R-value of 17.2.

Line 4. The first exterior door is solid wood with storm and has a combined R-value of 3.0. The second has an insulated core and R-value of 6.0.

Line 5. All of the windows are double glazed without storm windows (total R-value of 2.0). The total area of window sash is 84 square feet.

Line 6. The house sits on a crawl space that is ventilated in winter and is insulated with R-19 batts between the joists. Chapter 13 gives this type of floor an R-value of 20.9.

Line 9. The house is a recently built tract home, so its air change rate is about 0.50 changes per hour. The heated volume is the floor area times the ceiling height, 8 feet.

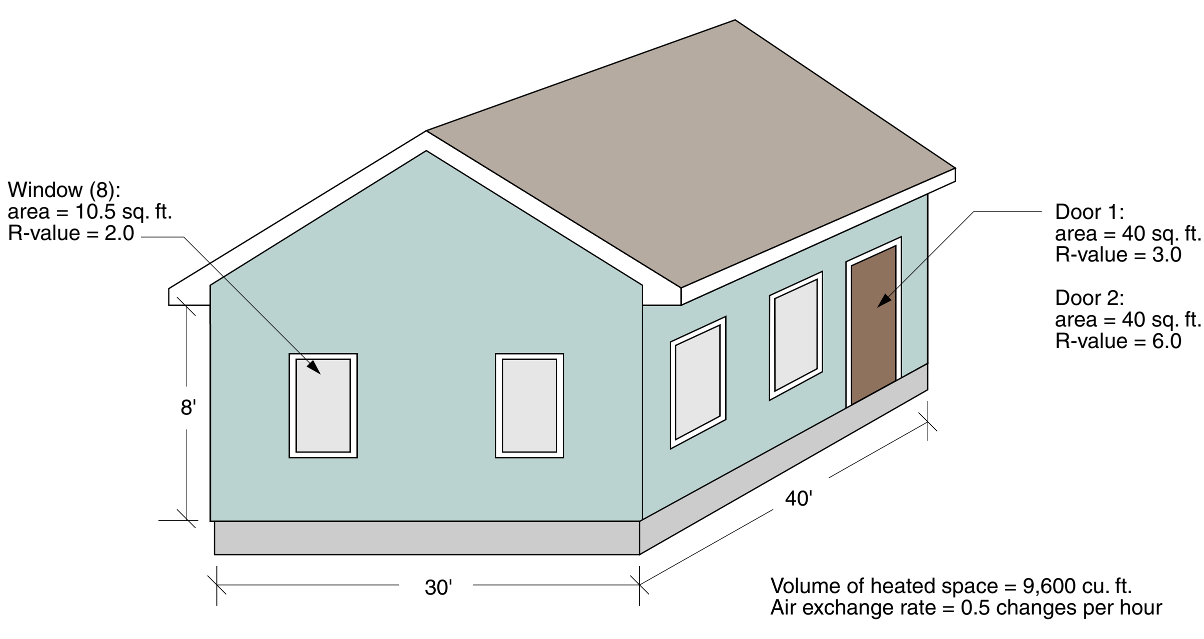
Line 10. The sum of all of the results in the right column is 287.5.

Line 11. From the table following the example work sheet, $DMT_{97.5\%}$ is 9°F for Boston. The result for this line is a design heat load at 9°F of 16,100 Btu per hour.

Line 12. From the same table, for Boston the HDD_{65} = 5,630. The result of multiplying the three numbers on line 12 is the annual heat load: 38,847,000 Btu.

If the house were heated with oil, the approximate winter fuel consumption would be the annual heat load divided by 100,000, or 388 gallons of oil.

Example House for Heat Load Calculation



Work Sheet for Heat Loads

Surface	Area, sq ft	÷	R-value	=	Result
1. Ceiling under attic #1	1,200	÷	35.5	=	33.8
Ceiling under attic #2		÷		=	
2. Cathedral ceiling or roof #1		÷		=	
Cathedral ceiling or roof #2		÷		=	
3. Exterior wall #1	996	÷	17.2	=	57.9
Exterior wall #2		÷		=	
Exterior wall #3		÷		=	
Exterior wall #4		÷		=	
Exterior wall #5		÷		=	
Exterior wall #6		÷		=	
4. Exterior door #1	20	÷	3.0	=	6.7
Exterior door #2	20	÷	6.0	=	3.3
Exterior door #3		÷		=	
5. Window type #1	84	÷	2.0	=	42.0
Window type #2		÷		=	
Window type #3		÷		=	
Window type #4		÷		=	
6. Floor over crawl space	1,200	÷	20.9	=	57.4
7. Slab on-grade		÷		=	
8. Foundation wall		÷		=	
9. Air changes per hr 0.50	× 0.018 × heated volume in cu. ft.		9,600	=	86.4
10. Sum of results of all lines above				=	287.5

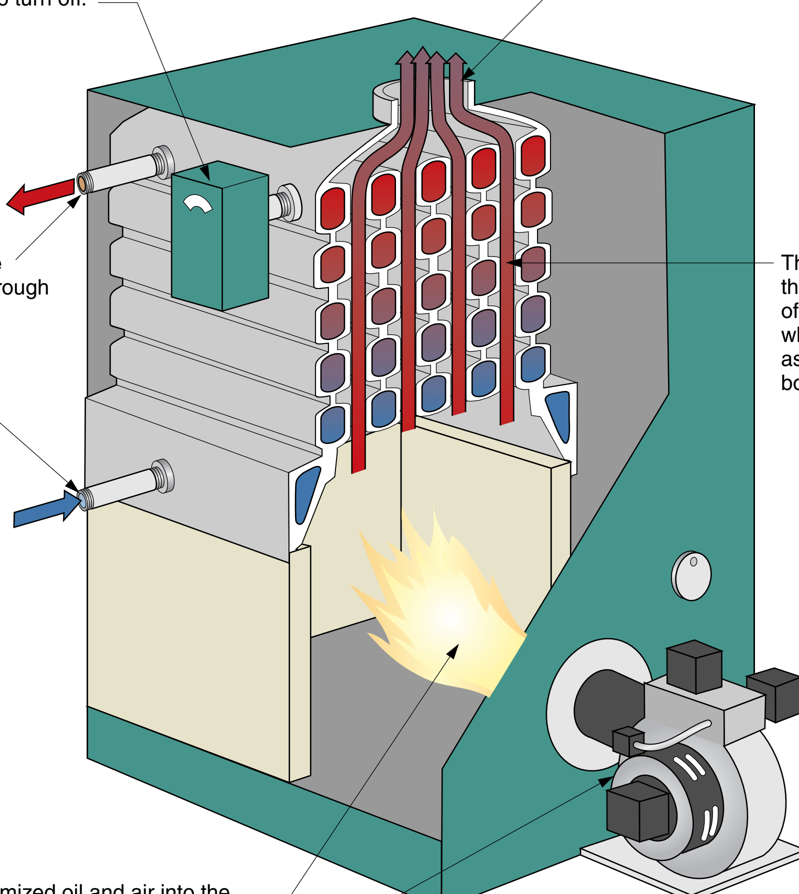
11. **Design heat load**: Line 10 287.5 × 56 (65°F – DMT) = 16,100 Btu/hour

12. **Annual heat load**: Line 10 287.5 × 24 × 5,630 HDD_{65} = 38,847,000 Btu/year

Heat Sources

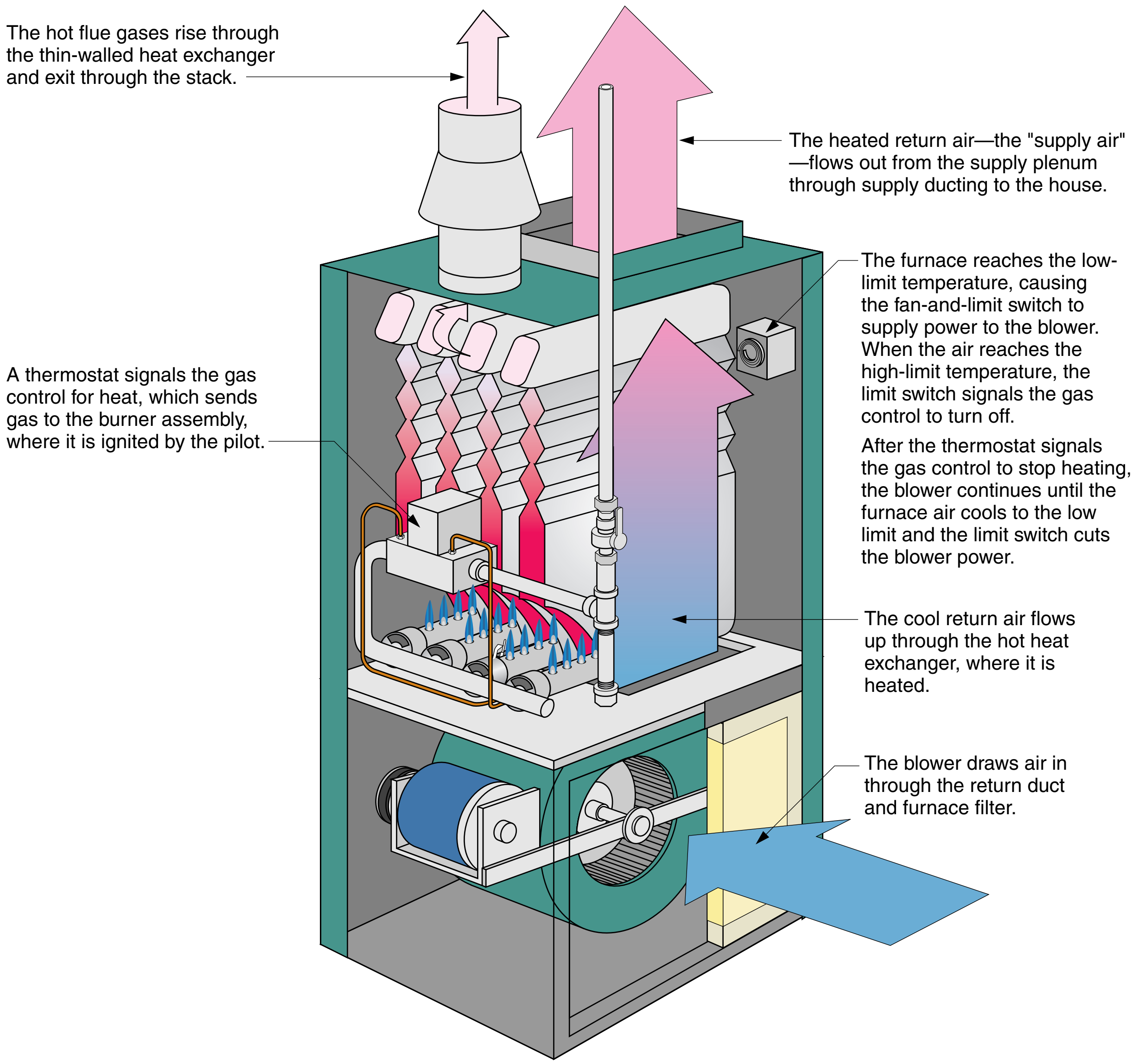
The hydronic, or forced-hot-water, system heats water in a gas or oil boiler and circulates it through loops of pipe to distribute heat to separate heating zones. Annual fuel utilization efficiencies (AFUEs) are similar to those of furnaces: about 85 percent for high-efficiency models and about 90 percent for condensing boilers. Pros include even heating, ease of zoning with separate thermostats, and small, easy-to-conceal pipes. Cons include no air cleaning or humidification and no sharing of ducts with central air-conditioning.

An Oil-Fired Hydronic Boiler



The first furnaces distributed heat by natural convection of buoyant heated air through large ducts. The modern warm-air furnace is a great improvement. Heat is produced by clean and efficient combustion of gas or oil, and the warm air is distributed evenly throughout the building by a blower, supply and return ducts, and registers. AFUEs average about 84 percent for high-efficiency furnaces and 93 percent for condensing furnaces. Pros include circulation and filtration of air, humidification and dehumidification, possible integration with heat exchangers, and ductwork that can be shared with air-conditioning. Cons include bulky, hard-to-conceal ducts, noise at high air velocity, and sound transmission between rooms.

A Gas Warm-Air Furnace



Direct-vent heaters require no chimney flue. Instead, the hot combustion gas exhausts through an inner pipe that is cooled by outside supply air entering through a concentric outer shell. The supply air is warmed, while the combustion gas is cooled.

Here is how a direct-vent gas stove works:

1. The pilot flame is first ignited by clicking a spark generator. This pilot flame remains lit throughout the heating season.

2. The fire can be turned on and off either manually or by a thermostat. The thermostat sends a voltage to the gas control to supply gas and light the fire.

3. Hot flue gases rise and exit through the inner cylinder of the double-wall pipe.

4. Combustion air is drawn in through the outer cylinder, cooling the double-wall pipe and becoming preheated.

5. A second thermostat senses the temperature rise in the enclosing chamber and activates a fan to circulate the warm air to the room.

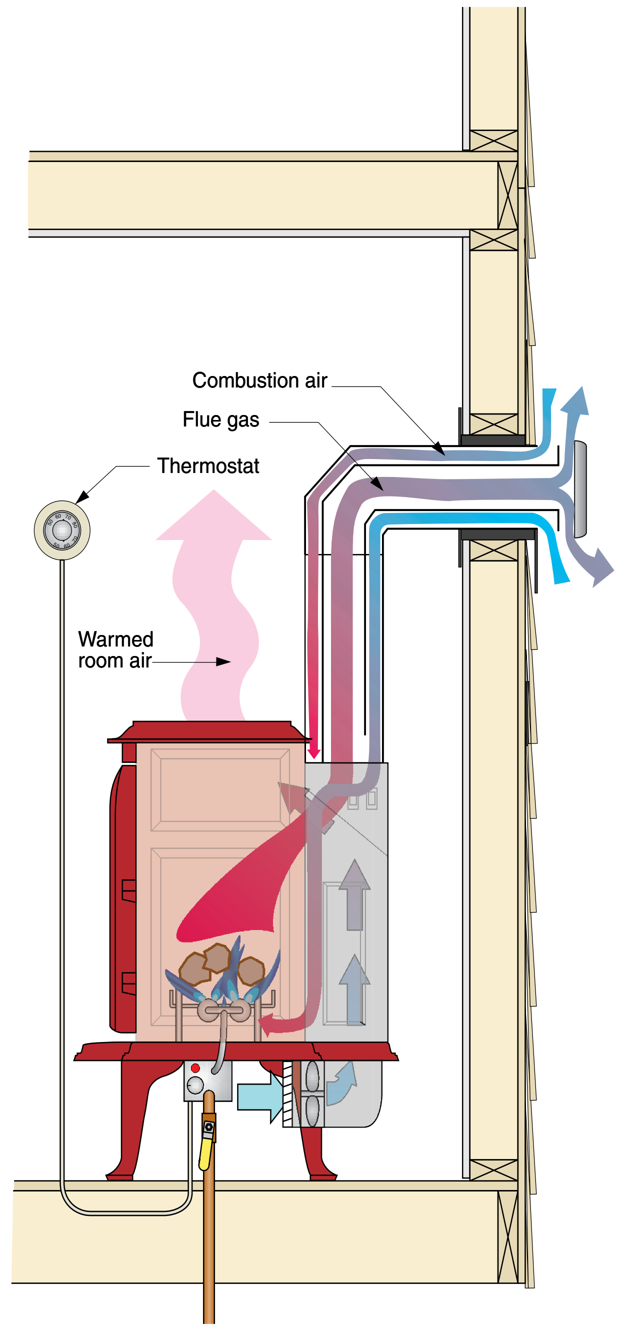
6. The double-walled pipe is so well insulated and cooled by the inflow of outside combustion air that it can be placed in direct contact with construction materials, eliminating the need for a chimney through the roof.

7. Room air is warmed either through natural convection or by a small fan, as shown in the illustration.

Efficiencies

Because the products of combustion are lost to the outdoors, the latent heat of the water vapor in the flue gas is lost, as well as a portion of the sensible heat in the gases. Efficiencies in most direct-vent stoves run between 80% and 85%.

A Direct-Vent Gas Stove

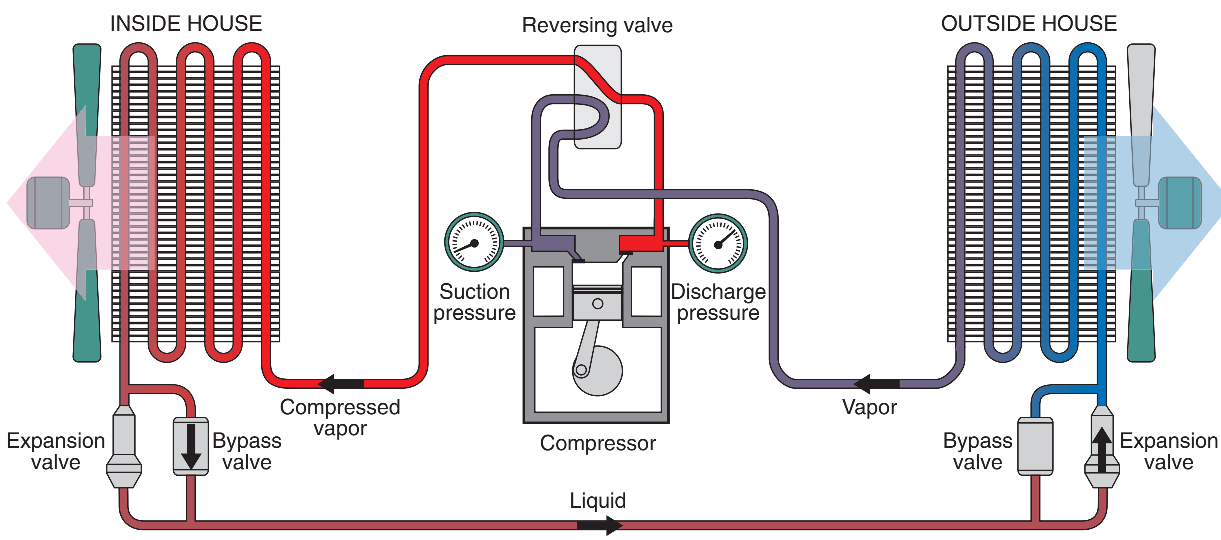


Heat pumps operate on the same principle as refrigerators. By compressing and expanding a gas they can extract heat from a cooler *source* and deliver it to a warmer *sink*. By reversing the pump, you can cool, as well as heat, a house.

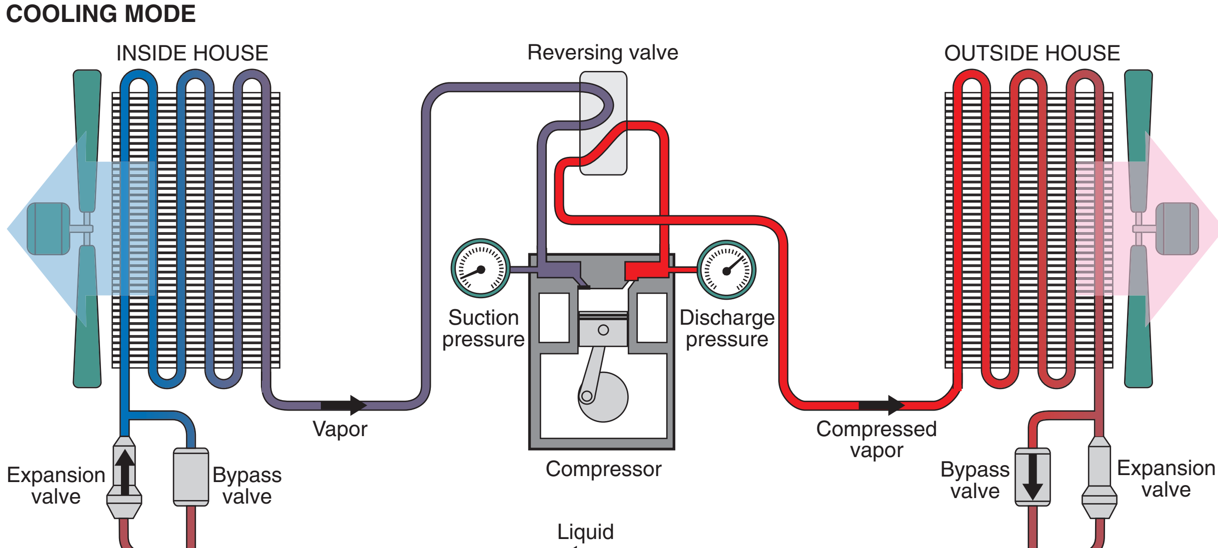
Most heat pumps extract heat from outside air. These air-source heat pumps are most cost-effective in warm regions where air temperature rarely dips below 45°F. For more northern areas, consider more expensive, but more efficient, water-source and ground-source heat pumps. Pros include circulation and filtration of air, humidification and dehumidification, and combined heating and air conditioning. The single disadvantage is high installation cost.

An Air-Source Heat Pump

HEATING MODE



COOLING MODE



Nothing warms the soul like a fireplace with a roaring fire. No method of heating your home is less efficient, either. Even the Rumford fireplace achieves a combustion efficiency of no more than 25%. Having to leave the chimney damper open until all embers are consumed subsequently wastes so much warm air up the chimney that the net efficiency is often less than zero!

Box Stove

A box stove increases efficiency in two ways:

1. Enclosing the fire in a steel or cast-iron box allows control of both the geometry and combustion air.

2. Bringing the fire out of the fireplace and into the room results in greater heat transfer by both radiation and convection. The box stove has an efficiency of 40% to 50%.

Air-Tight Stove

Air-tight joints and a gasketed door give complete control over the amount and location of combustion air. To start the fire, the air intake is opened fully. After the fuel is fully engaged, the air intake is reduced to control the burn rate.

Momentum carries the flue gases to the rear, but a horizontal baffle forces the gases to follow a long “S” path before exiting, transferring much of the gases’ heat to the stove’s cast-iron surfaces.

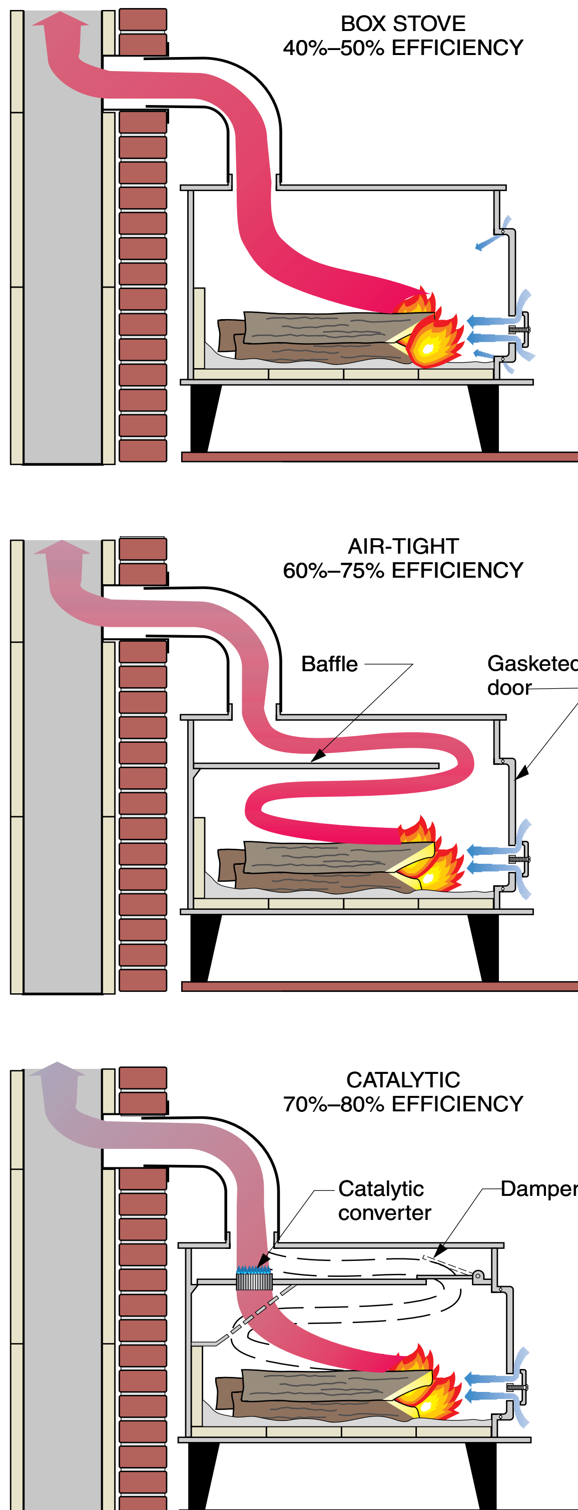
High-quality air-tight stoves achieve an efficiency of up to 75%.

Catalytic Stove

Again, air-tight joints and a gasketed door give complete control over the amount and location of combustion air. To start a fire, the air intake is opened wide. To increase the draft, a damper in the baffle is opened, allowing flue gas an unrestricted path to the chimney.

After the fire is well established, the damper is closed, forcing flue gas to pass through the catalytic converter, lowering the temperature required for combustion and resulting in a secondary burn of volatile gases and efficiencies of 70% to 80%.

Three Wood Stoves & Efficiencies



The pellet stove emulates liquid fuel burners in that the fuel (small compressed pellets of wood fiber) is fed into a small combustion chamber where it is met by just the right amount of combustion air. The result is near perfect combustion. In fact, combustion is so complete and particulate emission so small that the pellet stove is exempt from EPA approval. Due to the complete combustion, efficiencies range from 78% to 85%.

Here is how the pellet stove works:

1. A *pellet hopper* at the top of the stove holds one or more 40-lb. bags of wood pellets.

2. Controlled by a thermostat, a motor-driven *feed auger* forces pellets into the burn pot.

3. The fire in the *burn pot* may be ignited manually or by an automatic electric lighter.

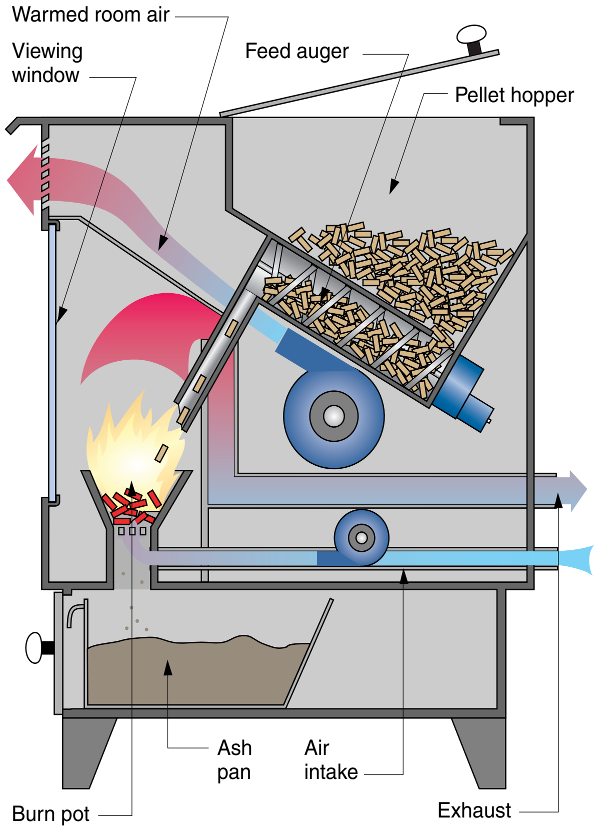
4. Combustion air is forced up through the burn pot grate by a thermostat-controlled fan to burn the pellets.

5. *Exhaust* gases flow around heat exchange tubes, then out to a chimney or stove pipe.

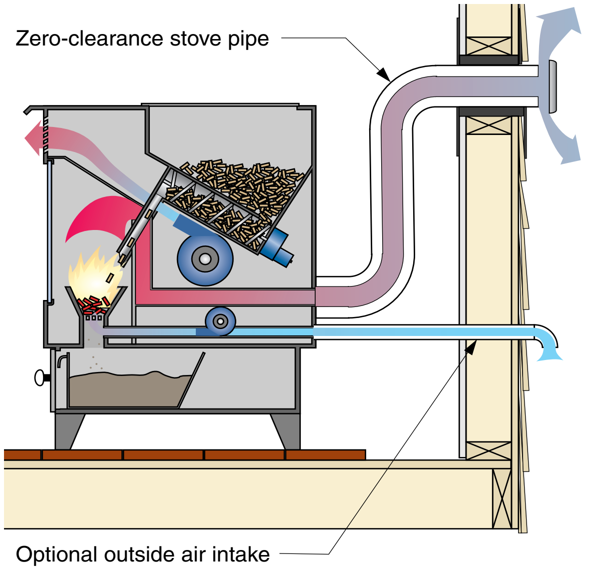
6. A separate fan blows room air through the heat exchanger tubes back into the room.

7. Ashes fall through the burn pot grate into an *ash pan* below. With complete combustion the ash pan requires emptying only after about 50 bags (equivalent to approximately one cord of wood) have been consumed.

Pellet Stoves



Direct Venting a Pellet Stove



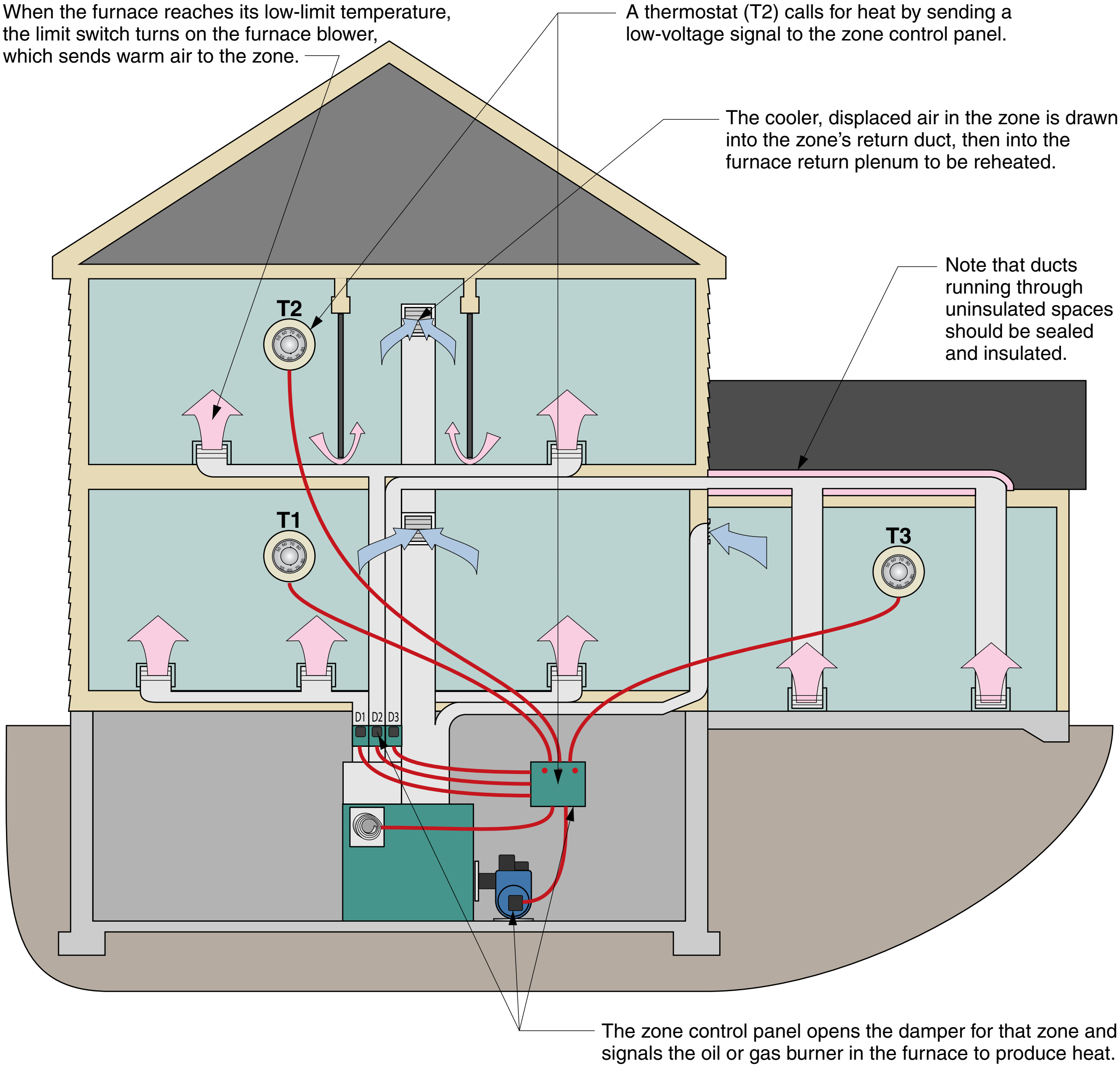
Distribution Systems

Warm-air furnaces are popular because they provide a single system of ducts that can be used for four purposes: heating, cooling, humidity control, and air purification.

A past drawback has been the size of the ducts, but there has recently been a trend toward the use of small, high-speed PVC piping for air delivery. The air speed is reduced at the points of discharge by diffusers.

A future advantage of the warm-air system is the possibility of replacing an original gas or oil furnace with a more efficient heat pump, and of incorporating an air-to-air heat exchanger into the ductwork.

Warm-Air Distribution



In the era of wood and coal stoves—even in the first wood and coal furnaces—heat was distributed by natural convection: simply warm air rising and cooler air falling. The advent of controlled distribution, made possible by forced warm air and forced hot water (hydronic) systems, made temperature control much more precise.

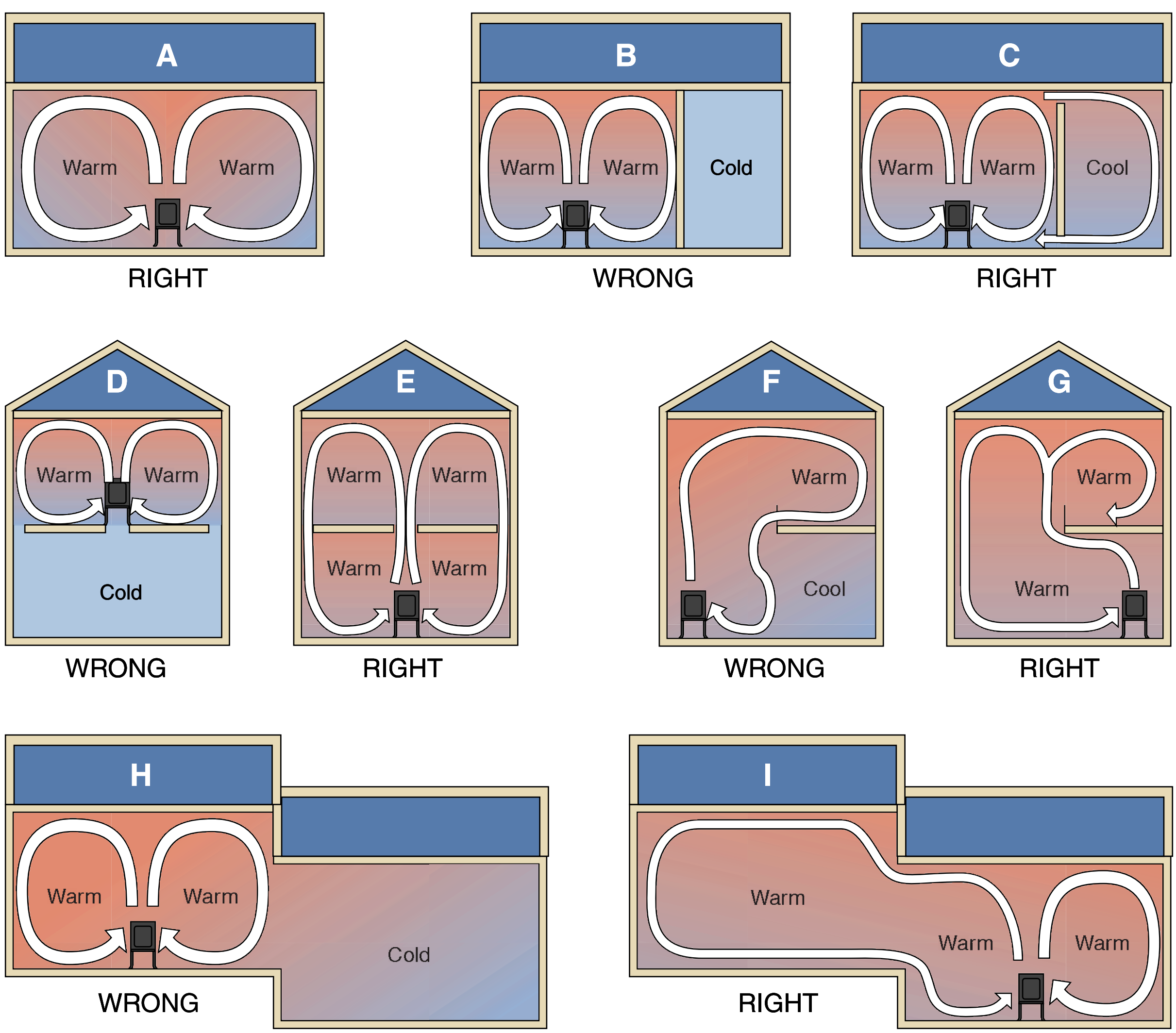
Two developments are bringing natural convection back, however:

1. Increased insulation and air-tightness, resulting in smaller temperature differences throughout the house.

2. Highly efficient wood and wood pellet direct-vent heaters with built-in air circulation.

The illustrations below show the right and wrong placements of freestanding heaters with the goal of uniformity of temperature. In deciding where to locate a heater, just remember, "Hot air rises; cold air falls."

Free Convection

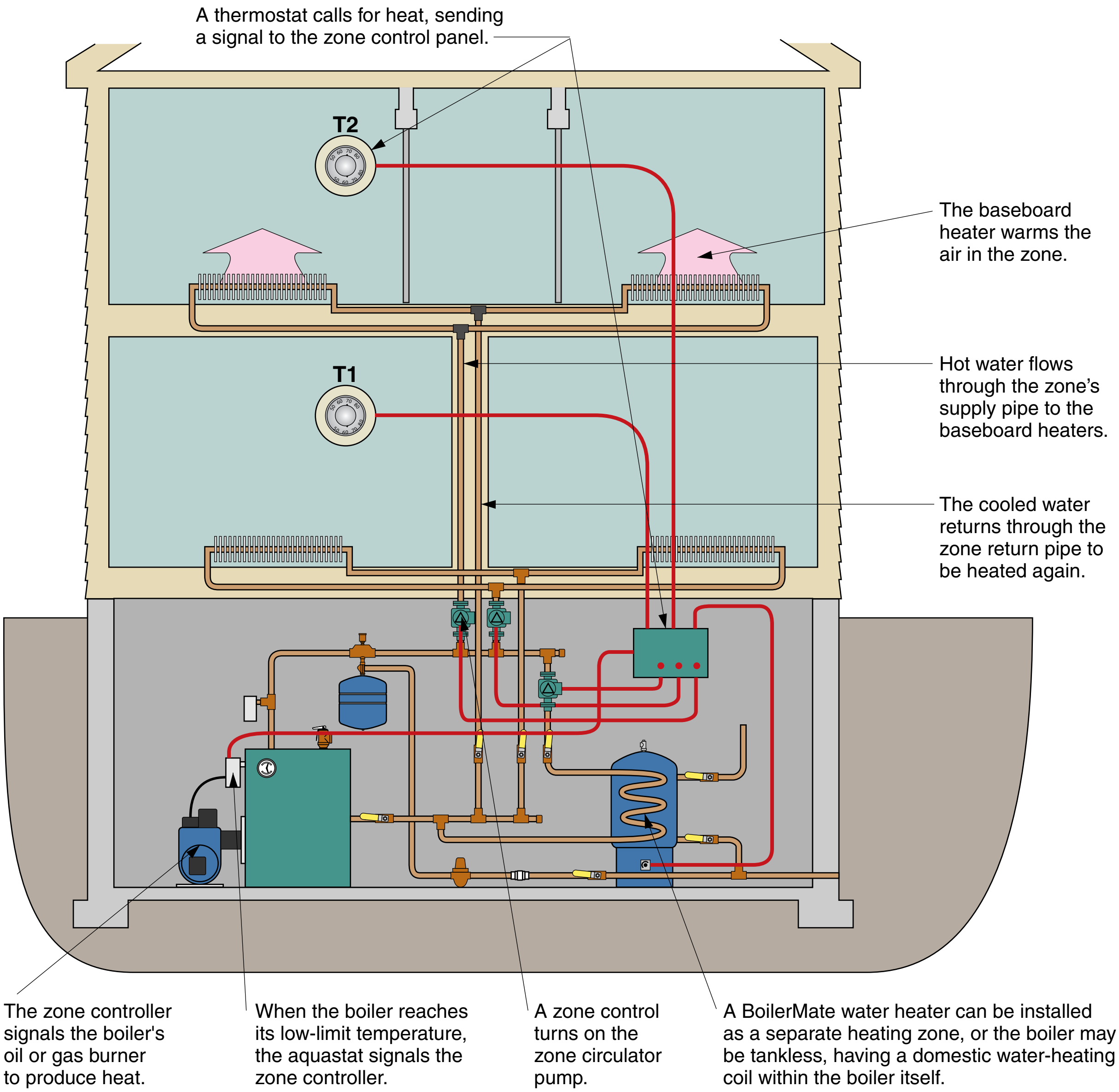


Distribution Systems—*Continued*

Hydronic (forced-hot-water) heating systems are popular because of the ease (relative to warm-air ductwork) of running the delivery and return piping. Creating a separate temperature zone requires only the addition of a thermostat and a small circulator pump.

A recent energy-efficiency improvement is the addition of an indirect water heater (BoilerMate®) as a zone. The highly-insulated, stand-alone tank with heat exchanger reduces both the standby loss of the common water heater and the cycling of boilers incorporating tankless coils.

Hydronic Distribution

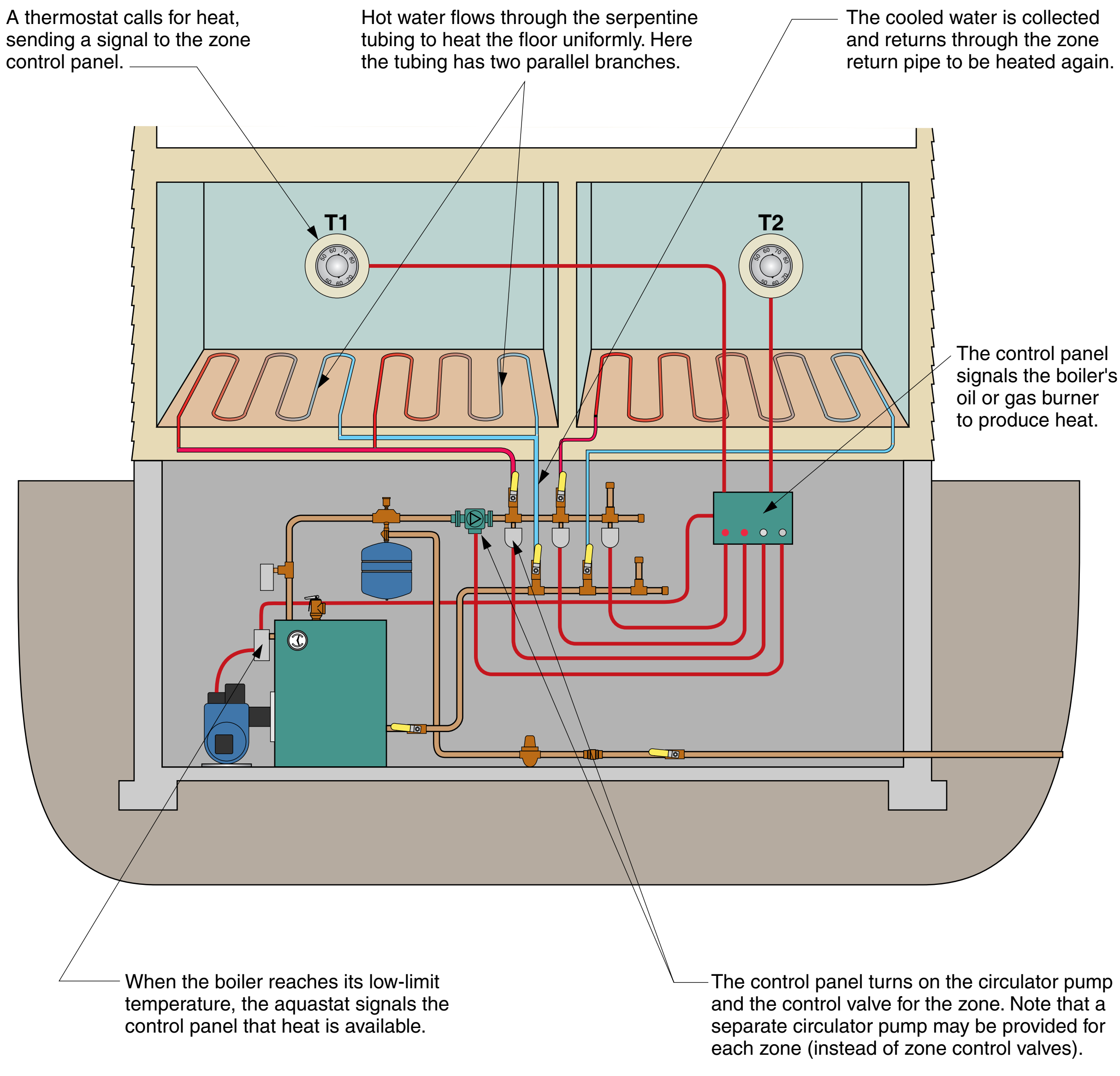


Anyone who has heated with a wood stove realizes that heat travels by radiation, as well as by conduction and convection. Because radiative heat transfer is independent of air temperature, a person receiving radiation can feel comfortable at a lower temperature (think of the effect of the sun).

Proponents of radiant heat cite the energy savings that results from a lowered thermostat and a much more uniform heat distribution.

Radiative piping can be installed in a wood-framed ceiling or floor, or buried in a concrete slab. For good or for bad, slabs have long thermal lag times.

Radiant Heat



Fuels and Efficiencies

The only way to compare heating costs is on an apple-to-apple basis, in this case cost per million Btu of delivered heat:

$$\text{Cost per million } (10^6) \text{ Btu} = \frac{10^8 \times P}{F \times AFUE}$$

where:

P = price of a unit of fuel, $

F = Btu content of the same unit of fuel

AFUE = annual fuel utilization efficiency, percent

The table at right lists the Btu contents of fuels in their usual unit quantities. Wood pellets are packaged in 40-lb bags, but are most often sold by the 50-bag pallet weighing 1 ton.

To simplify calculations even further, the table below shows cost per 10^6 Btu as a function of fuel price only.

Cost per Million Btu Delivered Heat

Fuel	Unit	System AFUE	Price Multiplier
Coal, anthracite	ton	80%	0.042
Electricity			
baseboard or furnace	kWhr	100%	293
heat pump, air-source	kWhr	230%	127
heat pump, ground-source	kWhr	330%	89
Gas, natural			
average. new furnace/boiler	ccf	80%	12.1
condensing furnace/boiler	ccf	93%	10.4
Gas, propane			
average. new furnace/boiler	gal	80%	13.6
condensing furnace/boiler	gal	93%	11.7
Oil			
average. new furnace/boiler	gal	80%	9.0
high-efficiency furnace/boiler	gal	84%	8.6
Wood[1]			
older stove, non-air-tight	cord	40%	0.104
Non-catalytic air-tight	cord	60%	0.069
Catalytic air-tight	cord	70%	0.059
Pellet stove	lb	80%	0.052

[1] Assuming average hardwood at 24.0×10^6 Btu per cord.

Energy Content of Fuels

Fuel		Btu per	Unit
Coal	Anthracite	30×10^6	ton
	Bituminous	26×10^6	ton
	Cannel	22×10^6	ton
	Lignite	22×10^6	ton
Electricity		3,412	kWhr
Gas	Natural	1,030	cu ft
		103,000	ccf
	Propane	91,600	gal
Oil	#1 (kerosene)	134,000	gal
	#2 (residential)	139,000	gal
	#4 (industrial)	150,000	gal
	#6 (industrial)	153,000	gal
Wood, pellets[1,2]	any species	17.0×10^6	ton
Wood, air-dried[3]	Alder	18.9×10^6	cord
	Ash	25.0×10^6	cord
	Aspen	17.5×10^6	cord
	Beech	29.5×10^6	cord
	Birch, white	23.4×10^6	cord
	Birch, yellow	25.8×10^6	cord
	Cedar, red	18.9×10^6	cord
	Cedar, western red	16.4×10^6	cord
	Fir, Douglas	25.0×10^6	cord
	Hemlock, eastern	18.5×10^6	cord
	Hickory	30.6×10^6	cord
	Maple, red	24.0×10^6	cord
	Maple, sugar	29.0×10^6	cord
	Oak, red	24.0×10^6	cord
	Oak, white	30.6×10^6	cord
	Pine, pitch	22.8×10^6	cord
	Pine, white	15.8×10^6	cord
	Poplar	17.4×10^6	cord
	Spruce	17.5×10^6	cord
	Tamarack	23.1×10^6	cord
	Walnut	25.2×10^6	cord

[1] Energy content depends on local wood species.

[2] Moisture content 4%.

[3] "Air-dried" moisture content 12%.

The cost-per-million Btu formula on the facing page can also be used to calculate the savings realized from increasing heating-system efficiency. Provided the type of fuel remains the same, the table below is more convenient because it shows the projected reduction in annual heating bill as a percentage of the existing bill.

Example 1: What savings would be realized on a heating bill of $2,000 by installing a new gas furnace if the AFUE is increased from 65% to 80%? From the table below, the annual savings would be 18.8% of $2,000, or $376.

Example 2: How long would it take for a flame-retention-head burner replacement to pay back its cost if the burner increases the estimated annual efficiency AFUE) of a boiler from 60% to 75%? The present fuel bill is $2,400 per year, and the new burner costs $600. From the table below, the annual savings would be 20% of $2,400, or $480. The $600 cost would be paid back in $600/$480 = 1.25 years. This is equivalent to receiving 80 percent interest on the $600 investment.

Example 3: How long would it take for an $8,500 air-source heat pump to pay for itself if replacing electric baseboard heat, where the present heating bill is $3,200 per year? Consulting the left table on the previous page, we see that the present AFUE (Electricity, baseboard) is 100% and the proposed AFUE (Electricity, air-source heat pump) is typically 230%. From the table below we find that the savings are between 50% and 60%, that is between $1,600 and $1,920. Using an average savings of $1,760, the payback will occur in $8,500/$1,760 = 4.8 years.

Percentage Fuel Savings From Increased Efficiency

From	to AFUE, %												
AFUE, %	60	65	70	75	80	85	90	95	100	150	200	250	300
30	50.0	53.8	57.1	60.0	62.5	64.7	66.7	68.4	70.0	80.0	85.0	88.0	90.0
35	41.7	46.2	50.0	53.3	56.3	58.8	61.1	63.2	65.0	76.7	82.5	86.0	88.3
40	33.3	38.5	42.9	46.7	50	52.9	55.6	57.9	60.0	73.3	80.0	84.0	86.7
45	25.0	30.8	35.7	40.0	43.8	47.1	50.0	52.6	55.0	70.0	77.5	82.0	85.0
50	16.7	23.1	28.6	33.3	37.5	41.2	44.4	47.4	50.0	66.7	75.0	80.0	83.3
55	8.3	15.4	21.4	26.7	31.3	35.3	38.9	42.1	45.0	63.3	72.5	78.0	81.7
60	0.0	7.7	14.3	20.0	25.0	29.4	33.3	36.8	40.0	60.0	70.0	76.0	80.0
65	—	0.0	7.1	13.3	18.8	23.5	27.8	31.6	35.0	56.7	67.5	74.0	78.3
70	—	—	0.0	6.7	12.5	17.6	22.2	26.3	30.0	53.3	65.0	72.0	76.7
75	—	—	—	0.0	6.3	11.8	16.7	21.1	25.0	50.0	62.5	70.0	75.0
80	—	—	—	—	0.0	5.9	11.1	15.8	20.0	46.7	60.0	68.0	73.3
85	—	—	—	—	—	0.0	5.6	10.5	15.0	43.3	57.5	66.0	71.7
90	—	—	—	—	—	—	0.0	5.3	10.0	40.0	55.0	64.0	70.0
95	—	—	—	—	—	—	—	0.0	5.0	36.7	52.5	62.0	68.3
100	—	—	—	—	—	—	—	—	0.0	33.3	50.0	60.0	66.7

Fireplace Construction

The energy-efficient conventional fireplace design, illustrated on the facing page, offers two key advantages over older designs: It uses outside air for combustion, and it cuts down on infiltration of cold air caused by replacement of warm air used for combustion. Both factors increase heating efficiency. To reduce infiltration when the fireplace is not in operation, tight-fitting dampers, louvers, and glass screens should be used.

Air Intake

Combustion air may be drawn from the outside or from any unheated area of the building, such as a crawl space. Building codes may restrict the location of the air intake, however. For example, codes usually prohibit the air being drawn from a garage to prevent the introduction of exhaust gases from automobiles into the house. Regardless of the location of the air intake, it requires a screened closable louver, preferably one that can be operated from inside the house.

To ensure sufficient air, the passageway should have a cross-sectional area of at least 55 square inches. The insulated passageway can be built into the base of the fireplace assembly or channeled between joists in the floor.

The inlet brings the outside air into the firebox. A damper is required for volume and direction control. The damper is located in the front of the firebox, and although its dimensions may vary, most openings will be about $4^1/_2 \times 13$ inches.

The air intake pit, located directly below the inlet, should have the same dimensions and should be about 13 inches deep.

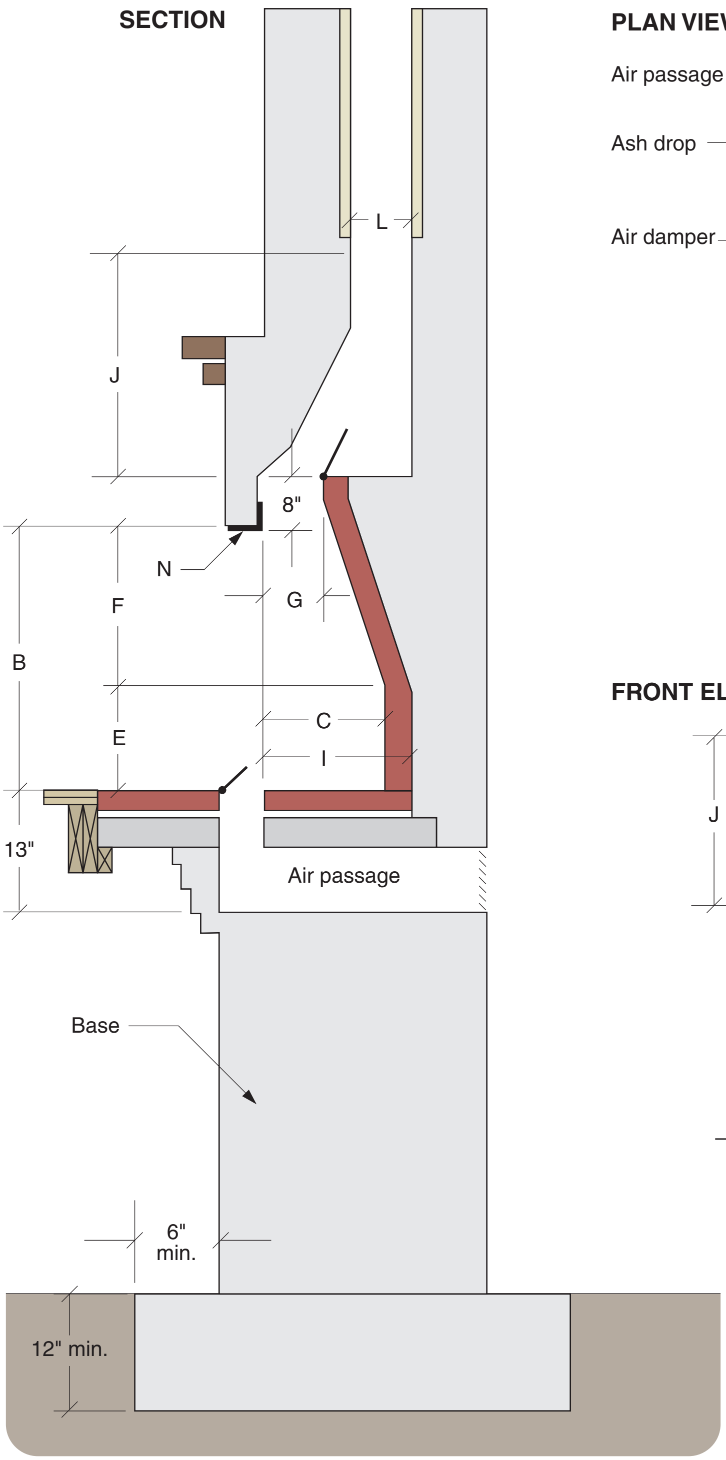
Lintel and Damper

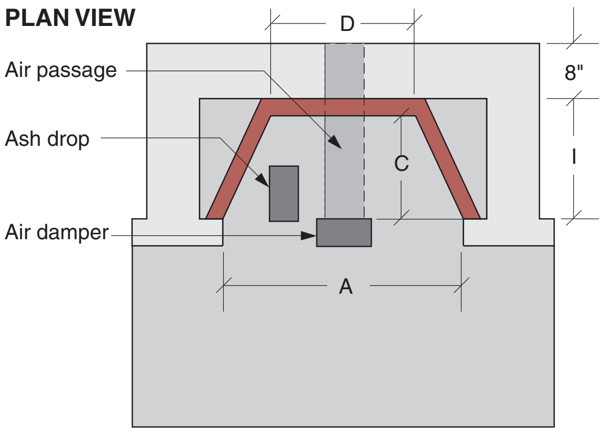
Both the steel lintel and the cast-iron damper assembly should be installed with precautions against thermal expansion damaging the masonry. To this end, a compressible, non-combustible material, such as fiberglass insulation, should be placed between the ends of the lintel and the masonry. Similarly, the damper should not be embedded or bonded to the masonry, but rest on a level mortar setting bed so it is free to expand.

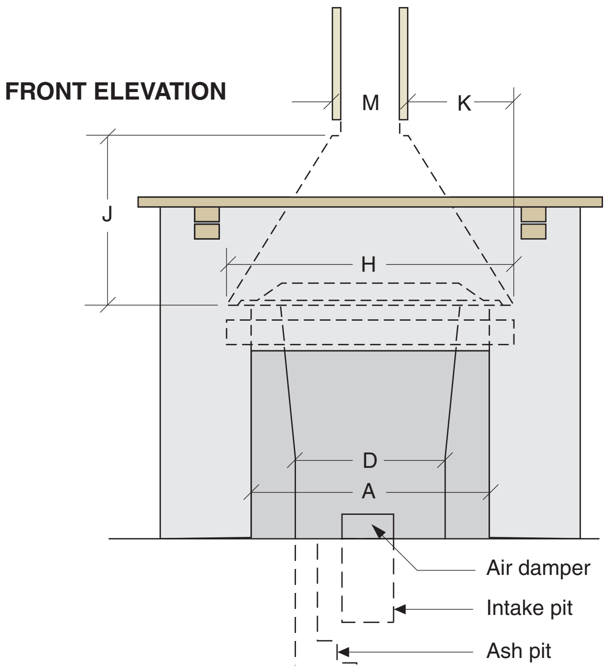
Conventional Fireplace Dimensions (in inches)

Finished Fireplace Opening							Rough Brickwork				Flue Size	Steel Angle
A	B	C	D	E	F	G	H	I	J	K	L × M	N
24	24	16	11	14	16	8¾	32	21	19	10	8 × 12	A-36
26	24	16	13	14	18	8¾	34	21	21	11	8 × 12	A-36
28	24	16	15	14	18	8¾	36	21	21	12	8 × 12	A-36
30	29	16	17	14	23	8¾	38	21	24	13	12 × 12	A-42
32	29	16	19	14	23	8¾	40	21	24	14	12 × 12	A-42
36	29	16	23	14	23	8¾	44	21	27	16	12 × 12	A-48
40	29	16	27	14	23	8¾	48	21	29	16	12 × 12	A-48
42	32	16	29	16	24	8¾	50	21	32	17	12 × 16	B-54
48	32	18	33	16	24	8¾	56	23	37	20	12 × 16	B-60
54	37	20	37	16	29	13	68	25	45	26	16 × 16	B-66
60	40	22	42	18	30	13	72	27	45	26	16 × 20	B-72
72	40	22	54	18	30	13	84	27	56	32	20 × 20	C-84

Conventional Fireplace with Outside Air Supply







Wood Stove Installation

Wood and coal stoves are classified as circulating, radiant, or cookstove. A circulating stove has two walls: an inner wall surrounding the firebox, and an outer wall. Heated air rises, drawing cool air from the floor into the space between the inner and outer walls. Because the air circulates, clearances for this type of stove are less than those needed for a radiant stove.

Much of the heat from the single-walled radiant stove is in the form of infrared radiation. Clearances are greater because the infrared radiation heats combustible materials and changes their composition, lowering the temperature at which they can spontaneously combust. Since the changes are not always evident, proper clearances should be maintained to prevent the possibility of fire.

Stovepipes ordinarily run cooler than the stoves to which they are connected. However, in case of a chimney fire, the stovepipe may temporarily become much hotter than the stove. Significant clearances are therefore specified for stovepipes as well.

Combustible materials include anything that can burn. Examples are the wood box, magazine racks, furniture, draperies, and wood paneling. Even a gypsum-drywalled or plastered wall is combustible since the wood studs behind the surface can burn.

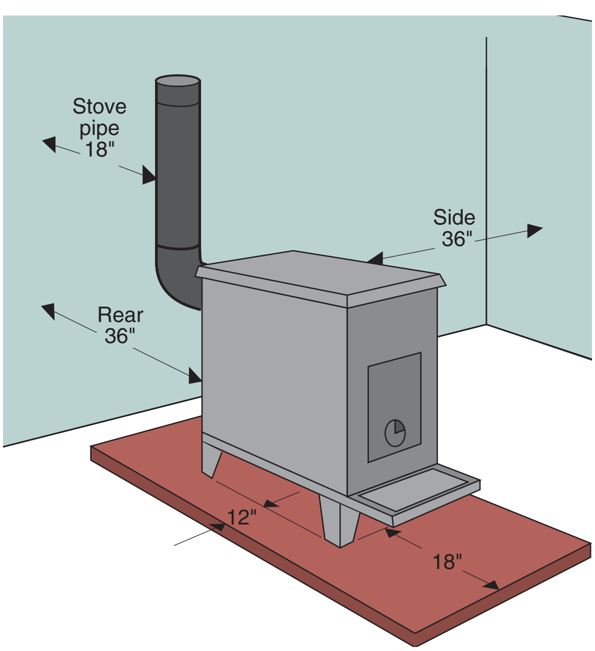
The illustrations below show minimum side and rear clearances for radiant stoves and single-walled stovepipes, both with and without protection of combustible surfaces.

The tables below and on the facing page list more detailed specifications.

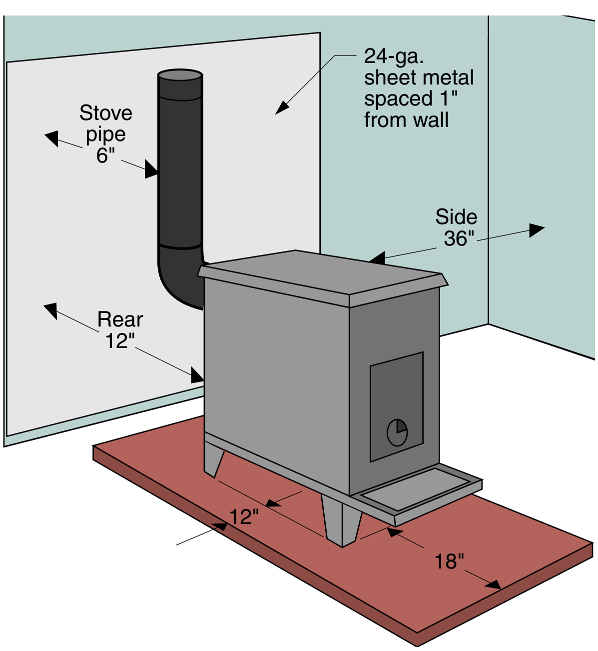
Floor Clearances

Stove Leg	Floor Clearance and Protection
<2"	Fire-resistant floor
2"–6"	Combustible floor protected by 4" of hollow masonry, laid to provide circulation through the masonry layer, covered by 24-ga. sheet metal
>6"	Combustible floor protected by 2"-thick masonry, placed over a sheet of 24-ga. sheet metal

Radiant Stove, No Rear Protection



Radiant Stove with Rear Protection



Minimum Clearances from Wood Burning Stoves to Combustible Surfaces with No Added Protection

Surface	Radiant	System Circulating	Cookstove Clay-Lined Firepot	Cookstove Unlined Firepot	Single-Wall Stovepipe	Listed Stoves
Ceiling	36″	36″	30″	30″	18″	Install according to manufacturer's recommendations
Front	36″	24″	—	—	18″	
Firing side	36″	12″	24″	36″	18″	
Opposite side	36″	12″	18″	18″	18″	
Rear	36″	12″	24″	36″	18″	

Minimum Clearances from Wood Burning Stoves with Specified Forms of Protection, inches[1–6]

	Where Required Clearance with No Protection									
	36		18		12		9		6	
	Use Col.1 above appliance or horizontal connector. Use Col. 2 for clearance from appliance, vertical pipe, and single-wall pipe.									
Type of Protection	Above Col. 1	Sides & Rear Col. 2	Above Col. 1	Sides & Rear Col. 2	Above Col. 1	Sides & Rear Col. 2	Above Col. 1	Side & Rear Col. 2	Above Col. 1	Sides & Rear Col. 2
3½" masonry wall without ventilated air space	—	24	—	12	—	9	—	6	—	5
½"-thick insulation board over 1" glass fiber or mineral wool batts	24	18	12	9	9	6	6	5	4	3
24-ga. sheet metal over glass/wool batts, wire-reinforced, with ventilated air space	18	12	9	6	6	4	5	3	3	3
3½" masonry wall with ventilated air space	—	12	—	6	—	6	—	6	—	6
24-ga. sheet metal with ventilated air space	18	12	9	6	6	4	5	3	3	2
½"-thick insulation board with ventilated air space	18	12	9	6	6	4	5	3	3	3
24-ga. sheet metal with vented space over 24-ga. sheet metal with ventilated air space	18	12	9	6	6	4	5	3	3	3
1" glass/wool batts between two sheets 24-ga. sheet metal with vented air space	18	12	9	6	6	4	5	3	3	3

[1] Reduction of clearances shall not interfere with combustion air, draft hood clearance and relief, and accessibility of servicing.

[2] Clearances measured from surface of combustible material to nearest point on the surface of the appliance.

[3] Spacers and ties to be of noncombustible material. No spacer or tie to be used directly opposite an appliance or connector.

[4] For all clearance reduction systems using a ventilated air space, adequate provision for air circulation shall be provided.

[5] There shall be at least 1" between the appliance and the protector.

[6] All clearances and thicknesses are minimum; larger clearances and thicknesses are acceptable.

Stovepipe Installation

Proper installation of the stovepipe that connects a stove to its chimney is important for both safety and performance. Make sure you observe the following rules:

1. The stovepipe should be as short as possible. Horizontal runs should be no longer than 75% of the vertical chimney height above the connecting thimble.

2. The stovepipe should be as straight as possible. No more than two 90° bends should be used. Additional bends could cause creosote to collect in the stovepipe or chimney, block flue gas flow, and increase the potential for fire.

3. Use a stovepipe that has a diameter as large as the collar where the pipe joins the stove.

4. Horizontal runs should rise ¼ inch per foot, with the highest point at the thimble.

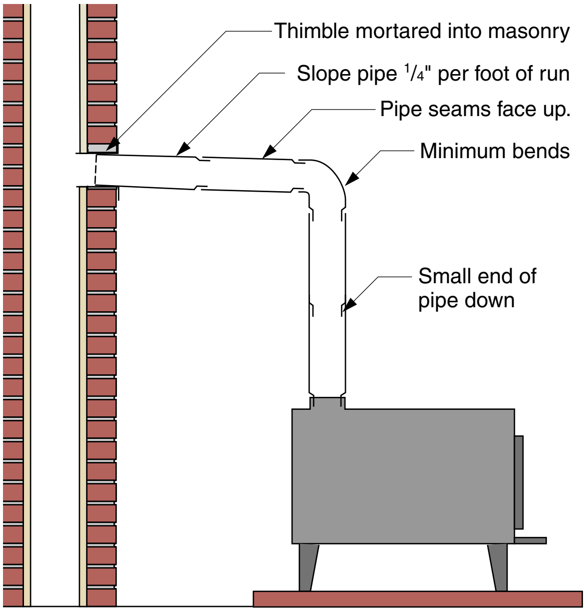
5. When joining stovepipe, overlap the joint at least 2 inches, with the crimped end pointing down to prevent creosote leaks. Secure each joint with three sheet-metal screws. A fireproof sealant (furnace cement) may be used as well.

6. All pipe joints should fit snugly, including connections with the stove and thimble. The pipe should not project into the chimney and hinder the draft.

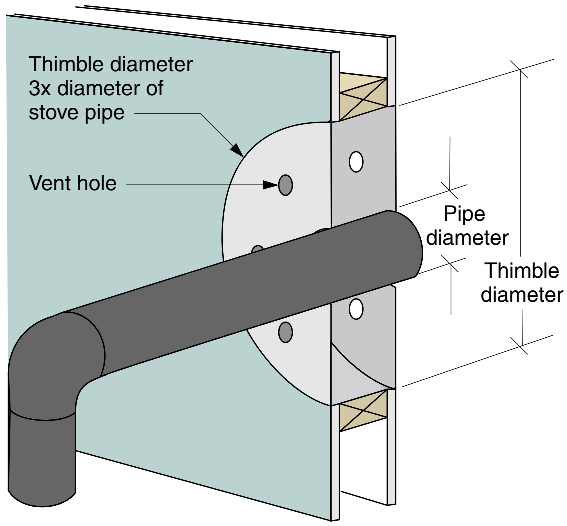
7. The stovepipe should not pass through ceilings. Factory-built, listed, all-fuel chimney should be used for passing through ceilings. Follow the manufacturer's directions.

8. A stovepipe passing through walls must be supported and spaced by vented thimbles of three times the diameter of the pipe. An alternative is a section of factory-built, listed, all-fuel chimney installed as directed.

Connecting to a Masonry Chimney

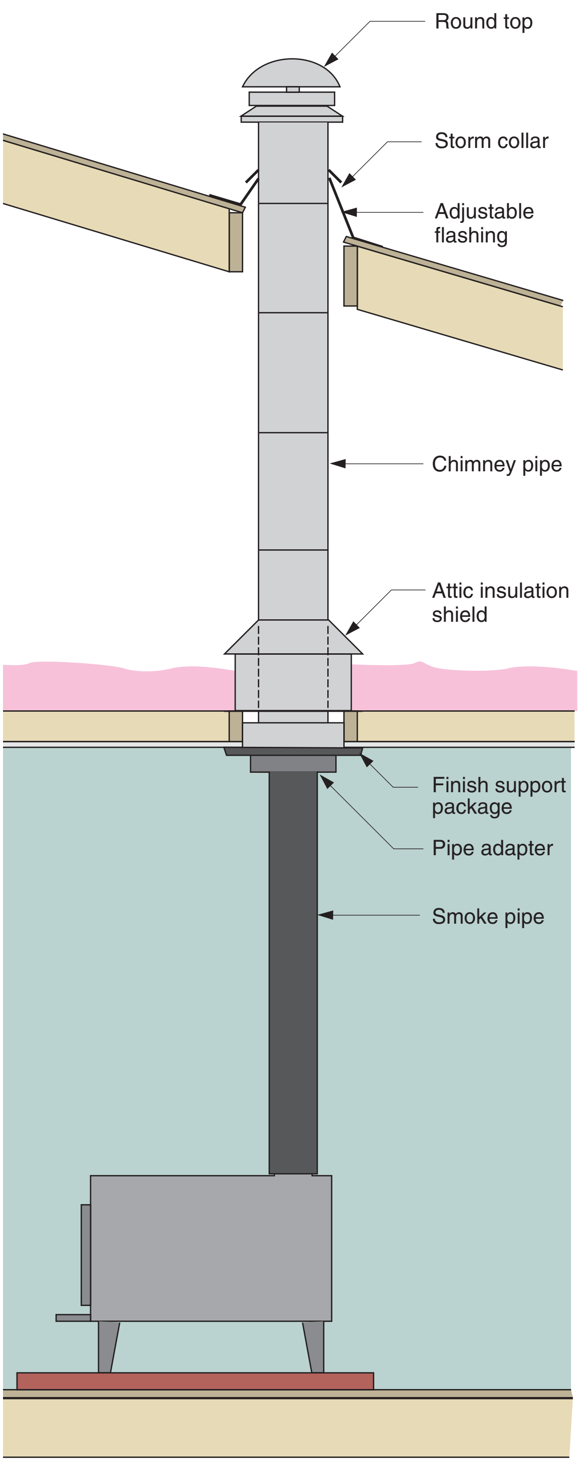


Passing through a Combustible Wall

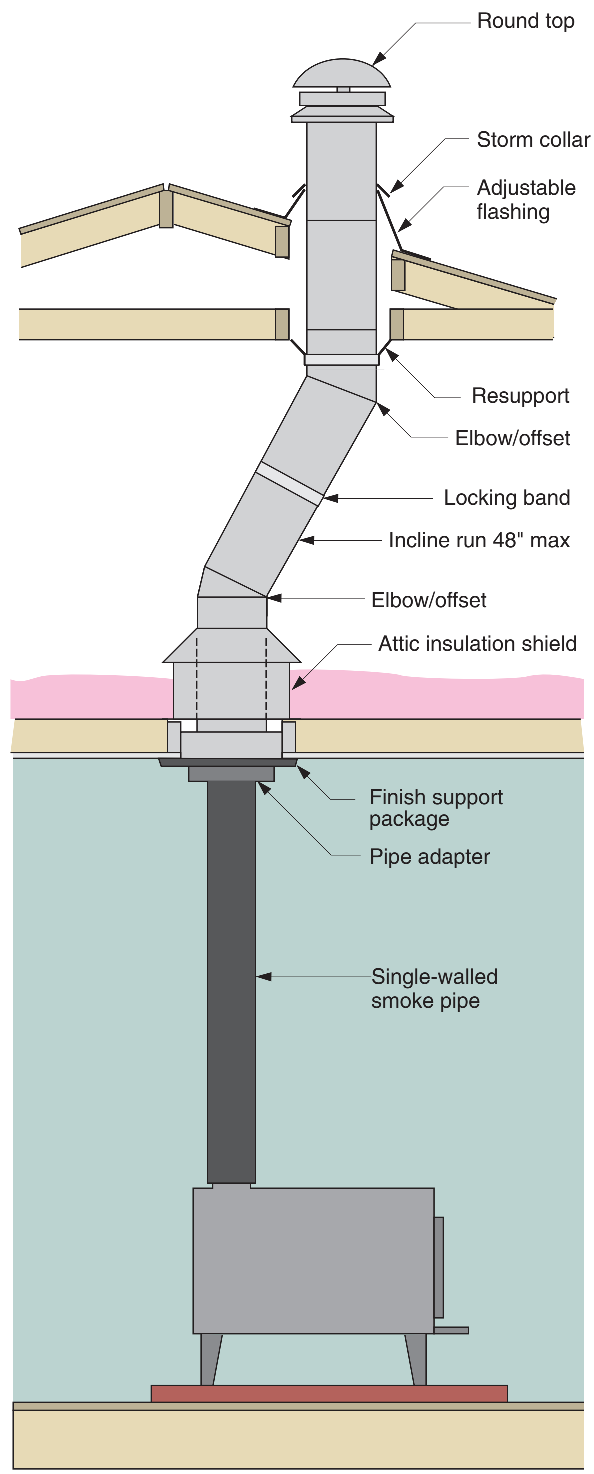


Metal Prefabricated Chimneys

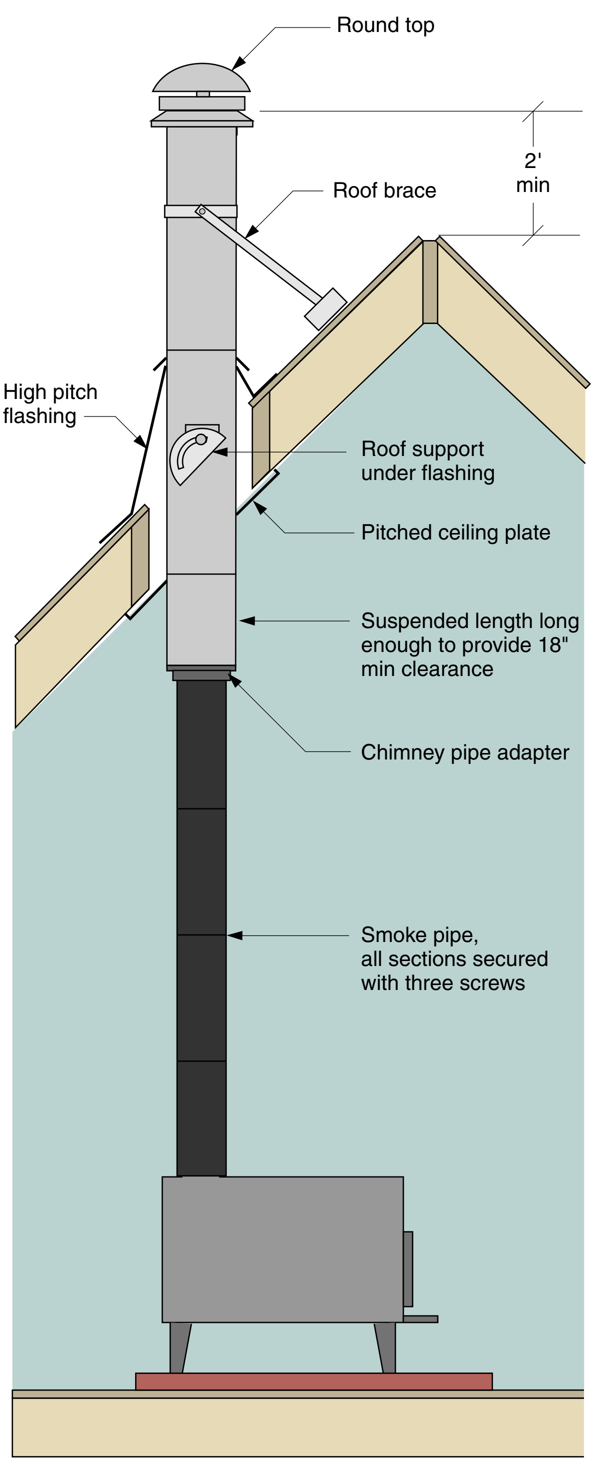
Through Attic Insulation



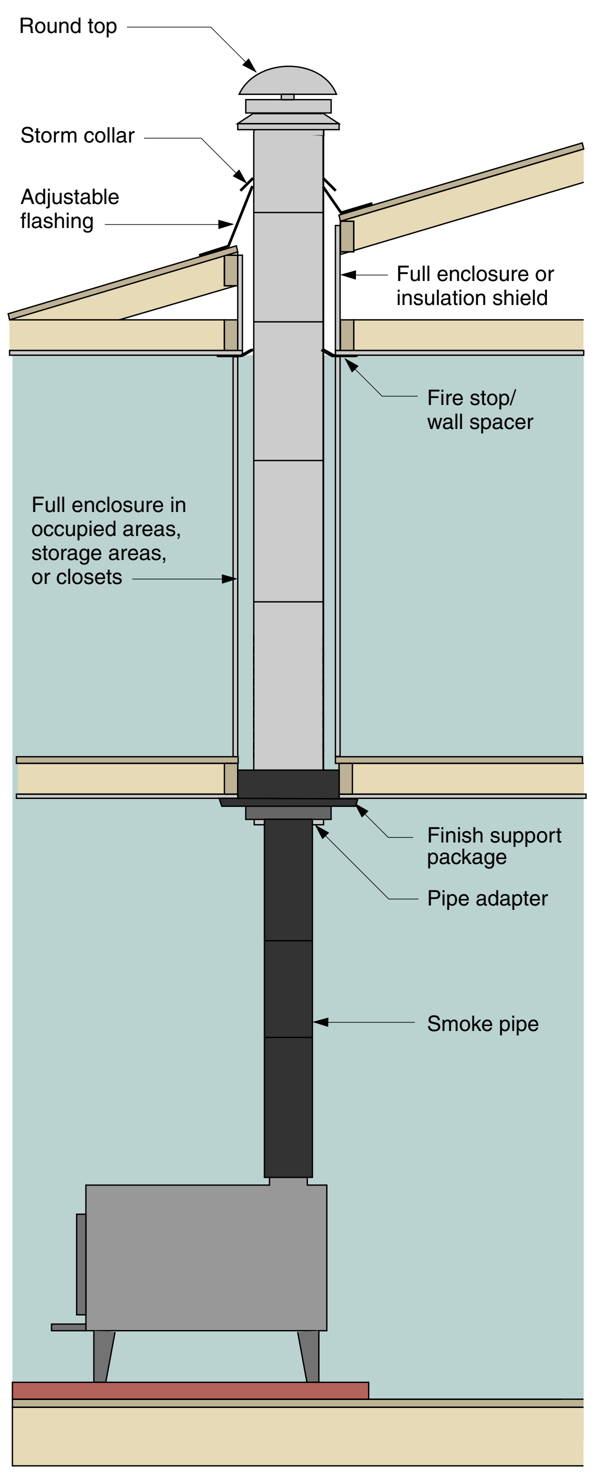
Attic Offset to Avoid Ridge



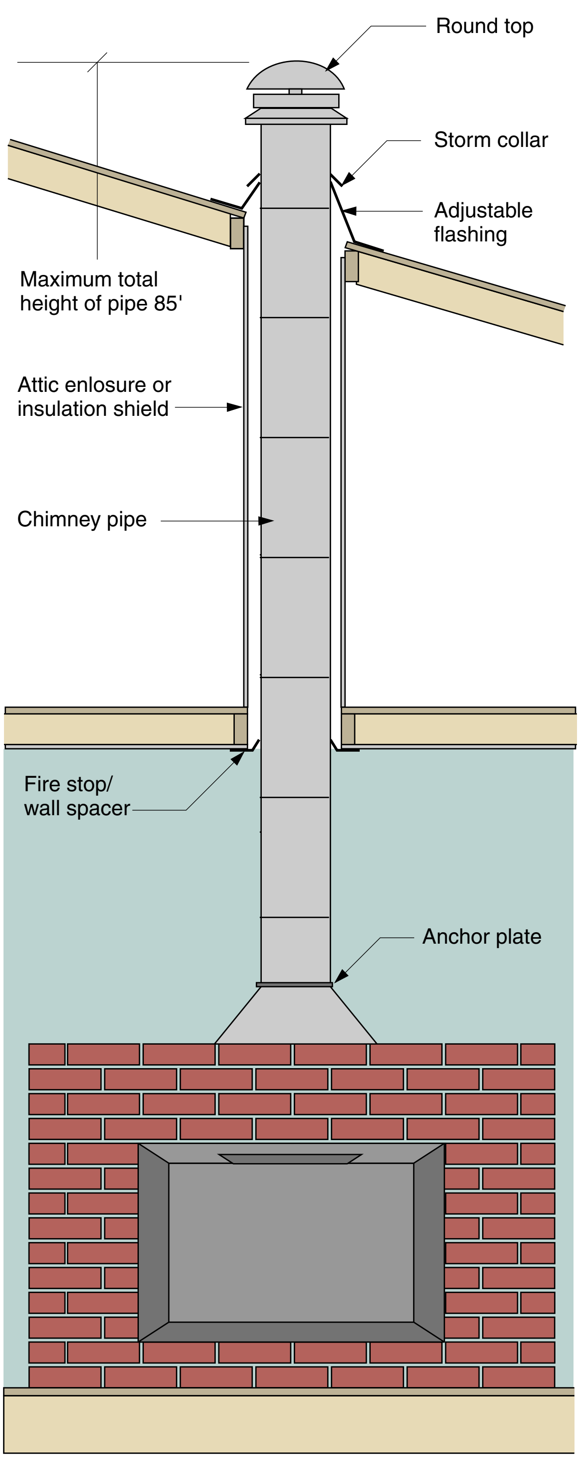
Through a Steep-Pitch Roof



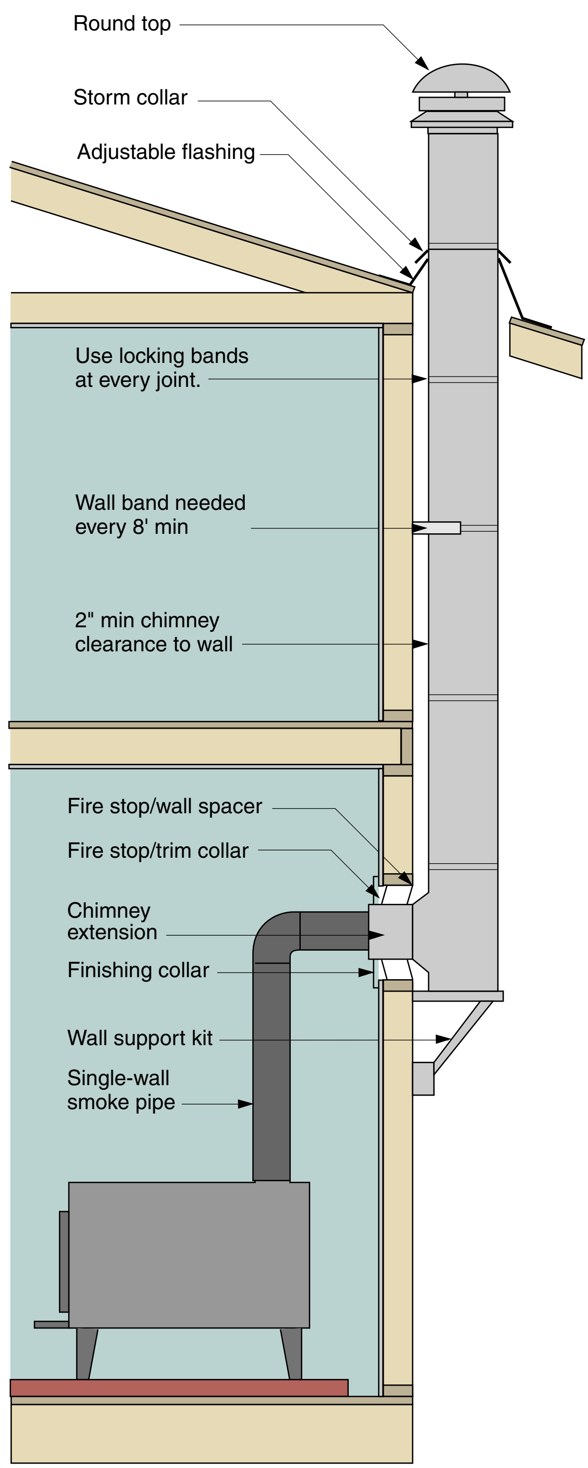
Through an Occupied Second Story



Chimney for a Fireplace



Tee-Supported Outside Chimney



Meet the Code (IRC)

The following is a partial list of requirements from the *2015 International Residential Code (IRC) for One- and Two-Family Dwellings.* Consult the publication for the full text and additional provisions.

Masonry Fireplaces (R1001)

Footings and foundations:

- of concrete or solid masonry ≥12" thick
- to extend ≥6" beyond face of fireplace on all sides
- on undisturbed earth or engineered fill below frost

Firebox dimensions:

- depth ≥20"
- throat ≥8" above fireplace opening and ≥4" deep
- passageway above firebox, including throat, damper, and smoke chamber, ≥cross-sectional area of flue

Exception Rumford fireplaces:

- depth ≥12" and ≥⅓ width of opening
- throat ≥12" above lintel
- throat opening ≥1⁄20 fireplace opening

Lintel, throat, and damper:

- noncombustible lintel over opening required
- throat or damper to be ≥8" above lintel
- ferrous metal damper ≥8" above opening required
- damper installed in fireplace or chimney
- damper operable from room containing fireplace

Hearth and extensions:

- of concrete or masonry, supported by noncombustible material, and reinforced for imposed loads
- no combustible material against the underside of hearths and hearth extensions after construction
- hearth thickness ≥4"; extension thickness ≥2"

Exception: if firebox opening ≥8" above hearth extension, extension thickness ≥⅜" permitted

- extensions to extend ≥16" front and ≥8" sides; where opening ≥6 sq ft, ≥20" front and ≥12" sides

Fireplace clearance:

- ≥2" from the front faces and sides
- ≥4" from the back faces

Masonry Chimneys (R1003)

- inlets to have thimble to prevent connector from pulling out or from extending beyond liner
- cleanout opening ≤6" of base of each flue

Exception: flues serving fireplaces

- spaces between chimneys and floors and ceilings to be fireblocked with noncombustible material
- chimneys ≥30" parallel to ridge to have crickets

Factory-Built Chimneys (R1005)

- in dwelling units with solid-fuel-burning appliances to comply with the Type HT requirements of UL 103

Exterior Air Supply (R1006)

- combustion air ducts for factory-built fireplaces to be a listed component of the fireplace
- exterior air intake capable of supplying all combustion air from exterior or from spaces ventilated with outside air such as vented crawl or attic spaces
- intake not to be located in a garage or basement
- intake not to be located higher than firebox
- intake covered with corrosion-resistant 1/4" mesh.
- passageway ≥6 and ≤55 sq in except constructed according to the fireplace manufacturer's instructions
- outlet to be in back or sides of firebox or within 24" of the firebox opening on or near the floor

Connectors (M1803)

- connectors for oil and solid-fuel-burning appliances to be of factory-built chimney material, Type L vent material or single-wall metal of thicknesses:
  diameter <6" —0.019", 6-10"—.024", >10"—.029"
- as short and straight as possible
- installed with a slope of ≥1/4" rise per 12" of run
- joints fastened with sheet-metal screws or rivets
- not to pass through floor or ceiling
- not to pass through wall unless listed or routed through a device listed for wall pass-through
- connectors for oil-fired appliances listed for Type L vents, passing through walls, to be installed with listed clearances to combustible material.

- single-wall metal pipe through walls to be through a ventilated metal thimble ≥4" larger in diameter, and with ≥6" clearance to combustibles
- horizontal run of uninsulated connector to natural draft chimney ≤75% of height of chimney above
- horizontal run of a listed connector to natural draft chimney ≤100% of height of chimney above
- connector diameter to be ≥ that of flue collar

Termination (M1804)

- vents for natural draft appliances to terminate ≥5' above highest connected appliance
- natural draft gas vents for wall furnaces to terminate ≥12' above bottom of furnace.
- Type L vents to terminate ≥2' above roof and ≥2' above any portion of the building within 10'
- direct-vent terminal to be installed in accordance with the manufacturer's installation instructions

Mechanical draft systems:

- vent terminal ≥3' above forced air inlet within 10'
- vent terminal ≥4' below, ≥4' horizontally from and ≥1' above door, window, or air inlet into a dwelling
- vent terminal ≥4' to an interior corner formed by two walls perpendicular to each other
- bottom of vent terminal ≥12" above grade
- vent terminal not directly above or ≤3' horizontally from oil tank vent or gas meter
- power exhaust terminations to be located ≥10' from lot lines and adjacent buildings

Chimney flues:

- effective area of a natural draft flue for one appliance to be ≥area of the connector to the appliance
- area of flues connected to more than one appliance to be ≥area of the largest connector plus 50% of areas of additional connectors
- area of flue connected to a solid-fuel-burning appliance to be ≥area of the flue collar or connector, and ≤3× area of the flue collar

Gas Piping Installation (G2415)

Prohibited locations:

- in circulating air duct, clothes chute, chimney or gas vent, ventilating duct, dumbwaiter, or elevator shaft
- through any townhouse unit other than the unit served by such piping
- in solid partitions/walls, unless in a chase or casing

In concealed locations:

- no unions, tubing fittings, right and left couplings, bushings, compression couplings, and swing joints made by combinations of fittings

Exceptions: brazed joints, listed fittings

Underground piping:

- in protective sleeve through foundation walls
- space between piping and sleeve to be sealed

Protective shield plates:

- where pipe <1.5" from edge of concealed framing
- to be minimum $^1/_{16}$"-thick steel
- to extend ≥4" above sole plates, below top plates, and to each side of framing member

Exceptions: black iron pipe, galvanized steel pipe

Above-ground piping outdoors:

- elevated ≥3$^1/_2$" above ground and roof surface
- securely supported and located where it will be protected from physical damage
- passing through an outside wall, piping protected against corrosion by coating or wrapping

Gas Shutoff Valves (G2420)

- not in concealed locations and furnace plenums
- access for operation and protected from damage
- on the supply side of every gas meter
- immediately ahead of each MP regulator
- in same room and ≤6' from each appliance

Exception: valves for vented decorative appliances may be remote from appliance if provided with ready access

Exception: in the firebox of a fireplace if installed according to manufacturer's instructions

19

Cooling

Our reason for cooling is to achieve *human comfort*. But, of course, we are interested in staying cool at the least cost. We begin, therefore, by considering methods utilized by past generations prior to the availability of mechanical cooling: *capturing breezes*, *shading windows*, *utilizing thermal mass,* and *venting heat with the stack effect*. We have also added the relatively new method of reducing the cooling load by installing *attic radiant barriers.*

After exhausting the free methods, we turn to the lowest-cost mechanical means: *creating breezes with box (window) fans*, moving interior air with *ceiling fans*, and, for those living in hot, dry climates, reducing air temperatures with *evaporative coolers*.

If all else fails, or if we simply don't care about the cost, we turn to window and central *air conditioners*. Of course, we have to know how large an air conditioner to install, so we include instructions for calculating a home's cooling load.

Human Comfort

We heat and cool our homes at significant expense in order to be comfortable, so it is worthwhile to consider exactly what determines comfort.

All of the environmental variables determining whether we feel comfortable are embodied in what is called the "human comfort zone" (illustration on the facing page). The variables are:

- air temperature, the vertical location on the chart as shown by the thermometer scale along the left edge
- relative humidity (ratio of the amount of water vapor in the air to the amount possible before saturation and condensation), the horizontal location on the chart shown as 0 to 100%
- radiation on our bodies, in Btus per sq. ft.-hr., shown by the horizontal curves under the central comfort zone
- air movement across our bodies, in miles per hour (mph), shown as the horizontal curves above the comfort zone.

The comfort zone, in the absence of radiation or moving air, is shown by the tinted zone containing two seated people. The significance of the comfort zone is the fact that most lightly clothed people—as you normally would be in your home—feel neither too cool nor too warm within the temperature and humidity boundaries of the zone. These limits are roughly 70°F to 82°F and 20% to 80% relative humidity. Ordinarily, below 70°F one would turn on the heating system, and above 82°F one would turn on the air conditioner.

Of course, turning on either the heating system or the air conditioner increases your energy bill. The reason we are exploring the comfort zone here is the possibility of achieving comfort for less money. As you may suspect, radiation and moving air offer those possibilities.

Effect of Radiation

Below the comfort zone are a series of horizontal curves labeled from 50 to 300 Btu per sq.ft.-hr. These curves show how far the bottom of the comfort zone can be depressed by radiation in the absence of moving air. For perspective, 300 Btu per sq. ft.-hr. is the approximate intensity of the sun's radiation at noon on a clear day.

For example, were you sitting in your normal clothing in the full noon sun with no air movement, you would feel as comfortable at 50°F in the sun as you would at 74°F out of the sun.

Effect of Air Movement

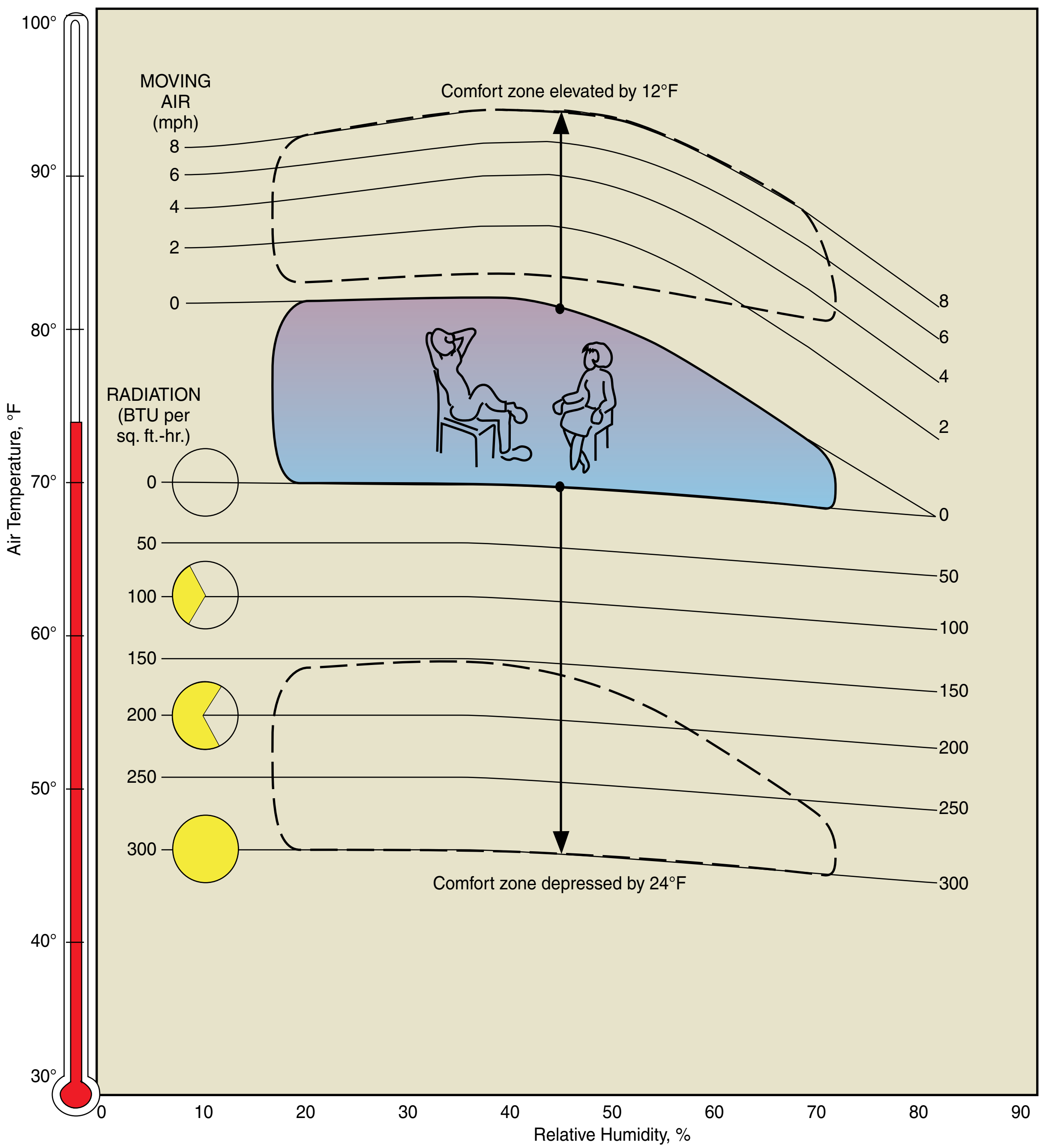
Our skin is normally about 98°F, so air moving across it convects heat away, giving us the feeling that the air is cool. Above the comfort zone are a series of horizontal curves labeled from 0 to 8 mph. These curves show how far the top of the comfort zone can be raised by moving air in the absence of radiation.

For example, were you sitting in the shade in your normal clothing, and an 8 mph breeze were blowing across your body, you would feel as comfortable at 94°F as you would at 82°F with no breeze.

Note how the upper edge of the comfort zone bends down as relative humidity increases. This explains why we feel high humidity to be oppressive. Some of the cooling effect of moving air is due to the evaporation of moisture from our skin. The higher the relative humidity, the less the ability of the air to evaporate surface moisture and cool our skin.

In the following pages we will see a number of ways one can take advantage of moving air, both natural and man-made, to achieve cooling without the expense of mechanical air-conditioning.

The Human Comfort Zone



Capturing Breezes

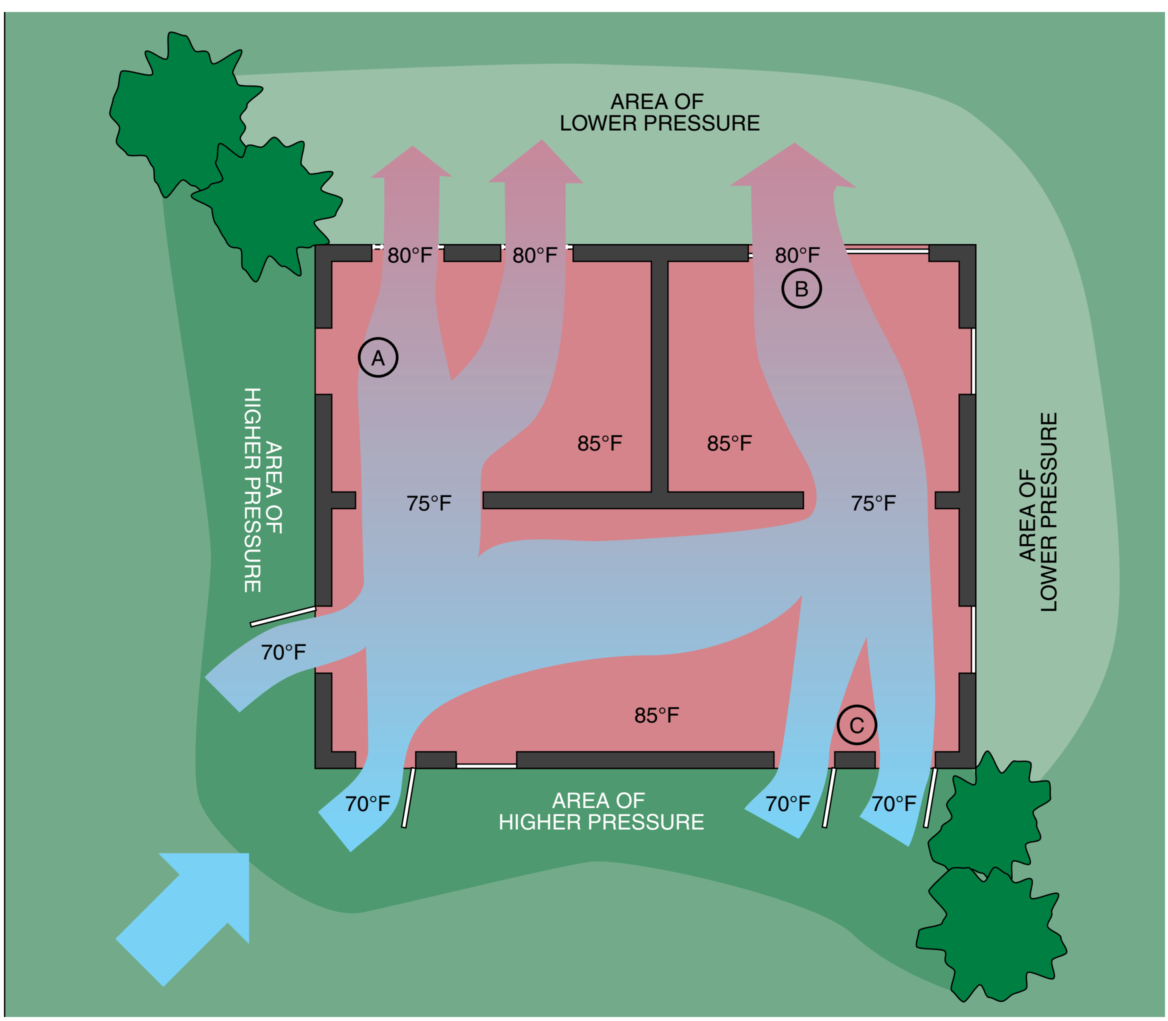
As we saw in the comfort zone diagram on p. 555, air movement across our bodies has the potential of raising our upper comfort limit from about 82°F to about 94°F in an 8-mph breeze. A breeze of only 2 mph makes us feel 4°F cooler. If you are fortunate (or smart) enough to have openable windows facing into the prevailing summer breeze, you can capture and funnel some of it through your sitting and sleeping areas.

The illustration below shows the pressure distribution around a house in a breeze. The side of the house facing the wind acts as an obstruction, so the momentum of the wind piling up causes a local increase in pressure. The effect is the opposite on the downwind side. Here, the shortage of air results in an area of lower pressure. Naturally, air will flow from an area of high pressure to an area of low pressure.

By operating windows strategically one can control the air flow within the house. In the illustration, opening all of the upwind and downwind windows overnight results in a rather uniform cooling of the house. Suppose you wished, however, to maximize the cooling breeze over your bed at location A. By closing the patio door at B, the air entering at windows, C, would be redirected to the remaining open downwind windows, increasing the flow over your bed.

Note that an additional effect of the breeze is to flush the heat accumulated during the day out of the house. So, you might choose to leave patio door at B open.

Capturing and Funneling Natural Breezes



Attic Radiant Barriers

A radiant barrier is a layer of aluminum foil installed in an interior space to block radiant heat transfer from a heat-radiating surface (such as a hot roof) to a heat-absorbing surface (such as conventional attic insulation). Radiant barriers are used predominately in attics in southern states, where they have proven effective in lowering cooling bills.

A radiant barrier is not insulation. It does not block *conducted heat*, as insulation does. You can pick up a foam cup of hot coffee because the foam is retarding the conduction of heat from the inside of the cup to the outside. But you'd have a rough time drinking hot coffee from an aluminum beer can. The heat would conduct right through to your skin.

Radiant heat consists of rays of energy that travel through air or space and don't turn into heat until they strike an object. An aluminum foil barrier works because it is capable of reflecting 95% to 98% of the radiant heat that strikes it. But since aluminum is a good heat conductor, there must be an air space between the radiating surface and the surface to be shielded from radiant energy. As a result, there are two recommended ways to install a radiant barrier in an attic:

Under Roof Sheathing Under the sheathing is the simplest and cheapest method for new construction. The barrier, usually consisting of aluminum foil backed by a tear-resistant material, is rolled out on top of the rafters before the sheathing is installed.

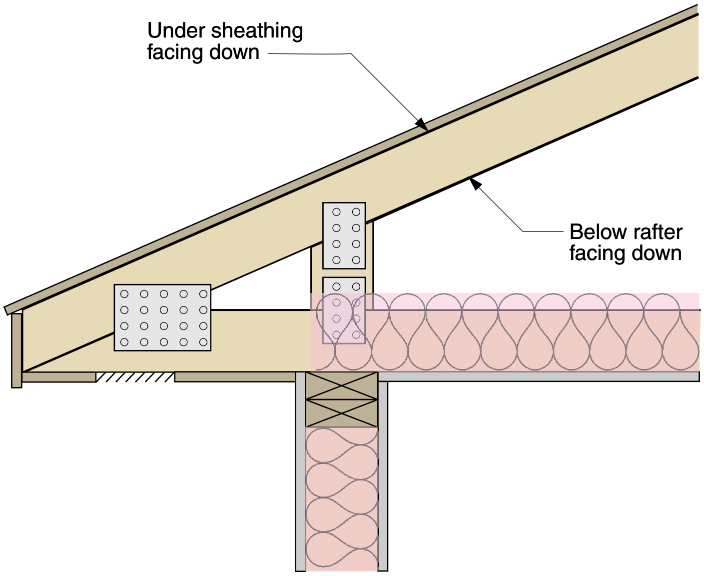
To Rafter Bottoms Attached to the bottom edges of the rafters is the easiest, most effective method for existing houses. Simply staple the material to the underside of the rafters.

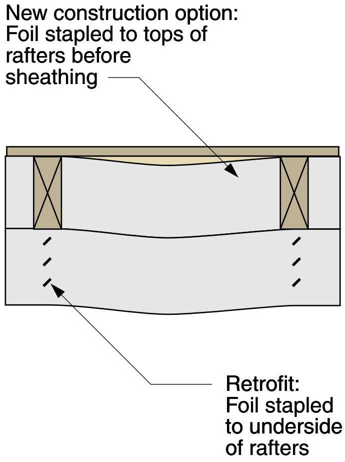
Whichever method you use, install the barrier with the foil facing down into the attic space. At first, the foil would work equally well facing up or down. However, dust would eventually collect on upward-facing foil, reducing the effectiveness of the barrier.

This dust problem also makes it ineffective to install the barrier over attic floor insulation, facing up.

Note that small tears or gaps in the radiant barrier will not significantly reduce overall performance.

Attic Section with Alternative Radiant Barrier Locations





Shading Windows

A high percentage of summer heat gain comes through windows as solar radiation. Much of the radiation is diffuse or reflected, not directly from the sun. As a result, it pays to shade all windows, regardless of the direction they face. The single exception is passive solar glazings in northern states, which should have calculated overhangs as shown in Chapter 20.

The illustration and table below show the percentage reductions in heat gain through the entire cooling season for 4- by 4-foot windows at 30° north latitude, when shaded by continuous overhangs of various lengths, L. The reductions are seen to be nearly independent of window orientation. Of course, there are reasons other than solar shading for building overhangs:

1. A 2-foot overhang protects siding, windows, and doors from the weathering effects of rain. In addition, windows can be left open without worrying about sudden showers.

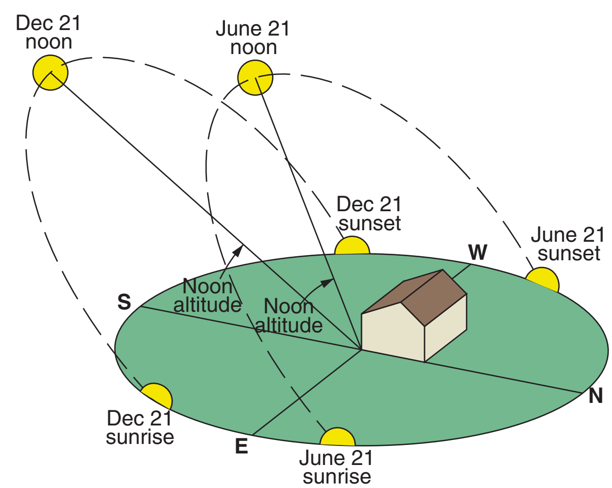
2. A 6- to 8-foot overhang is common for porch roofs, which are very common in the South.

3. A 10-foot overhang could be provided by a carport or vine-covered patio.

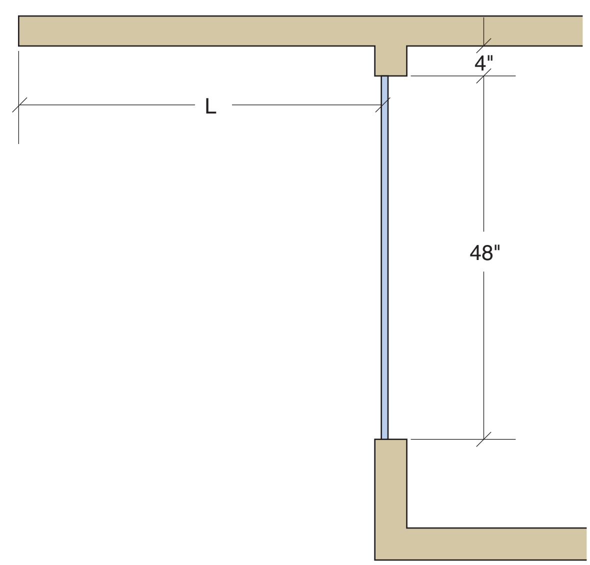
Percentage Summer Heat Gain Reduction from Roof Overhangs

Window Facing	Width of Overhang (L), feet 1	2	3	4	6	10
North	16	32	44	54	66	78
East	14	32	47	58	72	84
South	17	35	47	56	67	79
West	15	32	47	58	71	83
Average	16	33	46	57	69	81

Sun's Path in Winter and Summer



Overhang Geometry for Table



The illustration at right shows an adjustable opaque window awning with side panels. Both the awnings and windows measure 4 feet by 4 feet, so at a 90° slope, the awning would completely cover the window. The table below the illustration shows the cooling-season reductions in heat gain to be expected through single-glazed windows with different shading strategies.

As the slope of a shading device increases, visibility from the window decreases until, at 90° slope, nothing can be seen. Fortunately, much of the shading benefit is achieved with a slope of only 30°, at which point the top half of the view is blocked.

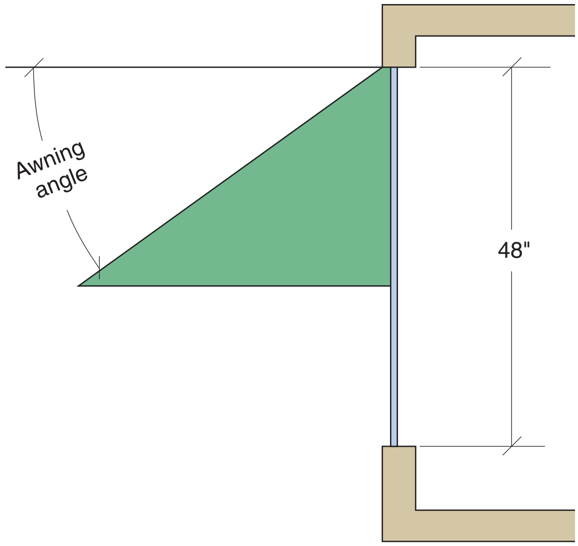
Canvas awnings can be rolled up, but the other shading options would be difficult or impossible to adjust in different seasons. We therefore need to know for each the net effect, or cooling-season savings less reduction in winter solar gain.

Both cooling and heating bills vary with latitude. As latitude increases, cooling bills decrease and heating bills increase. Net savings from fixed shading devices therefore vary with latitude. In the South, net savings are positive; in the North they can be negative.

The table at right shows how strongly net savings can vary. Savings in Miami (virtually zero winter heating load) are nearly three times those in Jacksonville, only 4.5° to the north. For example, permanent charcoal-colored screens over 100 square feet of uniformly distributed glazing would save 1,000 kWhr in Miami, but only 350 kWhr in Jacksonville.

Shading devices above 30° north latitude should be of the adjustable variety in order to maximize both summer and winter savings.

Adjustable Awning with Sides



Net Savings from Awnings, kWhr/sq ft-yr

Window Facing	Tinted Glass	Silver Film	Charcoal Screen	Awning No Side	Awning & Sides
Jacksonville, FL, 30.5° N Latitude					
North	1.5	3.6	3.8	2.9	4.2
East	1.5	3.4	3.6	4.1	4.5
South	0.4	0.9	1.0	0.4	0.9
West	2.3	5.4	5.6	5.6	6.8
Average	1.4	3.3	3.5	3.3	4.1
Miami, FL, 26° N Latitude					
North	3.1	7.4	7.7	5.8	8.6
East	4.5	10.5	11.0	10.2	13.1
South	17	35	47	67	79
West	15	32	47	71	83
Average	16	33	46	69	81

Utilizing Thermal Mass

Mass is a measure of inertia of rest—the difficulty of getting an object to move. "Thermal mass" is a concept used by building designers and engineers to describe the difficulty of getting a building's temperature to change. Given two otherwise identical buildings, the one with twice the thermal mass of the other would change in temperature only half as much.

Long before scientists defined and quantified heat, the Pueblo Indians of the Southwest United States were using thermal mass to great effect. There, the air temperature swings wildly from over 100°F during the day to 50°F overnight. Like the ocean, the massive mud walls of the pueblos required so much heat to change in temperature that the interior never reached the daily high air temperature. In fact, daytime heat gain was delayed about 12 hours in moving through the mud walls, so the walls actually acted as a heat source for the home during the cold night.

Insulation works to the same end. By reducing the amount of heat flowing through a building's walls, floor, and ceiling, it retards and diminishes the temperature swings due to changes in outdoor temperature. Put the two together—mass plus insulation—and you have the best of all possible worlds.

Your home was probably not built to maximize either mass or insulation. However, it has some amount of thermal mass, so let's consider how you might use it to your advantage.

The Effect of Thermal Mass

The top graph on the facing page shows how the interior temperatures of two houses respond to a cycling outdoor air temperature without intervention on the part of the homeowner. Note that these are idealized sinusoidal temperature swings. Real diurnal temperature swings are less symmetric, depending on length of day vs. night, percentage cloudiness, and effects of wind. However, the sinusoidal internal temperature swings accurately reflect the responses to a sinusoidal outdoor temperature swing.

The red curve is the outdoor temperature cycling through a 20°F range, from a low of 69°F at sunrise, to a high of 89°F at around 4 PM, and back to 69°F at sunrise.

The orange curve shows the temperature response of a typical insulated house having the low thermal mass typical of wood frame construction. Its temperature swing of 17°F is just a little less than that of the outside, and its peak temperature of 88°F occurs right at the family's evening social hours.

The blue curve shows the effect of adding thermal mass to the same house. Now the swing is reduced to 8°F, and the peak temperature is reduced to 83°F.

Thermal Pumping

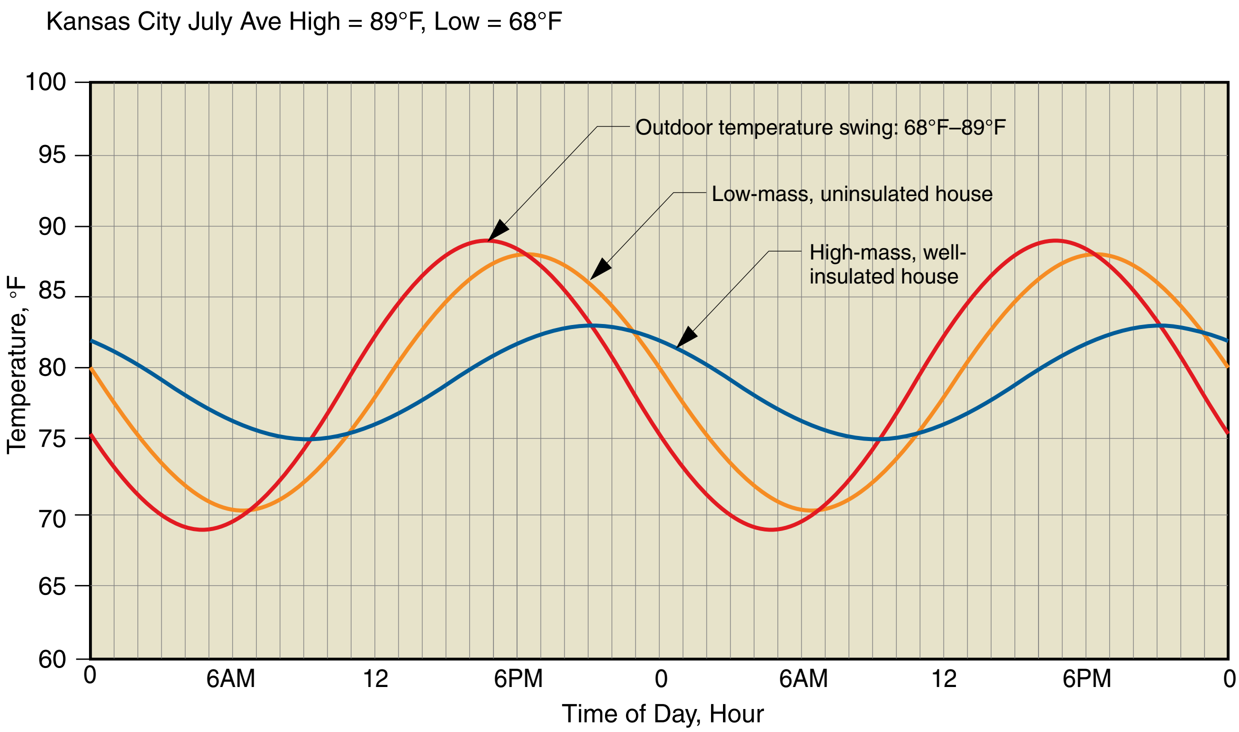
So far we have played the role of a passive occupant, just letting the building's thermal mass respond to the swings in outdoor temperature. But what if we were to open the house to the outside whenever the outdoor temperature fell below the inside temperature?

The bottom graph shows what would happen if we were to open all of the windows at the point in the evening when the indoor and outdoor temperatures crossed paths and then closed them as soon as the outdoor temperature began to rise again in the morning.

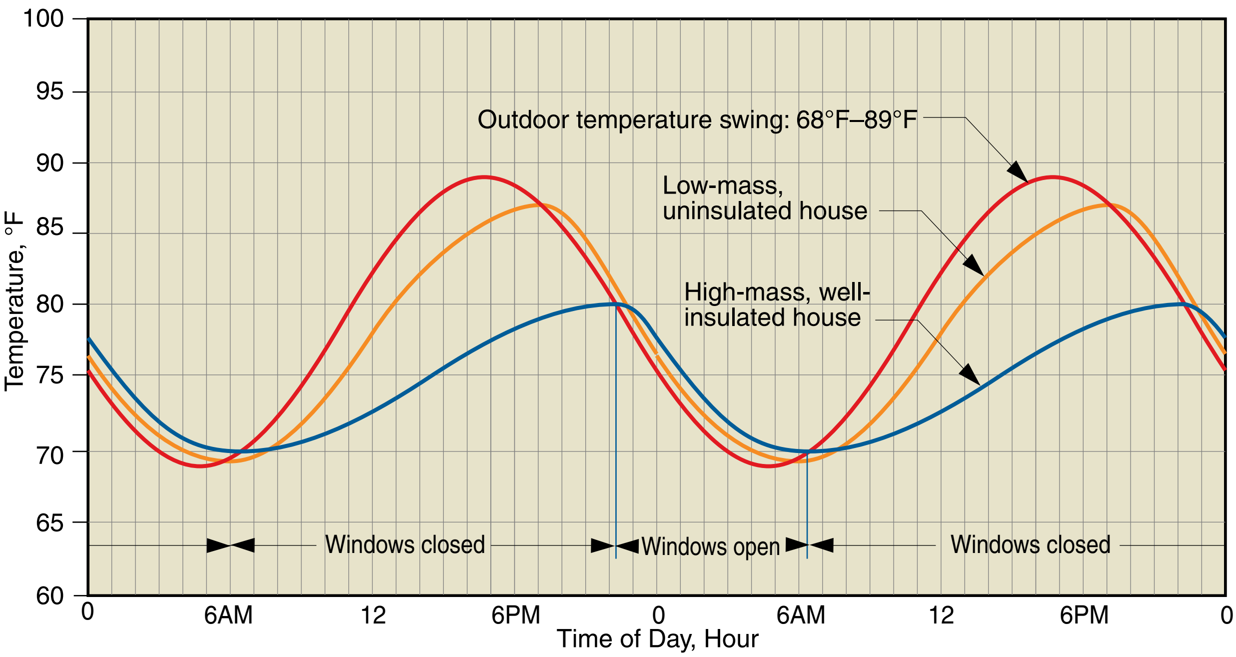
The low-mass house (orange curve) runs only about 1F° cooler than before. This is because the low mass of the building caused it to respond rapidly to the outdoor temperature anyway, without having to open the windows.

The high-mass house, however, behaves quite differently. With the windows shut from 6AM to 10PM, the thermal mass acts to soak up the heat and hold the temperature down. But with the windows open, the thermal mass is short-circuited, and the building tracks the outdoor temperature much more closely. The result is that the building cycles between only 70°F and 80°F—well within our comfort zone.

The Moderating Effect of Thermal Mass



Cooling a Building by Thermal Pumping



Venting Heat with the Stack Effect

The "stack effect" gets its name from the behavior of smoke stacks. If the gas inside the stack is warmer than the surrounding air, the gas is less dense and acts like a giant warm air balloon. The upward flow in the stack depends on the cross-sectional area and height of the stack and the temperature difference between the inside and outside air.

The actual formula uses absolute temperatures (where zero on the scale is -459°F) and the acceleration of gravity. However, over the limited range of temperatures involving houses in summer, we can approximate the formula as:

$$\text{Air flow, cfm} = 13.3A\sqrt{H\Delta T}$$

where:

A = *area of equal-sized openings in sq.ft.*
H = *height difference between openings in ft.*
ΔT = *temperature difference, inside – outside, °F*

Example 1: In the tall house in the illustration on the facing page, the effective areas of inlet and outlet are each 10 sq. ft. The difference in height between the patio door at ground level and the skylight and roof window at roof level is three stories, or 24 ft. The difference in temperature is 85°F inside minus 70°F outside, or 15F°. Running the numbers (which will require a calculator with the square root function), the result is an air flow of about 2,530 cu. ft. per min. With an interior volume of 30,000 cu. ft., the entire volume of building air is exchanged every 12 minutes or 5 times per hour.

Example 2: The typical house at the bottom of the illustration has the same footprint (24 ft. × 40 ft.), but only two floors instead of four. The average height difference is a lot less: 10 ft. All other factors remain the same. The resulting air flow is 1,570 cu. ft. per min. The 16,000-cu. ft. interior volume of the house is now exchanged in 10 minutes, or 6 times per hour.

Dual Cooling Effects

The stack effect cools in two ways:

1. It flushes out the accumulated heat from the day and replaces it with cooler nighttime air.

2. For anyone within the moving column of air, the comfort zone upper limit is lowered by the cooling effect of moving air.

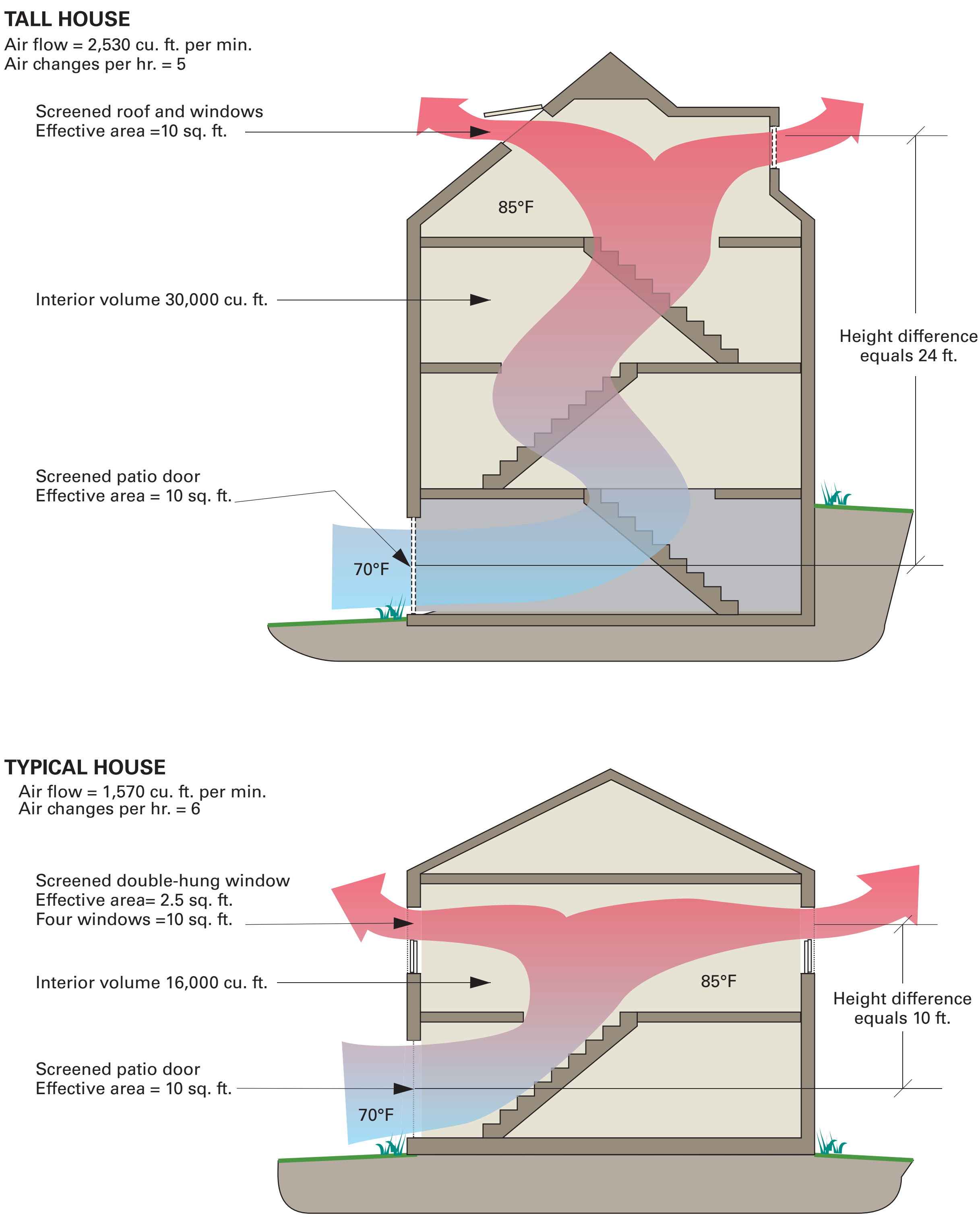
As heat is removed from the house, the temperature difference between inside and outside diminishes, so the airflow diminishes accordingly. However, because night ambient temperatures tend to drop from sunset to sunrise, the stack effect remains in operation to some degree all night long.

To maximize the cooling effect on your body:

1. Sleep inside the inlet stream of air where the air temperature is lowest.

2. Make the inlet area smaller than the sum of the outlet areas, forcing the volume of air through a smaller orifice, which results in a greater velocity.

Cooling with the Stack Effect



Creating Breezes with Box Fans

When the heat in your bedroom is oppressive, and there is not a breath of air outdoors, generate your own breeze. An inexpensive 20-in. box fan mounted in a double-hung window is a pretty fair substitute.

Box fans are designed to operate either in a window or on the floor, but they have no brackets or points of attachment. The illustration at right shows how to mount one in a double-hung window. Raise the bottom sash as high as possible, and place the fan on the inside window sill. If the fan is taller than the opening, push it up against the raised sash. If shorter than the opening, close the raised sash down on top of the fan. Push the fan to one side, and cut a piece of corrugated cardboard or plywood to fill the gap at the side. Apply 2-in.-wide blue "painter's tape" to the fan, filler strip, and window trim to seal the opening and hold the fan in place. Do not use duct tape as it will leave a residue when removed.

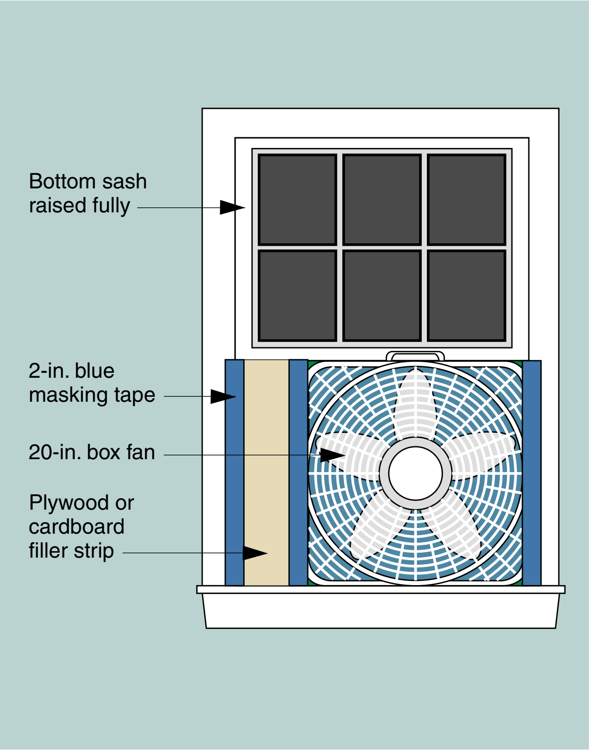
Most box fans offer three speeds and move in the neighborhood of 2,000 cfm of air on their high setting. At the fan outlet that number converts into a breeze of 8 mph. How much of that no-resistance speed is realized depends on the number and size of other open windows.

Another interesting number is the rate of flushing of stale, overheated air from the house As an example, assume the house on the facing page has a floor area of 1,000 sq. ft. and a volume of 8,000 cu. ft. At 2,000 cfm, a single fan could exchange the entire volume of interior air 15 times every hour!

Assuming the outdoor air is cooler than the indoor air, the box fan can thus cool you in two ways:

- by replacing warm inside air with cooler outside air
- by raising your personal comfort zone with a breeze

Box Fan Installation



Emulating Natural Breezes

One of the only complaints about box fans is their noise level. Some people have difficulty sleeping with the fan on high. The illustration on the facing page shows the solution: locate the fan not in the room where you are sleeping, but in a room as far away as possible. The fan noise will be so slight you will go to sleep thinking the breeze is natural.

Note that this technique requires that the fan now blow out of the house. If the fan isn't reversible (most aren't), just reinstall it to blow in the opposite direction.

Cooling with a Box Fan

Ceiling Fans

Ceiling fans don't lower air temperature. Like box fans, they produce a cooling effect on people by raising the upper limit of the human comfort zone. Before the widespread adoption of air-conditioning, ceiling fans were the predominant means of cooling, particularly in southern states. They nearly disappeared from 1930 until the early 1970s but came back into favor due to their much higher efficiencies compared to those of air conditioners. With further improvements in efficiency, noise level, lighting options, and the addition of remote controls, they have become a common design element in new homes.

Cooling Effect

The illustrations on the facing page depict the two primary uses of ceiling fans:

- creating a breeze onto a favorite sitting place
- creating a dream-inducing zephyr over your bed.

A quality fan of 48-in. blade diameter will move at least 5,500 cu. ft. of air per minute (cfm) directly below the blades. This translates into a downward velocity (breeze) of 5 mph. Consulting the human comfort zone on p. 555, we see the cooling effect is about 7F°. If the room air were actually 85°F, directly under the fan it would feel as if the air were 78°F.

Efficiency

To lower the temperature of the room air to 78°F would require a medium-size room air conditioner consuming about 600 watts of electricity. The most efficient 48-in. ceiling fan, by contrast, would consume only 60 watts in cooling the occupants—an energy and dollar saving of 90%!

Summer/Winter Operation

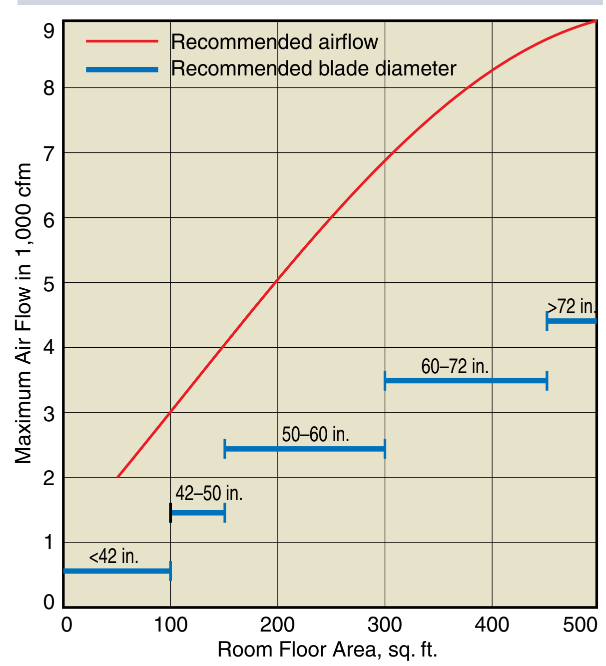
The primary purpose of a ceiling fan is to generate moving air that acts as a breeze to cool its subjects, not to homogenize the air in a room. Summertime operation, therefore, requires that the fan blow in a downward direction.

Much is made of the possibility of reversing the fan's direction in winter, the reason being room air in winter is stratified, with the air close to the ceiling much warmer than the air at floor level. In an uninsulated room heated by a point source such as a wood stove, that is true, but in a well-insulated room heated by a modern distribution system, it is not. However, if you do use a ceiling fan in winter, reverse its direction so that it blows upward. Otherwise, the direct breeze will cool you just as it does in summer, defeating your purpose!

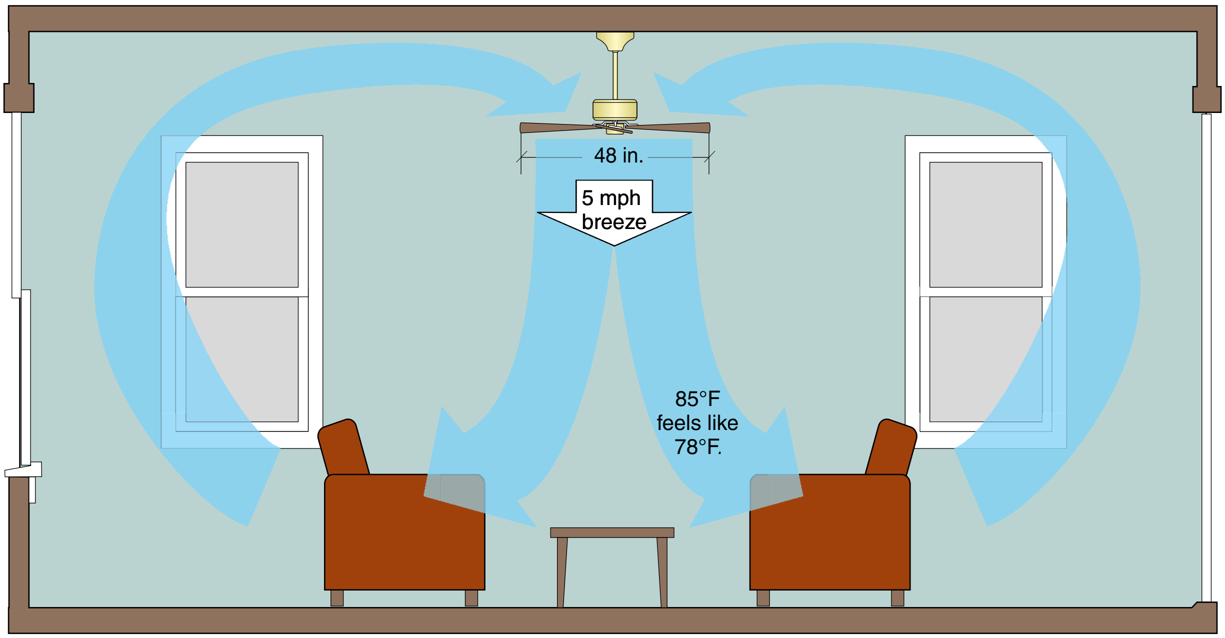
Sizing the Fan

Picking the best size for a ceiling fan depends on two factors: the floor area in sq.ft., and the shape of the room. The chart below shows both the recommended air flow at high speed and the blade span versus the floor area. Note that at over 300 sq. ft., an oblong room would benefit from a pair of smaller fans rather than a single fan. Two fans would result in two separate sitting areas being cooled.

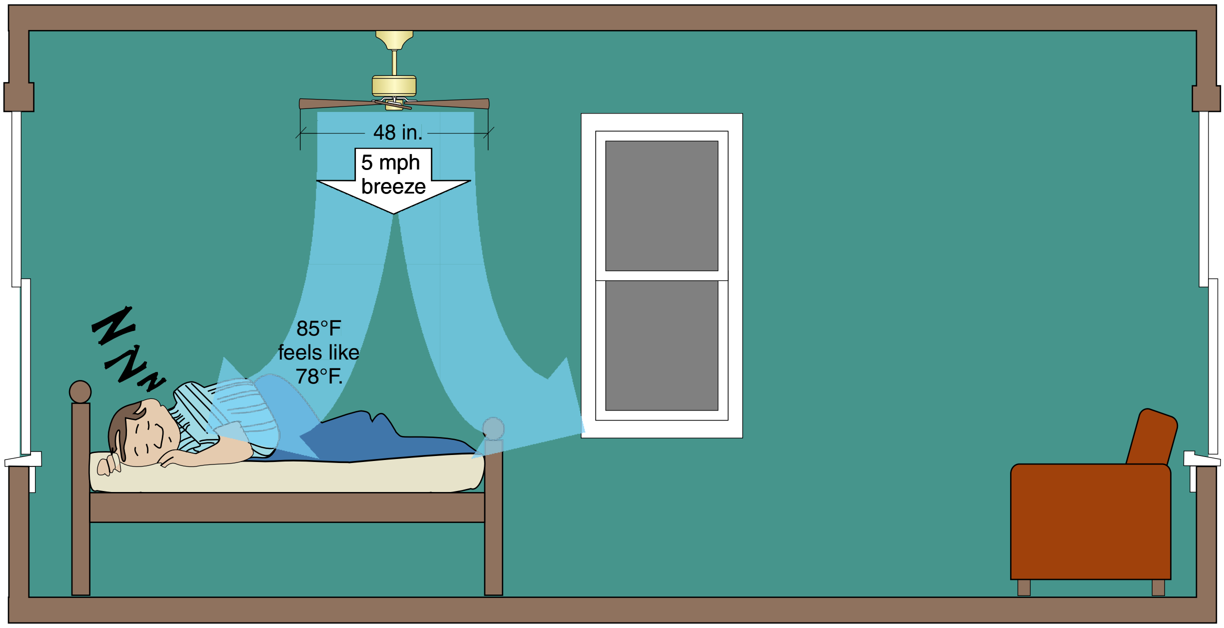
Sizing a Ceiling Fan



Cooling a Sitting Room with a Ceiling Fan



Cooling a Bedroom with a Ceiling Fan



Evaporative Coolers

In the process of evaporating, water absorbs heat. This is why you feel so cool when you emerge from swimming on a dry, breezy day. Evaporative coolers (also known as swamp coolers) utilize this phenomenon to lower air temperature. As the illustration on the facing page shows, hot dry air blown through a water-soaked pad emerges as humid, but much cooler, air. The temperature drop can be predicted from the equation:

Temperature drop = $E \times (DB - WB)$
where: E = *cooler efficiency, percent*
DB = *intake air dry bulb temperature*
WB = *intake air wet bulb temperature*

Evaporative coolers are recommended wherever the temperature drop (DB – WB) exceeds 20F°, and the cooled air would be below 79°F. The table below lists these criteria for selected cities. Cities that meet both criteria appear in italics. To size an evaporative cooler:

1. Compute the volume of house air in cu. ft.

2. Find the recommended minutes per air change for your location in the table.

3. Divide the house volume by minutes to find the recommended cooler capacity in cfm.

4. If your home is very energy efficient, divide cfm by 2; if not insulated, multiply by 2.

Potential for Evaporative Cooling

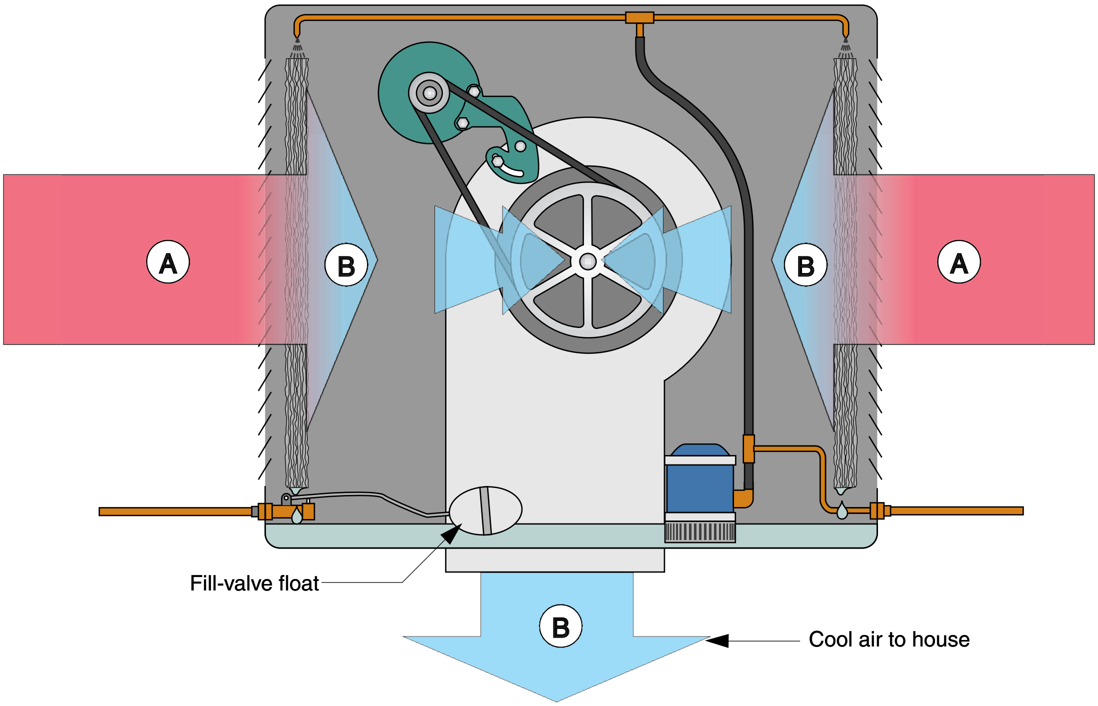
Location	DB °F	WB °F	Temp Drop F°	Cooled Temp °F	Minutes per Air Change
AL, Birmingham	96	74	18	78	NR[1]
AZ, Phoenix	*109*	*71*	*30*	*79*	*2*
AR, Little Rock	99	76	18	81	NR
CA, Los Angeles	93	70	18	75	2
CO, Denver	*93*	*59*	*27*	*66*	*4*
CT, Hartford	91	74	14	77	NR
DE, Wilmington	92	74	14	78	NR
DC, Washington	93	75	14	79	NR
FL, Orlando	94	76	14	80	NR
GA, Atlanta	94	74	16	78	NR
ID, Boise	*96*	*65*	*25*	*71*	*4*
IL, Chicago	94	75	15	79	NR
IN, Indianapolis	92	74	14	78	NR
IA, Des Moines	94	75	15	79	NR
KS, Topeka	*99*	*75*	*20*	*79*	*2*
KY, Louisville	95	74	17	78	NR
LA, Baton Rouge	95	77	14	81	NR
MA, Boston	91	73	14	77	NR
MI, Detroit	91	73	14	77	NR
MS, Jackson	97	76	17	80	NR
MO, St Louis	98	75	18	80	NR

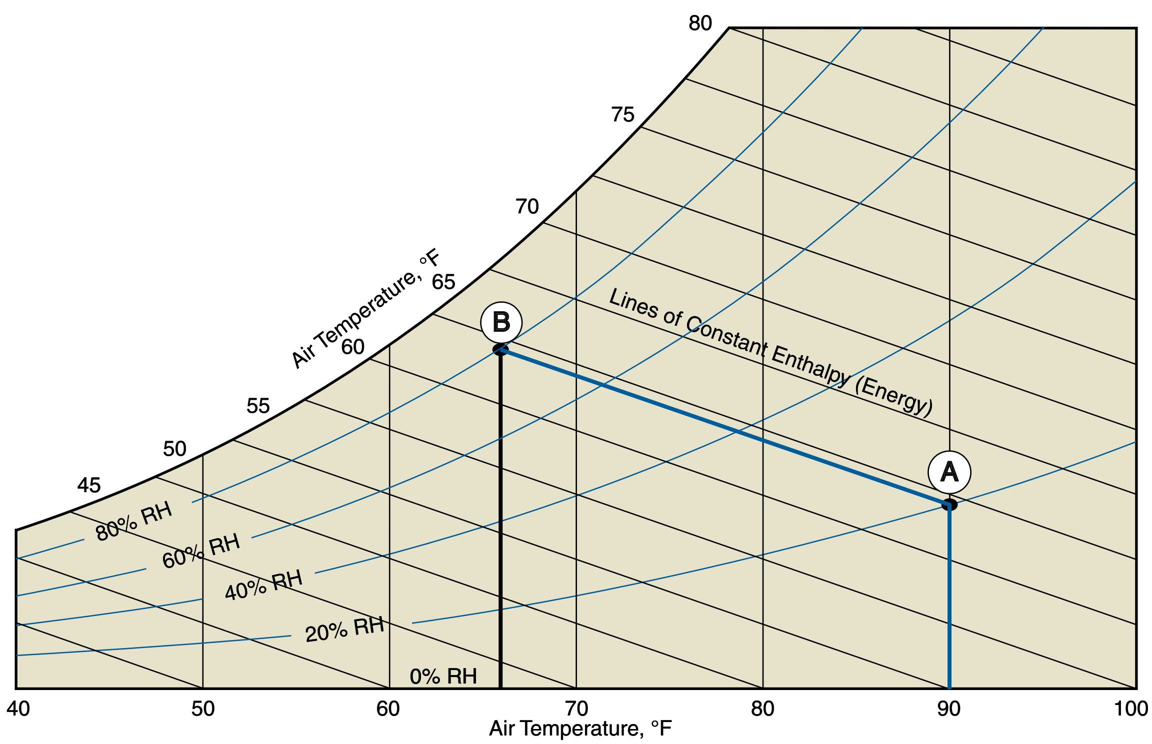
Potential for Evaporative Cooling

Location	DB °F	WB °F	Temp Drop F°	Cooled Temp °F	Minutes per Air Change
MT, Great Falls	*91*	*60*	*25*	*66*	*3*
NE, North Platte	*97*	*69*	*22*	*75*	*3*
NV, Las Vegas	*108*	*66*	*34*	*74*	*3*
NH, Concord	90	72	14	76	NR
NJ, Newark	94	74	16	78	NR
NM, Albuquerque	*96*	*61*	*28*	*68*	*3*
NY, Syracuse	90	73	14	76	NR
NC, Greensboro	93	74	15	78	NR
ND, Bismarck	*95*	*68*	*22*	*73*	*3*
OH, Columbus	92	73	15	77	NR
OK, Tulsa	*101*	*74*	*22*	*79*	*1*
OR, Portland	89	68	17	72	NR
PA, Pittsburgh	91	72	15	76	NR
RI, Providence	89	73	13	76	NR
SC, Columbia	97	76	17	80	NR
SD, Rapid City	*95*	*66*	*23*	*72*	*3*
TN, Nashville	97	75	18	79	NR
TX, Dallas	102	75	22	80	2
UT, Salt Lake City	*97*	*62*	*28*	*69*	*4*
VA, Richmond	95	76	15	80	NR
WY, Casper	*92*	*58*	*27*	*65*	*4*

[1] NR = Not Recommended

Evaporative Cooler at Work

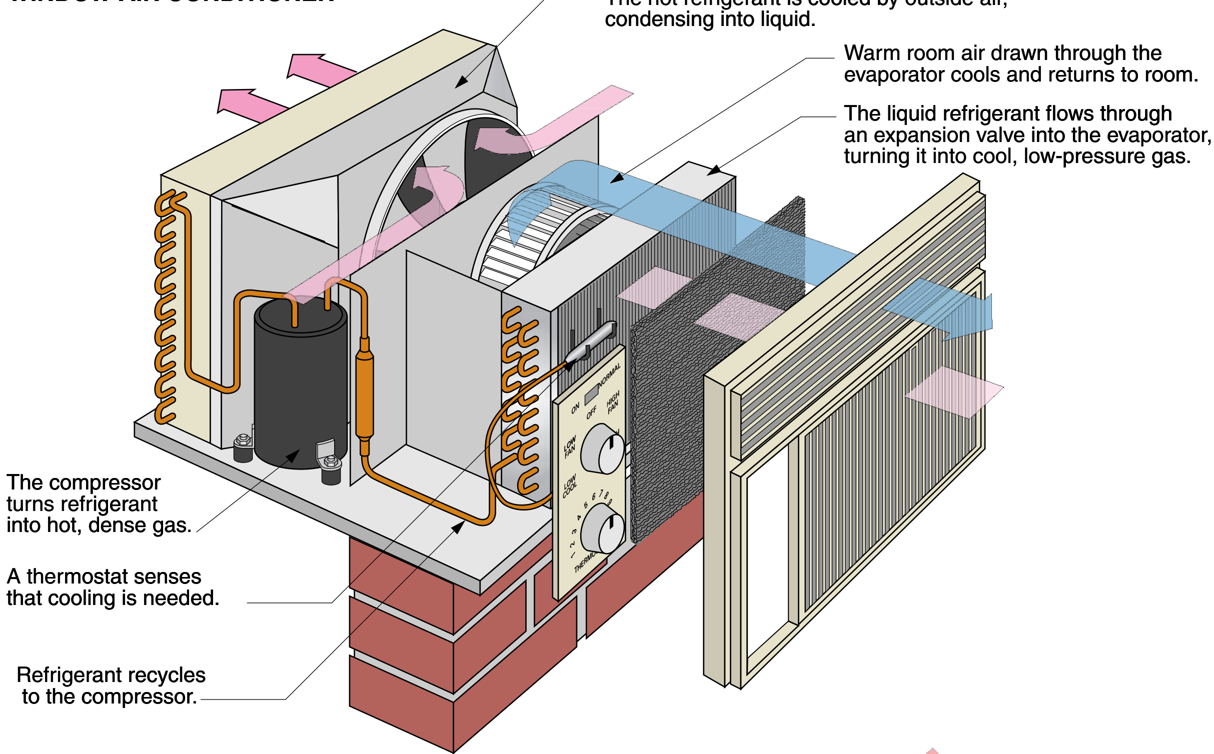




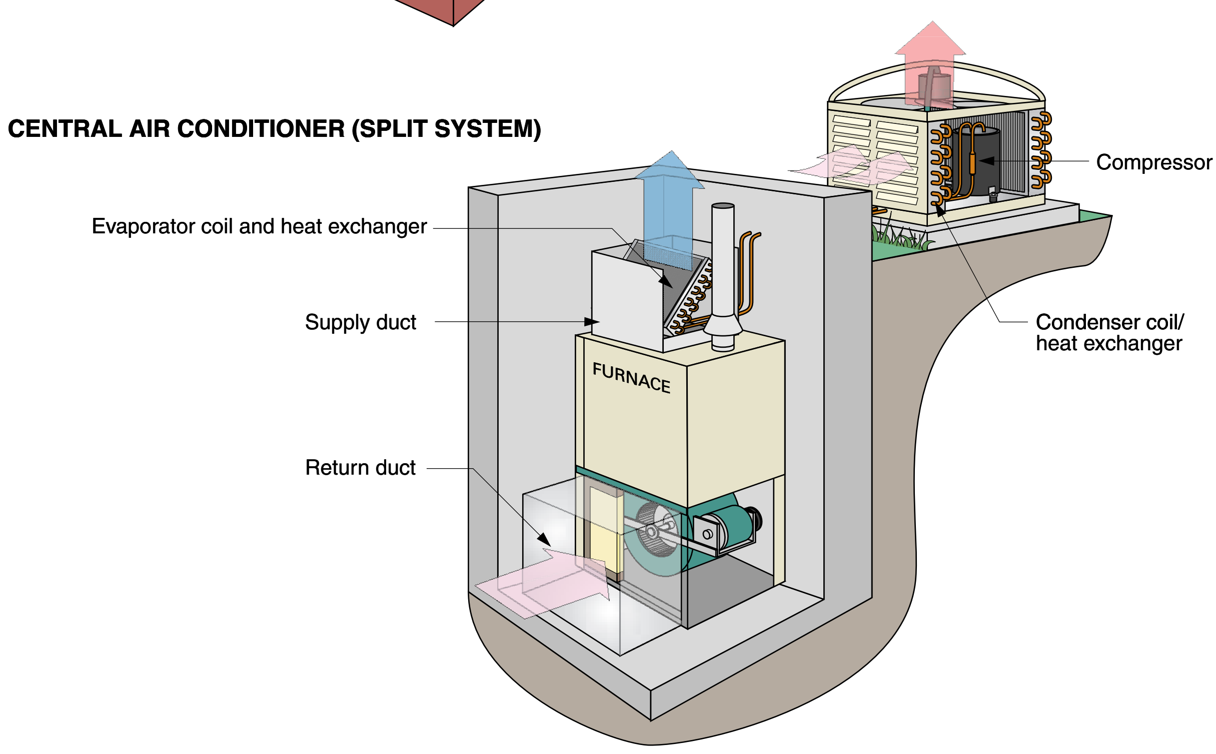
Air Conditioners

Window & Central Air Conditioners

WINDOW AIR CONDITIONER



CENTRAL AIR CONDITIONER (SPLIT SYSTEM)



If all else fails to cool you into the comfort zone, your next option is to air-condition. Air conditioners, powerful but expensive tools, lower both humidity and temperature.

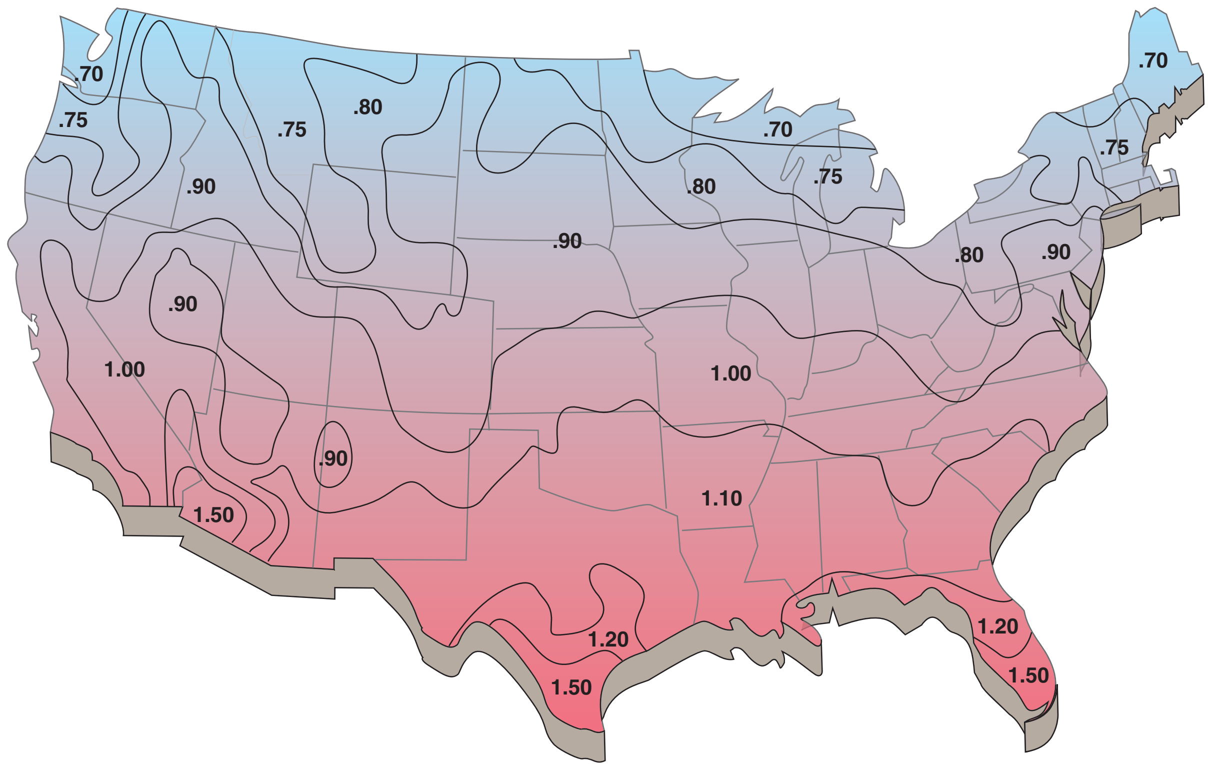
The first thing you will require is an estimate of your peak cooling load, the number of BTU/hr. that need to be removed under the worst conditions of the cooling season. The work sheet and tables on the following pages allow you to find that load, whether you are cooling just a bedroom or your entire house, no matter where you live in the United States.

You may wish to photocopy the work sheet so that you will be able to calculate the peak cooling load for additional rooms.

Read the instructions carefully for each line before entering any numbers. An example calculation follows the work sheet.

When you are finished, go to the Energy Star site at *www.energystar.gov.* There you will find an up-to-date list of all air conditioners, with their *rated cooling capacities* and *energy efficiency ratings (EER)*. Look for models with the highest EER (the ratio of BTUs removed to watts of electricity consumed) that also closely match your load. The most efficient air conditioner for your purpose will be one that is just capable of supplying your calculated load.

Cooling Factors for Air Conditioner Work Sheet, Line 9



Instructions for Work Sheet

Lines 1 and 2. Use line 1 if your house has a well-ventilated attic; otherwise use line 2. Find the shading factor in column 1 of Table 1. The insulation factor is 0.8 times the nominal R-value of the attic insulation. (See Chapter 13 for insulation R-values.) Use the value 2.4 if there is no insulation present.

Line 3. Follow the same instructions as for lines 1 and 2. Exterior walls are those facing the outdoors. Enter doors as exterior walls. Do not include windows as they will be entered below.

Line 4. Interior walls are those that separate the cooled space from unconditioned spaces. If you are cooling the entire house, there will be no interior walls. The insulation factor is 0.8 times the nominal R-value of the wall insulation (see Chapter 13 for insulation R-values), or 2.4 if there is none.

Line 5. Get the floor factor from Table 2; the insulation factor is as in line 4.

Line 6. Enter the total floor area of the cooled space. Estimate air changes per hour as 0.4 for the tightest possible house to 1.3 for a drafty one.

Line 7. Calculate window areas as height × width of the sash (the frames holding the glass). Get the glazing factors from Table 3.

Line 8. Get the shading factors from Table 1 and the glazing factors from Table 3.

Line 9. Add the results from lines 1 through 8 and multiply by the cooling factor for your geographic area shown on the map on p. 571.

Line 10. Multiply your average monthly spring or fall kilowatt-hours (get these from your utility bills or by calling your electric utility) by 1.4. For the average home the result should be about 600 kWhr/month.

Line 11. Enter the average number of people occupying the cooled space during the hot months.

Line 12. Add lines 9, 10, and 11, then multiply the result by the mass factor from Table 4.

Table 1. Shading Factors

Degree of Shading	Roof, Wall, Ceiling	Windows
Unshaded areas	1.00	1.00
Fully shaded areas	0.70	0.20
Partially shaded by awning overhang, or small trees	0.90	0.65
Shaded inside by window shades, drapes, or films		0.45

Table 2. Floor Factors

Floor Above	Factor
Open crawl space	1.0
Closed crawl space	0.0
Full basement	0.0
Unconditioned room	0.9
Ground (slab-on-grade)	0.1

Table 3. Glazing Factors

Type of Glazing	Line 7	Line 8
Single-glazed window	1.0	1.0
Double-glazed window	0.5	0.8
Triple-glazed window	0.33	0.65

Table 4. Thermal Mass Factors

Building Construction	Factor
Light wood frame	1.00
Solid masonry or wood frame with exterior masonry veneer	0.90
Wood frame with masonry interior walls, floors, or other mass	0.80
Earth-sheltered (underground) walls and roof	0.50

Work Sheet for Sizing Air Conditioners

Source of Heat Gain	Calculations	Results
1. Roof over ventilated attic	________ sq ft × 44 × ______ shading factor /______ insulation factor =	__________
2. Cathedral ceiling or roof over unventilated attic	________ sq ft × 48 × ______ shading factor /______ insulation factor =	__________
3. Exterior wall facing: North	________ sq ft × 18 × ______ shading factor /______ insulation factor =	__________
East	________ sq ft × 28 × ______ shading factor /______ insulation factor =	__________
South	________ sq ft × 24 × ______ shading factor /______ insulation factor =	__________
West	________ sq ft × 28 × ______ shading factor /______ insulation factor =	__________
4. Interior walls facing unconditioned rooms	________ sq ft × 12 / ______ insulation factor =	__________
5. Floors over unconditioned spaces	________ sq ft × 20 × ______ floor factor / ______ insulation factor =	__________
6. Infiltration: area of living space	________ sq ft × ______ air changes/hour × 1.6 =	__________
7. Window conduction	________ sq ft × 16 × ______ glazing factor =	__________
8. Window solar gain: North	________ sq ft × 16 × ______ shading factor /______ glazing factor =	__________
East, South, Southeast	________ sq ft × 80 × ______ shading factor /______ glazing factor =	__________
West, Southwest, Northwest	________ sq ft × 140 ×______ shading factor /______ glazing factor =	__________
Northeast	________ sq ft × 50 × ______ shading factor /______ glazing factor =	__________
9. Sum of lines 1 – 8	________ × ______ cooling factor from map on p. 571 =	__________
10. Utility gain	________ watts being consumed in space × 3.4 =	__________
11. People gain	________ number of people in space × 600 =	__________
12. Peak cooling load, BTU/hour: sum of lines 9 – 11 ×	______ thermal mass factor =	__________

Cooling Load Example

The facing page contains a completed form showing the calculations for the required capacity of a central air conditioner for the small house in Boston, Massachusetts, shown at right.

The house is deliberately kept simple in order to clarify the calculations. Many homes will have more than one type of exterior wall, foundation, or window, and they will require multiple entries for these line items.

Line 1. The ceiling measures 30 × 40 feet, so its area is 1,200 square feet. The roof, however, is pitched 30°, so its area is 1,386 square feet. (If you don't know how to do this calculation, see the relationships between the sides of a triangle in Chapter 25.) The unshaded roof has a shading factor of 1.00, from column 1 of Table 1. The insulation factor is 0.8 × the nominal R-value of 38.

Line 3. The north and south walls are each 320 square feet, less the window area of 21 square feet, or 299 square feet. The east and west walls measure 219 square feet by the same process. The west wall is fully shaded, so its shading factor (Table 1) is 0.70. The rest are unshaded, so their shading factors are 1.00. The nominal R-values of 19 are multiplied by 0.8 to get insulation factors of 15.2.

Line 4. The entire house is air-conditioned, so the interior walls have no effect and are left blank.

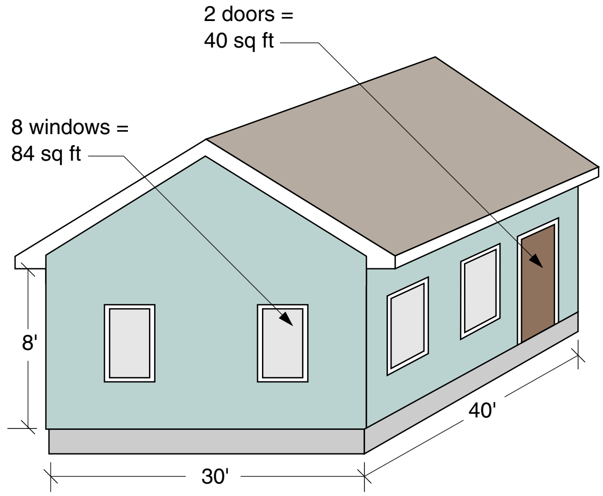
Line 5. The house sits on a vented (open) crawl space, so the floor factor is 1.0.

Line 6. The house is quite air-tight, so there are estimated to be 0.50 air changes per hour.

Line 7. The glazing factor, from column 1 of Table 3, for double-glazed windows is 0.5.

Line 8. Both east and south windows are entered on a single line. The shading factors are the same as for the walls in line 3. The glazing factor of 0.8 is found in column 2 of Table 3.

Example House for Cooling Load



Air exchange rate = 0.5 changes per hour

Ceiling R-38, walls R-19, floor R-19 over vented crawl space

Windows 21 sq ft each facing N, S, E, and W

West wall fully shaded; other walls and roof unshaded

Spring and fall utility bills average 350 kWhr/month

Three occupants in summer months

Line 9. The sum of the results column for all of the lines above is 13,921. Boston's cooling factor of 0.75 is found from the map on p. 571.

Line 10. The electric utility bills for the spring and fall months show an average consumption of 350 kWh per month.

Line 11. There are three occupants of the home during the cooling season.

Line 12. The thermal mass factor for a light wood frame house (1.00) is found in Table 4. The sum of lines 9 through 11 is 13,906, so the peak cooling load is 13,906 Btu/hr. This is a small cooling load for a house and could be satisfied easily by two 7,000 Btu/hr. room air conditioners.

Work Sheet for Sizing Air Conditioners

Source of Heat Gain	Calculations	Results
1. Roof over ventilated attic	1,386 sq ft × 44 × 1.00 shading factor / 30.4 insulation factor =	2,006
2. Cathedral ceiling or roof over unventilated attic	____ sq ft × 48 × ____ shading factor / ____ insulation factor =	
3. Exterior wall facing: North	299 sq ft × 18 × 1.00 shading factor / 15.2 insulation factor =	354
East	219 sq ft × 28 × 1.00 shading factor / 15.2 insulation factor =	403
South	299 sq ft × 24 × 1.00 shading factor / 15.2 insulation factor =	472
West	219 sq ft × 28 × 0.70 shading factor / 15.2 insulation factor =	282
4. Interior walls facing unconditioned rooms	____ sq ft × 12 / ____ insulation factor =	
5. Floors over unconditioned spaces	1,200 sq ft × 20 × 1.0 floor factor / 15.2 insulation factor =	1,579
6. Infiltration: area of living space	1,200 sq ft × 0.5 air changes/hour × 1.6 =	960
7. Window conduction	84 sq ft × 16 × 0.5 glazing factor =	672
8. Window solar gain: North	21 sq ft × 16 × 1.00 shading factor / 0.8 glazing factor =	420
East, South, Southeast	42 sq ft × 80 × 1.00 shading factor / 0.8 glazing factor =	4,200
West, Southwest, Northwest	21 sq ft × 140 × 0.70 shading factor / 0.8 glazing factor =	2,573
Northeast	____ sq ft × 50 × ____ shading factor / ____ glazing factor =	
9. Sum of lines 1 – 8	13,921 × 0.75 cooling factor from map on page 571 =	10,440
10. Utility gain	350 × 1.4 = 490 watts being consumed in space × 3.4 =	1,666
11. People gain	3 number of people in space × 600 =	1,800
12. Peak cooling load, Btu/hr. : sum of lines 9 – 11 ×	1.00 thermal mass factor =	13,906

0 1 2 3 4 5

20

Passive Solar

Since man constructed the first rudimentary shelter, he has always instinctively utilized free energy from the sun. What are our *passive solar possibilities* today? First you have to determine whether, and to what degree, your site has enough direct sun (solar access). To determine your site's solar access, we refer you back to the method given previously on pp. 386–392.

Next we look at the effects of *glazing orientation and tilt*. We find that good passive solar performance requires placing a high percentage of glazing (windows) on the south wall and little or none on the north. We also discover that ordinary vertical windows perform as well or better than tilted windows when the ground is covered with snow.

Of course, windows that gather the sun's heat in winter can also gain heat in the summer, so we look at techniques for *summer shading*.

If we want to get a high percentage of our heat from the sun, we have to take in as much radiation as possible while the sun is shining. In order that the building not overheat and that we have heat to carry us through the sunless night, we need some form of *heat storage*. Many ordinary building materials have significant ability to store heat. We show how to calculate the required surface areas of various heat-storing building materials in five different *thermal mass patterns*.

Utilizing all of the tricks above, we are able to predict the solar performance of our design using *a passive solar design procedure*.

Passive Solar Possibilities

What Is Passive Solar?

Of the many techniques for reducing energy consumption, increasing insulation, caulking, weather-stripping, and using high-performance windows and doors have been described in previous chapters. There are, however, techniques that capture free energy from the sun. These solar techniques can be roughly divided into two categories: active and passive solar heating. Passive techniques rely upon solar radiation, building mass, and siting; with these they capture, store, and release solar energy. With little if any increased cost, and with no noisy equipment to maintain, passive solar has become the technique of choice.

During the past 35 years, designers have learned a lot about the actual performance of passive solar structures. This chapter contains a condensation of that knowledge in the form of a simple design procedure that allows the design of near-optimum residential passive solar buildings anywhere in North America.

Conservation Requirements

Solar gain alone is no substitute for energy conservation. Guidelines for energy conservation in conjunction with passive solar design include the following:

- Insulate walls, roofs, and floors one step beyond the local norm; i.e., if the code calls for R-19 walls, make them R-25.
- Reduce air infiltration through the use of continuous air/vapor barriers and caulking and weather-stripping of all openings.
- Reduce the area of windows and doors on the north side of the building.
- Orient the building and openings to maximize the effects of cooling summer breezes and minimize the effects of winter winds.
- Utilize landscape elements to provide summer shade and to block winter winds.
- Provide overhangs and projections to shade glazings during the cooling season.
- Ventilate roofs and attics to avoid condensation damage and summer overheating.

Solar Access Requirements

The amount of solar radiation received by a passive solar structure's glazings during winter is critical. The design procedure that follows assumes nothing less than 100% solar access (zero shading by nearby buildings or trees) from 8AM to 4PM during the entire heating season. A method for determining degree of solar access for a specific site is given on pp. 386–392.

Direct Gain

Of all the passive solar types, direct gain is the easiest to understand, since it is a simple variation from an ordinary house with south-facing windows. A direct-gain design is one in which the solar radiation directly enters and heats the living spaces. The building itself is the solar collector.

In the heating season during daylight hours, sunlight enters through south-facing windows, patio doors, clerestories, or skylights. The radiation strikes and is absorbed by floors, walls, ceilings, and furnishings. As anyone who has ever been in a south-facing room in winter realizes, some of the heat is transferred to the air immediately, warming the room. Some of the heat is absorbed into the structure and objects in the room, to be released slowly during the night, filling some of the overnight heating requirement. In extreme designs, increased surface absorptivities and increased amounts of mass allow capture and storage of a full day's heat supply.

Although ceilings can be designed to store heat, common direct-gain storage materials are most easily incorporated into floors and walls, which frequently serve a structural purpose as well. Two very simple but effective storage masses that can be incorporated into any home are a masonry, tile, or slate floor, and walls with double layers of gypsum drywall.

Open floor plans are recommended, to allow distribution of the released heat throughout the house by natural air circulation.

Isolated Sunspace

Attached sunspaces are frequently constructed as extensions to homes. They are generally considered secondary-use spaces, in which heat is either collected and vented directly to the living space or is stored for later use. The energy collected is generally used to heat both the sunspace and the adjacent living space.

Sunspaces are designed for one of two basic modes of operation. In the first, the sunspace is isolated from the living space (illustration at middle right) by an insulated wall and doors that may be closed. As a result of this isolation, the sunspace is not treated as part of the conditioned space, and its temperature is allowed to fluctuate beyond the range of human comfort.

Integrated Sunspace

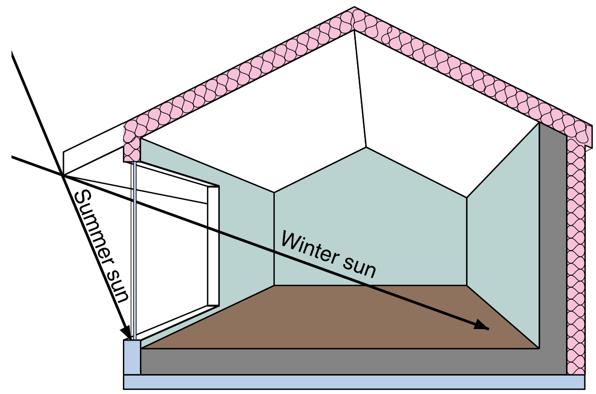
In the second case, the sunspace is integrated with the living space (illustration at bottom right), and its temperature is controlled with auxiliary heat or heat from the main living areas.

Integration is desirable when the space is primarily a living space. Isolation is desirable when the sunspace is used primarily as a greenhouse, generating more water vapor than the house can safely absorb without causing condensation and mildew.

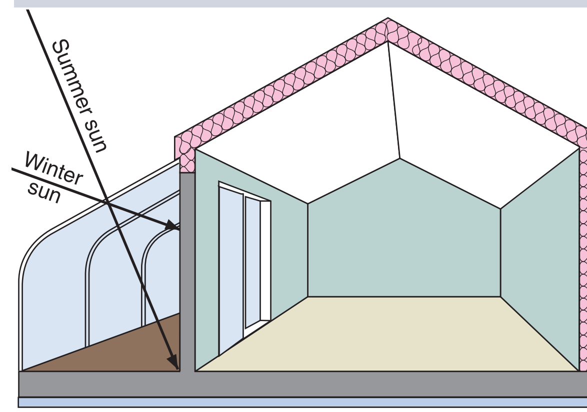
Sunspace glazings are often tilted for maximum light penetration and collection, but this exposes the glazings to increased summer heat gain. Two solutions are deciduous shade trees to block direct summer sun and ventilating windows and doors left open during the summer.

In northern areas, sunspace glazings should either be of a high-performance type (double-glazed with high-solar-gain low-E coating) or covered at night with a form of movable window insulation.

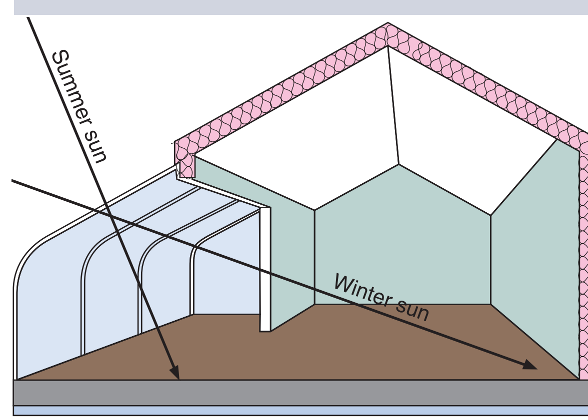
Direct Gain



Isolated Sunspace



Integrated Sunspace



Glazing Orientation and Tilt

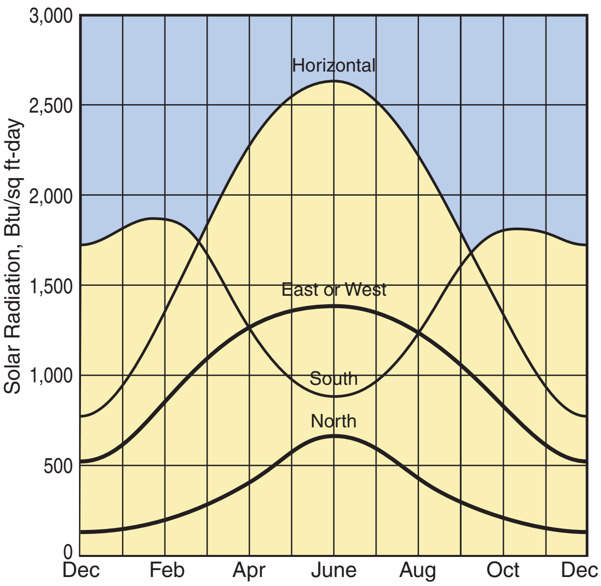
Glazing Orientation

A key circumstance that makes passive solar heating possible is the fact that the sun is lower in the southern sky in the winter than it is in the summer. As the graph at right shows, this means that south-facing windows will receive more solar heat in winter than in summer, while for north, east, and west exposures, the reverse is true.

This is why passive solar buildings usually have 50% to 100% of their windows on the south wall and little, if any, glazing on the north wall. Nonsolar houses usually have approximately 25% of their glazing on each of the four sides.

While the chart at right gives clear-day radiation at 40° north latitude, the principle applies throughout the northern hemisphere. The numbers of Btus will change, but the shapes of the curves will remain the same.

Clear-Day Radiation on Vertical Glazings at 40ºN

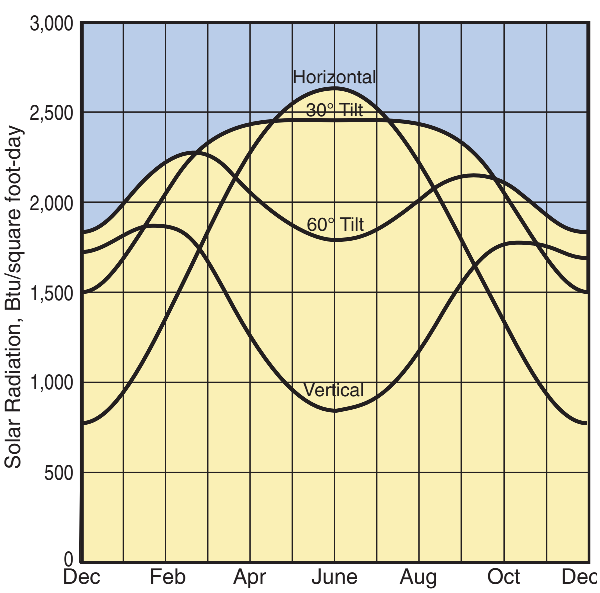


Glazing Tilt

Over the years, there has been controversy over the proper tilt for solar glazing. As the graph at right shows, tilted glazing receives slightly more *direct* radiation than vertical glazing. But vertical surfaces receive more *total* radiation if the foreground is covered with snow. The net effect is that tilt has little effect upon performance. Moreover, tilted glazing has practical disadvantages as compared with vertical glazing. Tilted glazing is more difficult to seal and is more prone to leaking. In fact, most glass companies will not guarantee the glazing unit seal when installed in any but the vertical position. In addition, building codes require tempered or safety glass for overhead installations. Finally, as the chart also shows, tilted glazings receive more summer radiation and therefore require shading.

Still, tilted glazing usually is favored for true plant-growing greenhouses because direct sunlight is needed throughout the structure.

Clear-Day Radiation on Tilted South-Facing Glazings at 40ºN



Summer Shading

As explained in Chapter 19, south vertical glazings must be shaded to prevent summer overheating. You can use a variety of awnings and inside or outside shades and shutters, but the most practical, attractive, and maintenance-free ways to provide shade are deciduous trees and roof overhangs.

Save existing shade trees and incorporate them into the siting of the building. If trees prove insufficient, roof overhangs can be incorporated into the building design. Use the formula and table below to find the proper overhang projection from the latitude of the site and the height of the eaves above the window sill. Use the May 10 to August 1 shade factor in the table if you have no shade trees on the south side of the house.

$$OH = H \times F$$

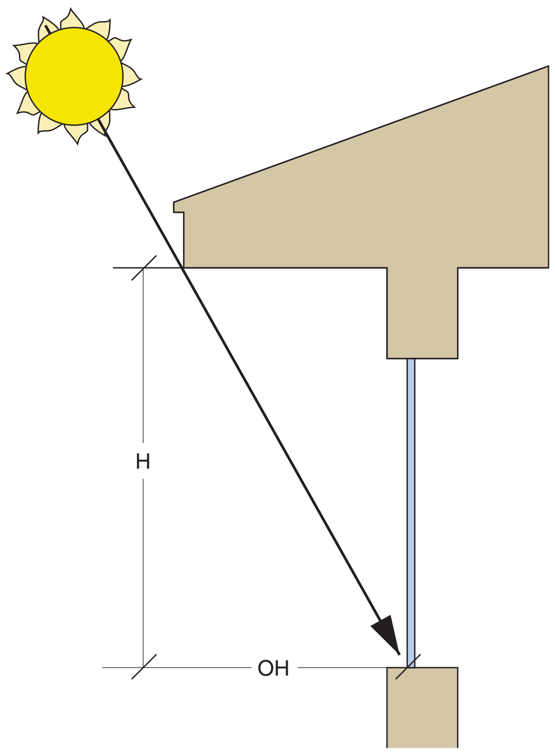
where:
OH = overhang's horizontal projection
H = height from eaves to window sill
F = factor found in the table below

Example: What is the required horizontal projection of eaves (beyond the plane of the glazing) to fully shade, on June 21, a south-facing window located at 40° north latitude if the window sill is 7 feet 2 inches lower than the eaves?

H = 7' 2"
= 86"
F = 0.29
OH = 86" × 0.29
= 25"

Roof overhangs are not practical for shading windows facing east or west or for tilted south-facing windows.

South-Facing Overhang Geometry



Factors for South-Facing Overhangs

North Latitude	For 100% Shading June 21 Only	For 100% Shading May 10–Aug 1
24	0.02	0.11
28	0.09	0.18
32	0.16	0.25
36	0.22	0.33
40	0.29	0.40
44	0.37	0.50
48	0.45	0.59
52	0.54	0.69
56	0.65	0.80

Heat Storage

Solar Absorptance

Once through the glazing, transmitted solar energy striking an interior surface can do one of two things:

1. Be reflected to another room surface or back through the glazing

2. Be absorbed (converted from radiant energy to sensible heat) by the surface

The fraction not reflected, but converted to heat, is termed the *absorptance* of the surface. The choice of absorptances of room surfaces is more complicated than one might at first assume. If all light were absorbed, room lighting conditions would be poor, with all of the light coming from a single direction. If little of the light were absorbed in the first several reflections, much of the radiation could escape back through the windows. And light absorbed by lightweight surfaces results in heated air and little thermal storage.

Solar designers recommend the following rules of thumb:

- Lightweight objects should be light in color to avoid overheating of the room air, promote more even light distribution, and reflect radiation onto more massive surfaces.
- Surfaces of massive objects, such as concrete slabs and fireplaces, should be dark in color and be placed to receive direct sunlight in order to efficiently collect and store heat.
- Ceilings should be white, and deep rooms should have light-colored back walls to diffuse light more evenly.
- Masonry floors receiving direct sun should not be covered with rugs or wall-to-wall carpeting.

Example: A room has both wood-paneled and brick walls. Make the paneled walls light in color and the brick walls dark.

Example: A combined living/kitchen space has both wood and slate floors. You may carpet the wood floor, but leave the slate floor uncovered.

Solar Absorptance of Surfaces

Material	Solar Absorptance
Flat black paint	0.95
Water	0.94
Gloss black paint	0.92
Black concrete	0.91
Gloss dark blue paint	0.91
Stafford blue bricks	0.90
Dark gray slate	0.90
Dark olive drab paint	0.89
Dark brown paint	0.88
Dark blue-gray paint	0.88
Dark green lacquer	0.88
Brown concrete	0.85
Medium brown paint	0.84
Silver gray slate	0.80
Medium Light brown paint	0.80
Medium rust paint	0.78
Light gray oil paint	0.75
Red oil paint	0.74
Red brick	0.70
Uncolored concrete	0.65
Light buff bricks	0.60
Medium dull green paint	0.59
Medium orange paint	0.58
Medium yellow paint	0.57
Medium blue paint	0.51
Kelly green paint	0.51
Light green paint	0.47
White semigloss paint	0.30
White gloss paint	0.25
White unpainted plaster	0.07
Aluminum foil	0.03

Heat Storage Capacity of Building Materials

Thermal mass is the amount of heat absorbed by a material as its temperature rises, expressed as Btu/°F. The specific heat of a material is its thermal mass per pound. Note that the *specific heat* of water is, by definition, exactly 1.00, coincidentally the highest of all natural materials.

As shown in the graph at right, the benefit of building thermal mass into a house is that the house becomes less responsive to outdoor temperature swings. This means the house won't get as hot during the day or as cold at night as it would without the added mass. In the graph, the outdoor temperature swings from an overnight low of 60°F to a daytime high of 80°F. An ordinary well-insulated house's interior temperature might swing from 65°F to 75°F, but the same house with added mass would swing only from 68°F to 72°F. The wider the outdoor temperature swing, the more beneficial the mass.

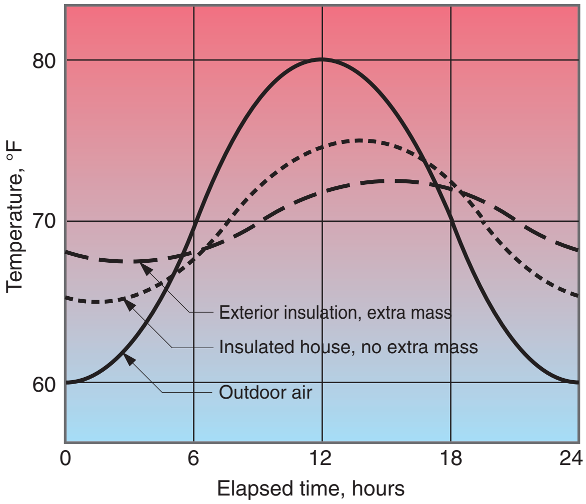
The table at right shows that there is little reason to turn to exotic materials. Masonry floors and walls, exposed wood, and extra-thick gypsum drywall can all be used effectively as storage masses. Water has been included in the table and in the design procedures at the end of the chapter, in case you wish to go supersolar.

You have already seen how material and color can affect the effectiveness of thermal mass. A third factor is thickness. When it comes to thermal mass, thicker is not necessarily better. If a wall is too thick, it remains always too cool to become a heat source. If it is too thin, it warms too quickly and begins returning heat before evening, when it is most needed.

Optimum thicknesses for common heat storage materials are:

- adobe 8 to 12 inches
- brick 10 to 14 inches
- concrete 12 to 18 inches
- water 6 or more inches

Temperature Swing vs. Thermal Mass



Heat Capacities of Materials

North Material	Specific Heat Btu/lb-F°	Density lb/cu ft	Heat Capacity Btu/cu ft-F°
Air (at 75°F)	0.24	0.075	0.018
Asphalt	0.22	132	29.0
Brick	0.20	123	24.6
Cement	0.16	120	19.2
Clay	0.22	63	13.9
Concrete	0.22	144	31.7
Copper	0.09	556	51.2
Glass	0.18	154	27.7
Gypsum drywall	0.26	78	20.2
Iron	0.12	450	54.0
Limestone	0.22	103	22.4
Marble	0.21	162	34.0
Sand	0.19	94.6	18.1
Steel	0.12	489	58.7
Water	1.00	62.4	62.4
White oak	0.57	47	26.8
White pine	0.67	27	18.1

Thermal Mass Patterns

Sizing and Placing Storage Mass

All buildings have mass in their floors, walls, ceilings, and furnishings. If they didn't, they'd all overheat on sunny days. The table below shows the approximate areas of south-facing windows in average-insulated and well-insulated wood frame homes before overheating occurs.

South Glazing Area Limits (glazed area as percent of floor area)

Degree-Days[1]	Ave. Jan. Temp, °F	Average House[2]	Well-Insulated House[3]
4,000	40	11	6
5,000	30	13	6
6,000	25	13	7
7,000	20	14	7

[1] See Chapter 18 for heating degree days, base 65°F.

[2] R-11 walls, R-19 ceiling, double-glazed windows.

[3] R-25 walls, R-38 ceiling, triple-glazed windows.

Example: With no additional mass, what is the maximum allowable area of south-facing window for a 1,800-square-foot home in Boston (6,000 DD_{65}) constructed with R-25 walls, R-49 ceiling, and R-3 windows? The energy efficiency of the home is close to the well-insulated house in the table, so the appropriate percentage is 7, and the maximum glazed area is 0.07 × 1,800 = 126 square feet.

The example above was a typical nonsolar home. To realize the higher fuel savings listed in the table on the facing page, however, a much greater window area is required. For example, the suggested window percentage for Boston is 15% to 29%, or two to four times the percentage in the example. Such a home will require additional storage mass.

Adding Mass

In the pages that follow, five distinctly different storage mass patterns are shown. For each, an accompanying table specifies the material, thickness, and surface area of mass required for each square foot of glazing in excess of the norm.

Example: Assuming you wish to achieve 25% solar savings for the home in Boston, you will need about 15% of the floor area in south glazing. You therefore need additional thermal mass to compensate for (15% minus 7% equals) 8% of the floor area, or 144 square feet of glazing. Using Pattern 1 (Floors and Walls in Direct Sunlight) and assuming a bare 6-inch concrete slab as the mass, you'll find you need 3 × 144 square feet, or 432 square feet of slab in direct sunlight. If you don't have the required area of slab, you'll have to add mass from other patterns.

The Mass Patterns

Pattern 1 corresponds to a home with a masonry floor. The floor may be a concrete slab-on-grade, or it may consist of a masonry veneer over a wood or concrete base.

Pattern 2 might represent a home with one or more exposed masonry walls or a home with an extra-thick plaster or drywall.

Pattern 3 might occur when a building is remodeled, exposing an interior masonry party wall. It could also represent a very large masonry fireplace.

Pattern 4 typically represents a sunspace with a masonry rear wall.

Pattern 5 is not very common but accounts for any massive structure in direct sunlight that does not reach the ceiling. A masonry planter/room divider would fall into Pattern 5.

Pattern 1

Pattern 1 is defined as thermal storage mass with one surface exposed to the living space and in direct sun for at least 6 hours a day. Architecturally, this pattern combined with Pattern 2 is useful for direct-gain passive solar rooms.

The mass can be either a directly irradiated floor slab, as shown, or a directly irradiated outside wall (inside walls are considered in Pattern 3). As with Patterns 2 and 3, the mass element is single-sided; that is, heat enters and exits the mass from the same surface.

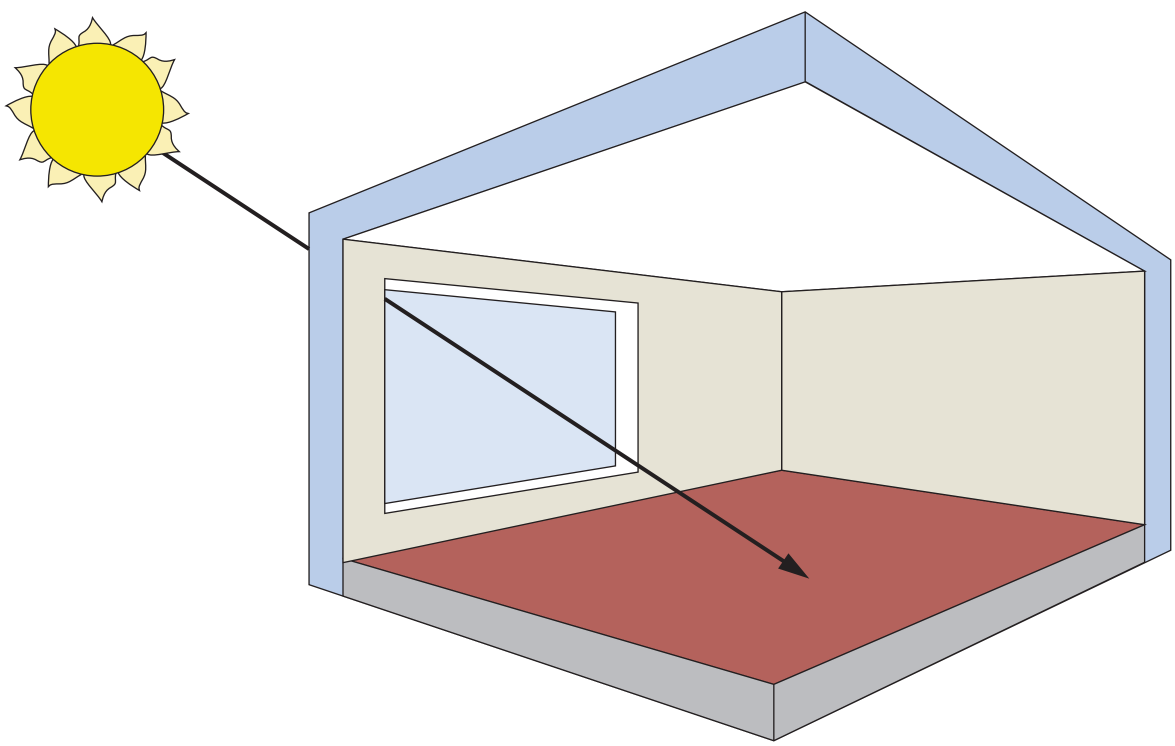
Example: The design procedure has called for 100 square feet of south-facing glass in a room with 200 square feet of floor and 380 square feet of windowless wall. Does a 4-inch concrete slab provide enough thermal mass to prevent overheating?

According to the table, you should provide 4 square feet of 4-inch concrete slab for each square foot of glazing. That would require 400 square feet of slab. Increasing the slab thickness to 6 inches would still require 300 square feet of slab. Therefore, you must either reduce the glazed area or add further mass, utilizing one of the other four mass patterns.

Mass Sizing for Floors and Walls in Direct Sun

Mass Thickness	Sq Ft of Mass per Sq Ft of Glazing				
	Concrete	Brick	Drywall	Oak	Pine
1/2″	—	—	76	—	—
1″	14	17	38	17	21
1 1/2″	—	—	26	—	—
2″	7	8	20	10	12
3″	5	6	—	10	12
4″	4	5	—	11	12
6″	3	5	—	11	13
8″	3	5	—	11	13

Thermal Mass Pattern 1



Thermal Mass Patterns—*Continued*

Pattern 2

The mass in Pattern 2 is like that in Pattern 1, that is, the mass is single-sided and insulated on the back side. The distinction here is that the mass is receiving not direct radiation, but reflected sun.

In a simple direct-gain space, some of the mass will be of Pattern 1 (a floor slab near the solar glazing, for example), and some mass will be of Pattern 2 (the ceiling, for example). Much of the mass in such a space will be directly irradiated some of the time and indirectly irradiated the rest of the day. In these cases, an interpolation between Pattern 1 and Pattern 2 must be carried out, as described in Pattern 1.

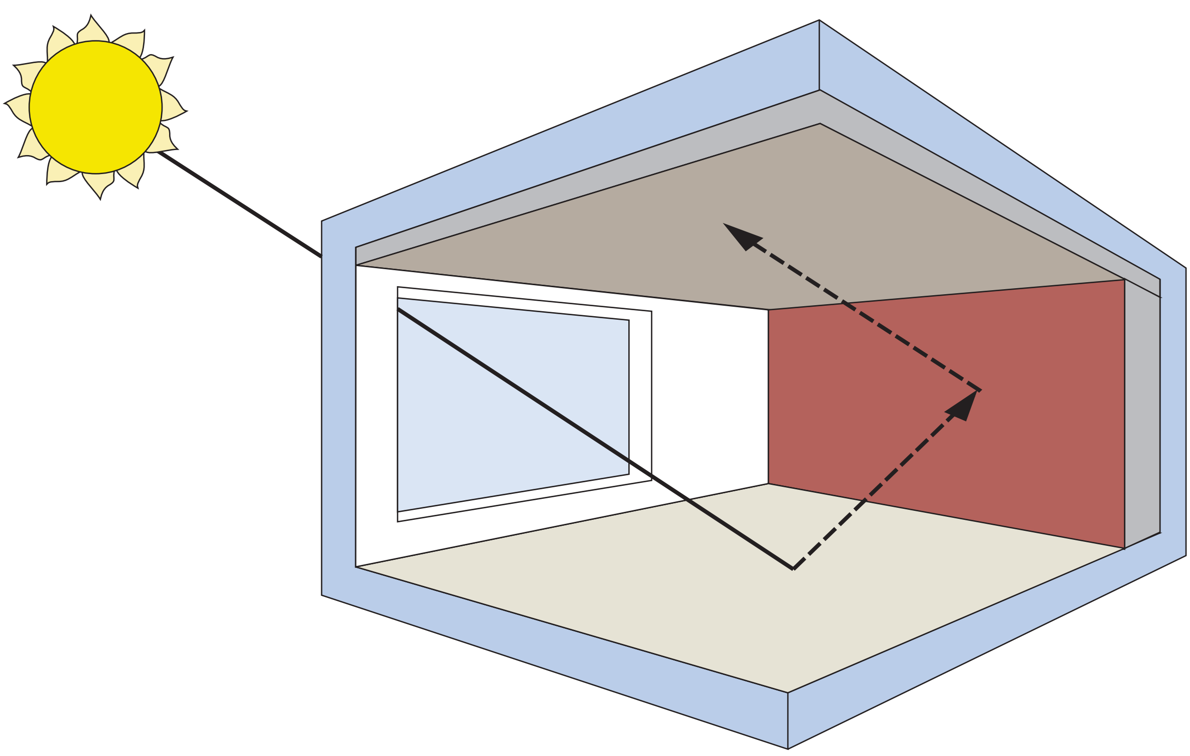
Example: You have decided to use an 8-inch concrete slab for the room described in mass Pattern 1. This leaves 33 square feet of glazing to provide mass for. How many square feet of 8-inch brick wall will be required to provide the mass?

Mass Sizing for Floor, Wall, or Ceiling in Indirect Sun

Mass Thickness	Sq Ft of Mass per Sq Ft of Glazing				
	Concrete	Brick	Drywall	Oak	Pine
1/2″	—	—	114	—	—
1″	25	30	57	28	36
1 1/2″	—	—	39	—	—
2″	12	15	31	17	21
3″	8	11	—	17	20
4″	7	9	—	19	21
6″	5	9	—	19	22
8″	5	10	—	19	22

According to the table above, 10 square feet of 8-inch brick wall is required to balance each square foot of glazing. You therefore need 330 square feet of brick wall. Since the total wall area is 380 square feet, this is a practical solution.

Thermal Mass Pattern 2



Pattern 3

As in Patterns 1 and 2, the mass in this pattern is one-sided. The difference is that the mass receives neither direct radiation nor reflected radiation. It is instead heated by the room air that is warmed as a result of solar gains elsewhere in the building.

This pattern is useful for mass deeper within a passive building. However, solar-heated air must reach the remote mass either by natural or forced-air circulation. Judgment is required here—a hallway open to a south room could be included, a back room closed off from the solar-heated space should be excluded.

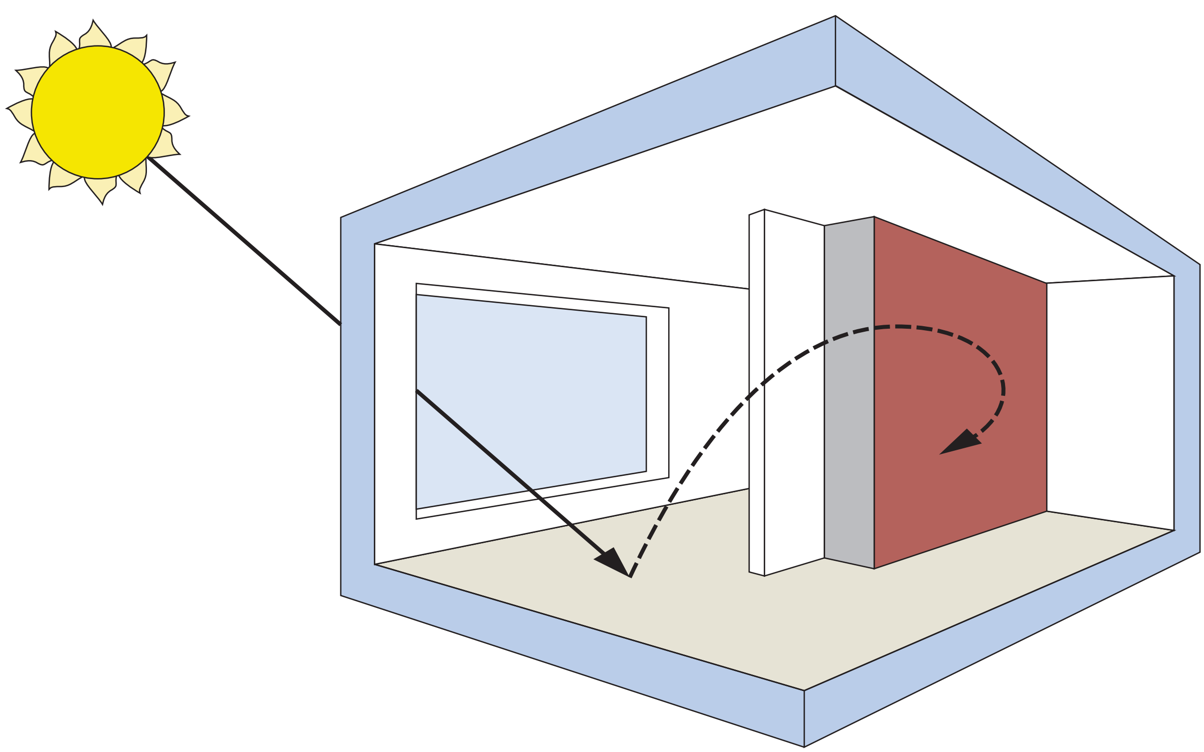
Mass Sizing for Floor, Wall, or Ceiling Remote from Sun

Mass Thickness	Sq Ft of Mass per Sq Ft of Glazing Concrete	Brick	Drywall	Oak	Pine
1/2″	—	—	114	—	—
1″	27	32	57	32	39
1 1/2″	—	—	42	—	—
2″	17	20	35	24	27
3″	15	17	—	26	28
4″	14	17	—	24	30
6″	14	18	—	28	31
8″	15	19	—	28	31

Example: Your remodeling plan calls for removing half of a wood-framed gypsum wall to open the south-facing kitchen to the living room. The remaining wall has an 80-square-foot fireplace of 8-inch brick on the living room side. You plan to add a south-facing window in the kitchen. How many square feet of window will the mass of the fireplace balance?

According to the table, the fireplace alone will account for only 4 square feet of window. You must look elsewhere for thermal mass.

Thermal Mass Pattern 3



Pattern 4

Pattern 4 is defined as a floor-to-ceiling wall of massive material that receives direct sun on one side and is exposed to the living space on the other side. In other words, the sunlit side is isolated from the living space.

This pattern is useful for isolated sunspaces and greenhouses. The storage wall may have high and low vents or be unvented, as shown, without affecting the values in the table.

The performance of the wall improves with thickness up to about 18 inches but is not very sensitive to variations in thickness within normal buildable ranges. For brick walls, higher density bricks (with water absorption of less than 6 percent) are recommended over bricks of lower density. Note that the mass surface area refers to the area of the sunlit side only.

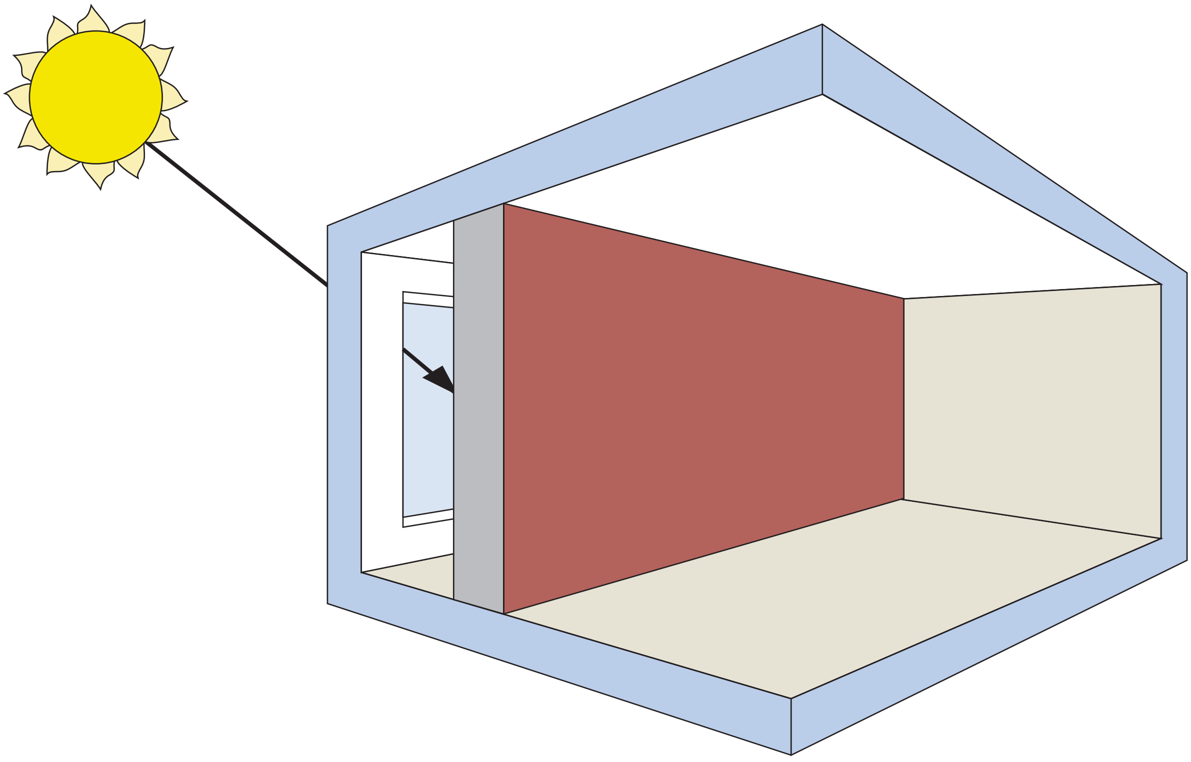
Mass Sizing for Mass Wall or Water Wall in Direct Sun

Material and Thickness	Sq Ft of Mass Surface per Sq Ft of Glazing
8″-thick brick	1
12″-thick brick	1
8″-thick water wall	1

Example: You are considering adding an attached solar greenhouse. The primary purpose of the greenhouse will be to grow plants. The greenhouse structure should therefore be isolated to avoid excess humidity in the living space.

As the table shows, 1 square foot of 8-inch brick, l2-inch concrete, or 8-inch water wall (water containers) for each square foot of glazing will conveniently provide all of the required thermal mass.

Thermal Mass Pattern 4



Pattern 5

Similar to Pattern 4, mass in this pattern is sunlit on one side and exposed to the living space on the other side. The distinction is that there is free air circulation around this mass material so that heat may be gained by the living space from either side of the partial wall or from all sides of the water containers.

This pattern may represent a freestanding masonry wall or a series of water containers.

The mass is assumed to be in full sun for at least 6 hours. As with Pattern 4, the wall thicknesses listed are not very sensitive to variations, and the wall surface area listed is for one side of the wall only. Water containers are listed in the table at right as gallons per square foot of glazing.

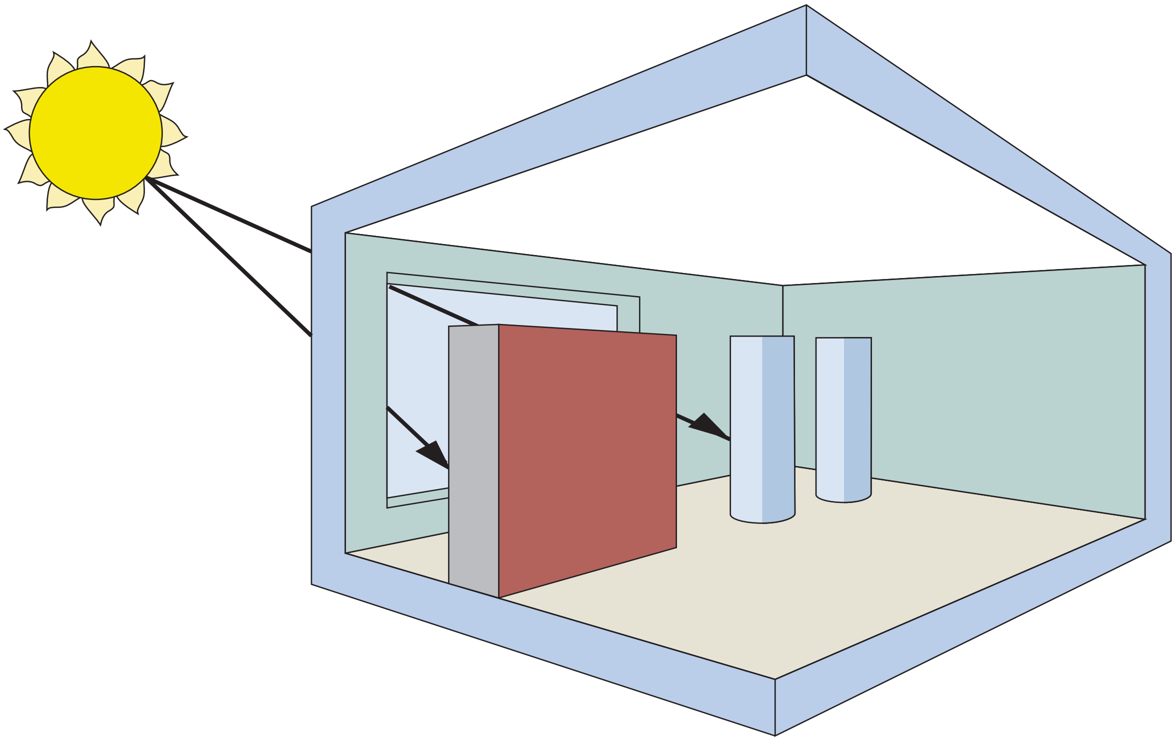
Example: You plan to add a sunspace with 160 square feet of south-facing glazing. Unlike the example in Pattern 4, however, you plan to use the space for living rather than growing. You'd like the sunspace to be open to the adjacent kitchen. Will a 3-foot high by 20-foot-long room divider constructed of 8-inch brick provide sufficient thermal mass?

The area of the room divider exposed to direct sunlight is 60 square feet. According to the table, the room divider alone will account for only 30 square feet of glazing. You will probably need to employ a Pattern 1 brick floor as well.

Mass Sizing for Partial Mass Wall or Water Containers in Direct Sun

Material and Thickness	Sq Ft of Mass Surface per Sq Ft of Glazing
8″-thick brick	2
6″-thick concrete	2
Water containers	7 gal per sq ft of glazing

Thermal Mass Pattern 5



A Passive Solar Design Procedure

The tables in this section provide a simple method for the preliminary design of passive solar buildings. Initial sizing of both window area and storage mass can be quickly achieved knowing only location, floor area, building insulation level, and window R-value.

The procedure yields the area of south-facing windows, amount and placement of storage mass, and estimated reduction in winter heating bills.

Glazed Area and Fuel Saving

Extensive computer simulations have been performed by researchers at Los Alamos Laboratory for passive solar homes in the cities listed in the table on the facing page. Interpretation of the table is simple:

"A south-facing window area of between XI and X2 percent of the floor area can be expected to reduce the winter fuel bill of a home by YI to Y2 percent."

The smaller window area and fuel-saving percentages (X1 and Y1) correspond to ordinary homes with ordinary window areas, with the exception that the windows have all been moved to the south wall. The larger figures (X2 and Y2) give the maximum recommended target percentages for the location.

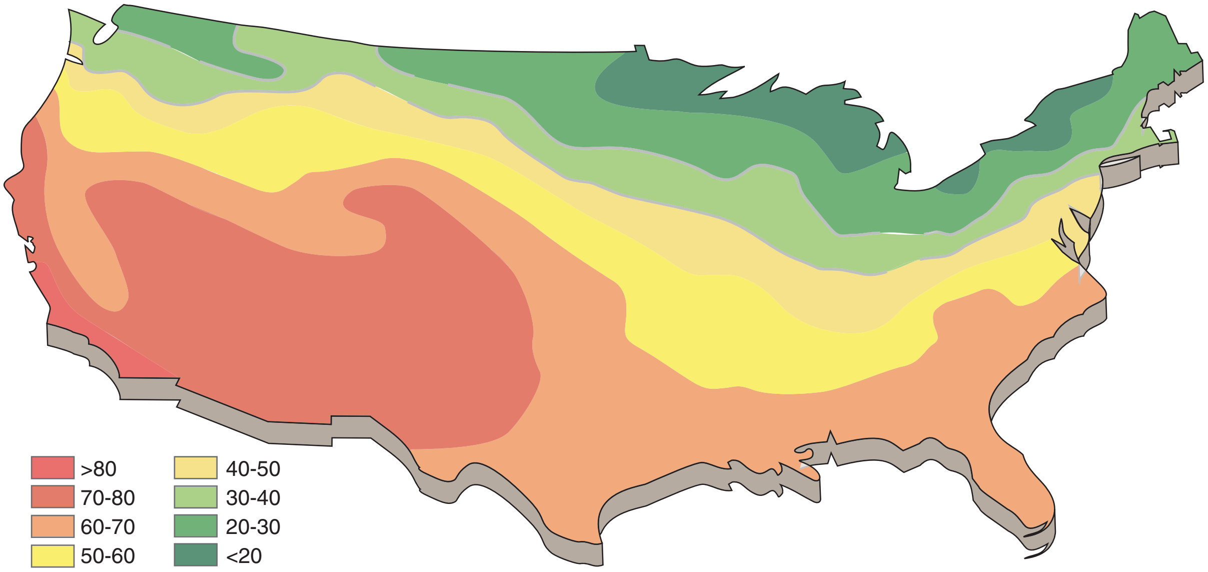
The predicted fuel saving depends on the type of window: double-glazed (DG), triple-glazed or equivalent R-3 glazing such as Low-E (TG), or double-glazed with R-9 night insulation (DG+R9).

Example: In Boston, Massachusetts, a south-facing window area of 15% to 29% of floor area can be expected to reduce the winter fuel bill by 17% to 25% if double glazed, 26% to 39% if triple glazed, or 40% to 64% if double glazed with R-9 night window insulation.

Assumed Heat Loss

The predictions assume a building heat loss of 6 BTU per degree-day per square foot of floor area. This corresponds roughly to R-19 walls, R-38 ceilings, double glazing, and an infiltration rate of $^3/_4$ air change per hour. If your home's insulation levels are different, the table values may be adjusted proportionally. For example, if your home has R-28 walls, R-57 ceilings, triple glazing, and $^1/_2$ air change per hour (one and a half times as much insulation and two-thirds as much heat loss as the standard), you can reduce your window areas by one-third and still achieve the same percentage fuel saving.

Typical Solar Savings for Passive Solar Heating, Percent



Glazed Area vs. Solar Savings

City	Glazed Area[1] X1 - X2	Percent Savings[2] for DG Y1 -Y2	TG Y1 -Y2	DG+R9 Y1 -Y2
AL, Birmingham	9–18	22–37	34–58	34–58
AZ, Phoenix	6–12	37–60	41-66	48-75
AR, Little Rock	10-19	23-38	28-47	37-62
CA, Los Angeles	5-9	36-58	39-63	44-72
CO, Denver	12-23	27-43	34-54	47-74
DE, Wilmington	15-29	19-30	26-42	39-63
DC, Washington	12-23	18-28	25-40	37-61
FL, Orlando	3-6	30-52	33-56	37-63
GA, Atlanta	8-17	22-36	26-44	34-58
ID, Boise	14-28	27-38	35-50	48-71
IL, Chicago	17-35	17-23	27-39	43-67
IN, Indianapolis	14-28	15-21	23-35	37-60
IA, Des Moines	21-43	19-25	30-44	50-75
KS, Topeka	14-28	24-35	32-48	45-71
KY, Louisville	13-27	18-27	24-39	35-59
LA, Baton Rouge	6-12	26-43	29-49	34-59
ME, Portland	17-34	14-17	25-36	45-69
MA, Boston	15-29	17-25	26-39	40-64
MI, Detroit	17-34	13-17	23-33	39-61
MN, Duluth	25-50	Not Rec	24-33	50-70
MS, Jackson	8-15	24-40	28-47	34-59
MO, St Louis	15-29	21-33	28-45	41-65
MT, Great Falls	18-37	23-28	35-46	56-77
NE, North Platte	17-34	25-36	34-51	50-76
NV, Las Vegas	9-18	35-56	40-63	48-75
NH, Concord	17-34	13-15	25-35	45-68
NJ, Newark	13-25	19-29	26-42	39-64
NM, Albuquerque	11-22	29-47	35-57	46-73

Glazed Area vs. Solar Savings

City	Glazed Area[1] X1 - X2	Percent Savings[2] for DG Y1 -Y2	TG Y1 -Y2	DG+R9 Y1 -Y2
NY, Syracuse	19-38	Not Rec	20-29	37-59
NC, Greensboro	10-20	23-37	28-47	37-63
ND, Bismarck	25-50	Not Rec	27-36	56-77
OH, Columbus	14-28	13-18	21-32	35-57
OK, Tulsa	11-22	24-38	30-49	41-67
OR, Salem	12-24	21-32	27-33	37-59
PA, Pittsburgh	14-28	12-16	20-30	33-55
RI, Providence	15-30	17-24	26-40	40-64
SC, Columbia	8-17	25-41	29-48	36-61
SD, Pierre	22-43	21-33	35-44	58-80
TN, Nashville	10-21	19-30	24-39	33-55
TX, Dallas	8-17	27-44	31-51	38-64
UT, Salt Lake City	13-26	27-39	31-51	48-72
VT, Burlington	22-43	Not Rec	23-33	46-68
VA, Richmond	11-22	21-34	27-44	37-61
WA, Seattle	11-22	21-30	28-41	39-59
WV, Charleston	13-25	16-24	22-35	32-54
WI, Madison	20-40	15-17	28-38	51-74
WY, Caper	13-26	27-39	38-53	53-78
AB, Edmonton	25-50	Not Rec	26-34	54-72
BC, Vancouver	13-26	20-28	27-40	40-60
MB, Winnipeg	25-50	Not Rec	26-34	54-74
NS, Dartmouth	14-28	17-24	27-41	45-70
ON, Ottawa	25-50	Not Rec	28-37	59-80
QC, Normandin	25-50	Not Rec	26-35	54-74

[1] Glazed area as percentage of heated floor area.

[2] Percent reduction in annual heating bill from that of an equivalent house having uniform distribution of windows of area totaling 15% of heated floor area.

21

Lighting

Proper lighting around the home is important for safety, for reading, for working, for atmosphere, for the long-term health of your eyes, and now for economy and the environment. In order to understand why different light sources and intensities are recommended for different applications, you need to understand the relationships between *light and seeing.*

Light Sources lists the efficiencies and color characteristics of more than 30 incandescent, fluorescent, high-intensity-discharge, and light-emitting diode (LED) lamps for use in and around the home.

Lamp Shapes and Bases illustrates the incredible variety of bulb shapes and bases available today.

Perhaps the most useful section in this chapter is *Residential Lighting Guidelines,* adapted from a publication of the California Lighting Technology Center, designed to aid builders in complying with California's rigorous 2005 energy code.

Finally, we provide you with a checklist to make sure your lighting design and techniques *meet the code.*

Light and Seeing

Light Units

The relationship between lighting units is displayed in the illustration at right. A point light source with a strength (candlepower) of 1 candela results in an *illuminance* of 1 *footcandle*, or 1 lumen per square foot. Since a sphere of radius 1 foot has a surface area of 12.57 square feet, the total light output is 12.57 *lumens*.

Illumination levels are usually given in footcandles, although lumens per square foot is equivalent. Total lamp output is always given in lumens.

The intensity of light falling on a surface is the illuminance. The intensity of light given off or reflected by a surface is its *luminance*. For non-light-emitting surfaces:

Luminance = illuminance × *reflectivity*

Example: What is the luminance of a surface of reflectivity 0.50 when illuminated at an intensity of 100 footcandles? Luminance = illuminance × reflectivity = 100 footcandles × 0.50 = 50 footcandles

Visual Acuity

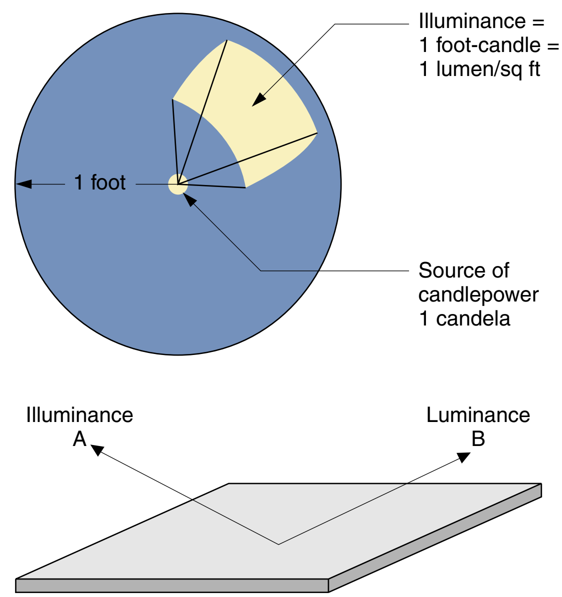
As shown in the illustration at right, the human eye can detect light from nearly an entire half sphere (radius 90°). The ability to discriminate among small details, however, is limited to a radius of about 1°, the *central field*. The area surrounding the central field is the *surround*.

The ability of the eye to discern the small details of a task within the central field is determined by four factors:

- size of the field
- contrast between detail and background
- time (eye fatigue)
- brightness of the task

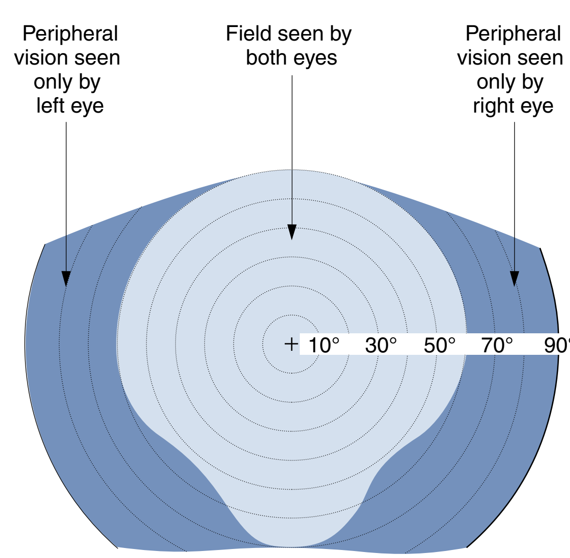
The size of a task can be magnified by a lens. In the case of printed material, contrast is maximized by printing black on white. Luminance is a function of both illumination and task reflectance. Deficiencies in size, contrast, and time can all be compensated to a degree by an increase in illumination.

Light Measurements



Surface reflectivity = R
B = R x A

The Visual Field of a Human



Angles are from straight ahead.

Glare

An area within the visual field that has sufficient luminance to cause either discomfort or a reduction in visual acuity is an area of *glare*. Direct glare is illumination direct from a light source, such as a window or exposed lamp. Reflected glare is light that has been reflected from a shiny or glossy surface, usually within the task area. For optimum visual comfort, the luminance of the task should be slightly greater than the luminance of the surround. The table at right lists maximum recommended luminance ratios.

Color

Most objects simply reflect incident light received from a light source. The perceived color of an object is determined by the color (energy content at different wavelengths) of the light source and the reflectivity of the object at the corresponding wavelengths.

Objects that reflect all wavelengths equally are termed *white*, and light sources that emit light of all frequencies are termed *white lights*. Not all wavelengths are emitted equally, however, even from white lights. The graphs at right show the distribution of power with frequency (spectral power curves) of various common lamps.

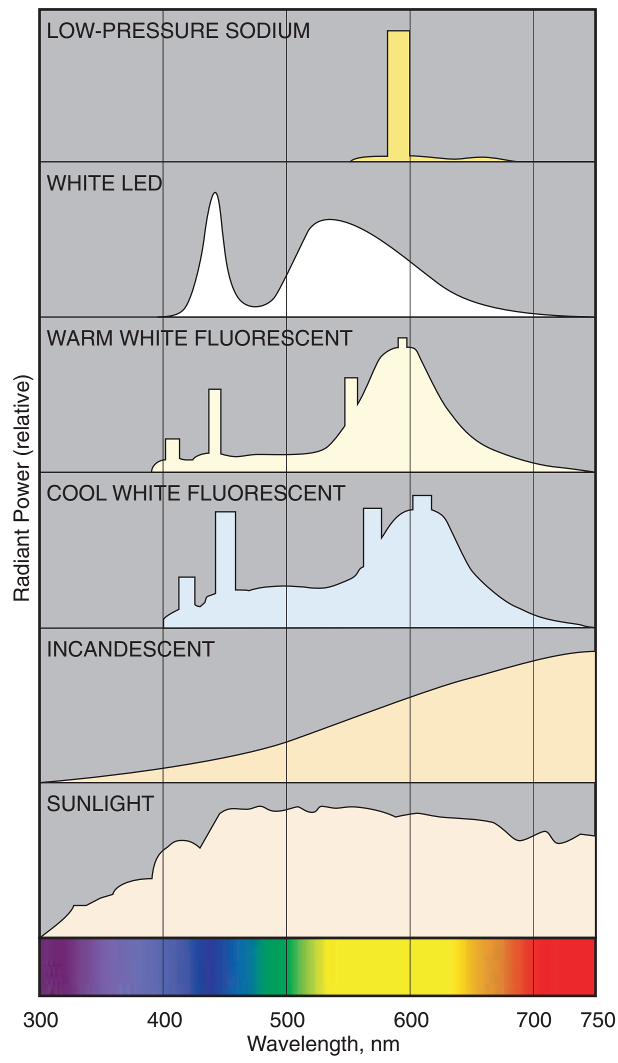
A measure of peak emission wavelength is the color-correlated temperature (CCT) of the source. Direct light from the sun is at a color temperature of about 6,000° Kelvin (K). The color-correlated temperatures of incandescent sources range from about 2,400°K to 3,100°K. Most fluorescent lamps have color-correlated temperatures between 3,000°K (warm white) and 4,200°K (cool white).

Incandescent lamps emit light at all wavelengths. Fluorescent and other gas-discharge lamps emit light only at specific wavelengths. Color rendition may therefore be different between incandescent and gas-discharge lamps even though their color-correlated temperatures may be the same. The color-rendering index (CRI) compares lamp output with natural daylight at all frequencies, with a CRI of 100 indicating a perfect match.

Glare Guidelines

Compared Areas	Luminance Ratio, Max
Task to adjacent area	3 to 1
Task to a remote dark surface	10 to 1
Task to a remote light surface	0.1 to 1
Window to adjacent wall	20 to 1
Task to any area within visual field	40 to 1

Spectral Power Curves of Lamps



Light Sources

Electrical lamps fall into one of four categories, depending on the way in which they convert electricity to light:

Incandescent lamps emit light from filaments heated to incandescence by an electric current. Efficiencies range from about 10 to 20 lumens per watt. Quartz-halogen lamps achieve higher efficiencies, of up to 24 lumens per watt, through the use of higher-temperature filaments. Strong points include a wide range of bulb styles, a wide range of available output for the same base style and bulb size, and ability to concentrate the light beam, Weak points are relatively low efficiency and short lives. Due to their low efficiencies, most versions are being passed out.

High-intensity discharge (HID) lamps emit light directly from electric arcs through metal vapor. Color rendition is inappropriate for residential applications, but efficiencies range up to 144 lumens per watt.

Fluorescent lamps emit light from phosphor coatings stimulated by high-voltage discharge through the mercury-vapor-filled bulbs. Rare earth phosphor additives modify color output. Efficiencies range from about 70 to 90 lumens per watt. Strong points include long life, efficiency, and low operating temperature, but mercury content remains a serious environmental issue.

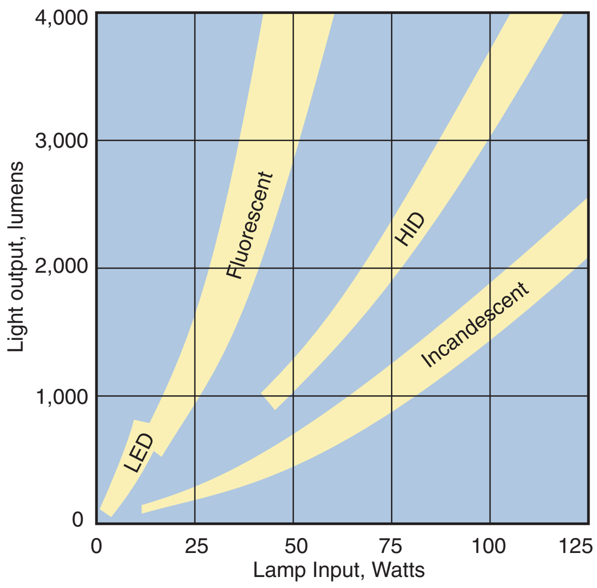
Light-emitting diode (LED) A light-emitting diode is a semiconductor diode emitting narrow-spectrum light when electrically biased in the forward direction of the p-n junction.

Individual LEDs are tiny and emit light from a flat surface. Most often they are encapsulated in a plastic lens to shape the radiation pattern. LEDs have long been used as small indicator lights on electronic devices and increasingly in applications such as flashlights. Compared to fluorescent lamps, LEDs offer longer lives and higher efficiencies, and they do not pose environmental risks. It is expected they will ultimately replace both incandescent and fluorescent lamps.

Efficiencies of Light Sources

Light Source	Type	Efficacy, Lumens/W
Incandescent	5W tungsten	5.0
	40W watt tungsten	12.6
	100W tungsten	16.8
	100W tungsten halogen	16.7
	2.6W tungsten halogen (5V)	19.2
	Quartz tungsten halogen (12V)	24
Fluorescent	5W to 24W compact bulb	45–60
	34W, T-12 tube	50
	32W, T-8 tube	60
	36W, T-8 tube	to 93
	28W, T-5 tube	104
HID	Xenon	30–50
	Mercury-xenon	50–55
	High-pressure sodium	150
	Low-pressure sodium	183–200
	1,400W sulfur	100
LED	White, available	80-100
	White, experimental	to 150

Lamp Efficiencies



Characteristics of Some Commercially Available Lamps

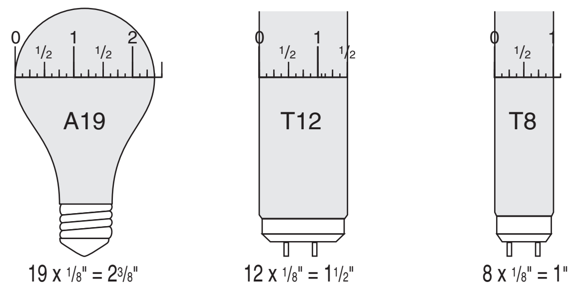
Type	Lamp	Color Temp, °K	CRI	Output, Lumens	Power, Watts	Lumens per Watt
Incandescent	A19, frosted, 25 watt	2,900	—	357	25	14
	A19, frosted, 40 watt	2,900	—	460	40	12
	A 19, frosted, 60 watt	2,950	—	890	60	15
	A 19, frosted, 75 watt	3,000	—	1,210	75	16
	A 19, frosted, 100 watt	3,050	—	2,850	150	18
	12V quartz-halogen, 20 watt	2,900	—	300	19.4	15
	12V quartz-halogen, 45 watt	3,100	—	980	44.5	22
Fluorescent	Dulux® EL, 11 watt	3,000	82	600	11	54
	Dulux EL, 19 watt	3,000	82	1,200	19	63
	Deluxe warm white	2,950	74	1,550	30	52
	Warm white	3,000	52	2,360	30	79
	Designer 3000K	3,000	67	3,300	40	83
	Royal white	3,000	80	2,400	30	80
	Octron® 3100K	3,100	75	3,650	40	91
	White	3,450	57	1,900	30	63
	Octron 3500K	3,500	75	3,650	40	91
	Natural white	3,600	86	3,050	55	55
	Designer 4100K	4,100	67	8,800	95	93
	Octron 4100K	4,100	75	3,650	40	91
	Deluxe cool white	4,100	89	2,100	40	53
	Lite white	4,150	48	4,300	60	72
	Cool white	4,200	62	3,150	40	79
	Design 50	5,000	90	1,610	30	54
	Daylight	6,300	76	1,900	30	63
HID	Mercury, Warmtone	3,300	52	3,700	100	37
	Mercury, Brite White Deluxe	4,000	45	3,650	100	37
	Mercury, clear	5,900	22	3,380	100	34
	Metal halide, clear	3,200	65	6,800	100	68
	Metal halide, coated	3,900	70	16,000	250	64
	High-pressure sodium, Lumalox	2,000	22	8,850	100	89
	High-pressure sodium, Unalox	1,900	20	11,700	150	78
LED	A19, warm white	3,000	—	43	1.3	33
	A19, cool white	8,000	—	42	1.3	32
	PAR38, warm white	3,000	—	182	4.5	40
	PAR38, pure white	5,500	—	230	5.0	46
	Chandelier, warm white	3,000	—	52	2.4	22

Lamp Shapes and Sizes

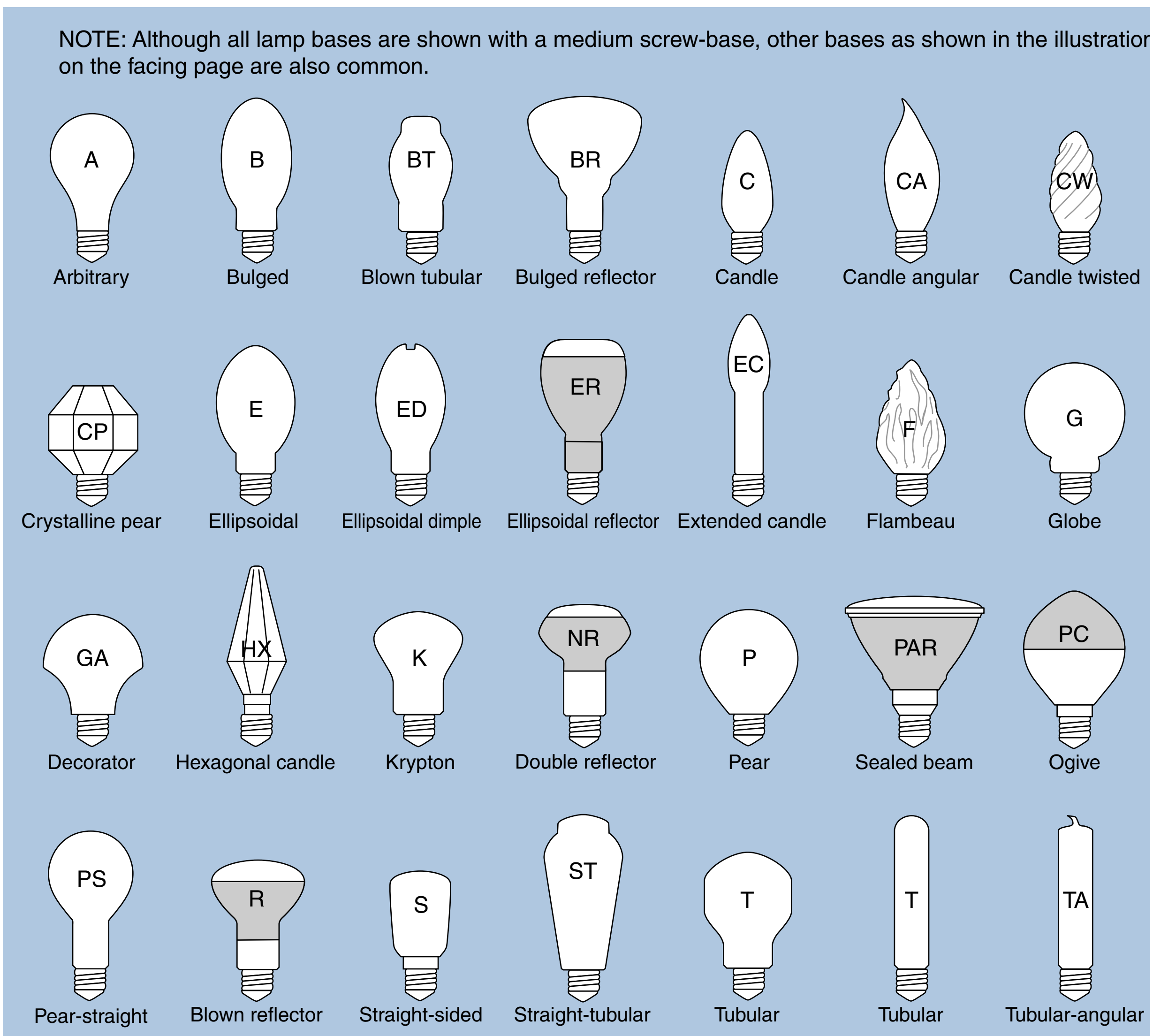
That old standby household lamp, the A19, is a direct descendent of Edison's original bulb. But what is the meaning of the designation, "A19?" As shown in the illustration below, "A" denotes the shape of the bulb.

What about the "19?" The number following the letter denotes the maximum diameter of the bulb in $^1/_8$ inches. See the illustration at right for examples.

Lamp Sizes



Standard Lamp Shapes



Lamp Bases

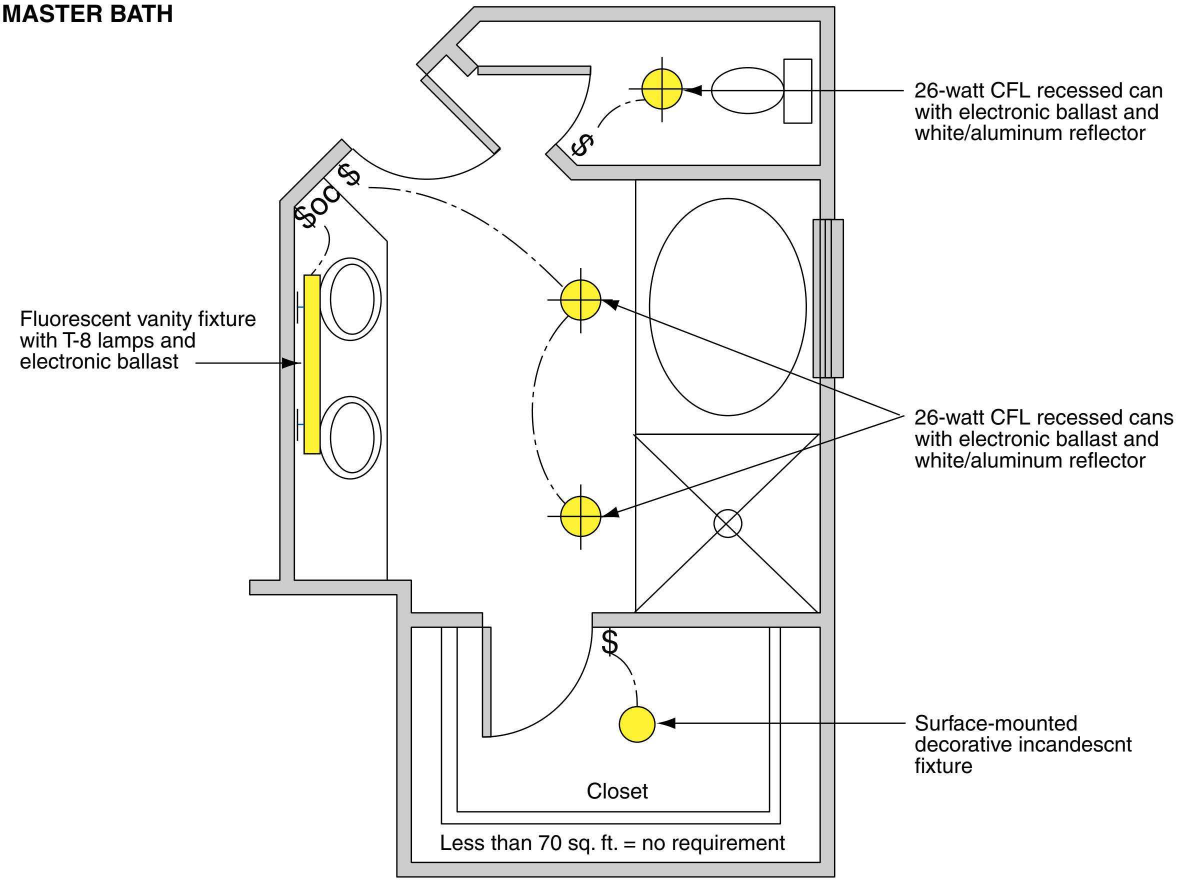
Standard Lamp Bases

Residential Lighting Guidelines

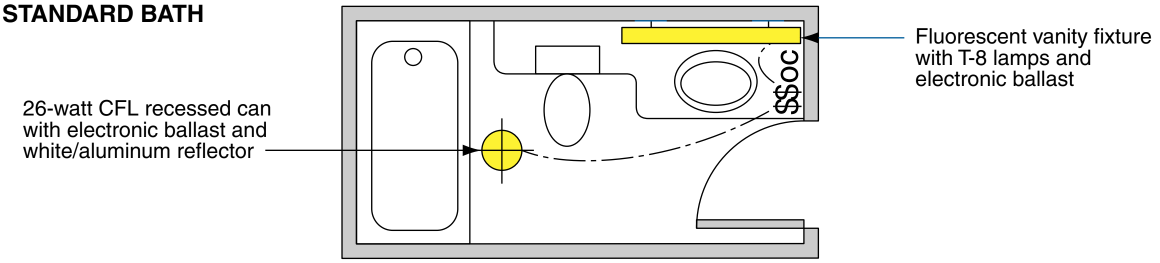
As the old saying goes, "A picture is worth a thousand words." By "picture" we mean, of course, a wiring plan. In the next four pages we present wiring plans that demonstrate a variety of ways of satisfying the energy code—specifically the 2005 California Energy Code. Since no state is more stringent than California, the ideas should work in your state, as well. However, LED lamps are now available in most configurations and at reasonable cost, so substitute them for the fluorescent versions wherever possible.

Bathrooms

MASTER BATH

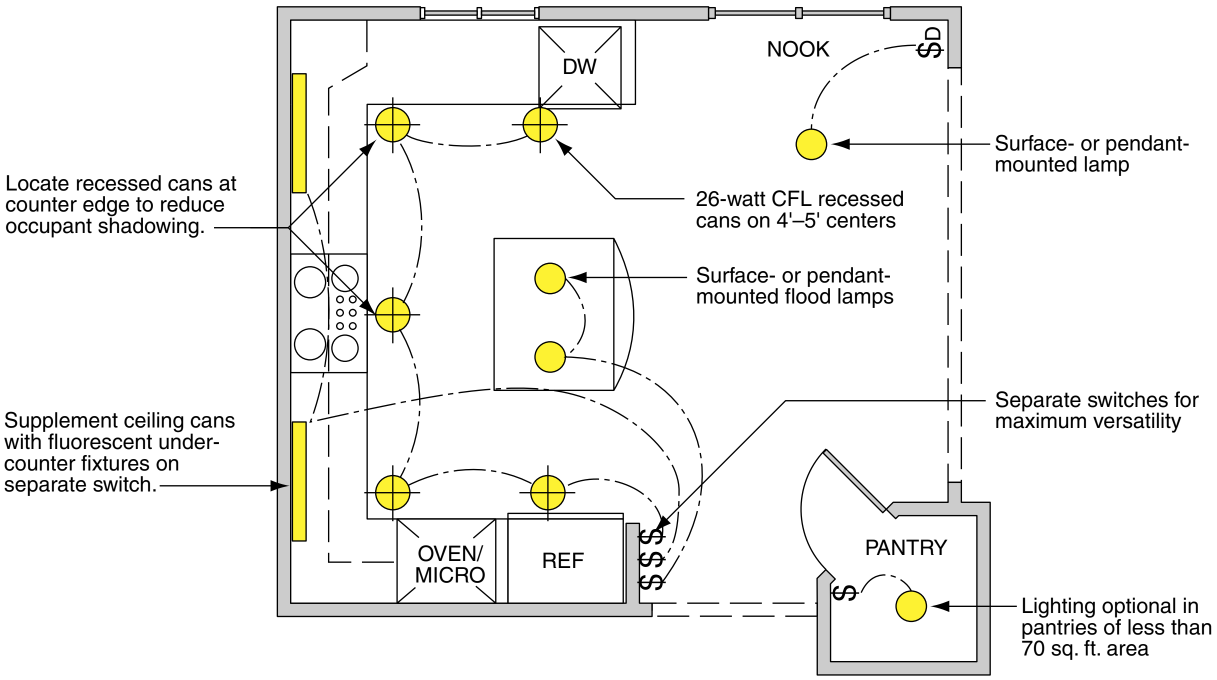


STANDARD BATH

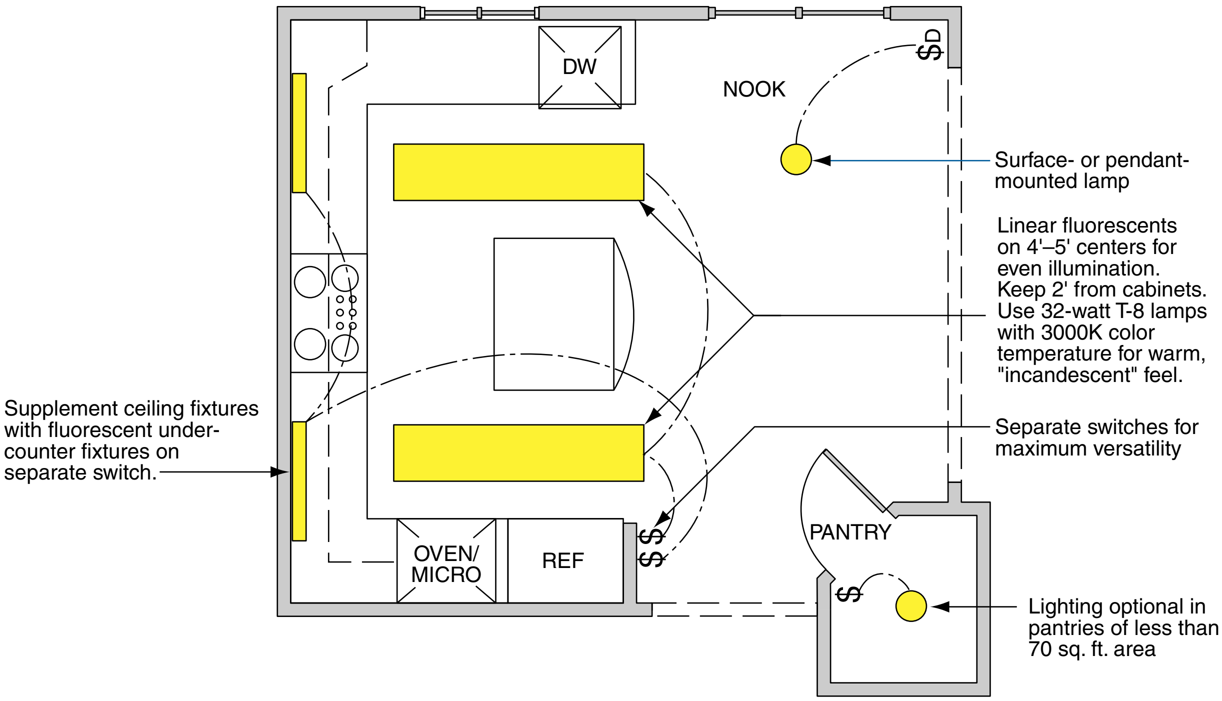


Kitchens

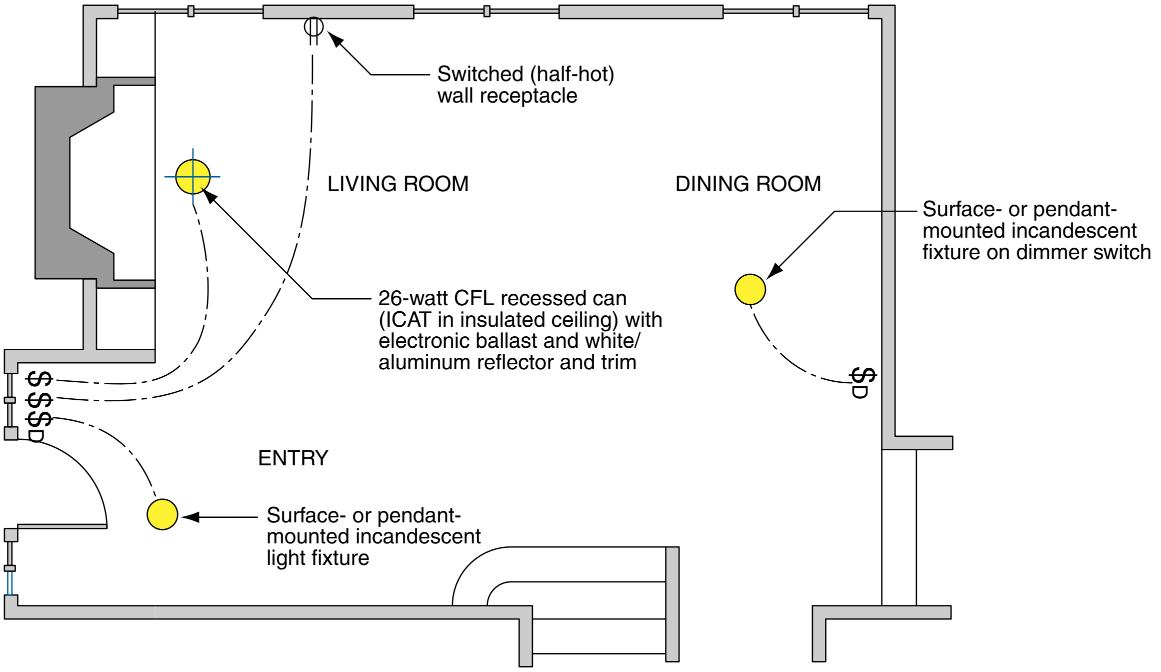
OPTION 1: RECESSED CEILING FIXTURES



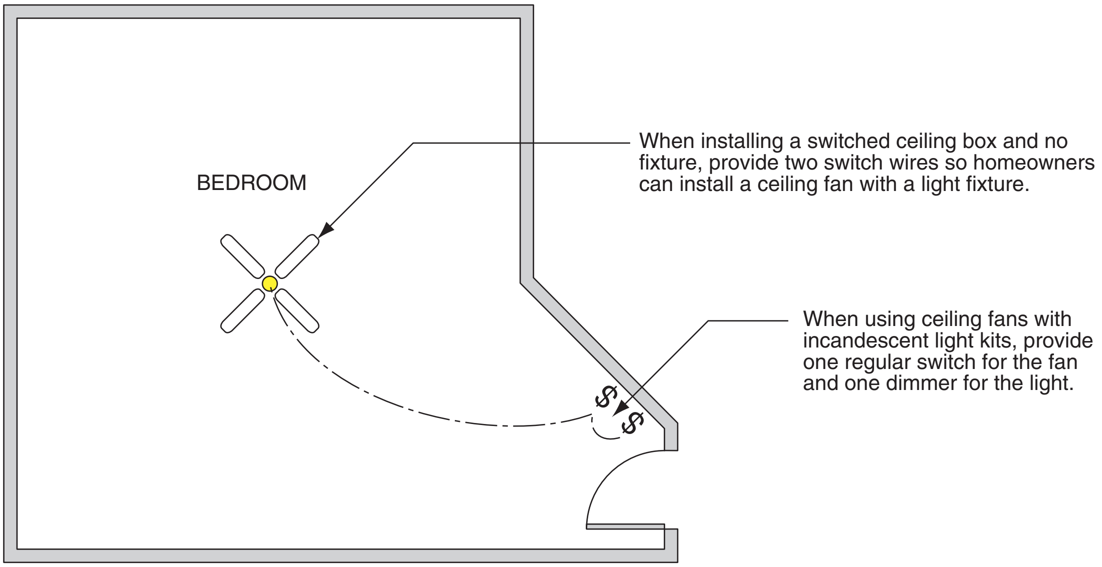
OPTION 2: LINEAR FLUORESCENT CEILING FIXTURES



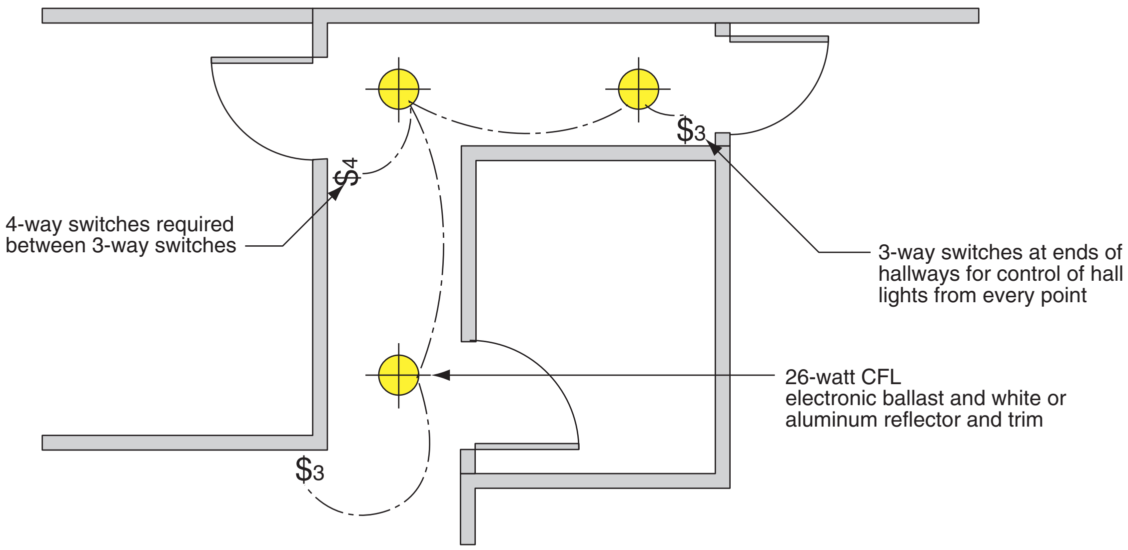
Dining Rooms and Living Rooms



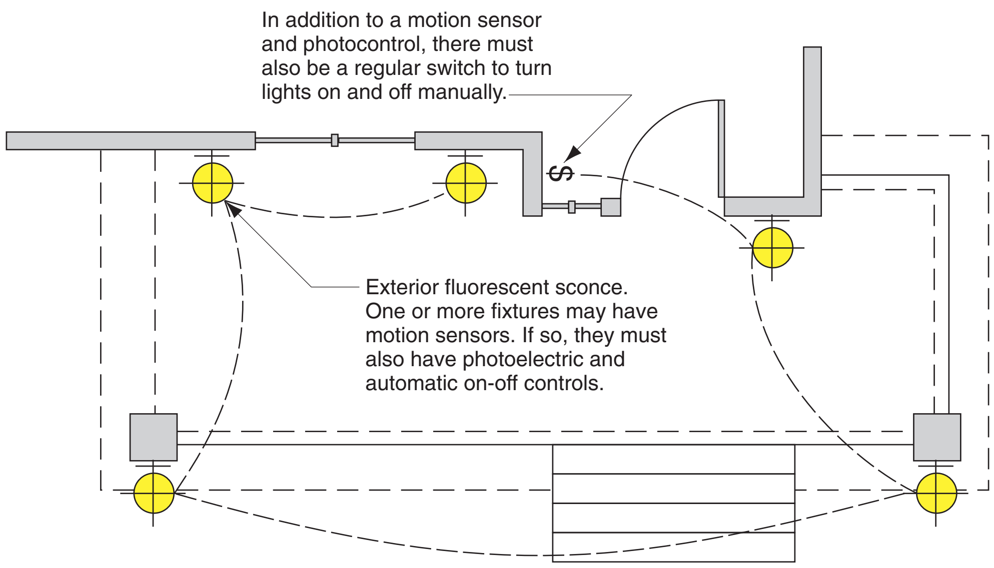
Bedrooms



Entry Areas, Foyers, and Hallways



Porches



Meet the Code (IRC)

The following is a partial list of requirements from the *2006 International Residential Code (IRC) for One- and Two-Family Dwellings.* Consult the publication for the full text and additional provisions.

Light and Ventilation (R303)

Habitable rooms:

- glazing area ≥8% of floor area unless lighting provides ≥6 foot-candles
- for purposes of light and ventilation, an adjoining room is considered part of a room when ≥50% of the common wall is open

Bathrooms:

- glazing area ≥3 sq. ft., half openable
- glazing not required if provided with artificial light and ventilation to outside of ≥50 cfm

Stairway illumination:

- interior stairs must be lighted to ≥1 foot-candle either at each landing or over each section of stairs
- exterior stairs must be lighted at top landing; basement bulkhead stairs at lower landing
- lighting for interior stairways of ≥6 stairs must be controllable from both levels
- unless continuous or automatic, lighting for exterior stairs must be controllable from inside

Required Branch Circuits (E3603)

Lighting and general-use receptacle loads:

- not less than 3 watts per sq. ft. of floor area
- floor area based on building outside dimensions, not including open porches, garages, or unused or unfinished spaces not adaptable for future use

Lighting Outlets (E3803)

Habitable rooms:

- switch-controlled lighting outlet to be installed in every habitable room and bathroom
- except in kitchens and bathrooms, a switched receptacle controlled by a wall switch OK
- lighting outlets may be controlled by occupancy sensors in addition to manual wall switches

Additional locations:

- switch-controlled lighting to be installed in hallways, stairways, attached garages, and detached garages with electric power
- switch-controlled lighting on exterior of egress door having grade level access, including egress doors for attached garages and detached garages with electric power
- for interior stairways having ≥6 risers between levels, a wall switch at each floor level and landing that includes an entryway

Exception: in hallways, stairways, and at outdoor egress doors, remote, central, or automatic control of lighting permitted

- a lighting outlet controlled by wall switch or integral switch in attics, under-floor spaces, utility rooms, and basements used for storage or containing equipment requiring servicing. At least one switch to be at the point of entry. A lighting outlet also to be provided near equipment requiring servicing.

Fixtures (E3903)

- luminaires, lampholders, lamps, and receptacles not to have energized parts exposed
- luminaires installed so that combustible material not subjected to temperatures >194°F
- exposed metal parts to be grounded or insulated from ground and other conducting surfaces
- screw-shell lampholders used as lampholders only
- recessed incandescent luminaires to have thermal protection and be listed as thermally protected

Exceptions:

1. recessed luminaires listed for the purpose and installed in poured concrete
2. recessed luminaires with design, construction, and thermal performance equivalent to thermally protected luminaires

- ballast of indoor fluorescent luminaire to have integral thermal protection.

Exception: simple reactance ballast in a fluorescent luminaire with straight tubular lamps not required to be thermally protected

- recessed high-intensity luminaires to have thermal protection and be identified as thermally protected.

Exceptions:

1. recessed luminaires listed for purpose and installed in poured concrete
2. recessed luminaires equivalent to thermally protected luminaires

Wet locations:

- luminaires to be installed so that water cannot enter or accumulate in wiring compartments, lampholders, or other electrical parts
- luminaires in wet locations to be marked SUITABLE FOR WET LOCATIONS
- luminaires in damp locations to be marked SUITABLE FOR WET LOCATIONS or SUITABLE FOR DAMP LOCATIONS
- lampholders to be weatherproof
- cord-connected luminaires, chain-, cable-, or cord-suspended-luminaires, lighting track, pendants, and ceiling fans to have no parts within 3' horizontally and 8' vertically from top of a bathtub rim or shower stall threshold. Luminaires located in this zone to be listed for damp locations and, where subject to shower spray, listed for wet locations.

Clothes closets:

- luminaires limited to surface-mounted or recessed incandescent with completely enclosed lamps, and surface-mounted or recessed fluorescent

Installation:

- Surface-mounted incandescent luminaires to be installed on wall above door or on ceiling, with clearance of ≥12" between fixture and storage space
- Surface-mounted and recessed fluorescent luminaires and recessed incandescent luminaires with completely enclosed lamps to be installed on wall above door or on ceiling, with clearance of ≥6" between fixture and storage space
- luminaires to be wired so screw shells of lampholders connected to same luminaire or circuit conductor or terminal. The grounded conductor to be connected to the screw shell.

Luminaire Installation (E3904)

- outlet boxes to have covers except where covered by luminaire canopy, lampholder, or device with a faceplate
- combustible finish exposed between edge of a canopy or pan and outlet box to be covered with a noncombustible material
- connections between luminaire conductors and circuit conductors to be accessible without disconnection
- luminaires weighing >6 lb or exceeding 16" in any dimension may not be supported by screw shell of a lampholder
- luminaires with exposed ballasts or transformers to be installed so ballasts or transformers not in contact with combustible material
- surface-mounted luminaires with ballasts on combustible low-density cellulose fiberboard must be listed for the purpose or spaced ≥1.5" from surface
- recessed luminaires not identified for contact with insulation (Type IC) to have all recessed parts spaced ≥0.5" from combustibles, except points of support and finish trim parts
- no thermal insulation above recessed luminaire or <3" from enclosure, wiring compartment, or ballast except if identified for contact with insulation, Type IC

Track Lighting (E3905)

- track to be permanently installed and connected to a circuit with rating ≤ that of track
- fittings for track designed specifically for the track
- electrical load on track not to exceed track rating
- track not to be installed in the following locations:
  1. subjected to physical damage
  2. wet or damp locations
  3. subject to corrosive vapors
  4. storage battery rooms
  5. hazardous locations
  6. concealed
  7. extended through walls or partitions
  8. <5' above floor except where protected from damage or track operates at <30 volts rms open-circuit voltage

22

Sound

The *quality of sound* in our homes has a great effect on the quality of our lives. When we play music or engage in conversation, we want to hear clearly and hear well. On the other hand, when junior is playing what teenagers call music, or the neighbors upstairs are fighting, we don't want to hear at all.

In this chapter you'll see how to choose materials with the proper *noise-reduction coefficients* to modify the *absorption and reverberation* of sound in a room and what to do about a room that either rings or is acoustically flat.

You'll also find guidelines for acceptable *sound transmission* between rooms and between floors. Tables of *sound transmission classes (STCs) of walls* and *STCs and impact insulation classes (IICs) of floor-ceilings* show specific construction techniques for reducing sound transmission to almost any level.

Quality of Sound

Sound is the sensation produced when pressure waves in the acoustic range of frequencies strike the eardrum. Typically, a young person can hear sound over the range of 20 to 20,000 cycles per second, or Hertz (Hz).

Sound quality involves sound source intensity, absorption, echo, standing-wave amplification, and reverberation time.

Intensity

Sound intensity is measured in decibels (db). The 0 db level is defined as a sound energy level of 10^{-16} watts per square centimeter and corresponds roughly to the smallest sound detectable by the human ear. Perceived intensity, or sound "volume," is logarithmic, that is a 10-db increase in intensity is an increase of 10 times the power of the sound wave, but is perceived as a doubling of volume. The table at right lists characteristic sound intensities of everyday sources.

Sound Intensities

Intensity, db	Sound Source
0	Threshold of hearing
10	Rustling leaves
20	Rural background
30	Bedroom conversation
40	Living room conversation
50	Large office activity
60	Face-to-face conversation
70	Auto interior at 55 mph
80	Face-to-face shouting
90	Downtown traffic
100	Tablesaw
110	Symphony orchestra maximum
120	Elevated train from platform
130	Threshold of pain (rock concert)
140	Jet engine

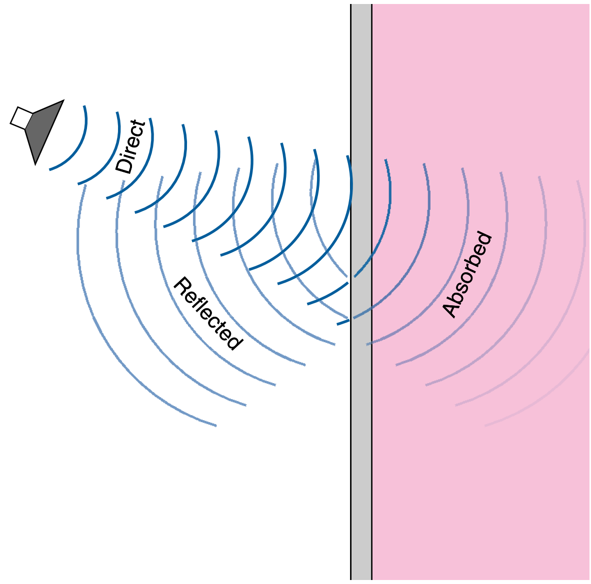
Absorption

The fraction of energy absorbed by a surface is its absorption coefficient, α. Gypsum drywall is highly reflective (α = 0.05 at 500 Hz), while heavy carpet is highly absorptive (α = 0.57 at 500 Hz). One unit of absorption is equivalent to an area of one square foot of perfect (α = 1.00) absorption.

High absorption does not reduce the intensity of sound received directly from a source but reduces the buildup of reflected sound. It thus reduces the total intensity of sound in a space.

Absorption is measured at 125, 250, 500, 1,000, 2,000, and 4,000 Hz. In order to give a material a single absorption figure, the noise-reduction coefficient (NRC) is defined as the average of coefficients at 250, 500, 1,000, and 2,000 Hz. The table on the facing page lists typical NRCs for surfaces in the home.

Reflection and Absorption



Noise Reduction Coefficients

Typical Noise Reduction Coefficients (NRCs)

Material		Absorption Coefficient at (Hertz)				
		250	500	1,000	2,000	NRC
Brick	Bare	0.03	0.03	0.04	0.05	0.04
	Painted	0.01	0.02	0.02	0.02	0.02
Carpet, heavy	On slab	0.06	0.14	0.37	0.60	0.29
	On 40-oz foam pad	0.24	0.57	0.69	0.71	0.55
	On foam with latex backing	0.27	0.39	0.34	0.48	0.37
Concrete block	Bare	0.44	0.31	0.29	0.39	0.36
	Painted	0.05	0.06	0.07	0.09	0.07
Fabric	10-oz velour hung straight	0.04	0.11	0.17	0.24	0.14
	14-oz velour pleated double	0.31	0.49	0.75	0.70	0.56
	18-oz velour pleated double	0.35	0.55	0.72	0.70	0.58
Floor	Bare concrete	0.01	0.02	0.02	0.02	0.02
	Resilient on concrete	0.03	0.03	0.03	0.03	0.03
	Bare wood	0.11	0.10	0.07	0.06	0.09
	Parquet on concrete	0.04	0.07	0.06	0.06	0.06
Furniture	Bare wood	0.04	0.05	0.07	0.07	0.06
	Metal	0.04	0.05	0.07	0.07	0.06
	Upholstered with plastic	0.45	0.50	0.55	0.50	0.50
	Upholstered with fabric	0.37	0.56	0.67	0.61	0.55
Glass	Plate	0.06	0.04	0.03	0.02	0.04
	Double strength	0.25	0.18	0.12	0.07	0.16
Wall	1/2″ gypsum drywall	0.10	0.05	0.04	0.07	0.07
	Marble	0.01	0.01	0.01	0.02	0.01
	Glazed tile	0.01	0.01	0.01	0.01	0.01
	Plywood paneling	0.22	0.17	0.09	0.10	0.15
Plaster	Smooth finish on brick	0.02	0.02	0.03	0.04	0.03
	Smooth finish on lath	0.03	0.04	0.05	0.04	0.04
	Rough finish on lath	0.02	0.03	0.04	0.04	0.04
Cellulose fiber	Sprayed ⅝" on solid backing	0.16	0.44	0.79	0.90	0.42
	Sprayed 1" on solid backing	0.29	0.75	0.98	0.93	0.74
	Sprayed 1" on timber lath	0.90	1.00	1.00	1.00	0.98
	Sprayed 1¼" on solid backing	0.30	0.73	0.92	0.98	0.73
	Sprayed 3" on solid backing	0.95	1.00	0.85	0.85	0.91

Absorption and Reverberation

Echo

An echo is a sound reflection. To be perceived as a distinct sound, the reflected wave must arrive at least 1⁄17 of a second after the direct wave. Because sound travels at about 1,000 feet per second, an echo must have travelled at least 60 feet further than the direct sound. Thus, echoes occur only in rooms more than 30 feet deep. Echoes are stronger when the reflecting surface is highly reflective and is concave toward the listener (focussing the reflected wave toward the listener).

Standing Waves

When the dimensions of a room are a multiple of the wavelength of a sound), the sound wave is reinforced by reflection. Frequencies are thus selectively amplified, distorting the original, direct sound. The problem is made worse by reflective room surfaces, parallel room surfaces, and room dimensions in simple ratios, such as 1:4, 1:3, etc.

Reverberation Time

The length of time required for the intensity of sound in a space to diminish by 60 db is the *reverberation time* of the space. A room with too short a reverberation time is acoustically dead; too long a reverberation time confuses sounds. Reverberation time can be calculated as:

T = V/20A

where
T = reverberation time in seconds
V = volume of room in cubic feet
A = total absorption of the room

The procedure is:

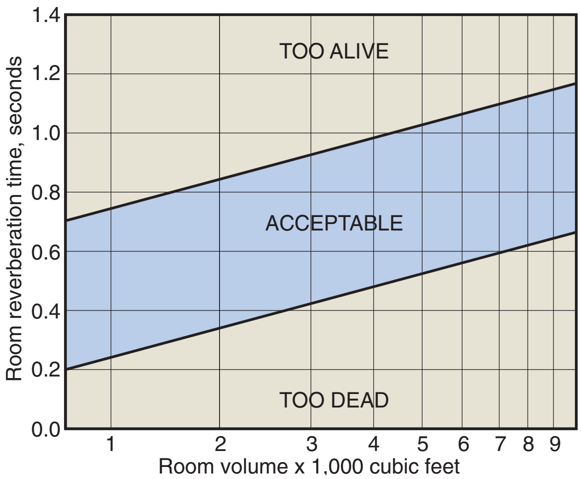
1. Calculate the areas of all surfaces, including furnishings.

2. Multiply each surface area by its 500 Hz absorption coefficient.

3. Sum the products to get total absorption, A.

4. Calculate reverberation time, T = V/20A.

Acceptable Reverberation Times



Example: What is the 500 Hz reverberation time of a 12 × 15 × 8-foot room having a bare wood floor, gypsum drywall ceiling, smooth plaster walls, two 3 × 5-foot windows covered by pleated 14-oz velour drapes, and 40 square feet (floor area) of fabric-upholstered furniture?

Surface	Area, sq ft	α at 500 Hz	Product
Floor	140	0.10	14.0
Ceiling	180	0.05	9.0
Wall	402	0.04	16.1
Drapes	30	0.49	14.7
Furniture	40	0.56	22.4
	Total room absorption, A = 76.2		

Reverberation time = 1,440/(20×76.2) = 0.94 seconds

The volume of the room in question is 12 × 15 × 8 feet = 1,440 cubic feet. Referring to the graph of acceptable reverberation times, you find 0.3 to 0.8 seconds for a room of this volume. Thus, the computed reverberation time falls outside the acceptable range. Carpeting the floor (carpet on foam pad, α = 0.57) would increase the total room absorption to 142 and bring the reverberation time down to an acceptable 0.51 seconds.

Sound Transmission

Sound can be transmitted through a wall, floor, or ceiling in three ways, as seen in the illustration at right:

Leaks or openings allow sound to propagate as though the wall, floor, or ceiling didn't exist. Examples are the space under a door, back-to-back electrical fixtures, rough-in holes for pipes, and heating ducts connecting rooms.

Airborne sounds set a building surface into vibration. The vibration is carried through the rigidly attached wall studs to the opposite surface, causing it in turn to reradiate to the other side, much like the two heads of a drum.

Impact of an object falling on a floor causes the ceiling attached to the same floor joists to radiate sound to the room below.

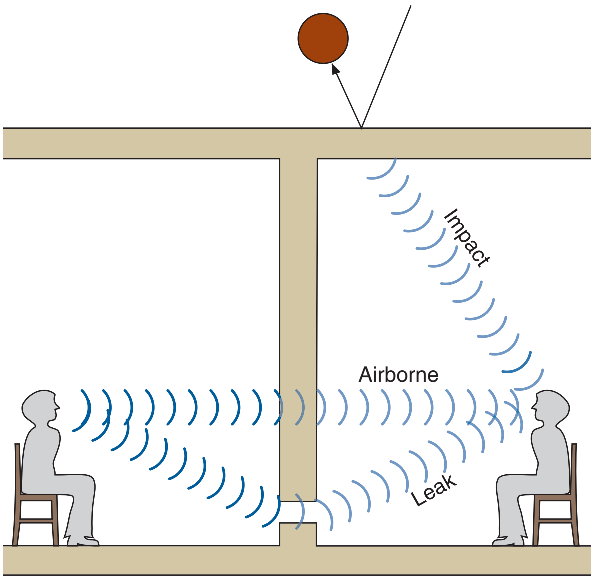
Walls and floor-ceilings are rated by their abilities to reduce sound transmission. The reduction is measured in decibels, where 10 db corresponds to a factor-of-10 difference in sound energy and a factor-of-2 difference in sound loudness (volume). The table at middle right shows the effects on hearing of various levels of sound reduction between spaces.

Walls are rated by *sound transmission class* (STC), roughly the sound reduction at 500 Hz, but taking into consideration frequencies from 125 to 4,000 Hz as well. Floor-ceilings are rated by both STC and impact insulation class (IIC), a measure of the noise transmitted when objects are dropped on the floor above.

The table at bottom right, from the U.S. Department of Housing and Urban Development (HUD) Minimum Property Standards, serves as a guide to minimum acceptable STCs and IICs for residential construction. Walls and ceilings with higher ratings are desirable in a quality home, especially one with children.

Further, the International Residential Code (IRC) requires, for walls and floor-ceilings separating dwelling units, values of at least STC 45 and IIC 45.

Types of Sound Transmission



Effectiveness of Sound Reduction

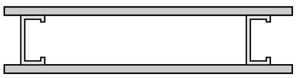
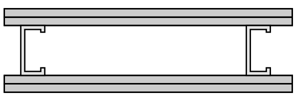
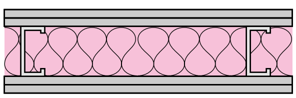
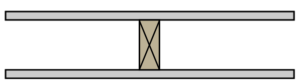
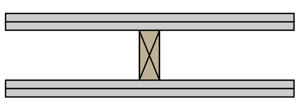
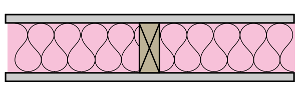
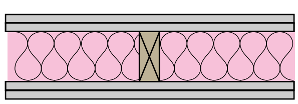
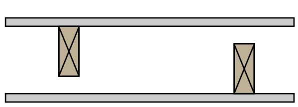
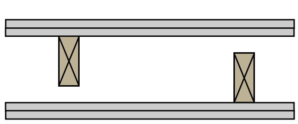
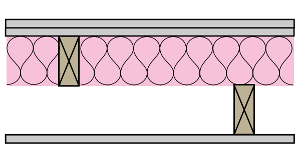
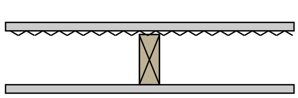
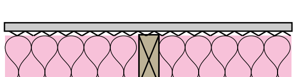
Reduction	Effect on Hearing
25 db	Little effect, normal speech heard clearly
30 db	Loud speech understood fairly well
35 db	Loud speech audible but not understood
40 db	Loud speech heard as a murmur
45 db	Loud speech a strain to hear
50 db	Loud speech not heard at all

Recommended Residential STC and IIC

STC	IIC	Effect on Hearing
45	—	Wall separating living space from living space or public space, such as corridor
50	—	Wall separating living space from commercial space or high-noise service space, such as boiler or mechanical room
45	45	Floor-ceiling separating living space from living space or public space, such as corridor
50	50	Floor-ceiling separating living space from commercial space or high-noise service space

STCs of Walls

Sound Transmission Classes of Wall Constructions

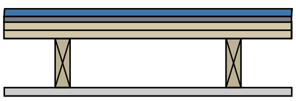
	**STC 42**	$^{5}/_{8}$" fire-rated gypsum wallboard screw-attached horizontally to both sides of $3^{5}/_{8}$" screw studs, 24" o.c. All wallboard joints staggered. Note that rating of 42 is below HUD and IRC minimums.
	**STC 48**	First layer $^{5}/_{8}$" fire-rated gypsum wallboard screw-attached vertically to both sides of $3^{5}/_{8}$" screw studs, 24" o.c. Second layer laminated vertically to both sides.
	**STC 56**	First layer $^{5}/_{8}$" fire-rated gypsum wallboard screw-attached vertically to both sides of $3^{5}/_{8}$" screw studs, 24" o.c. Second layer laminated or screw-attached vertically to both sides. 3" fiberglass in cavity.
	**STC 35**	$^{5}/_{8}$" fire-rated gypsum wallboard nailed to both sides of 2x4 wood studs, 16" o.c.
	**STC 40**	$^{5}/_{8}$" fire-rated gypsum wallboard. Base layer nail-applied to 2x4 wood studs, spaced 24" o.c. Face layer nail-applied.
	**STC 39**	$^{5}/_{8}$" fire-rated gypsum wallboard nailed to both sides of 2x4 wood studs, 16" o.c. $3^{1}/_{2}$" fiberglass in cavity.
	**STC 44**	$^{5}/_{8}$" fire-rated gypsum wallboard. Base layer nail-applied to 2x4 wood studs, spaced 24" o.c. Face layer nail-applied. $3^{1}/_{2}$" fiberglass in cavity.
	**STC 45**	$^{5}/_{8}$" fire-rated gypsum wallboard nailed on both sides to staggered 2x4 wood studs, 16" o.c., on single 6" plate.
	**STC 51**	Two layers of $^{5}/_{8}$" fire-rated gypsum wallboard screw-attached horizontally to both sides of $3^{5}/_{8}$" screw studs, 24" o.c. All wallboard nailed on both sides to staggered 2x4 wood studs, 16" o.c., on single 6" plate.
	**STC 58**	$^{5}/_{8}$" fire-rated gypsum wallboard. Base layer applied vertically, nailed 6" oc. Face layer applied horizontally, nailed 8" o.c. Nailed to double row of wood studs 16" o.c. on separate plates. $3^{1}/_{2}$" fiberglass in cavity.
	**STC 40**	$^{5}/_{8}$" fire-rated gypsum wallboard. One side screw-applied to resilient furring channel, spaced 24" o.c., on 2x4 studs spaced 16" o.c. Other side nailed direct to studs.
	**STC 51**	$^{5}/_{8}$" fire-rated gypsum wallboard. One side screw-applied to resilient furring channel, spaced 24" o.c., on 2x4 studs spaced 16" o.c. Other side nailed to studs. $3^{1}/_{2}$" fiberglass in stud cavity.

STCs and IICs of Floor-Ceilings

STCs and IICs of Floor-Ceiling Constructions

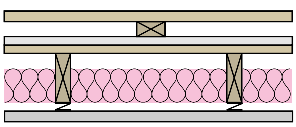
STC 37
IIC 32

1/8" vinyl tile on 1/2" plywood underlayment, over 5/8" plywood subfloor on 2x joists at 16" o.c. Ceiling 1/2" gypsum drywall nailed to joists.



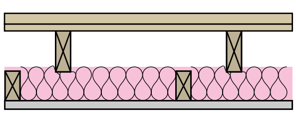
STC 37
IIC 66

1/4" foam rubber pad and 3/8" nylon carpet on 1/2" plywood underlayment, over 5/8" plywood subfloor on 2x joists at 16" o.c. Ceiling 1/2" gypsum drywall nailed to joists.



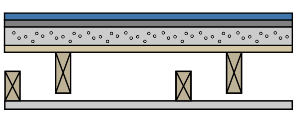
STC 53
IIC 51

25/32" wood strip flooring nailed to 2x3 sleepers, glued between joists to 1/2" insulation board, stapled to 1/2" plywood on 2x joists at 16" o.c. with 3" fiberglass batts. Ceiling 5/8" gypsum drywall screwed to resilient channels.



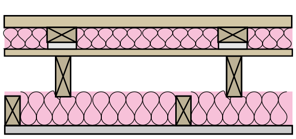
STC 53
IIC 45

25/32" wood strip flooring on 1/2" plywood subfloor on 2x joists at 16" o.c. with 3" fiberglass batts. Ceiling 5/8" gypsum drywall nailed to separate joists.



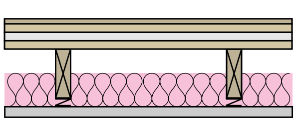
STC 53
IIC 74

44-oz carpet and 40-oz pad on 1 5/8" of 75 pcf perlite/sand concrete over 5/8" plywood subfloor on 2x joists at 16" o.c. Ceiling 5/8" gypsum drywall nailed to separate joists.



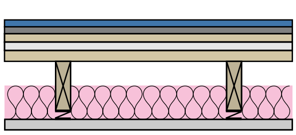
STC 54
IIC 50

25/32" wood strip flooring nailed to 2x3 sleepers, glued to 3" wide strips of 1/2" insulation board, nailed above the floor joists to 1/2" plywood on 2x joists at 16" o.c. Ceiling 5/8" gypsum drywall nailed to separate joists. 3" and 1 1/2" fiberglass batts between joists and sleepers.



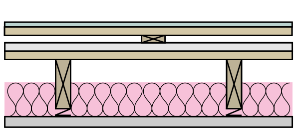
STC 54
IIC 51

5/16" wood block flooring glued to 1/2" plywood underlayment, glued to 1/2" soundboard over 1/2" plywood subfloor on 2x joists at 16" o.c. Ceiling 5/8" gypsum drywall screwed to resilient channels with 3" fiberglass between joists.



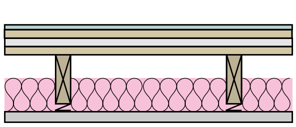
STC 55
IIC 72

Carpet and pad on 1/2" plywood underlayment, glued to 1/2" soundboard over 5/8" subfloor on 2x joists at 16" o.c. Ceiling 5/8" gypsum drywall screwed to resilient channels with 3" fiberglass between joists.



STC 57
IIC 56

Vinyl flooring glued to 1/2" plywood underlayment over 1x3 furring strips between joists, on top of 1/2" soundboard, over 5/8" plywood subfloor on 2x joists at 16" o.c. Ceiling 5/8" gypsum drywall screwed to resilient channels with 3" fiberglass between joists.



STC 58
IIC 55

Vinyl flooring on 1/2" plywood underlayment, over 1/2" soundboard over 5/8" subfloor on 2x joists at 16" o.c. Ceiling 5/8" gypsum drywall screwed to resilient channels with 3" fiberglass between joists.

23

Fasteners

Houses consist of thousands of pieces, held together by what seems like millions of fasteners. What is the right type, how long should it be, how much will it hold, and how many should I use? These are the questions that must be answered every day on a construction project. And these are the answers this chapter provides.

Nails provides a field guide to 38 types of nails and 52 different applications. A *fastening schedule for light construction* lists the type, size, and number of fasteners to use in every step of residential construction. A table for *estimating nail requirements* shows you the relationship between pennyweight (d) and nail length and how to calculate the number of nails for a variety of applications. It even contains tables showing you *the holding power of common nails* in 32 species of wood.

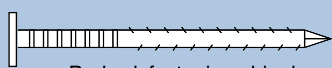
Wood screws shows how to drill just the right pilot hole for each size of screw. It also contains tables of allowable *holding power for screws* in different wood species.

Screws and bolts contains illustrations of screws, bolts, screw heads, and washers.

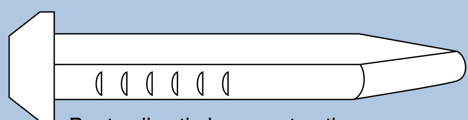
Metal framing aids are a boon to both contractors and do-it-yourselfers, resulting in stronger fastening in less time than required using more traditional methods of nailing. Illustrated are dozens of these useful aids.

Nails

Nails and Their Uses



Barbed: fastening shingles or other flexible materials



Boat spike: timber construction

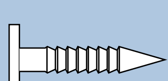
Brad: finishing nail <1" long

Box: nailing thin, dry wood close to edges

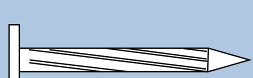
Cement-coated box: coated with resin that melts on driving and acts as adhesive

Casing: similar to finish nail but with dulled point for nailing trim without splitting

Common: rough and heavy construction such as house framing



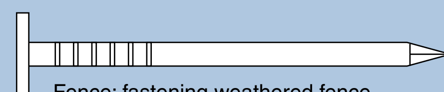
Concrete: hardened steel with diamond point to penetrate concrete



Fluted concrete: hardened steel with fluting for increased holding in concrete

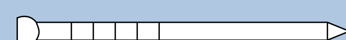
Dowel pin: alignment of removable parts and shelving support

Escutcheon pin: decorative nail for fastening escutcheons



Fence: fastening weathered fence rails (boards) to posts

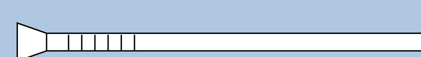
Fine: finishing nail 1" to $1\frac{1}{2}$" long



Finishing: small head for countersinking

Cut finishing: finishing nail for historic restoration

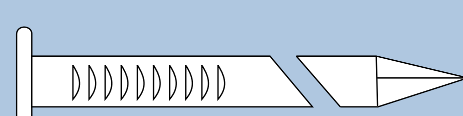
Flooring brad: thin nail for fastening hardwood flooring without splitting



Blunt flooring: blunt nail for fastening hardwood flooring without splitting

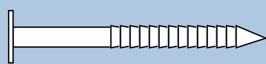
Cut flooring: flooring nail for historic restoration

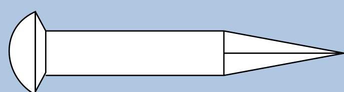
Drive-screw flooring: spiral fluting increases holding power

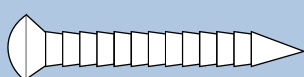


Gutter spike: attaching gutter to fascia

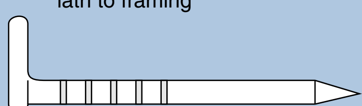
Nails and Their Uses—*Continued*


Annular drywall: attaching drywall to framing with maximum holding

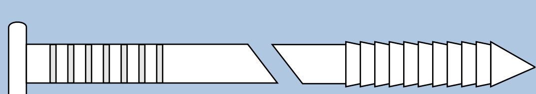

Hinge: attaching large hinges, such as those for barn doors

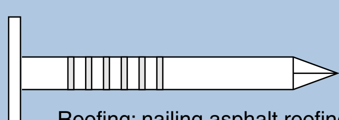

Annular hinge: hinge nail with maximum holding power

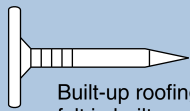

Lath: attaching wood lath to framing

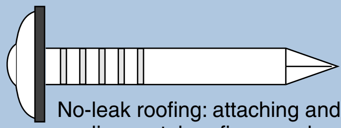

Offset head; many varieties for power nail guns

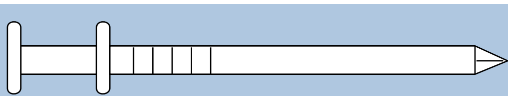

Parquet flooring: attaching parquet without splitting


Pole barn: attaching framing to poles in pole barns


Roofing: nailing asphalt roofing to roof sheathing


Built-up roofing: attaching roofing felt in built-up roofs

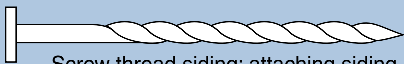

No-leak roofing: attaching and sealing metal roofing panels


Scaffold: fastening temporary scaffolding

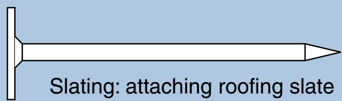

Shingle: attaching cedar shingles

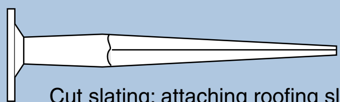

Cut shingle: attaching cedar shingles in historic restoration

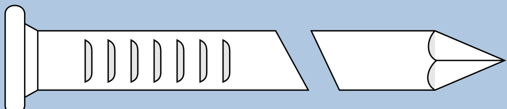

Siding: attaching beveled wood siding (clapboards)

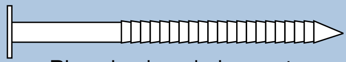

Screw thread siding: attaching siding with greater holding power


Cement-coated sinker: cement (resin) melts then adheres to fasten underlayment tightly


Slating: attaching roofing slate


Cut slating: attaching roofing slate in historic restoration


Spike: common nail over 4" in lengh—for timber construction


Ring-shank underlayment: annular rings increase holding power for tight floor

Fastening Schedule for Light Construction

Condensation of IRC Table R602.3(1)

Description of Building Elements	Number and Type of Fastener[a,b,c]	Spacing of Fasteners
Joist to sill or girder, toe nail	3-8d (2 1/2" × 0.113")	—
1×6 subfloor or less to each joist, face nail	2-8d (2 1/2" × 0.113") or 2 staples, 1 3/4"	— —
2" subfloor to joist or girder, blind and face nail	2-16d (3 1/2" × 0.135")	—
Sole plate to joist or blocking, face nail	16d (3 1/2" × 0.135")	16" o.c.
Top or sole plate to stud, end nail	2-16d (3 1/2" × 0.135")	—
Stud to sole plate, toe nail	3-8d (2 1/2" × 0.113") or 2-16d (3 1/2" × 0.135")	— —
Double studs, face nail	10d (3" × 0.128")	24" o.c.
Double top plates, face nail	10d (3" × 0.128")	24" o.c.
Sole plate to joist or blocking at braced wall panels	3-16d (3 1/2" × 0.135")	16" o.c.
Double top plates, minimum 24" offset of end joints, face nail in lapped area	8-16d (3 1/2" × 0.135")	—
Blocking between joists or rafters to top plate, toe nail	3-8d (2 1/2" × 0.113") or	—
Rim joist to top plate, toe nail	8d (2 1/2" × 0.113")	6" o.c
Top plates, laps at corners and intersections, face nail	2-10d (3" × 0.128")	—
Built-up header, two pieces with 1/2" spacer	16d (3 1/2" × 0.135")	16" o.c. along each edge
Continued header, two pieces	16d (3 1/2" × 0.135")	16" o.c. along each edge
Ceiling joists to plate, toe nail	3-8d (2 1/2" × 0.113")	—
Continuous header to stud, toe nail	4-8d (2 1/2" × 0.113")	—
Ceiling joist, laps over partitions, face nail	3-10d (3" × 0.128")	—
Ceiling parallel rafters, face nail	3-10d (3" × 0.128")	—
Rafter to plate, toe nail	2-16d (3 1/2" × 0.135")	—
1" brace to each stud and plate, face nail	2-8d (2 1/2" × 0.113") or 2 staples, 1 3/4"	— —
1×6 sheathing to each bearing, face nail	2-8d (2 1/2" × 0.113") or 2 staples, 1 3/4"	— —
1×8 sheathing to each bearing, face nail	2-8d (2 1/2" × 0.113") or 3 staples, 1 3/4"	— —
Wider than 1×8 sheathing to each bearing, face nail	3-8d (2 1/2" × 0.113") or 4 staples, 1 3/4"	— —
Built-up corner studs	10d (3" × 0.128")	24" o.c.
Built-up girders and beams, 2" lumber layers	10d (3" × 0.128")	Nail each layer 32" o.c. at top and bottom and staggered. Two nails at ends and splices.
2" planks	2-16d (3 1/2" × 0.135")	At each bearing
Roof rafters to ridge, valley or hip rafters, toe nail	4-16d (3 1/2" × 0.135")	—
face nail	3-16d (3 1/2" × 0.135")	—
Rafter ties to rafters, face nail	3-8d (2 1/2" × 0.113")	—
Collar tie to rafter, face nail, or 1 1/4" × 20-ga ridge strap	3-10d (3" × 0.128")	—

Condensation of IRC Table R602.3(1)—*Continued*

Description of Building Materials	Number and Type of Fastener[a,b,c]	Spacing of Fasteners: Edges, inches[h]	Spacing of Fasteners: Intermediate Supports, inches[c]
Wood structural panels, subfloor, roof and wall sheathing to framing, and particleboard wall sheathing to framing			
5/16" – 1/2"	6d common (2" × 0.113") nail (subfloor, wall) or 8d common (2-1/2" × 0.131") nail (roof)[e]	6	12[f]
19/32" – 1"	8d common (2-1/2" × 0.131")	6	12[f]
1-1/8" – 1-1/4"	10d common (3" × 0.148") nail or 8d (2-1/2" × 0.131") deformed nail	6	12
Other wall sheathing[g]			
1/2" structural cellulosic fiberboard sheathing	1-1/2" galvanized roofing nail 8d common or (2-1/2" × 0.131") nail or staple 16 ga., 1-1/2" long	3	6
25/32" structural cellulosic fiberboard sheathing	1-3/4" galvanized roofing nail 8d common or (2-1/2" × 0.131") nail or staple 16 ga., 1-3/4" long	3	6
1/2" gypsum sheathing[d]	1-1/2" galvanized roofing nail or 6d common (2" × 0.113") nail or staple galvanized 1-1/2" long or 1-1/4" screws, Type W or S	4	8
5/8" gypsum sheathing[d]	1-3/4" galvanized roofing nail or 8d common (2-1/2" × 0.131") nail or staple galvanized 1-5/8" long or 1-5/8" screws, Type W or S	4	8
Wood structural panels, combination subfloor underlayment to framing			
3/4" and less	6d deformed (2" × 0.120") nail or 8d common (2-1/2" × 0.131") nail	6	12
7/8" – 1"	8d deformed (2-1/2" × 0.120") nail or 8d common (2-1/2" × 0.131") nail	6	12
1-1/8" – 1-1/4"	8d deformed (2-1/2" × 0.120") nail or 10d common (3" × 0.148") nail	6	12

a. All nails are smooth-common, box, or deformed shanks except where otherwise stated. Nails used for framing and sheathing connections shall have minimum average bending yield strengths as shown: 80 ksi for shank diameter of 0.192" (20d common nail), 90 ksi for shank diameters larger than 0.142" but not larger than 0.177", and 100 ksi for shank diameters of 0.142" or less.

b. Staples are 16-ga wire and have a minimum 7/16" on diameter crown width.

c. Nails shall be spaced at not more than 6" o.c. at all supports where spans are 48" or greater.

d. 4' by 8' or 4' by 9' panels shall be applied vertically.

e. For regions having basic wind speed of 110 mph or greater, 8d deformed (2-1/2" × 0.120") nails shall be used for attaching plywood and wood structural panel roof sheathing to framing within minimum 48" distance from gable end walls, if mean roof height is more than 25', up to 35' maximum.

f. For regions having basic wind speed of 100 mph or less, nails for attaching wood structural panel roof sheathing to gable end wall framing shall be spaced 6" o.c. When basic wind speed is greater than 100 mph, nails for attaching panel roof sheathing to intermediate supports shall be spaced 6" o.c. for minimum 48" distance from ridges, eaves, and gable end walls; and 4" o.c. to gable end wall framing.

g. Gypsum sheathing shall conform to ASTM C 79 and shall be installed in accordance with GA 253. Fiberboard sheathing shall conform to ASTM C 208.

h. Spacing of fasteners on floor-sheathing panel edges applies to panel edges supported by framing members and required blocking and at all floor perimeters only. Spacing of fasteners on roof-sheathing panel edges applies to panel edges supported by framing members and required blocking. Blocking of roof- or floor-sheathing panel edges perpendicular to the framing members need not be provided except as required by other provisions of this code. Floor perimeters shall be supported by framing members or solid blocking.

Estimating Nail Requirements

Use the table below and the residential fastening schedule on pp. 618–619 to estimate your requirements, in pounds, for the most common residential building nails. Note that special coatings such as electroplating, etching, and resin add significantly to nail weight. Hot-dip galvanizing, in particular, can increase weight by 20%. You should also allow 5% for waste.

Example: How many pounds of nails are required to fasten the floor joists to the sills for a 24 × 40-foot floor? The IRC nailing schedule specifies toe-nailing three 8d common nails at each joint. Counting the doubled joists at the ends, there are 33 joists, so you need 3 nails × 33 joists × 2 connections = 198 nails. In the table below, you will find there are 106 8d common nails in a pound, so you need 1.77 pounds. Adding 20% weight for galvanized finish and an additional 5% for waste, you should allow 2.3 pounds.

Nails per Pound

Length inches	Penny weight, d	Type of Support							
		Box	Casing	Common	Drywall	Finishing	Roofing	Siding	Spike
1	2	—	—	876	—	1351	255	—	—
$1\frac{1}{4}$	3	635	—	568	375	807	210	—	—
$1\frac{1}{2}$	4	473	473	316	329	584	180	—	—
$1\frac{3}{4}$	5	406	406	271	289	500	150	—	—
2	6	236	236	181	248	309	138	236	—
$2\frac{1}{4}$	7	210	—	161	—	238	—	236	—
$2\frac{1}{2}$	8	145	145	106	—	189	118	210	—
3	10	94	94	69	—	121	—	94	—
$3\frac{1}{4}$	12	87	—	63	—	—	—	—	—
$3\frac{1}{2}$	16	71	71	49	—	90	—	—	—
4	20	52	—	31	—	62	—	—	—
$4\frac{1}{2}$	30	—	—	24	—	—	—	—	—
5	40	—	—	18	—	—	—	—	—
$5\frac{1}{2}$	50	—	—	18	—	—	—	—	—
6	60	—	—	14	—	—	—	—	—
7	—	—	—	11	—	—	—	—	6
8	—	—	—	—	—	—	—	—	5
10	—	—	—	—	—	—	—	—	3
12	—	—	—	—	—	—	—	—	3

Note: Sinkers up to 12d are $\frac{1}{8}$″ shorter than common nails of the same penny size. Sinkers of 16d and larger are $\frac{1}{4}$″ shorter than common nails of the same penny size.

Holding Power of Common Nails

The tables below show the lateral (sideways) resistance and the withdrawal (pulling out) resistance of common nails driven perpendicular to wood grain.

Holding power depends on species group and dry specific gravity (see table at right). Holding power can also be increased by:

- surface etching or coating
- annular or spiral threads
- clinching (hammering tips over)

Specific Gravities of Wood Species

Species Group	Specific Gravity	Wood Species
I	0.67	Oak, red and white
II	0.55	Southern pine
	0.51	Douglas fir-larch
III	0.45	Eastern hemlock
	0.42	Hem-fir, Spruce-pine-fir
IV	0.38	Eastern white pine
	0.31	Northern white cedar

Allowable Lateral Loads for Common Nails (pounds and inches penetration)

Species Group	Common Nail Size, d								
	6	8	10	12	16	20	30	40	60
I	77 (1.2)	97 (1.4)	116 (1.5)	116 (1.5)	133 (1.7)	172 (2.0)	192 (2.1)	218 (2.3)	275 (2.7)
II	63 (1.3)	78 (1.5)	94 (1.7)	94 (1.7)	108 (1.8)	139 (2.2)	155 (2.3)	176 (2.5)	223 (2.9)
III	51 (1.5)	64 (1.7)	77 (2.0)	77 (2.0)	88 (2.2)	114 (2.5)	127 (2.7)	144 (3.0)	182 (3.5)
IV	41 (1.6)	51 (1.9)	61 (2.1)	61 (2.1)	70 (2.3)	91 (2.7)	102 (2.9)	115 (3.2)	146 (3.7)

Allowable Withdrawal Loads[1] for Common Nails (pounds)

Specific Gravity[2]	Common Nail Size, d								
	6	8	10	12	16	20	30	40	60
0.75	76	88	99	99	109	129	139	151	177
0.68	59	69	78	78	86	101	109	118	138
0.66	55	64	72	72	79	94	101	110	128
0.62	47	55	62	62	68	80	86	94	110
0.55	35	41	46	46	50	59	64	70	81
0.51	29	34	38	38	42	49	53	58	67
0.47	24	27	31	31	34	40	43	47	55
0.45	21	25	28	28	30	36	39	42	49
0.43	19	22	25	25	27	32	35	38	44
0.41	17	19	22	22	24	29	31	33	39
0.39	15	17	19	19	21	25	27	29	34
0.37	13	15	17	17	19	22	24	26	30
0.33	10	11	13	13	14	17	18	19	23
0.31	8	10	11	11	12	14	15	17	19

[1] Loads are per inch of penetration into member holding point.

[2] Based on oven-dry weight and volume.

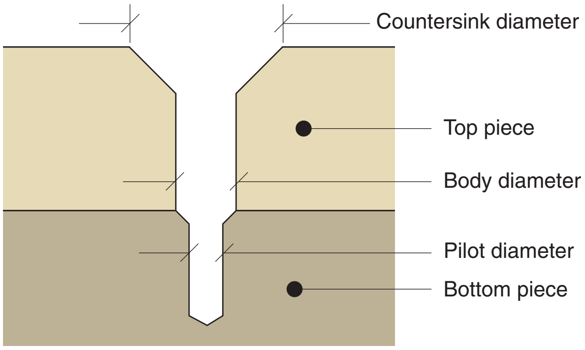
Wood Screws

Wood-screw size is specified by diameter gauge (see illustration below) and by length from tip to plane of the wood surface.

Screws are designed to draw two pieces together. For maximum effectiveness, the first piece is drilled out to the diameter of the screw body or shank, while the receiving piece is drilled just large enough to prevent splitting. Drill sizes for pilot holes are listed in the table below.

Maximum wood-screw loads for different wood species are listed in the tables on the facing page.

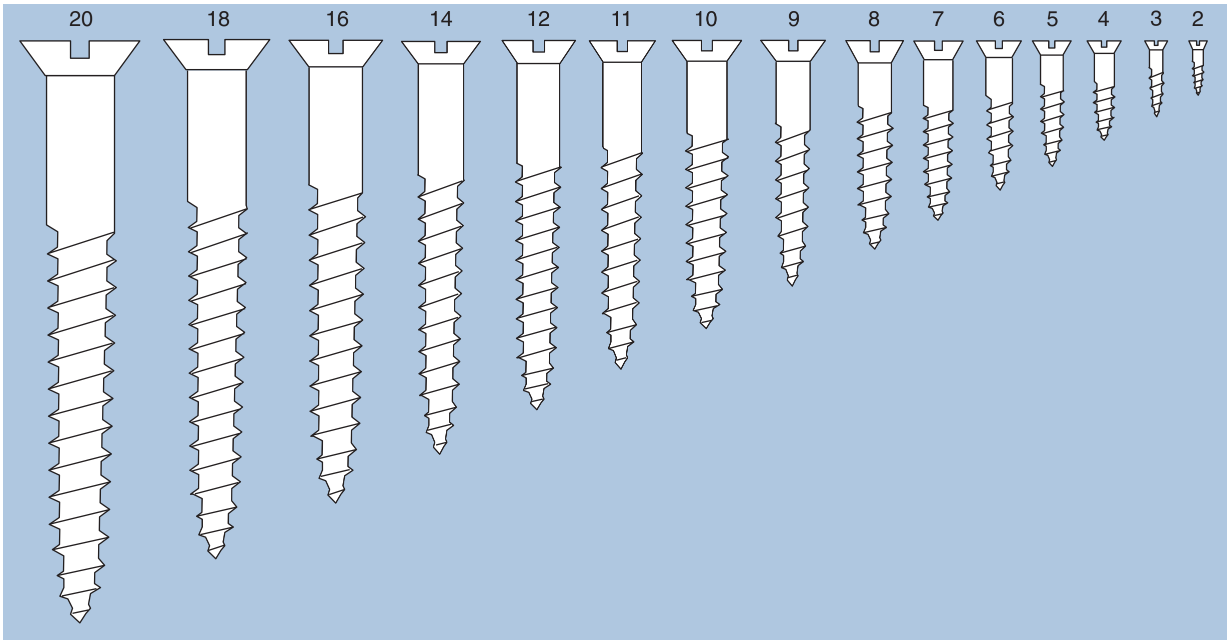
Pilot Holes for Wood Screws



Wood-Screw Pilot Hole Dimensions

	Screw Size									
Hole	**2**	**3**	**4**	**5**	**6**	**8**	**10**	**12**	**14**	**16**
Body diameter, in.	5/64	3/32	7/64	1/8	9/64	5/32	3/16	7/32	15/64	17/64
Pilot Drill: Softwood	#65	#58	1⁄16	5⁄64	5⁄64	3⁄32	7⁄64	1⁄8	11⁄64	3⁄16
Hardwood	#56	#54	5/64	3/32	3/32	7/64	1/8	5/32	7/32	15/64
Body Drill	#42	#37	1⁄8	9⁄64	9⁄64	11⁄64	3⁄16	7⁄32	1⁄4	9⁄32
Countersink diameter, in.	5/32	3/16	7/32	1/4	9/32	11/32	3/8	7/16	15/32	11/16

Wood-Screw Gauges (actual sizes)



Holding Power of Wood Screws

The tables below show the lateral (sideways) resistance and the withdrawal (pulling out) resistance of flathead wood screws driven perpendicular to wood grain.

Holding power depends on species group and dry specific gravity (see table at right). While the representative wood species for the holding power of common nails on p. 621 are those commonly used in framing, the wood species for screws in the table at right are those commonly used in millwork and cabinetry.

Specific Gravities of Wood Species

Species Group	Specific Gravity	Wood Species
I	0.67	Oak, red and white
	0.63	Sugar maple
II	0.55	Black walnut, Teak
	0.50	Black cherry
III	0.45	Honduras mahogany
IV	0.38	Eastern white pine
	0.31	Northern white cedar

Allowable Lateral Loads for Wood Screws (pounds and inches penetration)

	Wood-Screw Size							
Group	6	8	10	12	14	16	18	20
I	91 (0.97)	129(1.15)	173 (1.33)	224 (1.51)	281 (1.69)	345 (1.88)	415 (2.06)	492 (2.24)
II	75 (0.97)	106 (1.15)	143 (1.33)	185 (1.51)	232 (1.69)	284 (1.88)	342 (2.06)	406 (2.24)
III	62 (0.97)	87 (1.15)	117 (1.33)	151 (1.51)	190 (1.69)	233 (1.88)	280 (2.06)	332 (2.24)
IV	48 (0.97)	68 (1.15)	91 (1.33)	118 (1.51)	148 (1.69)	181 (1.88)	218 (2.06)	258 (2.24)

Allowable Withdrawal Loads[1] for Wood Screws (pounds)

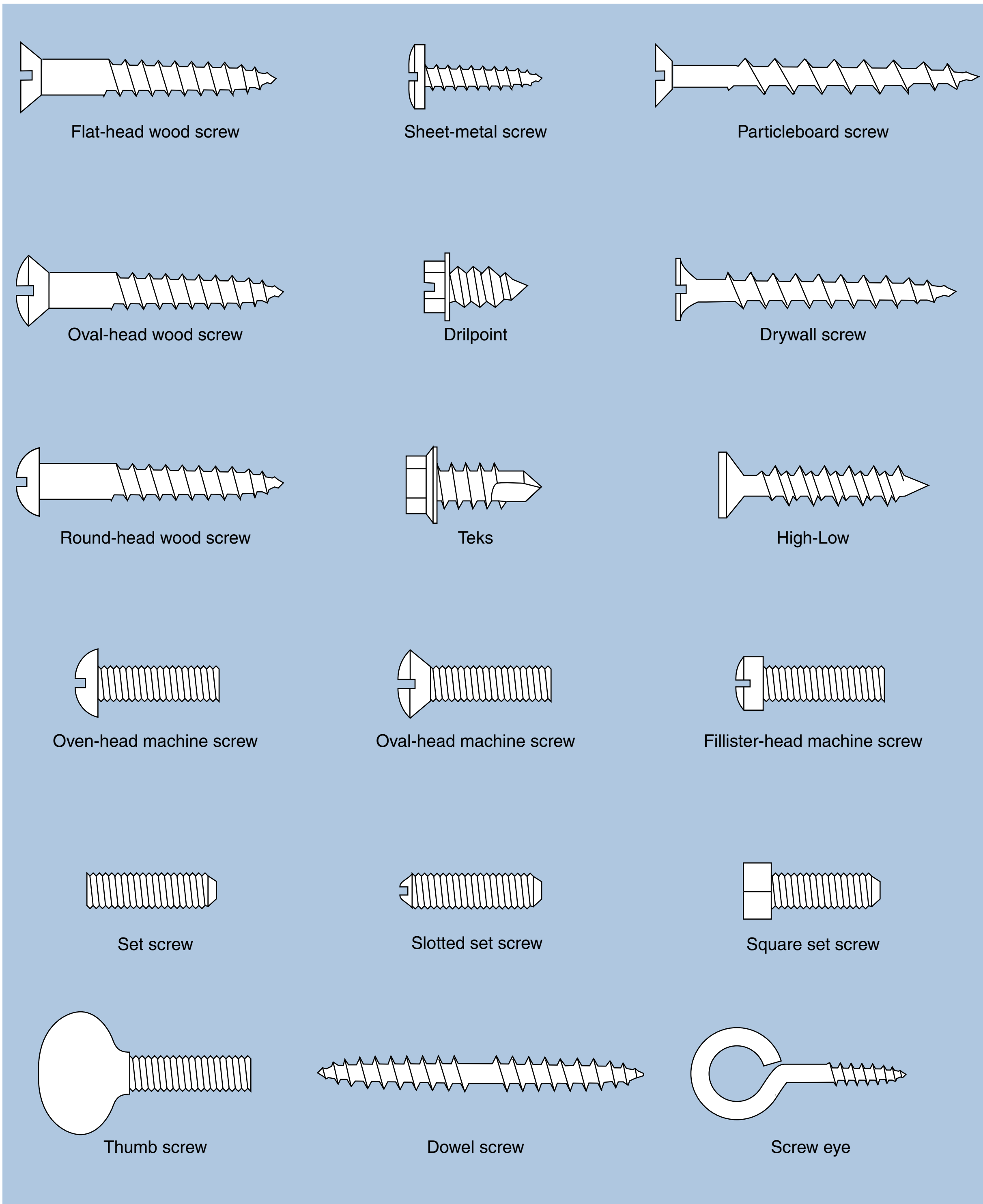
Specific Gravity[2]	Wood-Screw Size							
	6	8	10	12	14	16	18	20
0.75	220	262	304	345	387	428	470	511
0.68	181	215	250	284	318	352	386	420
0.66	171	203	235	267	299	332	364	396
0.62	151	179	207	236	264	293	321	349
0.55	119	141	163	186	208	230	253	275
0.51	102	121	140	160	179	198	217	236
0.47	87	103	119	136	152	168	184	201
0.45	79	94	109	124	139	154	169	184
0.43	72	86	100	113	127	141	154	168
0.41	66	78	91	103	116	128	140	153
0.39	60	71	82	93	105	116	127	138
0.37	54	64	74	84	94	104	114	124
0.33	43	51	59	67	75	83	91	99
0.31	38	45	52	59	66	73	80	87

[1] Loads are per inch of penetration into member holding point.

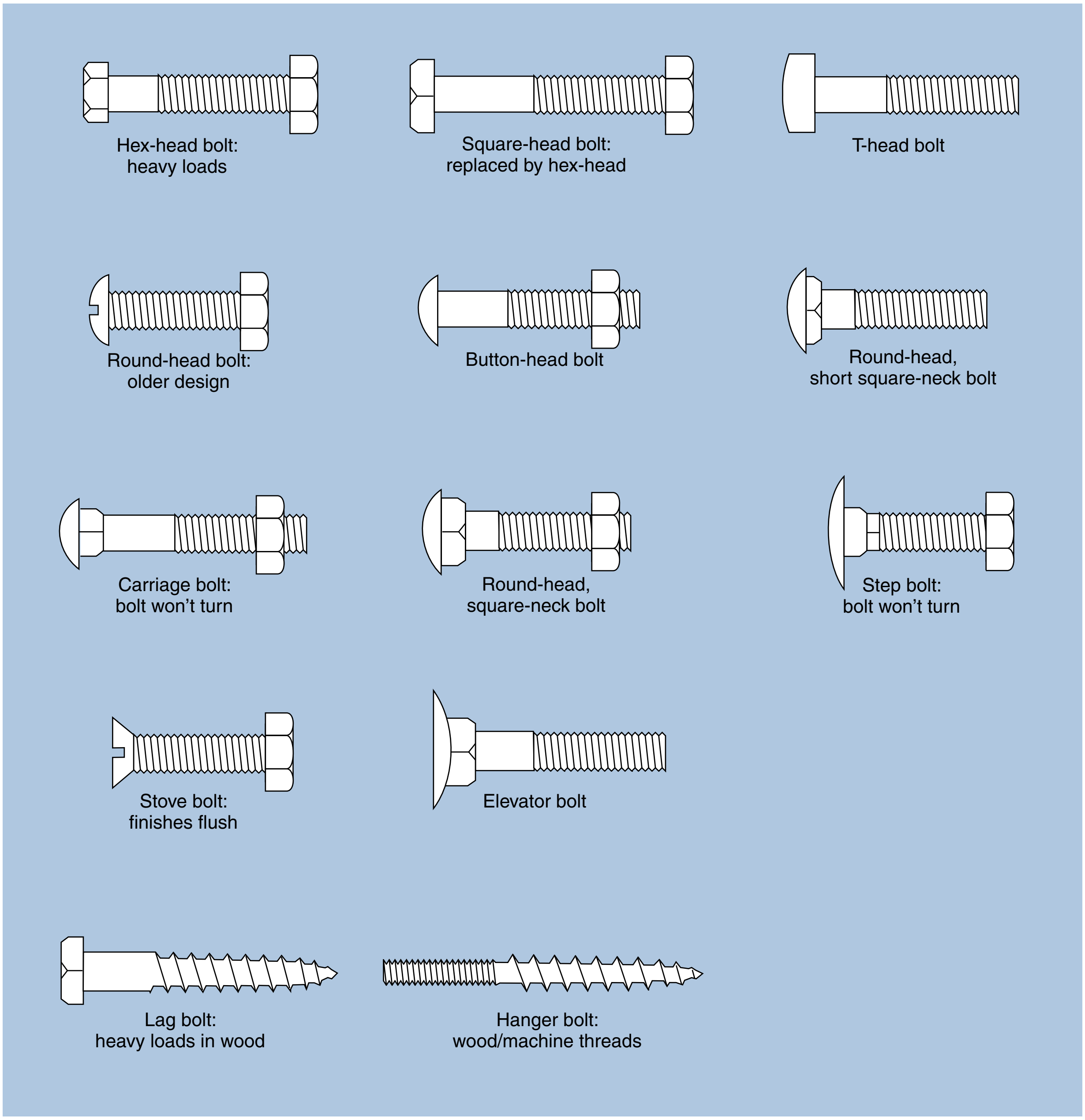
[2] Based on oven-dry weight and volume.

Screws and Bolts

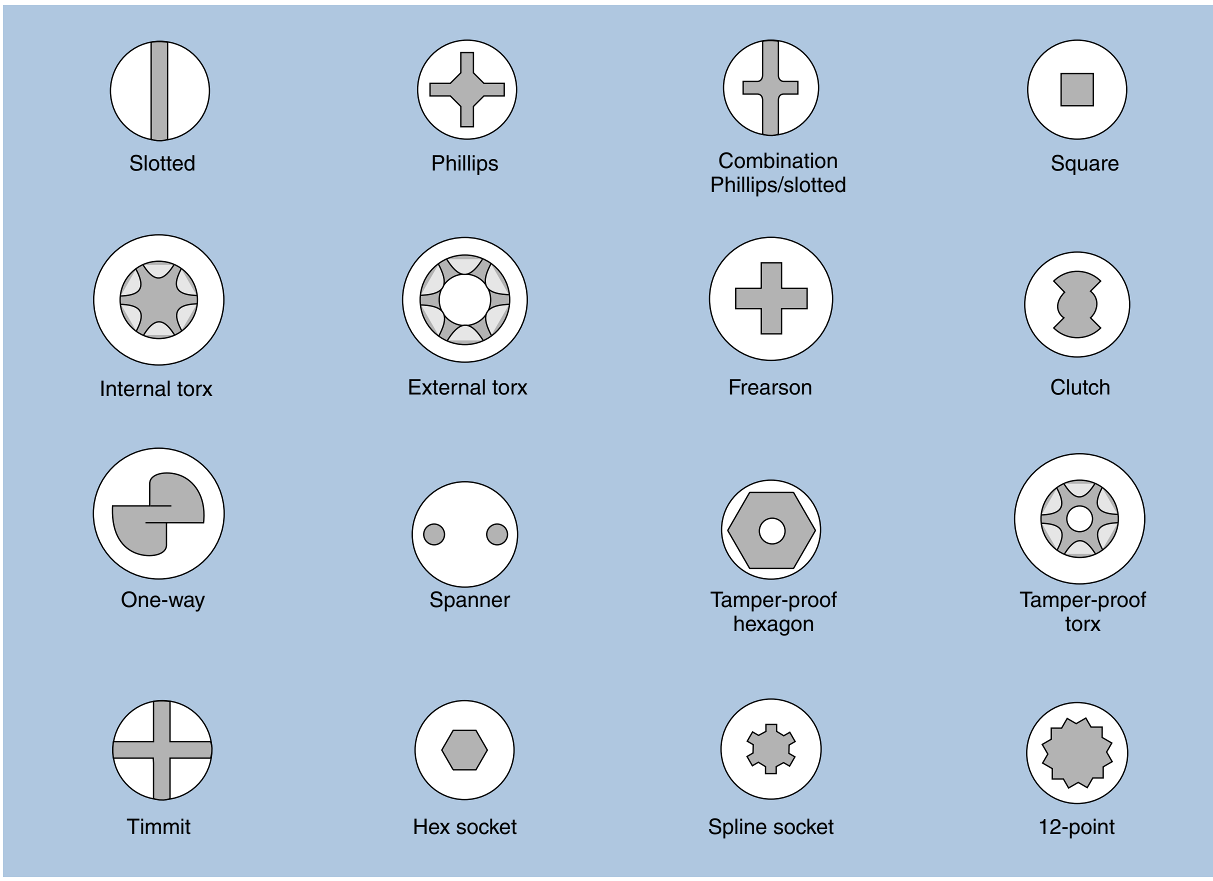
Screws



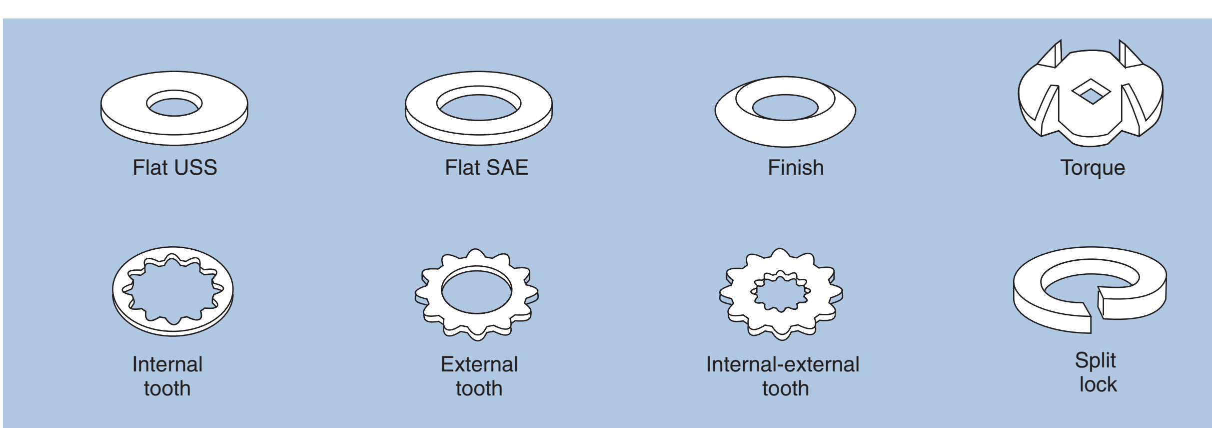
Bolts


Hex-head bolt:
heavy loads
Square-head bolt:
replaced by hex-head
T-head bolt
Round-head bolt:
older design
Button-head bolt
Round-head,
short square-neck bolt
Carriage bolt:
bolt won't turn
Round-head,
square-neck bolt
Step bolt:
bolt won't turn
Stove bolt:
finishes flush
Elevator bolt
Lag bolt:
heavy loads in wood
Hanger bolt:
wood/machine threads

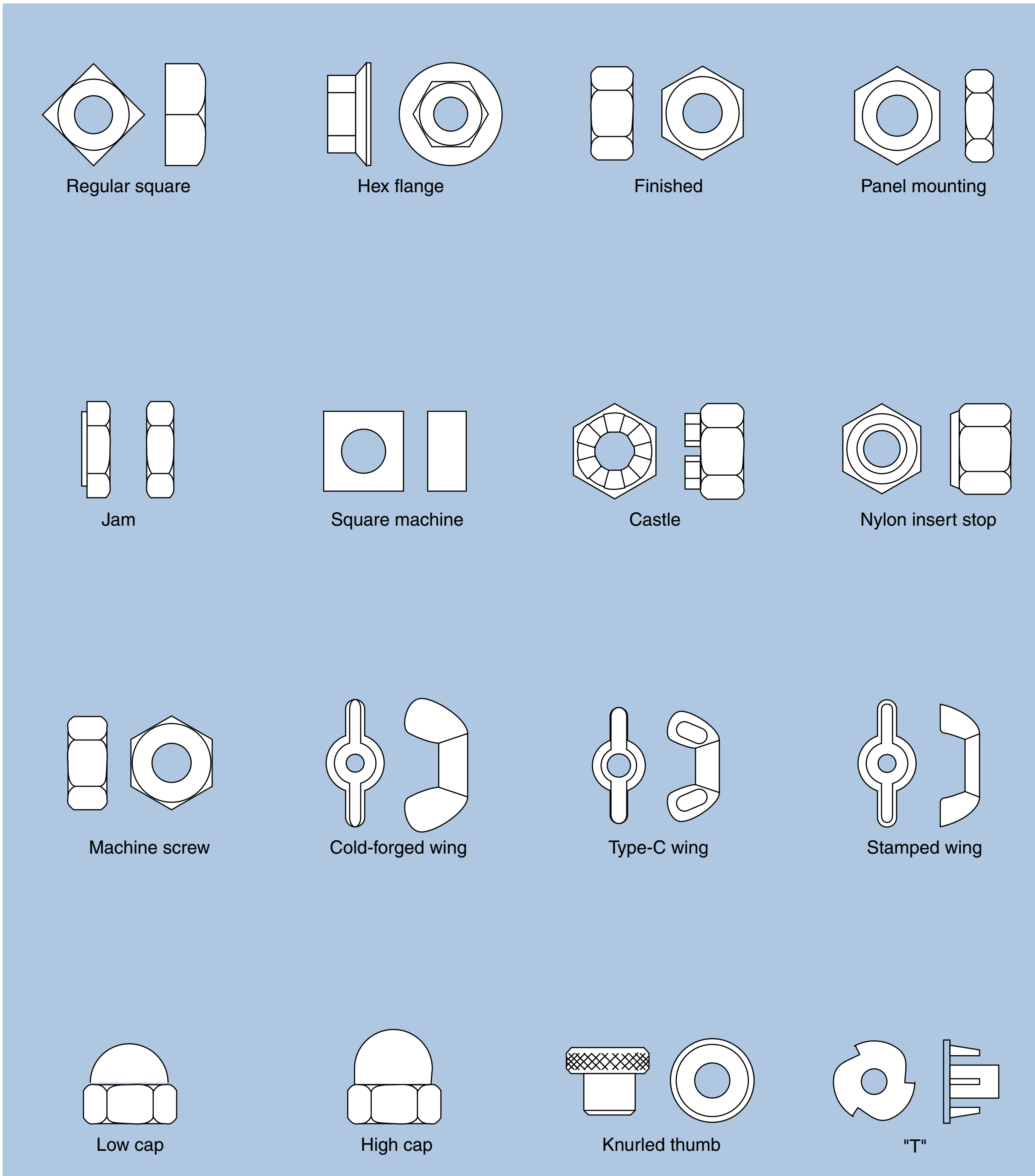
Drives



Washers

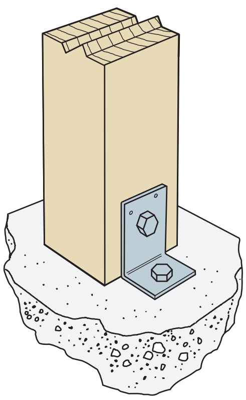


Nuts

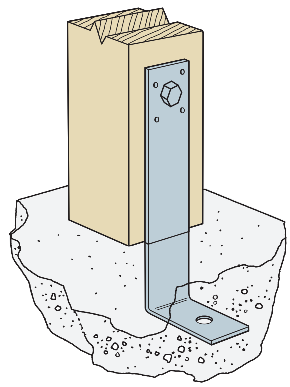

Regular square
Hex flange
Finished
Panel mounting
Jam
Square machine
Castle
Nylon insert stop
Machine screw
Cold-forged wing
Type-C wing
Stamped wing
Low cap
High cap
Knurled thumb
"T"

Metal Framing Aids

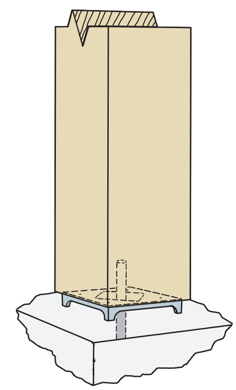
Post and Column Bases



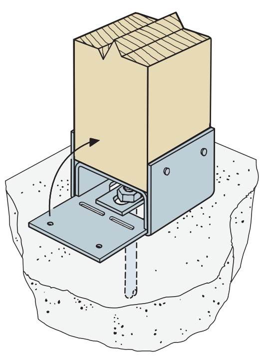
A Angle



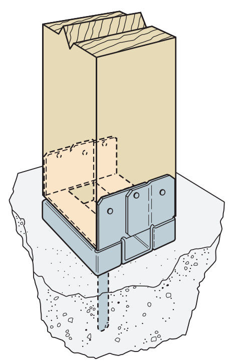
A3 Anchor



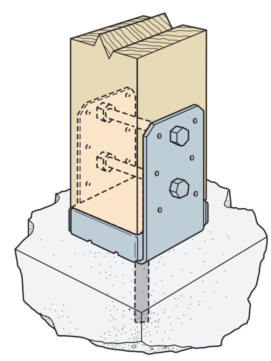
APS Standoff Base



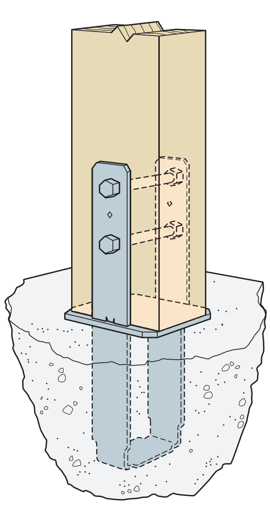
AB Post Base



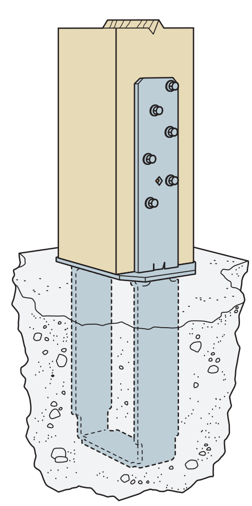
ABA Post Base



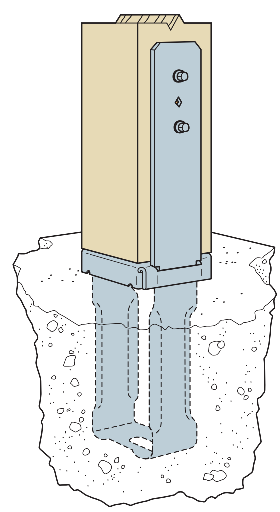
ABU Post Base



CB Column Base

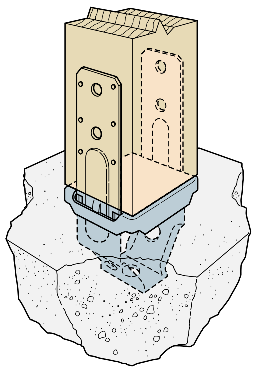


CBQ Column Base

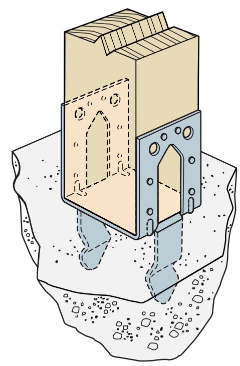


CBS Column Base

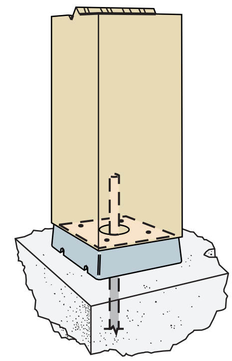
Post and Column Bases—*Continued*



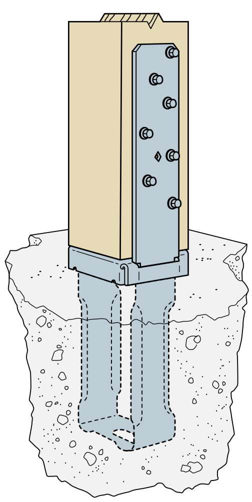
PBS Post Base



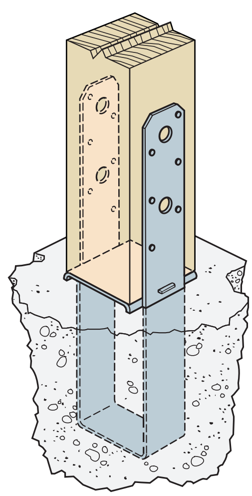
PB Post Base



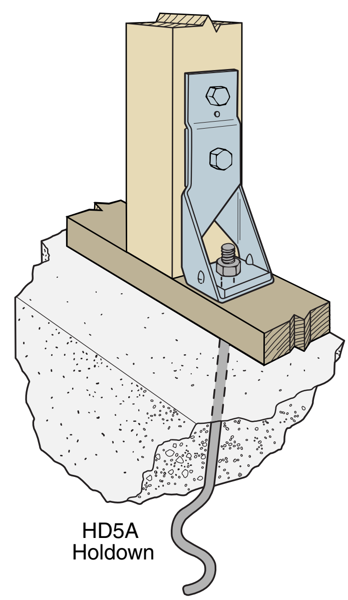
CBSQ Standoff Base



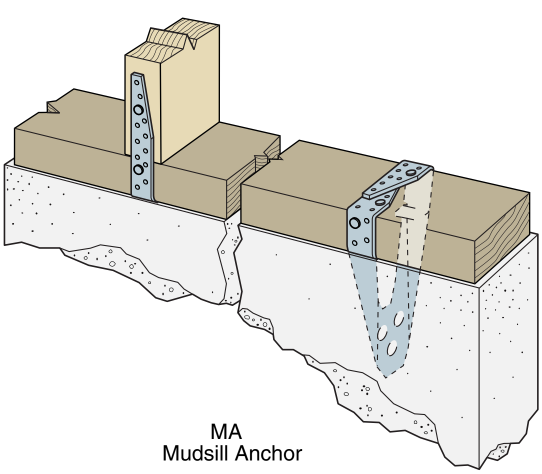
CBSQ Column Base



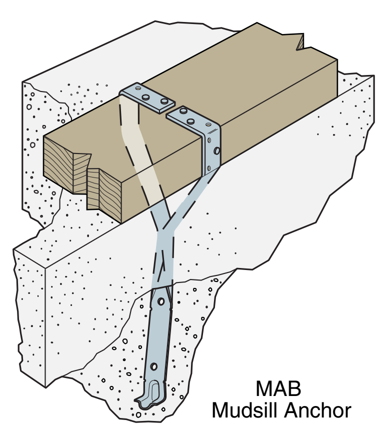
LCB Column Base



HD5A
Holdown

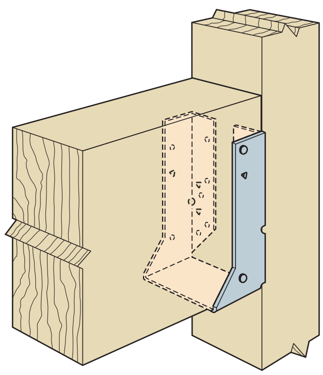


MA
Mudsill Anchor

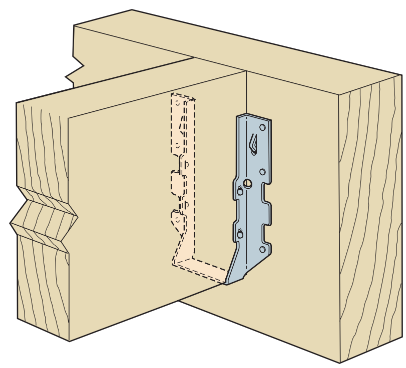


MAB
Mudsill Anchor

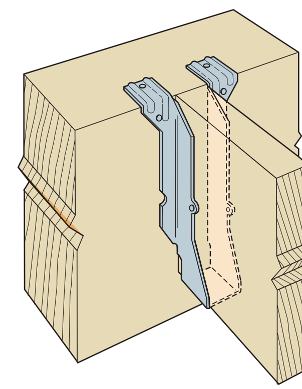
Hangers



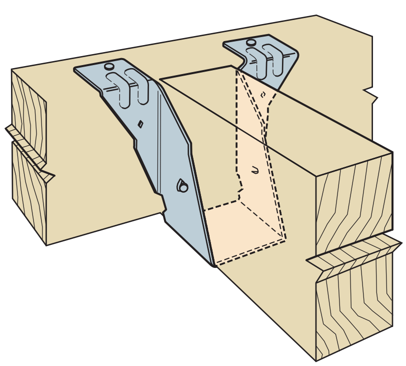
HUC Hanger



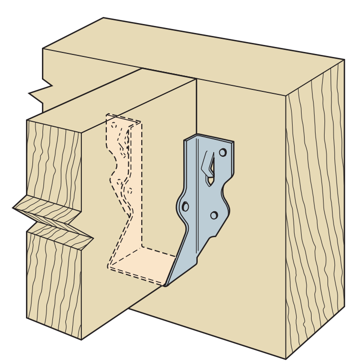
LUS Hanger



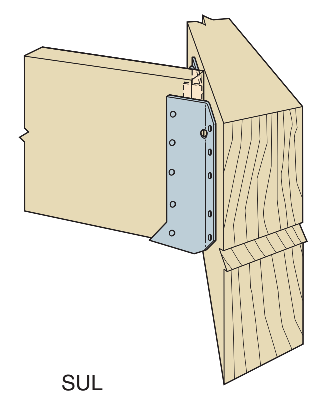
LB Hanger



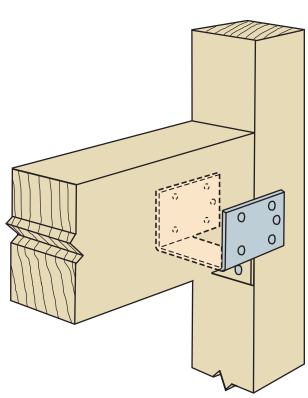
PF Hanger



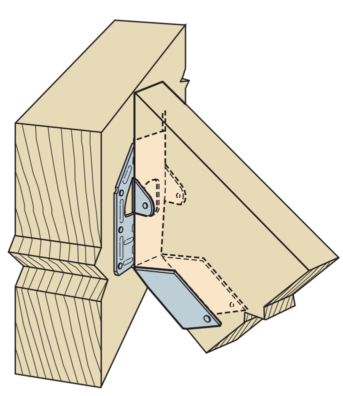
U Hanger



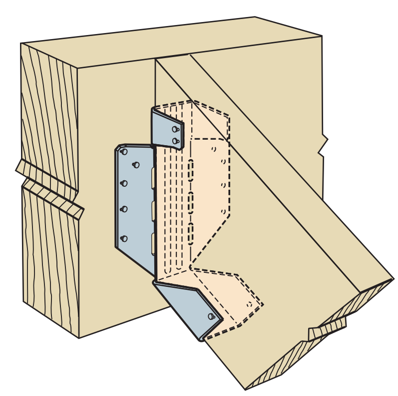
SUL



HH Hanger

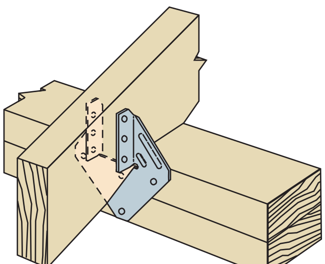


LSU Hanger

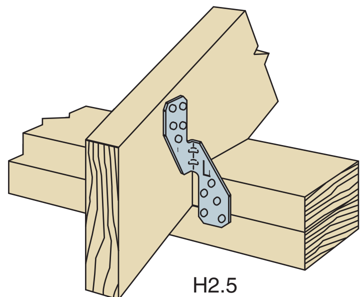


LSSU Hanger

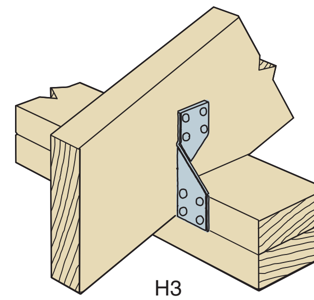
Rafter Ties



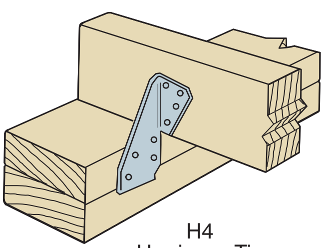
H1
Hurricane Tie



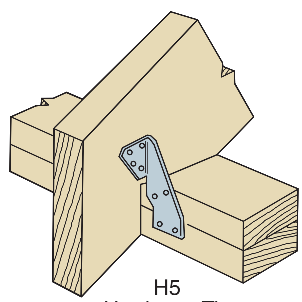
H2.5
Hurricane Tie



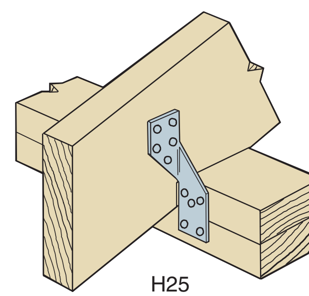
H3
Hurricane Tie



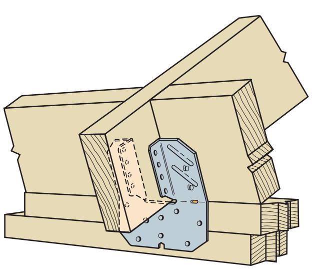
H4
Hurricane Tie



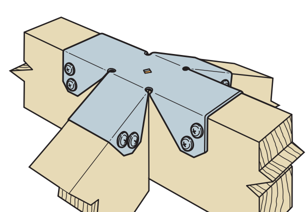
H5
Hurricane Tie



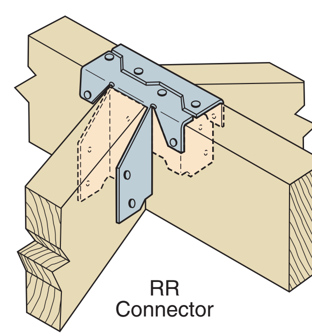
H25
Hurricane Tie



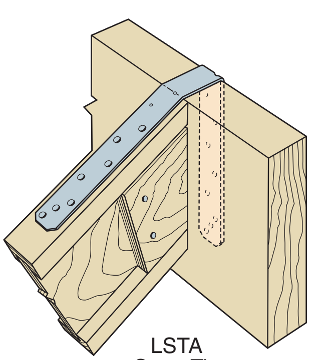
H10
Hurricane Tie



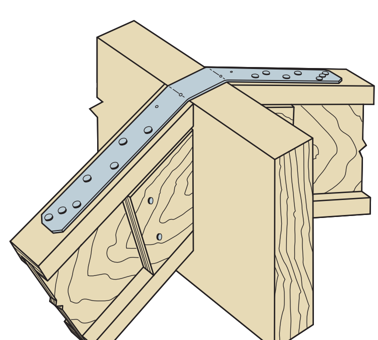
FWH
Rigid Tie



RR
Connector

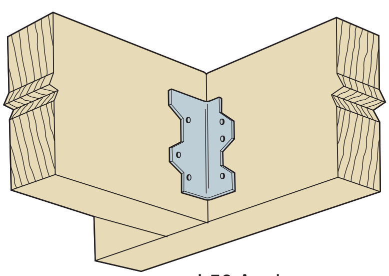


LSTA
Strap Tie

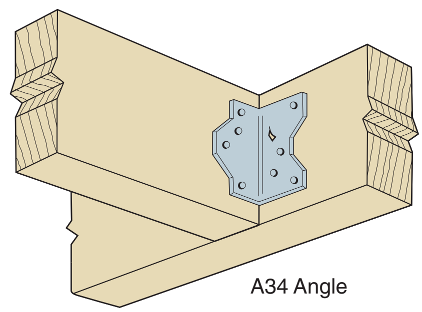


LSTA
Strap Tie

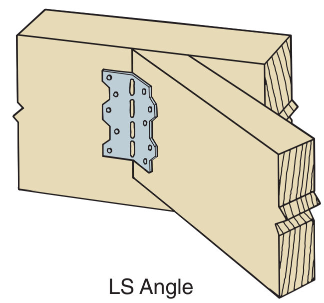
Angles



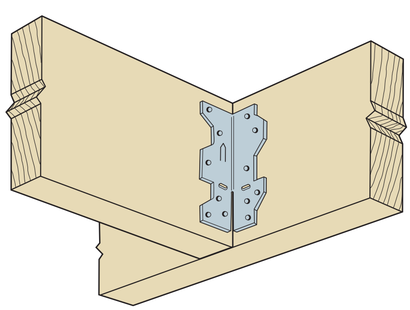
L50 Angle



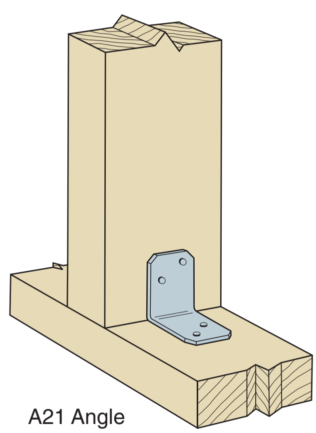
A34 Angle



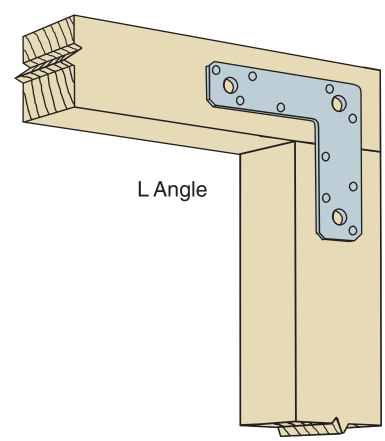
LS Angle



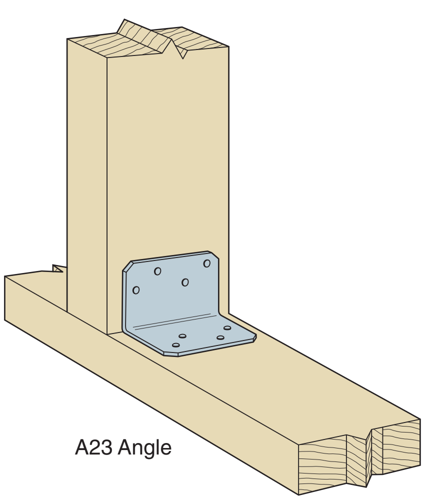
A35-type 3 Angle



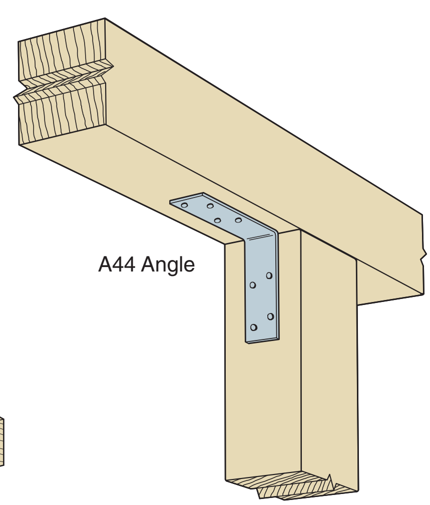
A21 Angle



L Angle

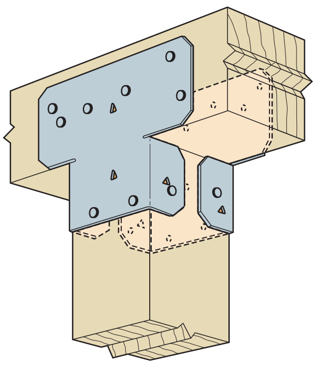


A23 Angle

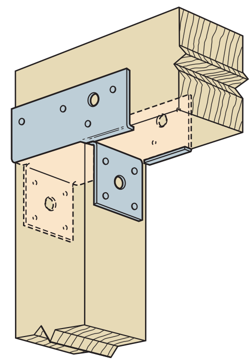


A44 Angle

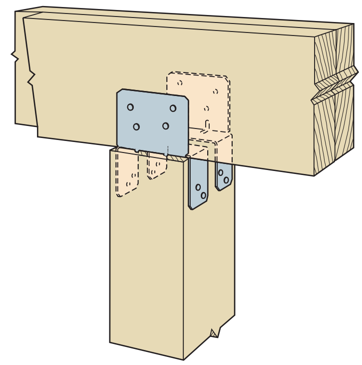
Post Caps



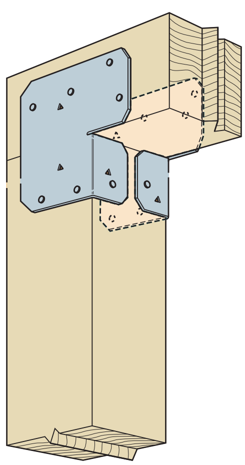
AC4
Post Cap



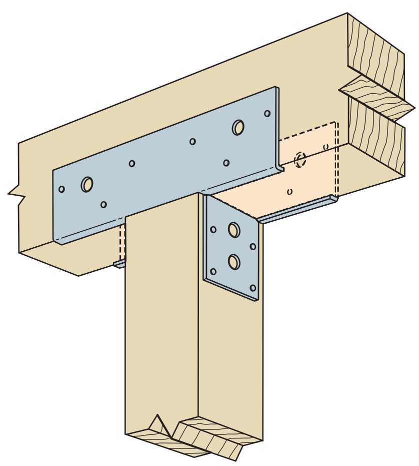
EPC
Post Cap



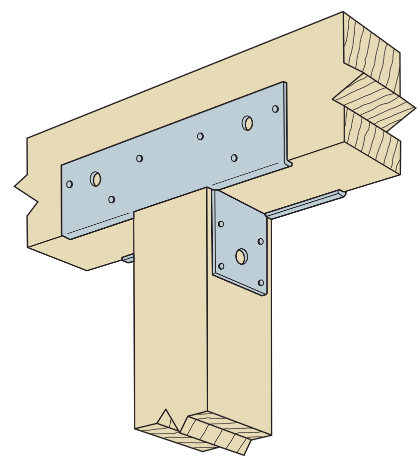
LPC4
Post Cap



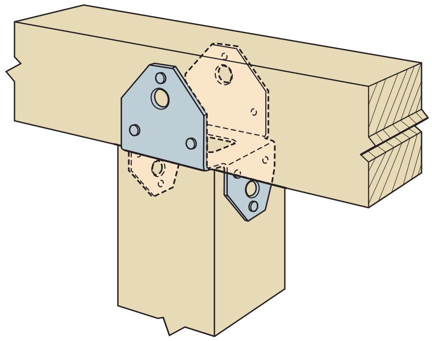
ACÉ4
Post Cap



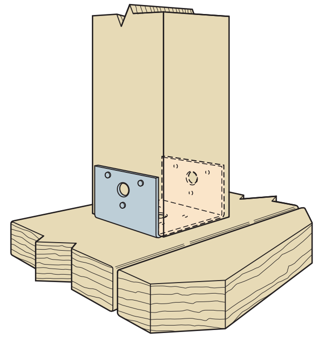
PC44
Post Cap



PC
Post Cap

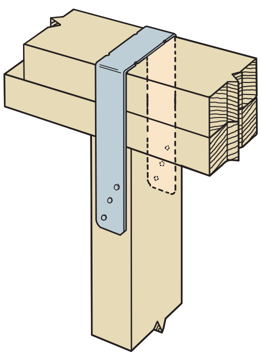


BC4in
Cap/Base

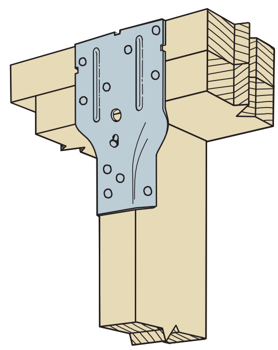


BC40IN
Cap/Base

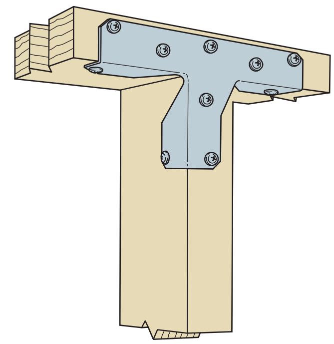
Ties and Braces



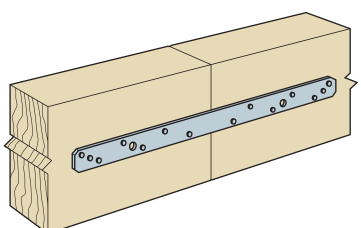
SP4
Stud Plate Tie



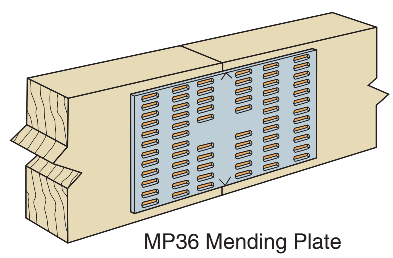
SP2
Stud Plate Tie



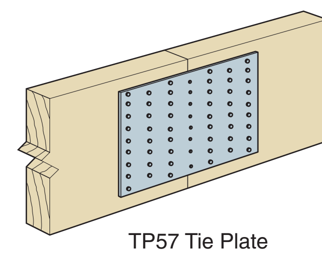
RTT22
Rigid Tie



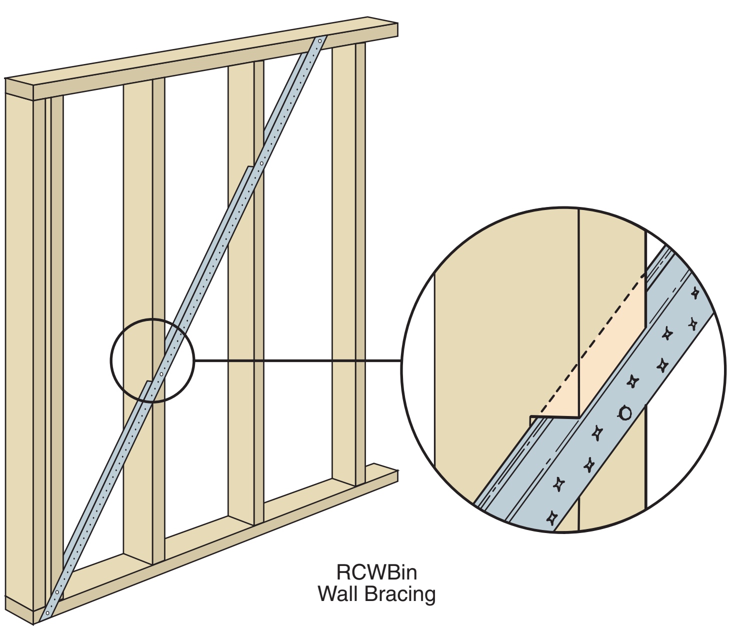
MSTA18Z Strap Tie



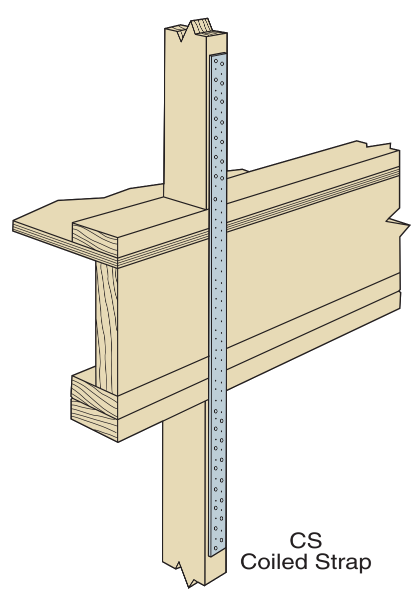
MP36 Mending Plate



TP57 Tie Plate

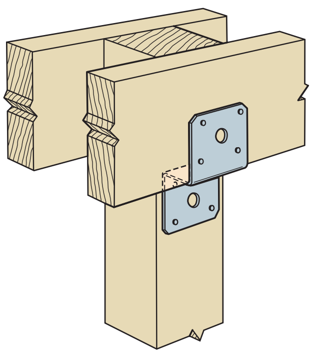


RCWBin
Wall Bracing

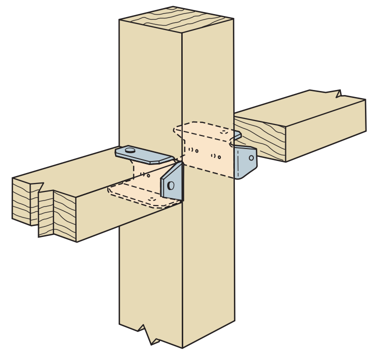


CS
Coiled Strap

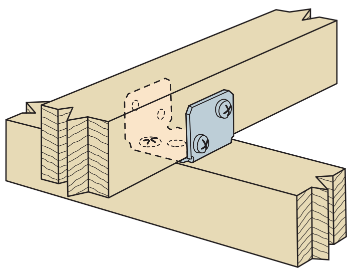
Deck Ties and Fence Brackets



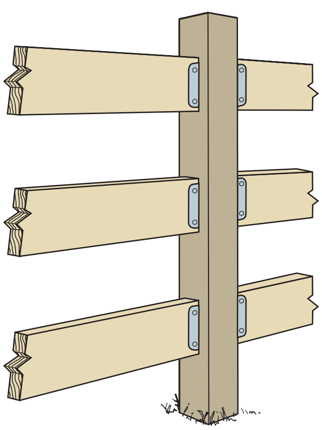
DJT14 Deck Tie



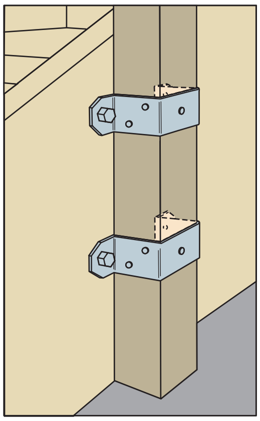
FB24 Fence Bracket



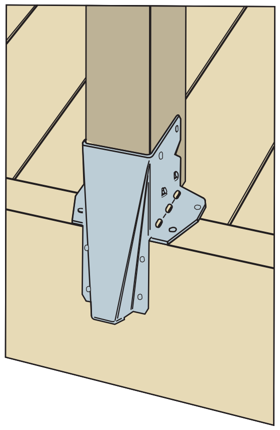
RTU2 Rigid Tie



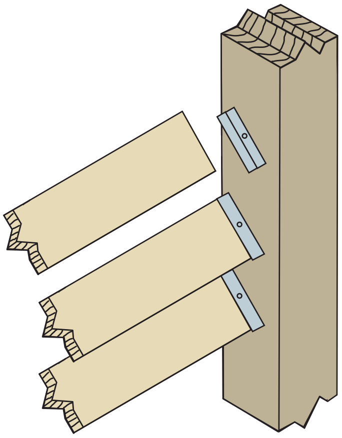
FB26 Fence Bracket



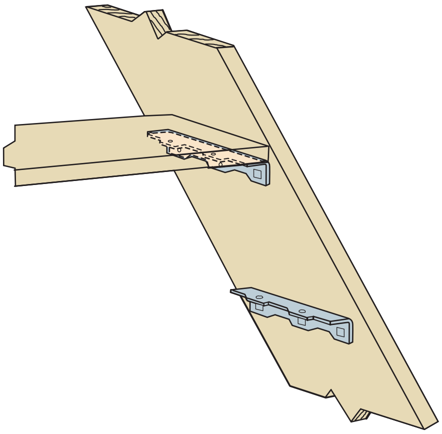
DPT5 Deck Tie



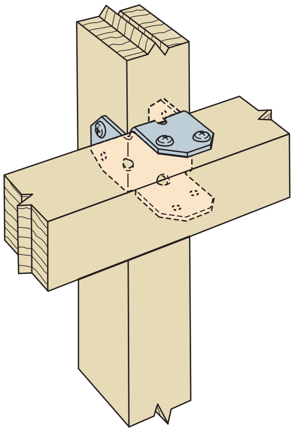
DPT6 Deck Tie



FB14 Fence Bracket



TA9 Staircase Angle



RTB22 Rigid Tie

24

Decks and Railings

Good residential design incorporates outdoor spaces into the overall living area.

After settling on a design, the first task is the *layout* of the deck's outside frame dimensions. This allows for precise location of the *foundation*.

Framing consists of connecting the posts, beams, and joists. A wide variety of metal framing aids (see Chapter 23, "Fasteners") make assembling the frame simpler than ever.

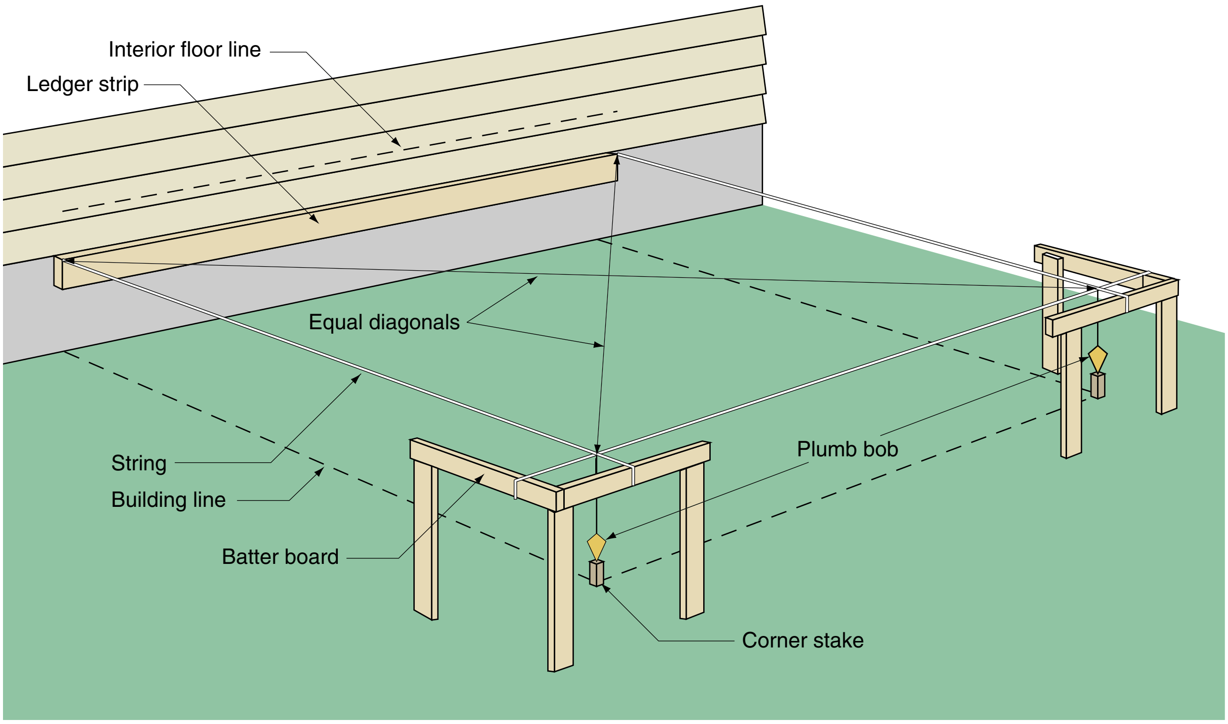
Grade-level changes allow for interesting *level changes* in the deck itself. Visual interest can also be increased by varying the *decking patterns*.

Rails and guards are required whenever a deck is more than 30" above the ground, whereas *stairs* provide access to ground-level spaces.

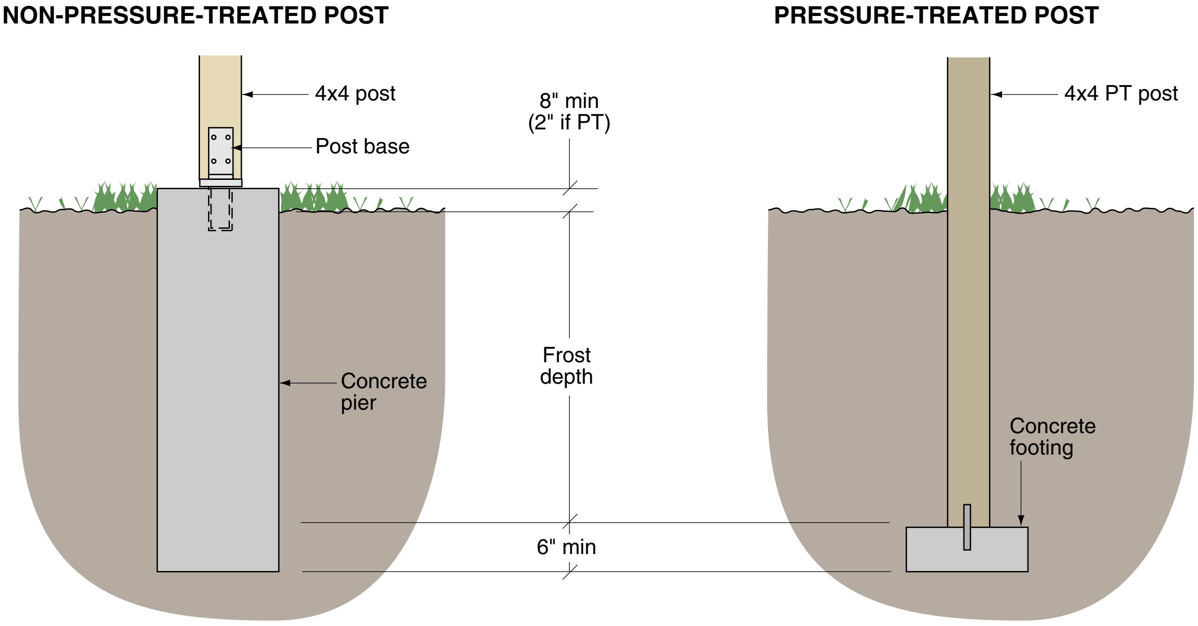
No matter how ambitious your design, you will find that complex decks are really nothing more than combinations of simple deck designs, We include three *design examples* of varying complexity to get you started.

Layout and Foundation

Establishing a Square-Cornered Layout



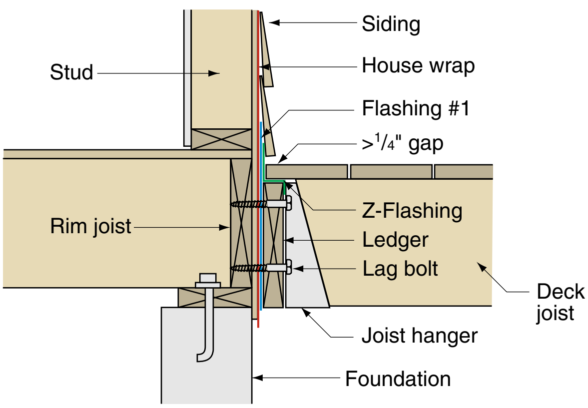
Setting the Posts

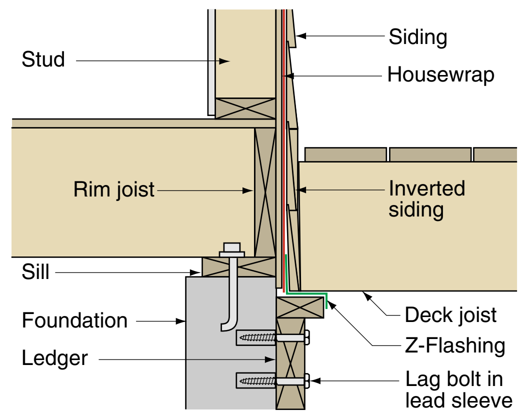


Framing

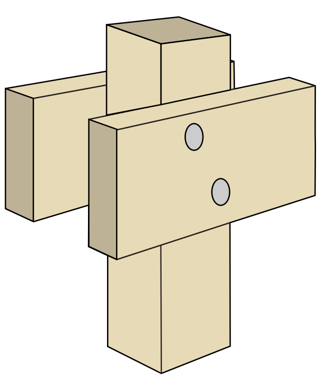
Framing Connections

ATTACHING TO BUILDING

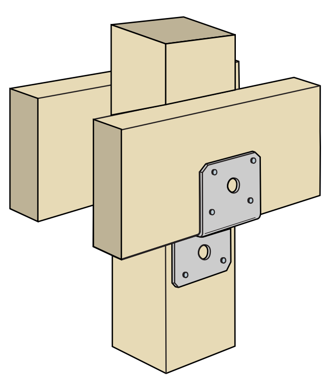




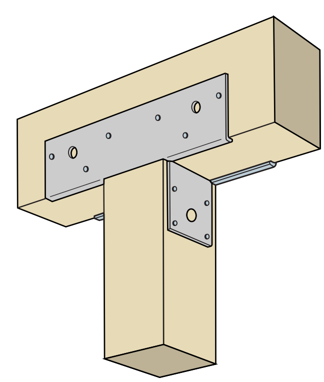
POSTS AND BEAMS



Through bolted

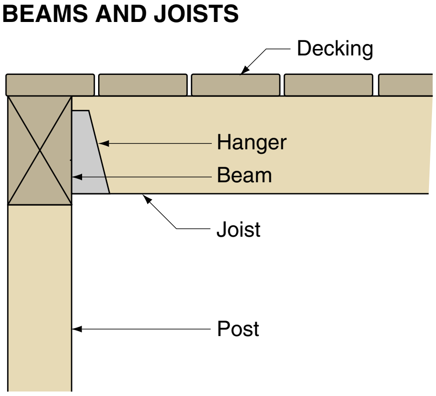


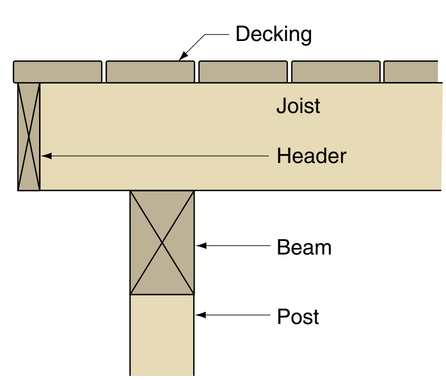
Deck tie



Post cap

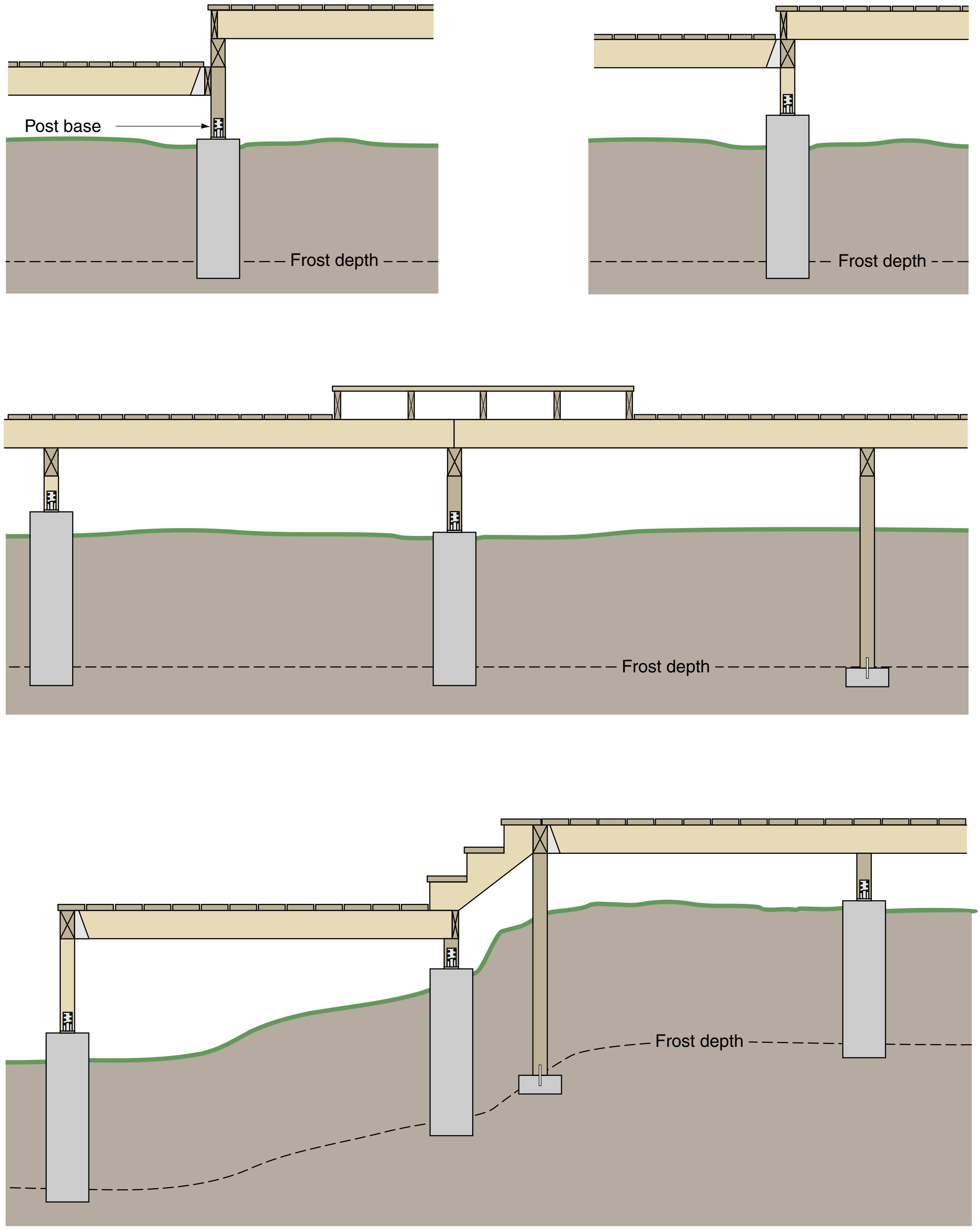
BEAMS AND JOISTS





Level Changes

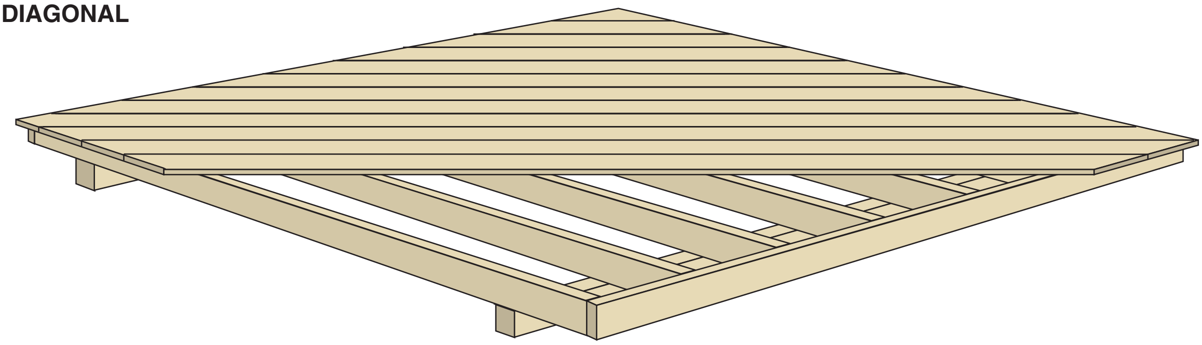
A Variety of Methods for Making Elevation Changes



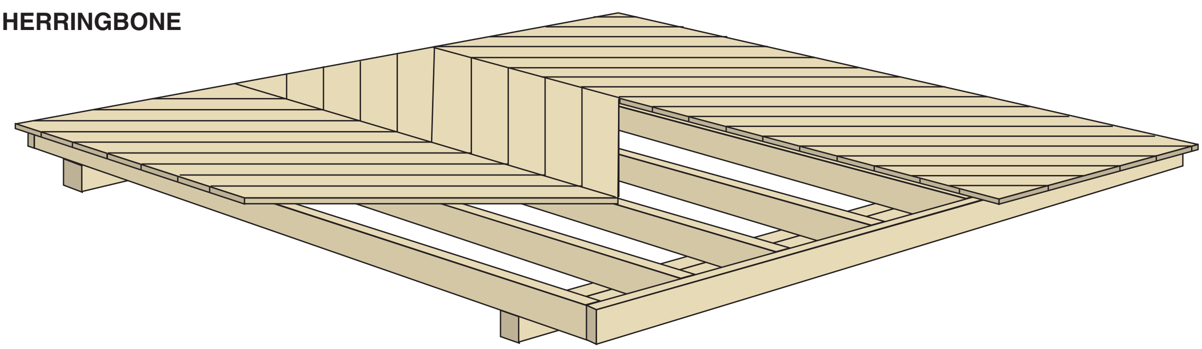
Decking Patterns

A Variety of Decking Patterns

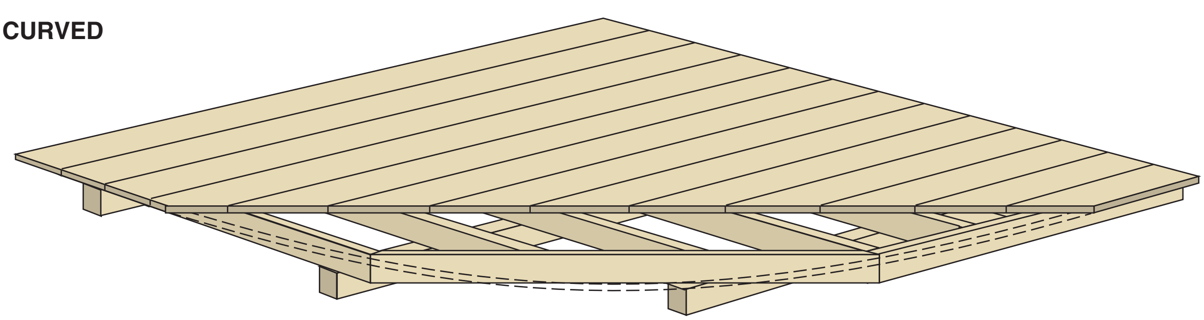
DIAGONAL



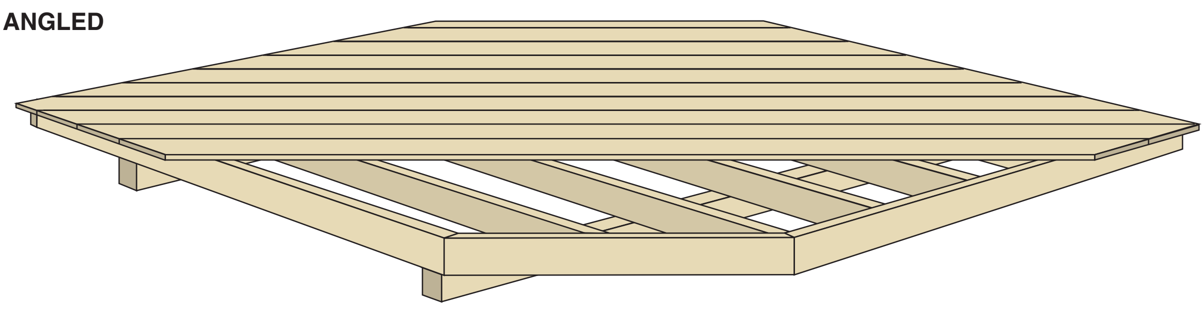
HERRINGBONE



CURVED



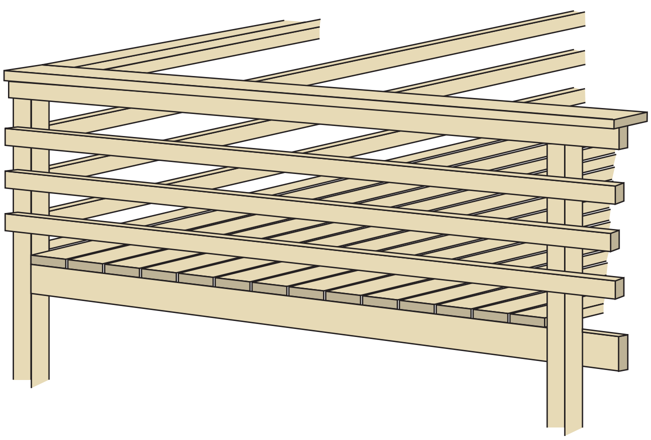
ANGLED

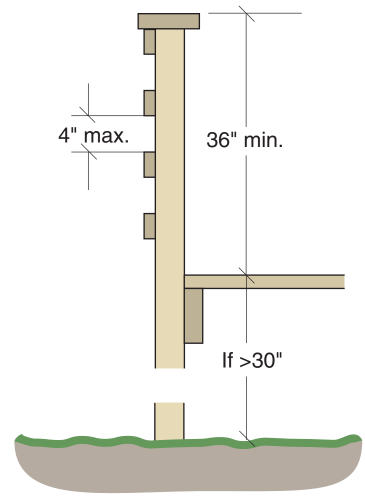


Rails and Guards

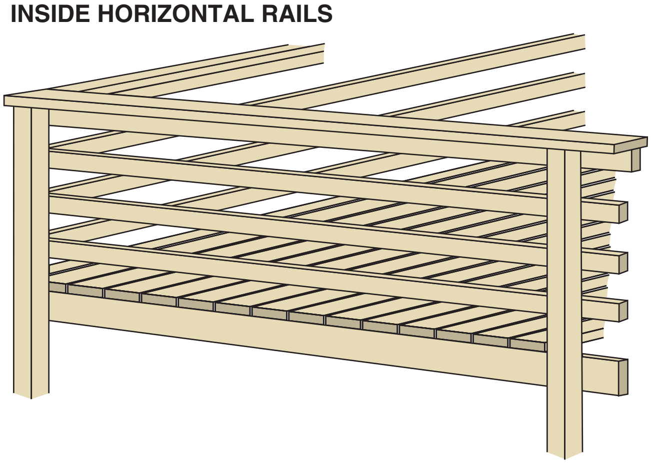
Code Requirements for Guard Rails

OUTSIDE HORIZONTAL RAILS



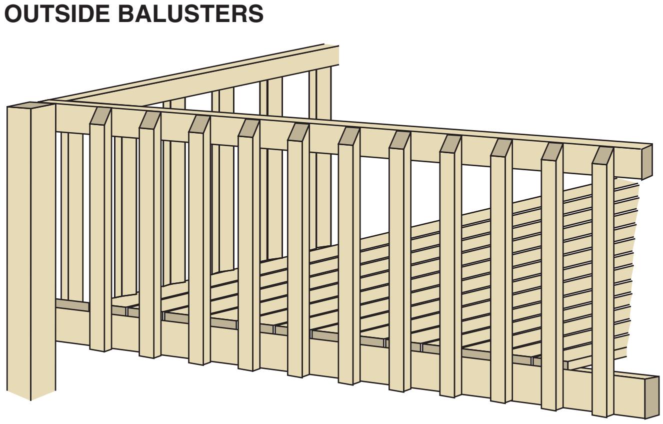


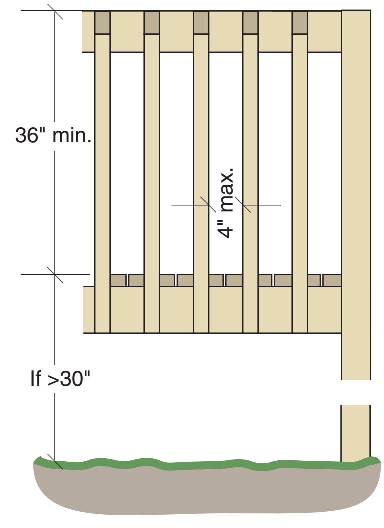
INSIDE HORIZONTAL RAILS



SAME AS ABOVE

OUTSIDE BALUSTERS

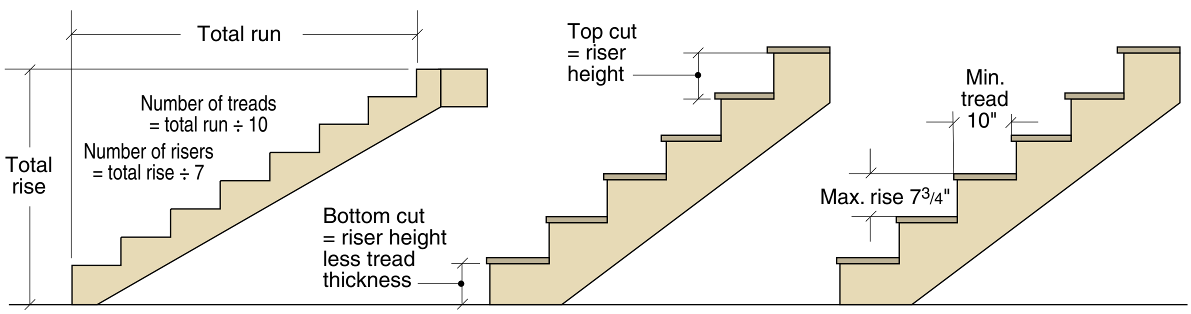




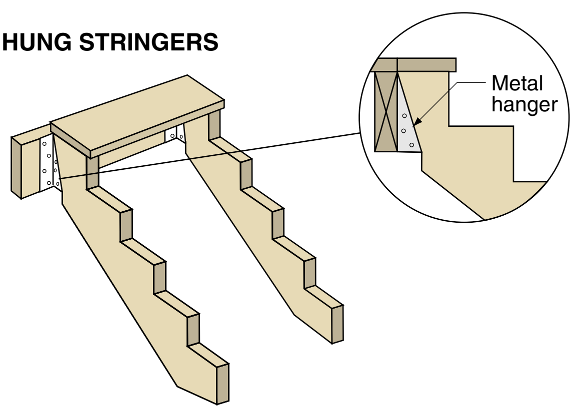
Stairs

Code Requirements for Stairs

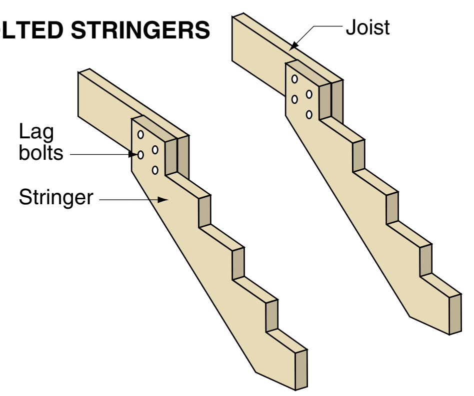
FIGURING RISE AND RUN



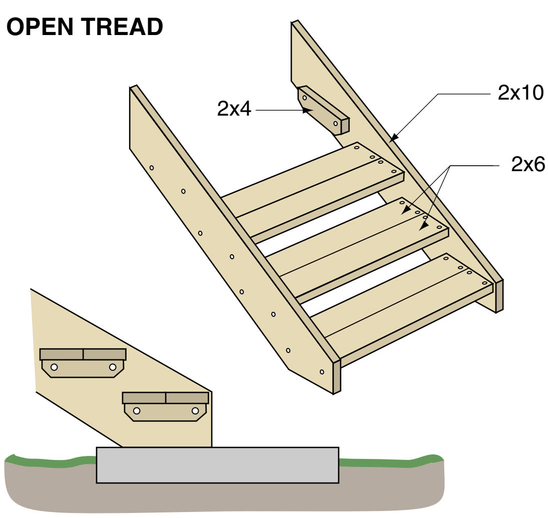
HUNG STRINGERS



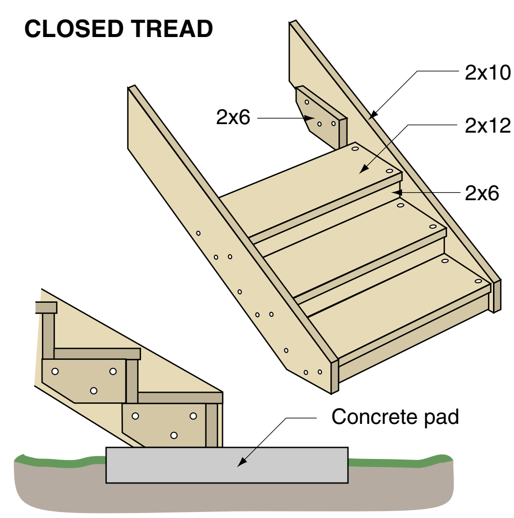
BOLTED STRINGERS



OPEN TREAD

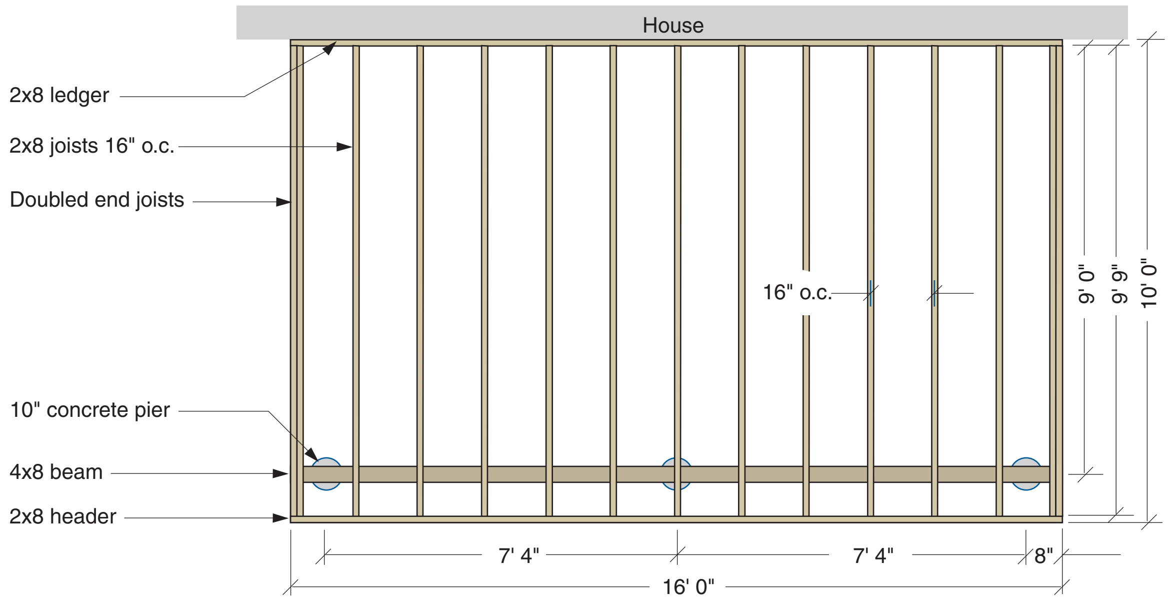


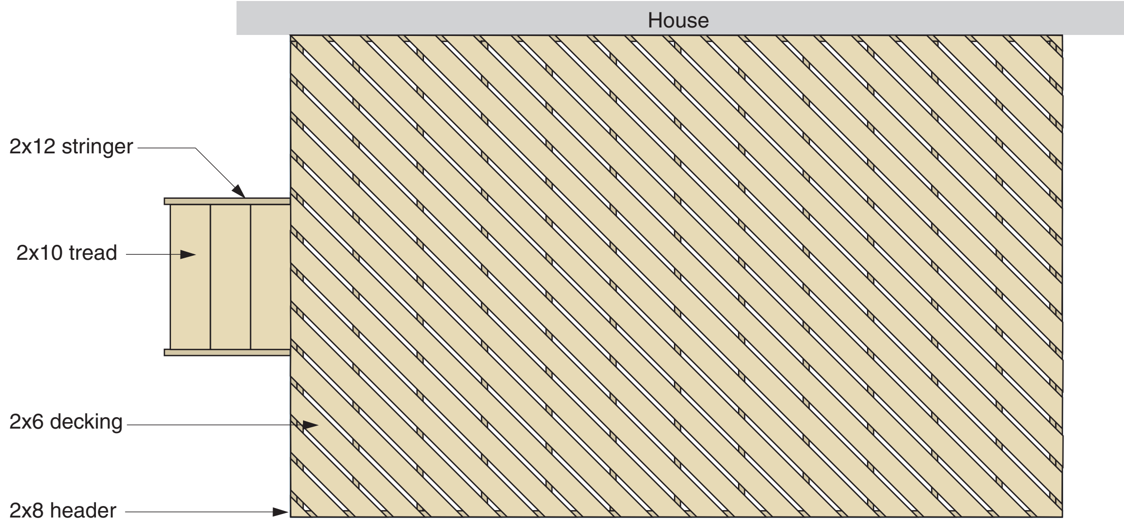
CLOSED TREAD

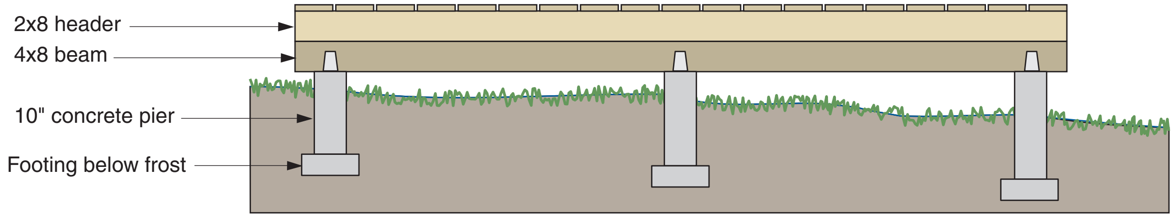


Design Examples

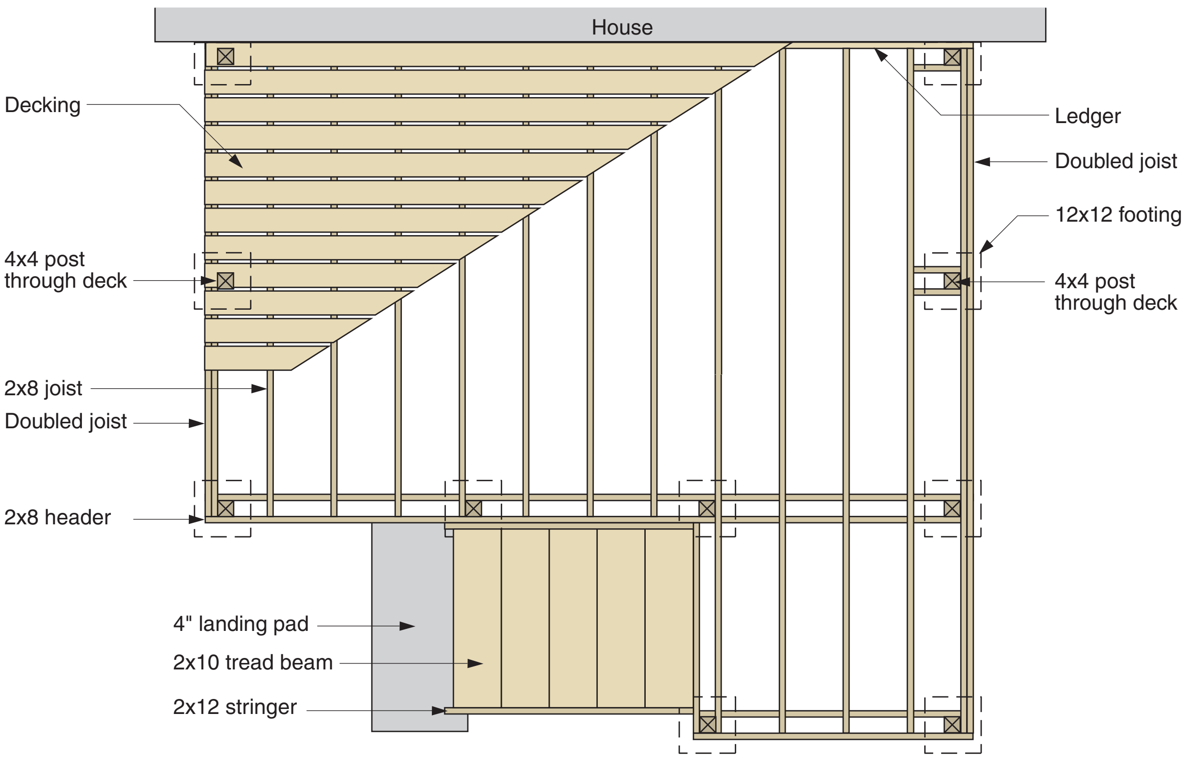
Simple Design 1

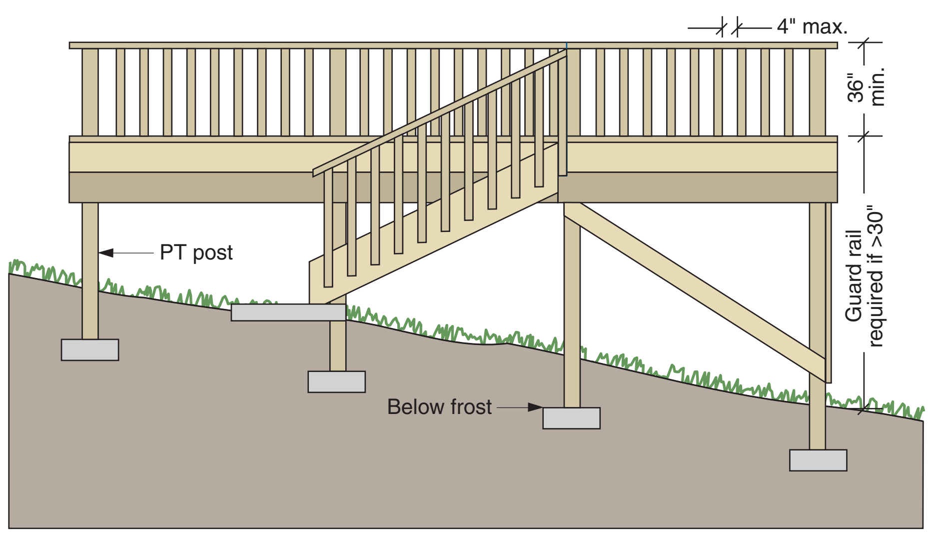




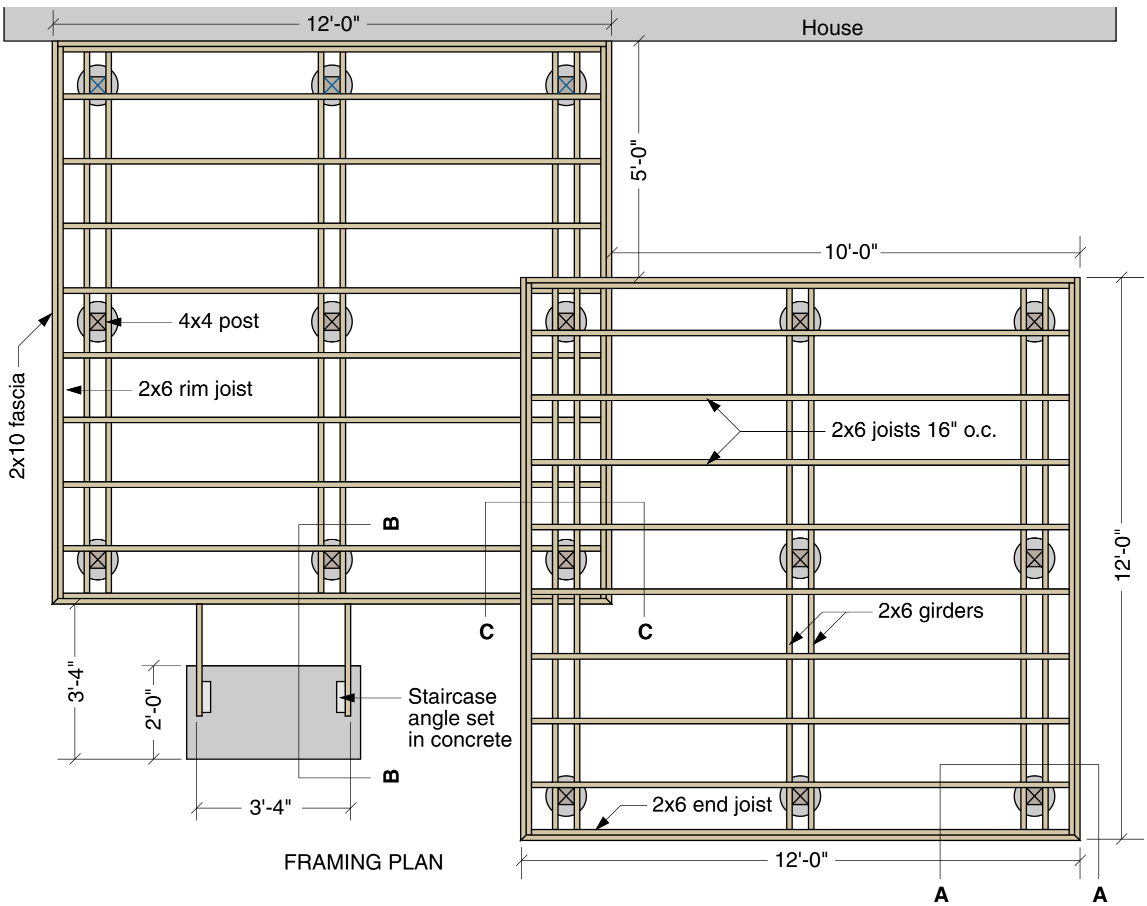


Simple Design 2

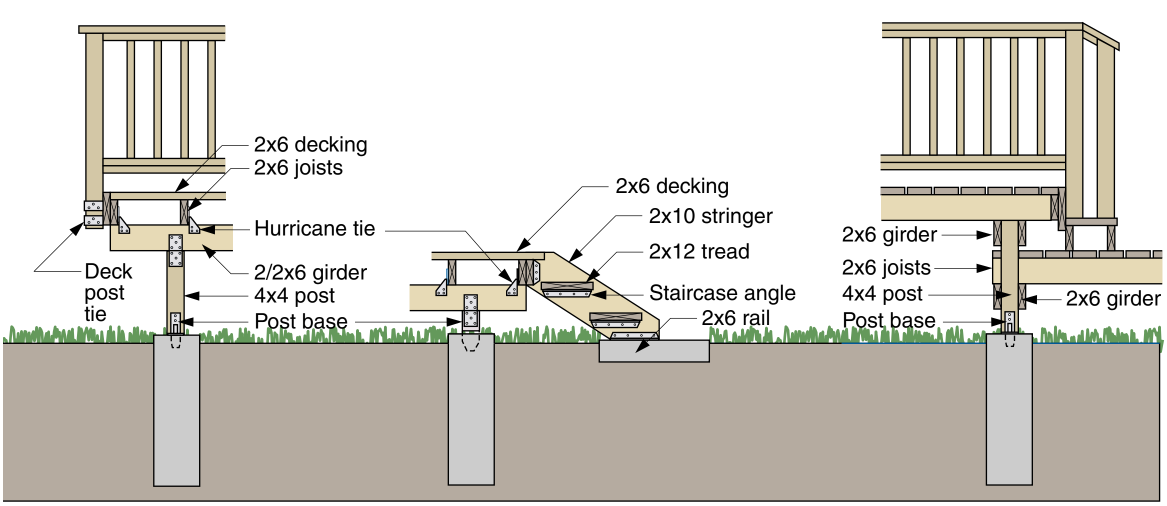




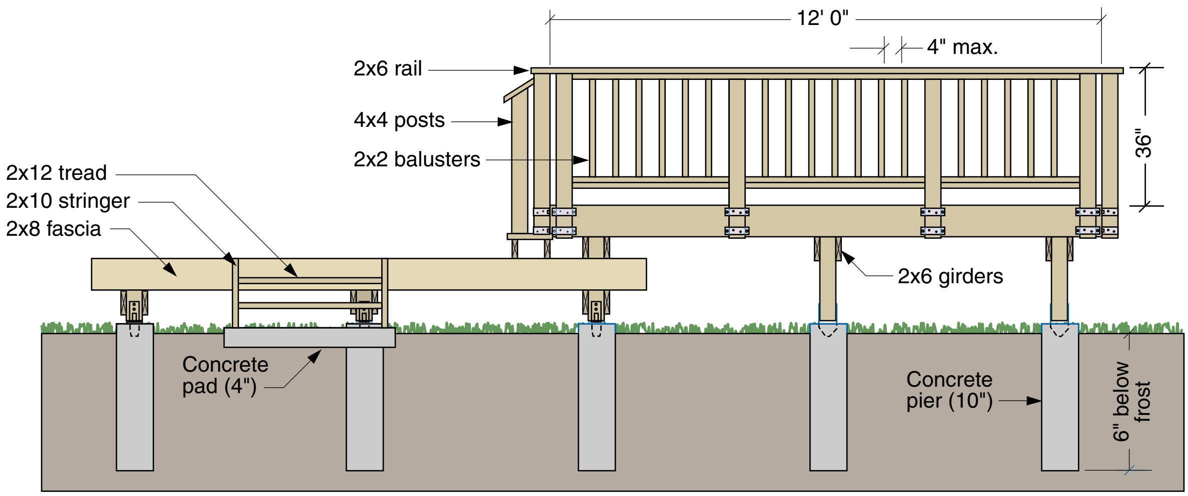
Multilevel Design



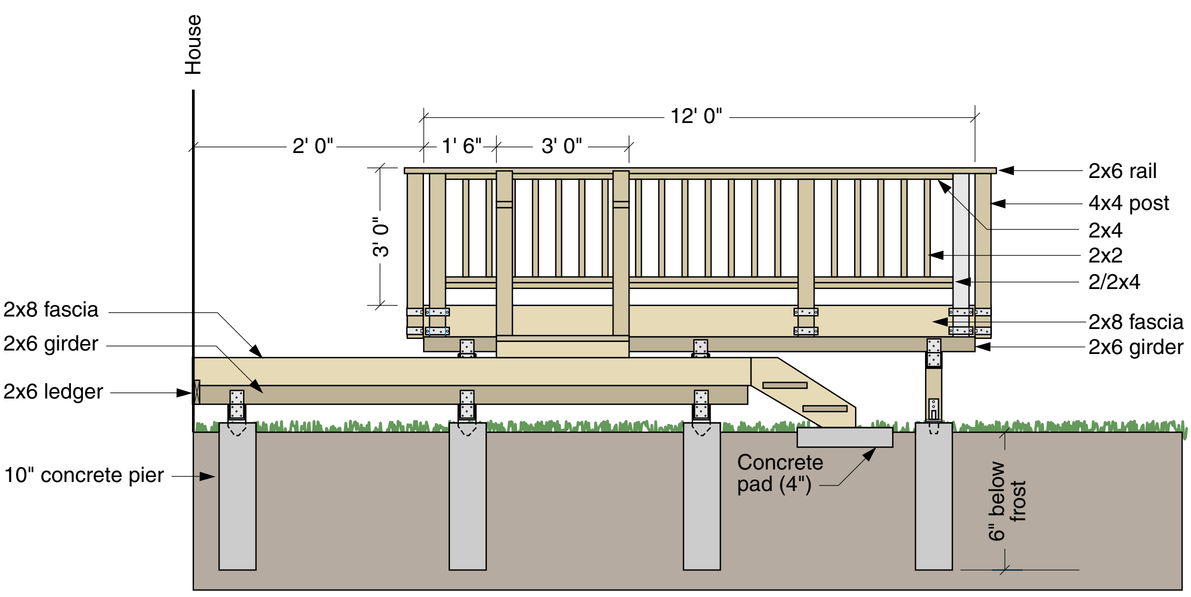
FRAMING PLAN



SECTION A SECTION B SECTION C



FRONT ELEVATION



LEFT ELEVATION

25

Measuring and Finance

Few building projects are paid for with cash; usually somebody must obtain a mortgage. This chapter contains a guide to *home mortgage types* that will let you in on what the banker and the real estate broker are talking about. The table of *interest on loans* will help you calculate the monthly payments.

Geometric figures and *trigonometry* may bring back bad memories, but sooner or later you'll find it useful or even necessary to compute the volume of a space, an area of carpeting, or the angle of a saw cut. This chapter contains the formulae for all of the shapes you could think of.

How many square feet are there in an acre, how many ounces in a kilogram, what is the metric equivalent of 3 feet $4\frac{5}{16}$ inches? The answers to these and a hundred more building questions are all contained in *units and conversion factors*.

Home Mortgage Types

Loan Type	How Loan Works	Pros and Cons
Adjustable-rate (ARM)	Interest rate tied to published financial index such as prime lending rate. Most have annual and lifetime caps.	Interest rate lower initially. Interest and payments usually increase over time.
Assumable	Buyer takes over seller's mortgage.	Mortgage usually fixed-rate at below-market interest rate.
Balloon	Payments based on long term (usually 30 years), but entire principal due in short term (usually 3 to 5 years).	Refinancing required at unknown interest rate at time of balloon payment.
Buy-down	Seller pays part of interest for first years.	Loan more affordable for buyer whose income is expected to rise.
Fixed-rate (FRM)	Interest rate and monthly payments constant for life of loan (usually 30 years).	Interest rate usually higher. Equity grows slowly in early years.
Graduated-payment (GPM)	Payments increase for first few years, then remain constant. Interest rate may vary.	Loan more affordable for buyer whose income is expected to rise.
Growing-equity (GEM)	Payments increase annually, with increase applied to principal. Interest rate usually constant.	Buyer equity increases rapidly, but buyer must be able to make increased payments.
Interest-only	Entire payment goes toward interest only. Principal remains at original amount.	Requires lowest payments. Owner equity consists of down payment plus appreciation.
Owner-financed (seller take back)	Seller holds either first or second mortgage.	Interest rate may be higher than market rate.
Renegotiable (rollover)	Same as adjustable-rate mortgage, but interest rate adjusted less often.	Interest rate and monthly payment variable, but fixed for longer periods.
Reverse annuity (reverse mortgage)	Lender makes monthly payments to borrower. Debt increases over time to maximum percentage of appraised value of property.	Provides monthly income to borrower but decreases equity.
Shared-appreciation (SAM)	Lender charges less interest in exchange for share of appreciation when the property sold.	Makes property more affordable. Reduces owner's gain upon sale.
Wraparound (blended-rate)	Existing lower-interest loan combined with new additional loan for single loan with intermediate interest rate.	Decreases interest rate.
Zero-interest (no-interest)	No interest charged. Fixed monthly payments usually over short term.	Sale price usually inflated. One-time fee may be charged. No tax deduction allowed.

Interest on Loans

Monthly Payment

The table below shows monthly payments for each $1,000 borrowed for fixed-interest rates from 0 to 18% and for periods from 1 to 40 years. Monthly payments at other interest rates can be accurately interpolated using the figures in the table.

Example: What are the monthly payments on a 10-year, $1,000 loan at 5.5% interest? From the table, the payments at 5% and 6% are $10.61 and $11.11. Since 5.5% is the average of 5% and 6%, the monthly payment is ($10.61 + $11.11) ÷ 2 = $10.86 for each $1,000 borrowed.

Total Interest Paid

Knowing the monthly payment, it is easy to find the total interest paid over the life of a loan. Total interest is the difference between the sum of the payments over life and the original amount.

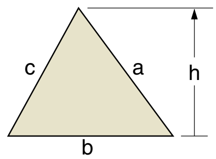
Example: For a 30-year, 12%, $100,000 mortgage, what is the total interest paid? From the table, the monthly payment for each $1,000 is $10.29. Therefore, the total lifetime payment is 100 × 12 months × 30 years × $10.29 = $370,440. Since the original loan is for $100,000, the total interest paid is the difference: $270,440.

Monthly Payments for Fixed-Rate Loans ($ for each $1,000)

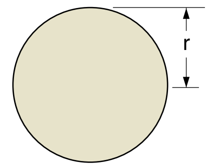
Rate	Life of Loan, years									
%	1	2	3	4	5	10	15	20	30	40
0	83.33	41.67	27.78	20.83	16.67	8.33	5.56	4.17	2.78	2.08
1	83.79	42.10	28.21	21.26	17.09	8.76	5.98	4.60	3.22	2.53
2	84.24	42.54	28.64	21.70	17.53	9.20	6.44	5.06	3.70	3.03
3	84.69	42.98	29.08	22.13	17.97	9.66	6.91	5.55	4.22	3.58
4	85.15	43.42	29.52	22.58	18.42	10.12	7.40	6.06	4.77	4.18
5	85.61	43.88	29.98	23.03	18.88	10.61	7.91	6.60	5.37	4.83
6	86.07	44.33	30.43	23.49	19.34	11.11	8.44	7.17	6.00	5.51
7	86.53	44.78	30.88	23.95	19.81	11.62	8.99	7.76	6.66	6.22
8	86.99	45.23	31.34	24.42	20.28	12.14	9.56	8.37	7.34	6.96
9	87.46	45.69	31.80	24.89	20.76	12.67	10.15	9.00	8.05	7.72
10	87.92	46.15	32.27	25.37	21.25	13.22	10.75	9.66	8.78	8.50
11	88.38	46.60	32.73	25.84	21.74	13.77	11.36	10.32	9.52	9.28
12	88.85	47.08	33.22	26.34	22.25	14.35	12.01	11.02	10.29	10.09
13	89.31	47.54	33.69	26.82	22.75	14.93	12.65	11.71	11.06	10.89
14	89.79	48.02	34.18	27.33	23.27	15.53	13.32	12.44	11.85	11.72
15	90.25	48.48	34.66	27.83	23.78	16.13	13.99	13.16	12.64	12.53
16	90.74	48.97	35.16	28.35	24.32	16.76	14.69	13.92	13.45	13.36
17	91.20	49.44	35.65	28.85	24.85	17.37	15.39	14.66	14.25	14.18
18	91.68	49.93	36.16	29.38	25.40	18.02	16.11	15.44	15.08	15.02
19	92.15	50.40	36.65	29.90	25.94	18.66	16.82	16.20	15.88	15.84
20	92.63	50.89	37.16	30.43	26.49	19.32	17.56	16.98	16.71	16.67

Geometric Figures

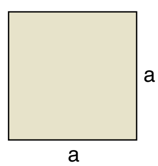
Areas and Perimeters of Two-Dimensional Figures



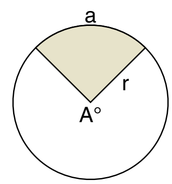
TRIANGLE
Area = $bh/2$
Perimeter = $a + b + c$



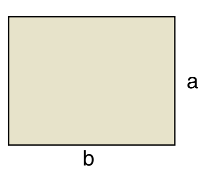
CIRCLE
Area = πr^2
Perimeter = $2\pi r$



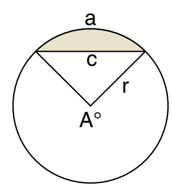
SQUARE
Area = a^2
Perimeter = $4a$



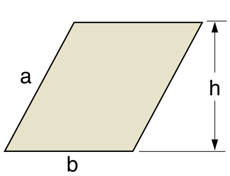
CIRCULAR SECTOR
Area = $\pi r/360$
Perimeter = $0.01745rA°$



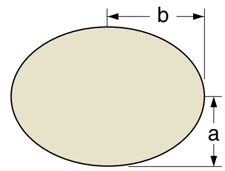
RECTANGLE
Area = ab
Perimeter = $2a + 2b$



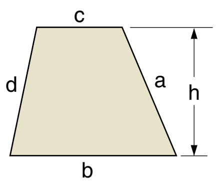
CIRCULAR SEGMENT
Area = $r^2(\pi A° - \sin A°)/360$
Perimeter = $2r \sin A°/2$



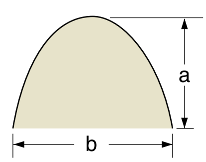
PARALLELOGRAM
Area = bh
Perimeter = $2a + 2b$



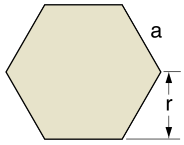
ELLIPSE
Area = πab
Perimeter = $\pi\sqrt{2(a^2 + b^2)}$



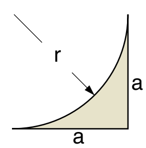
TRAPEZOID
Area = $h(b + c)/2$
Perimeter = $a + b + c + d$



PARABOLA
Area = $2ab/3$
Perimeter = $b(1 + 8a^2/3b^2)$

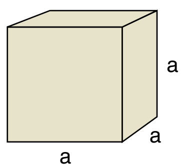


N-SIDED POLYGON
Area = $N(ra)/2$
Perimeter = Na

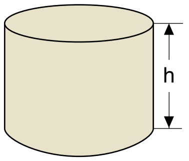


CIRCLE/SQUARE
Area = $0.2146a^2$
Perimeter = $2a + \pi a/2$

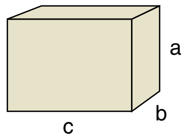
Areas and Volumes of Three-Dimensional Bodies



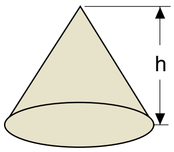
CUBE
Area = $6a^2$
Volume = a^3



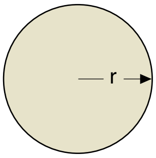
CYLINDER
Area = $2\pi r^2 + 2\pi rh$
Volume = $\pi r^2 h$



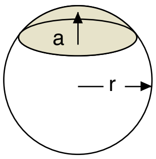
RECTANGULAR PRISM
Area = $2(ab + ac + bc)$
Volume = abc



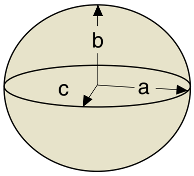
CONE
Area = $\pi r\sqrt{r^2 + h^3 + \pi r^2}$
Volume = $\pi r^2 h/3$



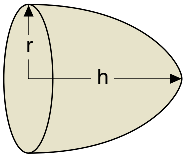
SPHERE
Area = $4\pi r^2$
Volume = $4\pi r^3/3$



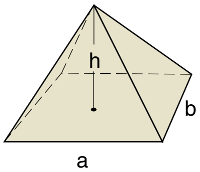
SPHERICAL SEGMENT
Area = $2\pi ra$
Volume = $\pi a^2(3r - a)/3$



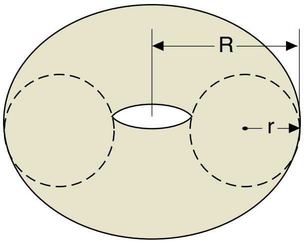
ELLIPSOID
Volume = $\pi abc/3$



PARABOLOID
Volume = $\pi r^2 h/2$



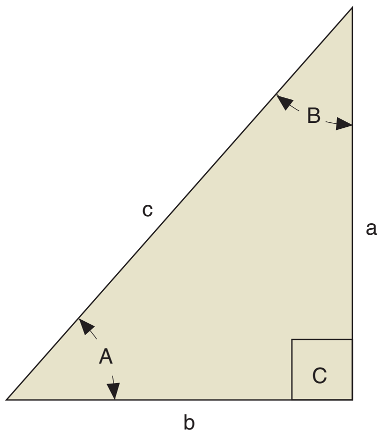
PYRAMID
Volume = $abh/3$



TORUS
Area = $\pi^2(R + r)(R - r)$
Vol = $\pi^2(R - r)^2(R + r)/4$

Trigonometry

Right (angled) Triangles



Ratios of Sides (Trig Functions)

sin A = a/c   sin B = b/c   sin C = 1

cos A = b/c   cos B = a/c   cos C = 0

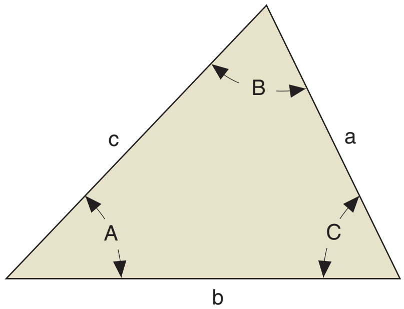
tan A = a/b   tan B = b/a   tan C = ∞

Pythagorean Theorem

$a^2 + b^2 = c^2$

$c = \sqrt{a^2 + b^2}$

Any Triangle



Law of Cosines

$a^2 = b^2 + c^2 - 2bc \cos A$ $\cos A = (b^2 + c^2 - a^2)/2bc$

$b^2 = a^2 + c^2 - 2ac \cos B$ $\cos B = (a^2 + c^2 - b^2)/2ac$

$c^2 = a^2 + b^2 - 2ab \cos C$ $\cos C = (a^2 + b^2 - c^2)/2ab$

Law of Sines

a/sin A = b/sin B = c/sin C

a/b = sin A/sin B, etc.

Trigonometry Tables

Deg	Sin	Cos	Tan
1	.0175	.9998	.0175
2	.0349	.9994	.0349
3	.0523	.9986	.0524
4	.0698	.9976	.0699
5	.0872	.9962	.0875
6	.1045	.9945	.1051
7	.1219	.9925	.1228
8	.1392	.9903	.1405
9	.1564	.9877	.1584
10	.1736	.9848	.1763
11	.1908	.9816	.1944
12	.2079	.9781	.2126
13	.2250	.9744	.2309
14	.2419	.9703	.2493
15	.2588	.9659	.2679
16	.2756	.9613	.2867
17	2924	.9563	.3057
18	.3090	.9511	.3249
19	.3256	.9455	.3443
20	.3420	.9397	.3640
21	.3584	.9336	.3839
22	.3746	.9272	.4040
23	.3907	.9205	.4245
24	.4067	.9135	.4452
25	.4226	.9063	.4663
26	.4384	.8988	.4877
27	.4540	.8910	.5095
28	.4695	.8829	.5317
29	.4848	.8746	.5543
30	.5000	.8660	.5774

Deg	Sin	Cos	Tan
31	.5150	.8572	.6009
32	.5299	.8480	.6249
33	.5446	.8387	.6494
34	.5592	.8290	.6745
35	.5736	.8192	.7002
36	.5878	.8090	.7265
37	.6018	.7986	.7536
38	.6157	.7880	.7813
39	.6293	.7771	.8098
40	.6428	.7660	.8391
41	.6561	.7547	.8693
42	.6691	.7431	.9004
43	.6820	.7314	.9325
44	.6947	.7193	.9657
45	.7071	.7071	1.0000
46	.7193	.6947	1.0355
47	.7314	.6820	1.0724
48	.7431	.6691	1.1106
49	.7547	.6561	1.1504
50	.7660	.6428	1.1918
51	.7771	.6293	1.2349
52	.7880	.6157	1.2799
53	.7986	.6018	1.3270
54	.8090	.5878	1.3764
55	.8192	.5736	1.4281
56	.8290	.5592	1.4826
57	.8387	.5446	1.5399
58	.8480	.5299	1.6003
59	.8572	.5150	1.6643
60	.8660	.5000	1.7321

Deg	Sin	Cos	Tan
61	.8746	.4848	1.8040
62	.8829	.4695	1.8807
63	.8910	.4540	1.9626
64	.8988	.4384	2.0503
65	.9063	.4226	2.1445
66	.9135	.4067	2.2460
67	.9205	.3907	2.3559
68	.9272	.3746	2.4751
69	.9336	.3584	2.6051
70	.9397	.3420	2.7475
71	.9455	.3256	2.9042
72	.9511	.3090	3.0777
73	.9563	.2924	3.2709
74	.9613	.2756	3.4874
75	.9659	.2588	3.7321
76	.9703	.2419	4.0108
77	.9744	.2250	4.3315
78	.9781	.2079	4.7046
79	.9816	.1908	5.1446
80	.9848	.1736	5.6713
81	.9877	.1564	6.3138
82	.9903	.1392	7.1154
83	.9925	.1219	8.1443
84	.9945	.1045	9.5144
85	.9962	.0872	11.4301
86	.9976	.0698	14.3007
87	.9986	.0523	19.0811
88	.9994	.0349	28.6363
89	.9998	.0175	57.2900
90	1.000	.0000	∞

Units and Conversion Factors

Multiply	By	To Get
LENGTH		
Centimeter	0.3937	Inches
Centimeter	10	Millimeters
Centimeter	0.01	Meters
Inch	2.54	Centimeters
Inch	0.0833	Feet
Inch	0.0278	Yards
Foot	30.48	Centimeters
Foot	0.3048	Meters
Foot	12	Inches
Foot	0.3333	Yards
Yard	91.44	Centimeters
Yard	0.9144	Meters
Yard	36	Inches
Yard	3	Feet
Meter	39.37	Inches
Meter	3.281	Feet
Meter	1.094	Yards
Meter	100	Centimeters
Meter	0.001	Kilometers
Kilometer	3,281	Feet
Kilometer	1,094	Yards
Kilometer	0.6214	Miles
Kilometer	1,000	Meters
Mile	5,280	Feet
Mile	1,760	Yards
Mile	1,609	Meters
Mile	1.609	Kilometers
AREA		
Square centimeter	0.1550	Square inches
Square centimeter	100	Square millimeters
Square centimeter	0.0001	Square meters
Square inch	6.4516	Square centimeters
Square inch	0.0069	Square feet
Square inch	7.72×10^{-4}	Square yards
Square foot	929	Square centimeters
Square foot	0.0929	Square meters
Square foot	144	Square inches

Multiply	By	To Get
Square foot	0.1111	Square yards
Square yard	8,361	Square centimeters
Square yard	0.8361	Square meters
Square yard	1,296	Square inches
Square yard	9	Square feet
Square meter	1,550	Square inches
Square meter	10.765	Square feet
Square meter	1.1968	Square yards
Square meter	10,000	Square centimeters
Square meter	1.0×10^{-6}	Square kilometers
Square kilometer	1.076×10^{7}	Square feet
Square kilometer	1.197×10^{6}	Square yards
Square kilometer	0.3861	Square miles
Square kilometer	1.0×10^{6}	Square meters
Square mile	2.788×10^{7}	Square feet
Square mile	3.098×10^{6}	Square yards
Square mile	640	Acres
Square mile	2.590	Square kilometers
SURVEYOR'S MEASURE		
Link	7.92	Inches
Rod	16.5	Feet
Chain	4	Rods
Rood	40	Square rods
Acre	160	Square rods
Acre	43,560	Square feet
Square mile	640	Acres
Township	36	Square miles
VOLUME		
Cubic centimeter	0.0610	Cubic inches
Cubic centimeter	1,000	Cubic millimeters
Cubic centimeter	1.0×10^{-6}	Cubic meters
Cubic inch	16.387	Cubic centimeters
Cubic inch	5.787×10^{-4}	Cubic feet
Liter	0.2642	Gallons, US
Liter	1.0568	Quarts
Liter	1,000	Cubic centimeters
Gallon, US	0.0238	Barrels (42 gallon)
Gallon, US	4	Quarts

Multiply	By	To Get
Gallon, US	231	Cubic inches
Gallon, US	3,785	Cubic centimeters
Cubic foot	2.832×10^4	Cubic centimeters
Cubic foot	0.0283	Cubic meters
Cubic foot	1,728	Cubic inches
Cubic foot	0.0370	Cubic yards
Cubic yard	7.646×10^5	Cubic centimeters
Cubic yard	0.7646	Cubic meters
Cubic yard	4.667×10^4	Cubic inches
Cubic yard	27	Cubic feet
Cubic meter	6.102×10^4	Cubic inches
Cubic meter	35.320	Cubic feet
Cubic meter	1.3093	Cubic yards
Cubic meter	1.0×10^6	Cubic centimeters
Cubic meter	1,000	Liters
ENERGY		
Erg	1.0×10^{-7}	Joules
Joule	1	Newton-meters
Joule	1.0×10^7	Ergs
Joule	0.2389	Calories
Joule	9.48×10^{-4}	British thermal units
Joule	0.7376	Foot-pounds
Calorie	3.97×10^{-3}	British thermal units
Btu/hour	0.293	Joules/second
Btu/hour	252	Calories/hour
LIGHT		
Lux	1	Lumens/square meter
Lux	0.0929	Lumens/square foot
Lux	0.0929	Footcandles
Footcandle	10.76	Lux
Lumen/square foot	10.76	Lux
TEMPERATURE		
Degree C	1.8	Degree F
Degree F	0.5556	Degree C
Degree K	1	Degree C
Degrees C	1.8 (°C+32)	Degrees F
Degrees F	0.556 (°F-32)	Degrees C
Degrees K	(°K-273)	Degrees C

Multiply	By	To Get
MASS		
Pound	4.448	Newtons
Pound	32.17	Poundals
Ton, US short	2,000	Pounds
Ton, US long	2,240	Pounds
Ton, metric	2,205	Pounds
Ton, metric	1,000	Kilograms
Gram	0.0353	Ounces
Gram	2.205×10^{-3}	Pounds
Gram	0.001	Kilograms
Gram	15.432	Grains
Ounce	28.35	Grams
Ounce	0.0284	Kilograms
Ounce	0.0625	Pounds
Pound	453.6	Grams
Pound	0.4536	Kilograms
Pound	16	Ounces
Kilogram	35.28	Ounces
Kilogram	2.205	Pounds
Kilogram	1,000	Grams
Ton, US	0.9070	Tons metric
Ton, US	907	Kilograms
Ton, US	2,000	Pounds
Ton, metric	1.102	Tons, US
Ton, metric	2,205	Pounds
Ton, metric	1,000	Kilograms

Abbreviations

AASHO: American Association of State Highway Officials
ABS: acrylonitrile-butadien-estyrene
AC: armored cable
ACA: ammoniacal copper arsenate
ACZA: ammoniacal copper zinc arsenate
ADA: Americans with Disabilities Act
AFCI: arc fault circuit interrupter
AFUE: annual fuel utilization efficiency
ag: above grade
amp: ampere
ANSI: American National Standards Institute
APA: The Engineered Wood Association (formerly known as the American Plywood Association)
ARM: adjustable-rate mortgage
ASTM: American Society of Testing Materials
avg: average
AWPA: American Wood Preservers Association
AWPB: American Wood Preservers Bureau
b: breadth
bg: below grade
Btu: British thermal unit
Btu/hr: British thermal unit per hour
BUR: built-up roof
BX: armored cable (interchangeable with AC)
C: centigrade; corrosion resistant
CABO: Council of American Building Officials
CCA: chromated copper arsenate
CCF: hundred cubic feet
CCT: color-correlated temperature
Co: duration of load factor
CDD: cooling degree-days
CDH: cooling degree-hours
C_F: size factor
CFL: compact fluorescent lamp
cfm: cubic feet per minute
CFR: Code of Federal Regulations
C_H: horizontal shear adjustment
CMU: concrete masonry unit
CPSC: Consumer Product Safety Commission
CPVC: chlorinated polyvinyl chloride
C_r: repetitive member factor
CRI: color-rendering index
cu ft: cubic foot
d: depth; pennyweight
D: deciduous
DB: dry bulb temperature
db: decibel
dbl: double
DD_{65}: base 65°F degree day
dfu: drainage fixture unit
dia: diagonal; diameter
DMT: design minimum temperature
DS: double-strength
DST: daylight saving time
DWV: drain, waste, and vent
E: east; modulus of elasticity; evergreen; excellent
EER: energy efficiency ratio
EMC: equilibrium moisture content
EMT: thin-wall metal conduit
EPA: US Environmental Protection Agency
EPDM: ethylene propylene polymer membrane
EWS: Engineered Wood Society
Exp 1: exposure 1
EXT: exterior
F: Fahrenheit; fair; feeder; female
Fb: extreme fiber stress in bending
Fc: compression parallel to grain
FHA: Federal Housing Administration
fipt: female iron pipe thread
fnpt: female national pipe thread tapered
FRM: fixed-rate mortgage
Ft: fiber stress in tension
Fv: horizontal shear stress
G: good
ga: gauge
gal: gallon
GEM: growing-equity mortgage
GFCI: ground fault circuit interrupter
GPM: graduated-payment mortgage; gallon per minute
H: heat-resistant; height; run
HDD: heating degree-days
HDO: high-density overlay
hp: horsepower
hr: hour
HEPA: High-efficiency particulate arrestance
HID: high intensity discharge
HUD: US Department of Housing and Urban Development

HVAC: heating, ventilating, and air-conditioning
Hz: hertz
IC: insulation contact
ICF: insulated concrete form
ID: internal diameter
IIC: impact insulation class
IMC: intermediate metal conduit
ins: insert thread
INT: interior
IRC: International Residential Code
IRMA: insulated roof membrane assembly
K: Kelvin
kwhr: kilowatt-hour
L: left; length
LCC: life-cycle cost
LED: light-emitting diode
LSG: light-to-solar gain
lb: pound
lin ft: linear feet
M: male
max: maximum
MC: moisture content
MDF: medium-density fiberboard
MDO: medium-density overlay
min: minimum; minute
mipt: male iron pipe thread
mnpt: male national pipe thread tapered
mph: miles per hour
MPPT: maximum power point tracking
MW: moderate weather
N: north
NFRC: National Fenestration Research Council
NKBA: National Kitchen and Bath Association
NM: nonmetallic
NRC: noise-reduction coefficient
NREL: National Renewable Energy Laboratory
NSRDB: national solar radiation data base
NWWDA: National Wood Window and Door Association
o.c.: on-center
OD: outside diameter
ORNL: Oak Ridge National Laboratory
OSB: oriented-strand board
OVE: optimum value engineered
oz: ounce
P: perennial; plasticweld; poor
PB: polybutylene
pcf: pounds per cubic foot
PE: polyethylene
perm: measure of permeability
PS: product standard
psf: pounds per square foot
psi: pounds per square inch
PVC: polyvinyl chloride
PWM: pulse width modulation
R: right; riser; rubber
rec: recommended
Ref: reference point
RMC: rigid metal conduit
RNC: rigid nonmetallic conduit
RTV: room temperature vulcanized
R-value: thermal resistance
S: south
SAM: shared-appreciation mortgage
SE: service entrance
sel str: select structural
sgl: single(s)
SHGC: solar heat gain coefficient
SIP: structural insulating panel
SJ: slip joint
slip: slip fitting
spig: spigot fitting
sq ft: square feet
sq in: square inch
STC: sound transmission class
std: standard
SW: severe weather
S1S: surfaced one side
S4S: surfaced four sides
T: texture; thermoplastic; tread
T&G: tongue-and-groove
TCE: trichloroethylene
THM: trihalomethane
U: underground
USCS: United Soil Classification System
USDA: U.S. Department of Agriculture
V: rise
VAC: volts alternating current
VB: vapor barrier
VT: visible transmittance
W: water-resistant; west; width
WB: wet bulb temperature
WMMPA: Wood Moulding and Millwork Producers Association
WWPA: Western Wood Products Association
yr: year

Glossary

Absorptance: ratio of energy absorbed by a surface to the amount striking it.

Absorption: weight of water absorbed, expressed as percentage of dry weight; interception of radiant energy or sound waves.

Absorptivity: see *absorptance*.

Accelerator: chemical added to concrete to speed setting.

Active solar collector: mechanical system for collecting solar heat.

Admixture: substance added to mortar to change its properties.

Aggregate: granular materials used in masonry.

Air barrier: material or surface designed to prevent passage of air but not water vapor.

Air-entrained concrete: concrete containing microscopic air bubbles to make it less susceptible to freeze damage.

Alternating current (AC): electrical current that reverses direction regularly (60 hertz, or cycles per second, in the U.S.).

Altitude: vertical angle of the sun above the horizon.

Ampacity: ampere-carrying capacity of a wire.

Ampere: unit of electrical current. Often abbreviated *amp*.

Anchor bolt: bolt set into a foundation to fasten it to the building sill.

Apron: vertical panel below the window sill.

Ash drop: opening in the floor of a fireplace for ash disposal.

Ashlar: one of several masonry patterns, consisting of large rectangular units of cut stone.

Asphalt plastic cement: asphalt used to seal roofing materials together.

Awning: shading device mounted above a window.

Awning window: single window sash hinged at the top and swinging outward.

Azimuth angle: direction to the sun, usually measured from true north. Solar azimuth is measured east or west from true south.

Backer rod: foam rope used to fill large gaps before caulking.

Backfill: material used to fill excavation around a foundation.

Balloon frame: wood frame in which studs are continuous from the sill to the top plate of the top floor.

Baluster: vertical member under railing.

Baseboard: horizontal molding at the base of a wall. Also known as *mopboard*.

Batten: thin molding of rectangular section used to cover a joint.

Bay window: window that projects from a wall.

Beam: horizontal member designed to support loads in bending.

Bearing wall: wall that supports load from above.

Bevel cut: wood cut made at any angle other than 0° or 90°.

Bitumin: substance containing oil or coal-based compounds; asphalt.

Blocking: short member bracing between two longer framing members.

Boiler: central heating appliance that generates either hot water or steam.

Bond: strength of adhesion. Also one of several patterns in which masonry units may be laid.

Bow window: same as a bay window, except the projection approximates a circular arc.

Braced frame: heavy-timber frame braced in the corners by lighter members.

Branch circuit: a circuit in a building, originating at the service entrance panel and protected by a separate circuit breaker or fuse.

Brick: rectangular masonry unit hardened by firing in a kiln.

Brick mold: standard wood molding used as outside casing around doors and windows.

Brick veneer: brick facing over wood or masonry.

Bridging: bracing between floor joists to prevent twist.

British thermal unit (Btu): amount of heat required to raise the temperature of 1 pound of water 1F°.

Brown coat: next-to-last plaster or stucco coat.

Building code: rules adopted by a government for the regulation of building.

Built-up roof: roofing consisting of many alternating layers of asphalt and felt.

Bull nose: rounded masonry unit for use in comers.

Bundle: package of shingles.

Bus bar: rectangular metal (usually copper) bar for carrying large electrical current.

Butt: bottom edge of a roof shingle.

Butt joint: joint in which two members meet without overlap or miter.

Calcium chloride: concrete accelerator.

Candela: Metric unit of luminous intensity.

Cantilever: beam projecting from a wall to support a balcony, cornice, or similar structure.

Cant strip: beveled strip around the perimeter of a roof.

Capillarity: movement of water through small gaps due to adhesion and surface tension.

Casement window: window hinged on the side and opening outward.

Casing: inside or outside molding that covers space between a window or door jamb and a wall.

Caulk: material used to fill building joints and cracks.

Cavity wall: masonry wall with a continuous space between the inside and outside bricks that acts as a capillary break.

Cellulose insulation: loose-fill insulation consisting of shredded and treated newspaper.

Ceramic mosaic: sheet of small ceramic tiles.

Chalk line: straight line made by snapping a taut string coated by colored chalk.

Check: crack in the surface of wood resulting from drying (and shrinking) of the surface faster than of the interior.

Chimney: vertical tube for venting flue gases by natural convection.

Circuit: two or more wires carrying electricity to lights, receptacles, switches, or appliances.

Circuit breaker: electromechanical device that opens when the current exceeds its rating.

Clapboard: board for overlapping as horizontal siding.

Closed valley: roof valley where the shingles extend in an unbroken line across the valley intersection.

Collar: preformed vent pipe flashing. Also the part of an appliance that connects to a stove or vent pipe.

Collar tie: rafter tie beam.

Column: structural member designed to carry a vertical load in compression.

Common nail: large-diameter nail for rough framing.

Compression: action of forces to squeeze or compact.

Concealed-nail roofing: method of applying asphalt roll roofing where all nails are in the underlying layer and the top layer is attached by asphalt cement only.

Concrete: hardened mixture of portland cement, sand, gravel, and water.

Condensation: process of water vapor turning to liquid water.

Conduction: transfer of heat through an opaque material. Also the transfer of electrons (current) through a material.

Conductor: wire intended to carry electric current.

Conduit: metal or plastic pipe that surrounds electrical wires and protects them from physical damage.

Control joint: groove in concrete to control the location of cracking.

Convection: heat transfer through either the natural or forced movement of air.

Corner bead: strip of metal designed to provide protection of a plaster or drywall corner.

Corner board: vertical board at a wall intersection for butting siding.

Corner bracing: diagonal boards, metal strips, or rigid panels used at building corners to prevent racking.

Cornice: top, projecting molding of the entablature.

Countersink: to sink a nail or screw below the surface.

Course: row of roofing or siding.

Cove molding: popular molding (trim) for ceiling/wall intersections.

Coverage: minimum number of layers of roofing at any section.

Crawl space: space beneath a building not high enough for a person to stand in.

Creosote: a dark brown oil distilled from coal or wood, used as a wood preservative.

Cricket: small roof for diverting water.

Curing: process of hardening of concrete over time.

Cut-in brace: corner brace of framing lumber cut into studs.

Cutout: space between tabs in a roofing shingle.

Cycle: one complete reversal of electrical current and voltage. Cycles per second are called hertz.

Dado: rectangular groove cut across the grain of wood.

Damper: valve designed to control the flow of air or smoke.

Dampproofing: treating a masonry surface to retard capillary action.

Dead load: load imposed on a structure by the weight of the building materials only.

Decay: deterioration of wood from attack by fungi or insects.

Decibel (db): logarithmic measure of sound intensity. An increase of 6 db is the same as doubling the sound pressure.

Deciduous plant: one that loses its leaves in winter.

Deck: roof surface to which roofing is applied.

Deflection: distance moved upon application of a specified load on a structural member.

Deflection ratio: ratio of clear span to deflection at design load.

Degree-day: difference between the average of daily high and low temperatures and a fixed temperature—usually 65°F.

Dew point: air temperature at which water vapor begins to condense as either water or ice (frost).

Diffuse radiation: solar energy received from a direction different from that of the sun.

Dimension lumber: framing lumber 2 to 5 inches in nominal thickness and up to 12 inches in nominal width.

Direct current (DC): electrical current that flows in a single direction.

Direct gain: system in which energy received from the sun directly enters and heats the living spaces.

Dormer: vertical window projecting from a roof. Gabled dormers have peaked roofs; shed dormers have shed roofs.

Double coverage: result of applying asphalt roll roofing with sufficient overlap to get a double layer. See *coverage*.

Double-hung window: window with vertically sliding upper and lower sash. If the upper sash is fixed, the window becomes single-hung.

Double-strength glass: sheet glass of nominal thickness 0.125 inch.

Dovetail: flared mortise and tenon that form a locking joint.

Downspout: vertical section of pipe in a gutter system.

Draft: air pressure difference between the inside and outside of a chimney. Also the rate of flue gas or combustion airflow.

Drip cap: molding at the top of a window or door.

Drip edge: material designed to force water to drip from roof rakes and eaves.

Drywall: interior finish material in large sheets. Plywood paneling and gypsum drywall are two examples.

Drywall nail: special, ringed nail for fastening drywall.

Duct: enclosure for distributing heated or cooled air.

Eaves: lower edge of a sloped roof.

Eaves flashing: flashing at eaves designed to prevent leaking from an ice dam.

Egress window: window whose clear dimensions are large enough that it can serve as a fire exit.

Elastic modulus: ratio of stress to strain in a material. Also known as the modulus of elasticity.

Elbow: right-angle bend in stovepipe.

Electroplated: coated by electrolytic deposition with chromium, silver, or another metal.

Elevation: view of a vertical face of a building.

Ell: L-shaped pipe fitting.

Envelope: collection of building surfaces that separate the building interior from the outside, i.e., roof, walls, floor, windows, and doors.

Evaporative cooler: an air conditioner that cools air by evaporating water.

Exposed-nail roofing: mineral surfaced roll roofing where nails are exposed.

Exposure: portion of roofing or siding material exposed after installation.

Extension jamb: addition to a door or window jamb to bring the jamb up to full wall thickness. Also known as a jamb extender.

Face: side of a masonry unit or wood panel intended to be exposed.

Face brick: brick intended to be used in an exposed surface.

Face nailing: nailing perpendicular to the face or surface. Also called direct nailing.

Fahrenheit: temperature scale defined by the freezing (32°) and boiling (212°) points of water.

Fascia: vertical flat board at a cornice. Also spelled *facia*.

Fastener: any device for connecting two members.

Felt: fibrous sheet material for roofing.

Fenestration: the arrangement of windows and doors on a building.

Fiberboard: a building material made of wood or other plant fibers compressed into boards.

Fiber cement: a siding material made of cement and wood fiber.

Finger joint: wood joint formed by interlocking fingers.

Finish coat: final coat of a material.

Finish grade: final ground level around a building.

Finish nail: thin nail intended to be driven flush or countersunk.

Fire pot: the combustion chamber where fuel is burned.

Fire-stop: framing member designed to block the spread of fire within a framing cavity.

Fixture: tub, toilet. or sink consuming water.

Flashing: material used to prevent leaks at intersections and penetrations of a roof.

Float glass: glass formed by floating molten glass on molten tin.

Floating floor: flooring that is unattached to joists or subfloor.

Flue: passage in a chimney for the venting of flue gases or products of combustion.

Flue gases: mixture of air and the products of combustion.

Fluorescent light: lamp that emits light when an electric discharge excites a phosphor coating.

Foot candle: illumination given by a source of one candela at a distance of one foot (equivalent to one lumen per square foot).

Footing: bottom section of a foundation that rests directly on the soil.

Forced-air system: heat transfer system using a blower.

Foundation: section of a building that transfers the building load to the earth.

Frame: assemblage of structural support members.

Frieze: middle section of an entablature, between the architrave below and the cornice above. In wood construction, the horizontal board between the top of the siding and the soffit. Also a decorative band near the top of a wall.

Frost heave: expansion of the earth due to freezing of interstitial water.

Frost line: maximum depth of freezing in the soil.

Fuel efficiency: percentage of energy in fuel that is converted to useful energy.

Furnace: appliance that generates hot air.

Furring: strip of wood that provides space for insulation or that levels an uneven surface.

Gable: upper, triangular portion of an end wall.

Gable roof: roof having gables at opposite ends, each equally pitched.

Galvanized: (iron or steel) coated with a protective layer of zinc.

Gasket: elastic strip that forms a seal between two parts.

Girder: main supporting beam.

Girt: horizontal beam framed into the posts.

Glare: excessive contrast in lighting.

Glass: transparent material composed of sand, sodium carbonate, calcium carbonate, and small quantities of other minerals.

Glass block: glass molded into hollow blocks that serve to support loads and pass light.

Glazing: glass or other transparent material used for windows.

Gloss paint: paint with a high percentage of resin that dries to a highly reflective finish.

Glulam: a beam made of glued wood laminations.

Grade: level of the ground.

Ground: any metal object that is connected to and serves as the earth in an electrical system.

Grounded wire: wire in a circuit that is connected to the ground and serves to return current from the hot wire back to the ground. Identified by a white insulation jacket.

Ground fault circuit interrupter: circuit breaker that trips on leakage of current.

Grounding wire: bare or green wire in a circuit that connects metal components, such as appliance cabinets, to the ground.

Grout: very thin mortar applied to masonry joints.

Gusset: flat plate used on either side of a wood joint to aid in connection.

Gutter: horizontal trough for collecting rain water from a roof.

Gypsum: calcium sulfate, a naturally occurring mineral.

Gypsum drywall: rigid paper-faced board made from hydrated gypsum and used as a substitute for plaster and lath.

Handrail: top rail in a balustrade.

Hardboard: stiff board made of compressed and treated wood pulp.

Hard water: calcium-rich water.

Hardwood: wood from a deciduous tree.

Head: top element in many structures.

Header: beam over a door or window for supporting the load from above. Also any beam that crosses and supports the ends of other beams. Also a brick placed to tie two adjacent wythes together.

Heartwood: portion of the tree from the pith (center) to the sapwood.

Heat-absorbing glass: glass containing additives that absorb light in order to reduce glare, brightness, and solar heat gain.

Heat capacity: quantity of heat required to raise the temperature of 1 cubic foot of a material 1°F.

Heat load: rate of heat loss in Btu per hour from a structure maintained at a constant temperature.

Heat Mirror®: a plastic film treated with selective coating.

Heat pump: mechanical device that transfers heat from a cooler to a warmer medium.

Hip: convex intersection of two roof planes, running from eaves to ridge.

Hip shingle: shingle covering a hip.

Hot wire: current-carrying wire that is not connected to the ground.

Humidifier: appliance for adding water vapor to the air.

Hydrated lime: quicklime and water combined. Also called *slaked lime*.

Hydronic: method of distributing heat by hot water.

I-beam: steel beam whose section resembles the letter I.

Ice dam: ridge of ice at roof eaves.

Incandescent: heated to the point of giving off light.

Infiltration: incursion of outdoor air through cracks, holes, and joints.

Infrared radiation: radiation of a wavelength longer than that of red light. Also known as heat radiation.

Inside sill: window stool.

Insulating glass: factory-sealed double or triple glazing.

Insulation: material with high resistance to heat flow.

Insulation board: wood fiber board available in $\frac{1}{2}$-inch and $\frac{25}{32}$-inch thicknesses.

Inverter: an electrical device that converts direct current into alternating current.

Jamb: top and sides of a door or window.

Jamb extender: same as an extension jamb.

Joint compound: material used to finish joints in gypsum drywall. Also known as *mud*.

Joist: repetitive narrow beam supporting the floor load.

Kiln-dried: lumber dried in a kiln at elevated temperatures. The process removes cellular water.

kiloWatt: 1,000 watts. Abbreviated *kW*.

kiloWatt-hour: unit of electrical energy consumed. One thousand watts of power for a 1-hour duration. Abbreviated *kWhr*.

Knot: section of the base of a branch enclosed in the stem from which it arises. Found in lumber such as pine.

Landing: platform between or at the ends of stairways.

Latent heat: the heat required to convert a solid into a liquid or vapor, or a liquid into a vapor, without change of temperature.

Lath: perforated base for application of plaster. Formerly wood, now usually metal.

Lattice: framework of crossed strips of wood, plastic, or metal.

Leader: horizontal section of downspout.

Ledger strip: strip of wood forming a ledge on a girder or sill for supporting the bottoms of joists.

Let-in brace: corner brace of 1×4 lumber cut into studs.

Lime: calcium carbonate. When heated, it becomes quicklime.

Lintel: solid member above a door or window that carries the load above.

Live load: temporary load imposed on a building by occupancy and the environment.

Lookout: wood member supporting ing the end of an overhanging rafter.

Louver: slanted slat of wood, plastic, or metal. Used to admit air but block rain and visibility.

Lumen: measure of total light output. A wax candle gives off about 13 lumens, a 100-watt incandescent bulb about 1,200 lumens.

Luminance: intensity of light emitted from a surface per unit area in a given direction.

Masonry: construction consisting of stone, brick, or concrete block.

Masonry cement: cement to which water and sand must be added.

Masonry primer: asphalt primer for bonding asphalt-based products to masonry.

Mastic: thick-bodied adhesive or sealant.

Membrane roof: roofing consisting of a single waterproof sheet.

Metal lath: sheet metal slit and formed into a mesh for use as a plaster base.

Mil: one-thousandth of an inch.

Millwork: building components manufactured in a woodworking plant.

Miter: to cut at an angle other than 90°.

Miter joint: joint where each member is mitered at equal angles.

Module: repeated dimension.

Modulus of elasticity: see *elastic modulus*.

Moisture barrier: material or surface with the purpose of blocking the diffusion of water vapor. The same as a vapor barrier.

Moisture content: amount of moisture in a material, expressed as the percentage of dry weight.

Moment: the product of a force and the distance from its line of action to a given point.

Mortar: plastic mixture of cement, sand, and water.

Mortise: hole into which a tenon (tongue) fits.

Natural finish: wood finish that does not greatly alter the unfinished color.

Natural ventilation: air movement in a building due only to natural pressure differences caused by air temperatures.

Neoprene: synthetic rubber.

Neutral wire: grounded wire.

Nonbearing wall: wall or partition that does not carry a load from above.

Nosing: projection of a stair tread beyond the riser; the amount by which the actual tread is wider than the mathematical tread.

Ohm: measure of resistance to electric current.

On-center (o.c.): framing measurement from the center of one member to the center of the other.

Open valley: roof valley where shingles do not cross the valley intersection; flashing does.

Orientation: placement relative to the sun, wind, view, and so forth.

Overhang: portion of a roof extending beyond the wall line.

Overload: excessive electric current in a conductor. The danger is from overheating. Circuit breakers interrupt circuits upon detecting overloads.

Panel: thin, flat piece.

Parget: a surface coat of cement over masonry. Also known as *parge*.

Parquet: thin strips of wood applied in geometric patterns on floors and furniture.

Partition wall: nonbearing wall.

Party wall: common wall that separates two properties.

Passive solar collector: system for collecting solar energy without use of mechanical devices such as fans or pumps.

Penetrating finish: finish that sinks into wood grain and does not leave a hard skin.

Penny: formerly the price in pennies of 100 nails of a certain size; now a measure of length. A 6-penny (6d) nail is 2 inches long.

Perlite: expanded volcanic glass. Used as an insulator and as a lightweight additive to concrete.

Perm: 1 grain of water vapor per square foot per hour per inch of mercury difference in water vapor pressure.

Permeability: ability to transmit water vapor, measured in perms.

Picture window: large fixed window.

Pier: isolated masonry column.

Pitch: ratio of rise in feet to span in feet of a roof.

Pith: soft core of a tree that represents the original shoot.

Plaster: mortar-like material that hardens after application. Stucco is simply exterior plaster.

Plasterboard: gypsum drywall.

Plate: horizontal member at the top or bottom of a wall. The top plate supports the rafter ends. The bottom or sill plate supports studs and posts.

Plenum: ductwork chamber that serves as a distribution point.

Plumb: vertical.

Plywood: wood panel made of three or more veneers of wood alternating in direction of grain.

Pocket door: door that slides into a wall.

Portland cement: strong, water resistant cement consisting of silica, lime, and alumina.

Preservative: water-repellent liquid containing fungicide.

Pressure-treated wood: wood that has been injected with preservative under pressure.

Psychrometric chart: graph showing the properties of water vapor in air.

Purlin: a horizontal member perpendicular to, and supporting, rafters.

Rabbet: a rectangular shape consisting of two surfaces cut along the edge or end of a board.

Racking: distortion of a building surface from the rectangular in its plane.

Radiant heating: method of heating whereby much of the heat transfer is accomplished by radiation through space from warm building surfaces such as floors, walls, or ceilings.

Rafter: roof beam running in the direction of the slope.

Rail: horizontal member of a door or window sash. Also the top member of a balustrade.

Rebar: abbreviation for reinforcing bar. Usually applied to steel bars used in concrete.

Receptacle: electrical device into which a plug may be connected.

Reflectance: decimal fraction of light incident on a surface reflected and not absorbed. Absorptance equals 1 minus reflectance.

Reflective glass: glass treated to reflect a fraction (the reflectance) of incident light.

Reflectivity: see *reflectance.*

Register: grill or grate covering the outlet of a duct.

Reinforcement: see *rebar.*

Relative humidity: amount of water vapor in air compared with the maximum amount possible, expressed as a percentage.

Retrofit: to upgrade a structure using modern materials.

Return: general term for a right-angle turn.

Reverberation time: measure of the length of time a sound wave will bounce around a space before being absorbed.

Ribbon: horizontal strip (usually 1×4) let into studs to support joist ends. Also called a *ribband*.

Ridge: junction of the top of opposing roof planes.

Ridge board: vertical board between the upper ends of rafters.

Ridge vent: continuous, prefabricated outlet ventilator placed over an opening at the ridge.

Rise: vertical increase in one step of a stair. Also the total vertical span of a stairway from landing to landing, or any vertical change.

Riser: vertical board between stair treads. Also a vertical pipe.

Roll roofing: low-cost asphalt roofing in roll form.

Roof overhang: horizontal projection of the roof beyond the wall.

Run: horizontal span of a flight of stairs.

R-value: measure of resistance to heat flow.

Saddle: pitched section of roof behind a chimney or between a roof and the wall toward which it slopes. Its purpose is to avoid trapped water.

Safety glass: one of a number of types of glass that have been strengthened or reinforced for safety.

Sapwood: wood between the heartwood and the bark, in which the sap runs.

Sash: frame holding the panes of glass in a window or door.

Saturated felt: felt impregnated with asphalt in order to make it water resistant.

Scratch coat: first coat of plaster. It is scratched to provide better bonding with the next coat.

Screen molding: thin wood molding for covering the edge of screening.

Sealant: compressible material used to seal building joints, etc.

Sealed glass: panes of glass with a sealed air space between.

Sealer: liquid applied to unfinished wood to seal the surface.

Selvage: portion of roll roofing meant to be overlapped by the succeeding course.

Sensible heat: heat required to raise the temperature of a material without changing its form.

Service drop: wiring from the utility pole to the service entrance conductors leading to the meter.

Service entrance box: box housing the electrical panel containing the main breaker and branch circuit breakers.

Shading coefficient: ratio of solar gain to the solar gain through a single layer of clear, double-strength glass.

Shake: wood shingle formed by splitting rather than sawing. Also a lumber defect in which the growth rings separate.

Shear: the effect of opposing forces acting in the same plane of a material.

Sheathing: layer of boards over the framing but under the finish.

Shellac: resinous secretion of the lac bug, dissolved in alcohol.

Shelter belt: band of trees and shrubs planted to reduce wind speed.

Shim: thin, tapered piece of wood used to level or plumb.

Shingle: small, thin piece of material, often tapered, for laying in overlapping rows as in roofing or siding.

Shiplap: rabbeted wood joint used in siding.

Siding: exterior finish for a wall.

Sill: lowest horizontal member in a frame. Also the bottom piece of the window rough opening.

Single-phase wiring: wiring in which the voltage exists only as a single sine wave. This is the type used in residences.

Single-strength glass: glass of thickness 0.085 to 0.100 inches.

Siphon: convey liquid upward from a container and then down to a lower level by gravity, the liquid being made to enter the pipe or tube by atmospheric pressure.

Skylight: window set into a roof.

Slab-on-grade: concrete slab resting directly on the ground at near-grade level.

Sleeper: wood strip set into or on concrete as a fastener for flooring.

Slider: window that slides horizontally. Also called a *sliding window*.

Slope: angle of a roof from horizontal in degrees.

Soffit: underside of a roof overhang, cornice, or stairway.

Soffit vent: inlet vent in the soffit.

Softwood: wood from coniferous, mostly evergreen, trees.

Soil pipe: pipe carrying human waste.

Solar radiation: total electromagnetic radiation from the sun.

Solar-tempered heating system: system deriving a significant fraction of the heating requirement from the sun.

Solder: metal alloy with a low melting point used in joining pipes, electrical wiring, and sheet metal.

Span: distance between supports.

Specific gravity: the ratio of the density of a substance to the density of water.

Specific heat: ratio of the heat storage capacity of a material to that of an equal weight of water.

Square: 100 square feet of coverage. Also a carpentry tool for measuring and laying out.

Stack effect: buoyancy of warm gases within a chimney.

Standing-seam: metal roofing technique of folding the upturned edges of adjacent sheets to form a weatherproof seam.

Standing wave: sound wave in a space of a dimension equal to a multiple of the sound's wavelength.

Stile: vertical outside frame member in a door or window sash.

Stool: interior horizontal, flat molding at the bottom of a window.

Stop (molding): thin molding for stopping doors on closure or holding window sash in place.

Story: space between two floors. Also spelled *storey*.

Strain: the magnitude of deformation, equal to the change in the dimension of a deformed object divided by its original dimension.

Stress: pressure or tension exerted on a material object measured in units of force per unit area.

Stringer: side member into which stair treads and risers are set.

Strip flooring: flooring of narrow strips with matched edges and ends.

Stucco: plaster applied to exterior.

Stud: vertical framing member to which wall sheathing and siding are attached.

Subfloor: first floor laid over the floor joists. The subfloor may also serve as the finish floor.

Supply plumbing: pipes supplying water to a building.

Suspended ceiling: modular ceiling panels supported in a hanging frame.

Tab: exposed portion of an asphalt shingle between the cutouts.

Taping: finishing gypsum drywall joints with paper tape and joint compound.

Tempered glass: glass that has been cooled rapidly to produce surface tension. The result is a stronger-than-normal glass that shatters into relatively harmless cubical fragments when broken.

Tenon: beam-end projection fitting into a mating tenon or hole in a second beam.

Tension: pulling apart; the opposite of compression.

Termiticide: chemical for poisoning termites.

Terne metal: sheet metal coated with a lead-and-tin alloy. Used in roofing.

Theodolite: surveying instrument with a rotating telescope for measuring both horizontal and vertical angles.

Therm: 100,000 Btu.

Thermal envelope: the complete collection of building surfaces separating the conditioned interior from the unconditioned exterior.

Thermal mass: measure of the ability of a material to store heat (for later release).

Thimble: protective device installed in a combustible wall through which a stovepipe passes.

Threshold: beveled wood strip used as a door sill.

Tie beam: beam placed between mating rafters to form a triangle and prevent spreading. Also known as a *collar tie*.

Tilt angle: angle of a collector or window from the horizontal.

Timber: lumber that is 5 or more inches thick.

Toenailing: nailing a butt joint at an angle.

Tongue and groove: flooring and sheathing joint in which the tongue of one piece meets a groove in a mating piece.

Transit: surveying instrument, usually mounted on a tripod, for measuring horizontal and vertical angles.

Trap: section of plumbing pipe designed to retain water and block the flow of sewer gas into a building.

Tread: horizontal part of a step. The nosing is physically part of the tread but doesn't count from the design standpoint.

Trim: decorative building elements often used to conceal joints.

Truss: framing structure for spanning great distances, in which every member is purely in tension or in compression.

Ultraviolet radiation: radiation of wavelengths shorter than those of visible radiation.

Underlayment: sheet material or wood providing a smooth, sound base for a finish.

U-value: inverse of R-value.

Valley: intersection of two pitched roofs that form an internal angle.

Vapor barrier: material or surface designed to block diffusion of water vapor.

Varnish: mixture of drying oil and resin without pigment. With pigment added, it becomes enamel.

Veneer: thin sheet of wood formed by slicing a log around the growth rings.

Vent: pipe or duct allowing inlet or exhaust of air.

Vermiculite: mica that has been expanded to form an inert insulation.

Wane: area of missing wood in lumber due to misjudgment of the log during sawing.

Water hammer: sound made by supply pipes when water is suddenly stopped by the quick closing of a valve.

Water softener: appliance that removes calcium ions from water.

Water table: level of water saturation in soil. Also a setback at foundation level in a masonry wall.

Watt: unit of electrical power. Watts equal volts across the circuit times amps flowing through it.

Weather strip: thin, linear material placed between a door or window and its jambs to prevent air leakage.

Weep hole: hole purposely built into a wall to allow drainage of trapped water.

Wind brace: T-section of metal strip let in and nailed diagonally to studs to provide racking resistance to a wall.

Wythe: single thickness of masonry in a wall.

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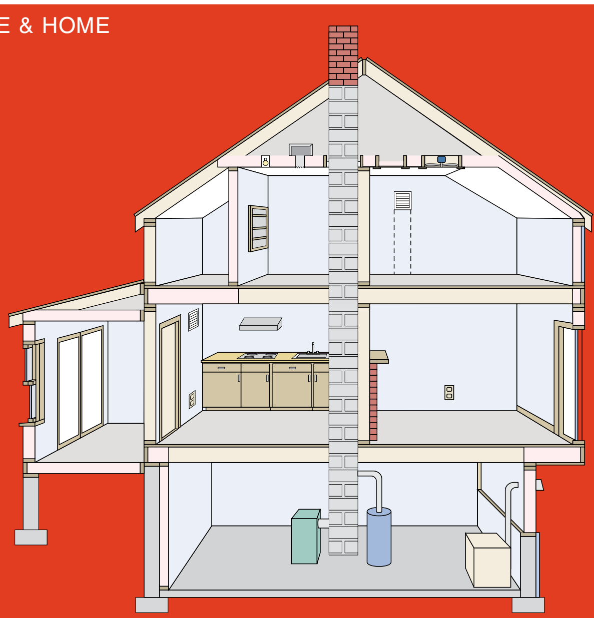

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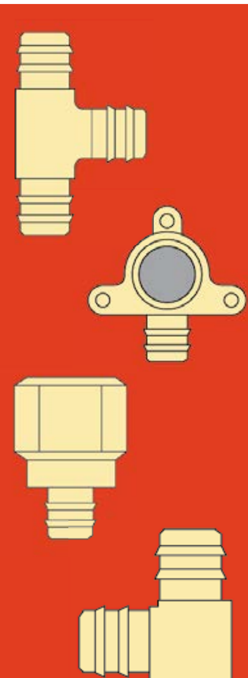

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