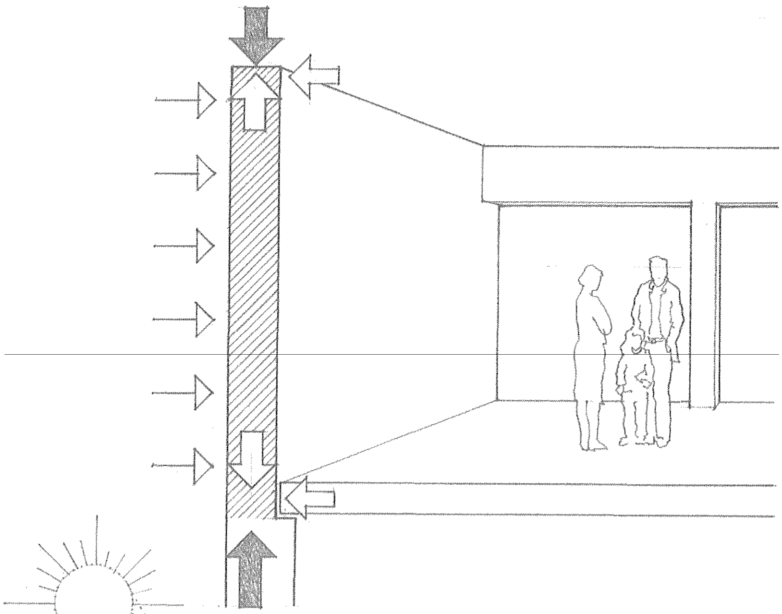
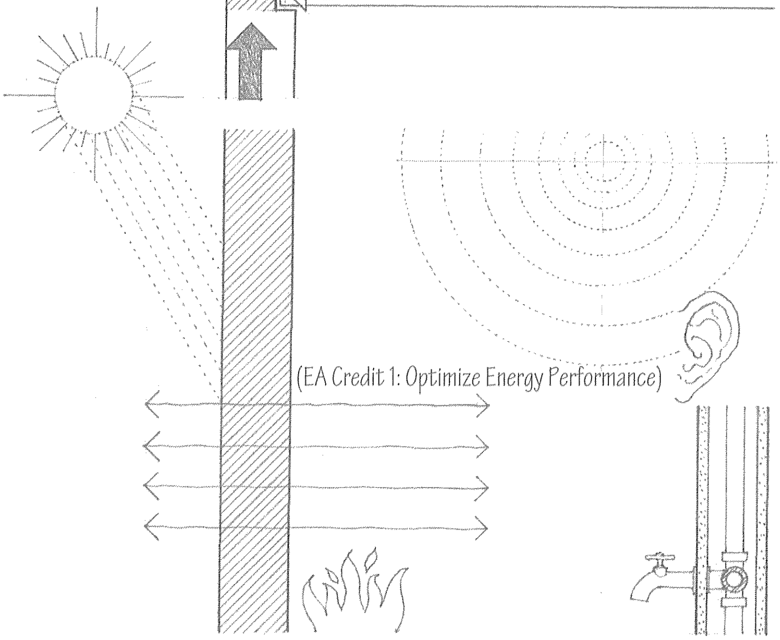


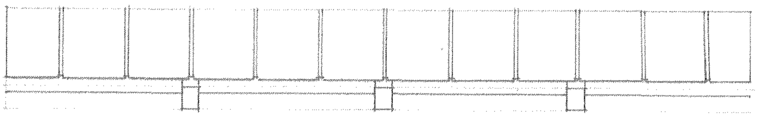
Walls are the vertical constructions of a building that enclose, separate, and protect its interior spaces. They may be loadbearing structures of homogeneous or composite construction designed to support imposed loads from floors and roofs, or consist of a framework of columns and beams with nonstructural panels attached to or filling in between them. The pattern of these loadbearing walls and columns should be coordinated with the layout of the interior spaces of a building.

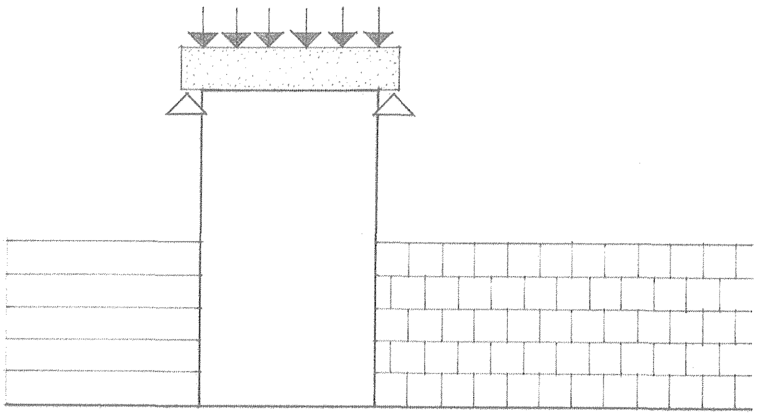
In addition to supporting vertical loads, exterior wall constructions must be able to withstand horizontal wind loading. If rigid enough, they can serve as shear walls and transfer lateral wind and seismic forces to the ground foundation.



Because exterior walls serve as a protective shield against the weather for the interior spaces of a building, their construction should control the passage of heat, infiltrating air, sound, moisture, and water vapor. The exterior skin, which may be either applied to or integral with the wall structure, should be durable and resistant to the weathering effects of sun, wind, and rain. Building codes specify the fire-resistance rating of exterior walls, loadbearing walls, and interior partitions.

The interior walls or partitions, which subdivide the space within a building, may be either structural or nonloadbearing. Their construction should be able to support the desired finish materials, provide the required degree of acoustical separation, and accommodate when necessary the distribution and outlets of mechanical and electrical services.

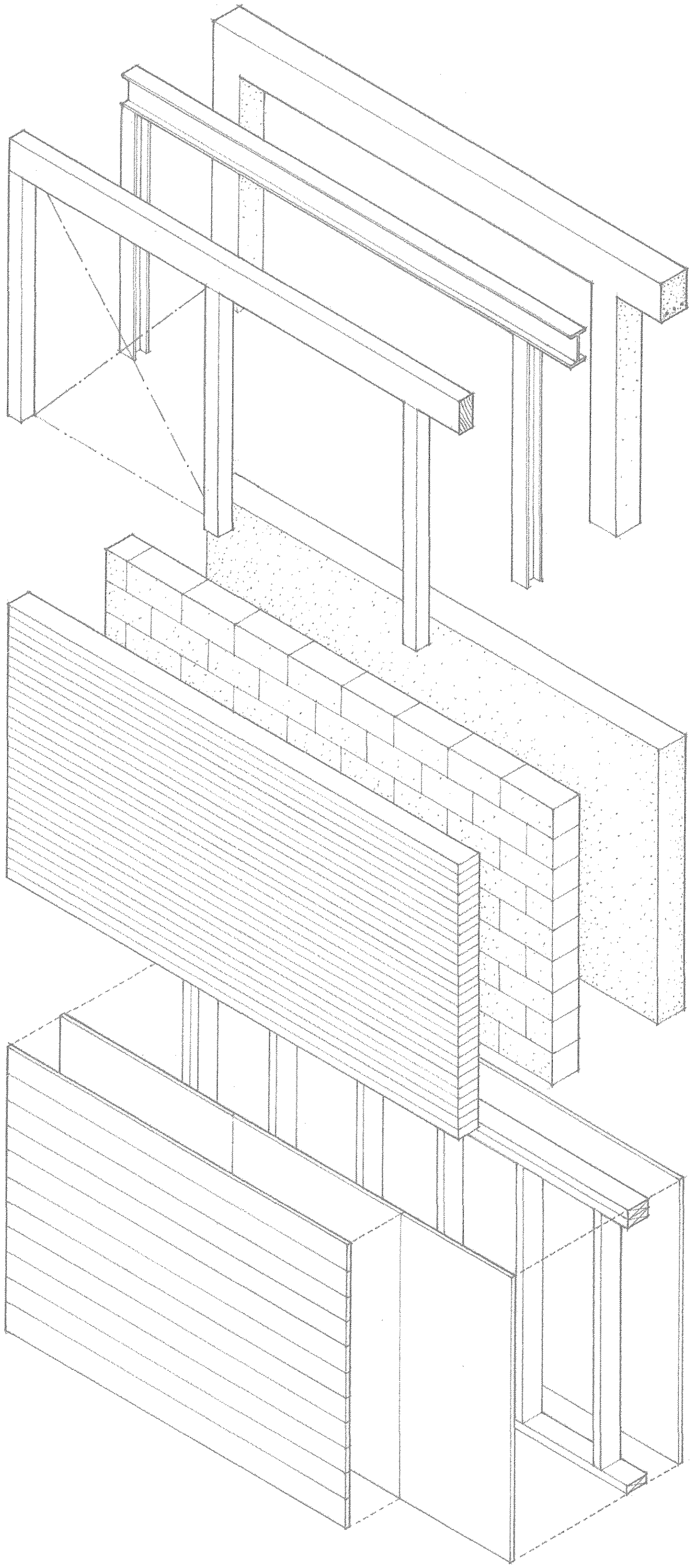




Openings for doors and windows must be constructed so that any vertical loads from above are distributed around the openings and not transferred to the door and window units themselves. Their size and location are determined by the requirements for natural light, ventilation, view, and physical access, as well as the constraints of the structural system and modular wall materials.

Structural Frames

- Concrete frames are typically rigid frames and qualify as noncombustible, fire-resistive construction.
- Noncombustible steel frames may utilize moment connections and require fireproofing to qualify as fire-resistive construction.
- Timber frames require diagonal bracing or shear planes for lateral stability and may qualify as heavy timber construction if used with noncombustible, fire-resistive exterior walls and if the members meet the minimum size requirements specified in the building code.
- Steel and concrete frames are able to span greater distances and carry heavier loads than timber structures.
- Structural frames can support and accept a variety of nonbearing or curtain wall systems.
- The detailing of connections is critical for structural and visual reasons when the frame is left exposed.



Concrete and Masonry Bearing Walls

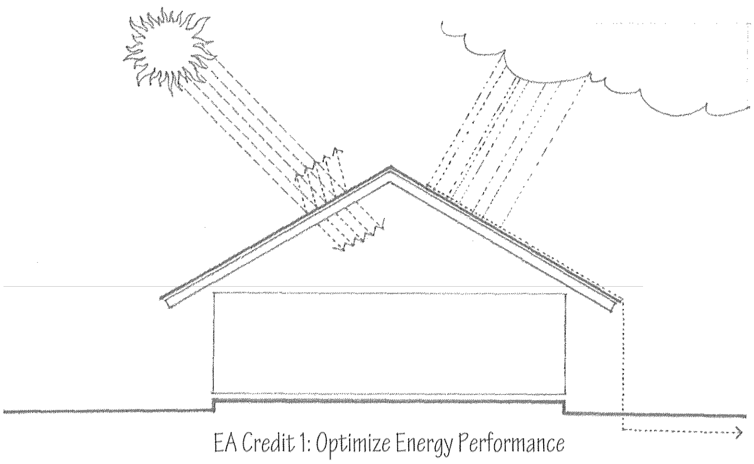
- Concrete and masonry walls qualify as noncombustible construction and rely on their mass for their load-carrying capability.
- While strong in compression, concrete and masonry require reinforcing to handle tensile stresses.
- Height-to-width ratio, provisions for lateral stability, and proper placement of expansion joints are critical factors in wall design and construction.
- Wall surfaces may be left exposed.

Metal and Wood Stud Walls

- Studs of cold-formed metal or wood are normally spaced @ 16" or 24" (406 or 610) o.c.; this spacing is related to the width and length of common sheathing materials.
- Studs carry vertical loads while sheathing or diagonal bracing stiffens the plane of the wall.
- Cavities in the wall frame can accommodate thermal insulation, vapor retarders, and mechanical distribution and outlets of mechanical and electrical services.
- Stud framing can accept a variety of interior and exterior wall finishes; some finishes require a nail-base sheathing.
- The finish materials determine the fire-resistance rating of the wall assembly.
- Stud wall frames may be assembled on site or panelized off site.
- Stud walls are flexible in form due to the workability of relatively small pieces and the various means of fastening available.

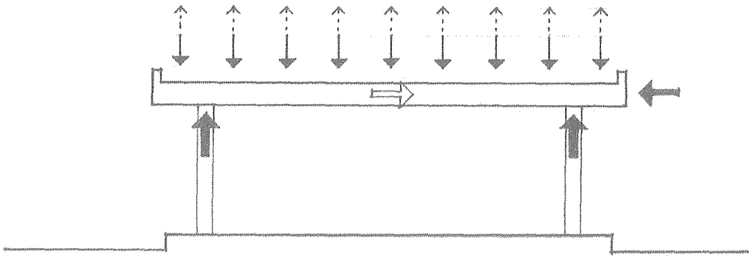
6

ROOF SYSTEMS



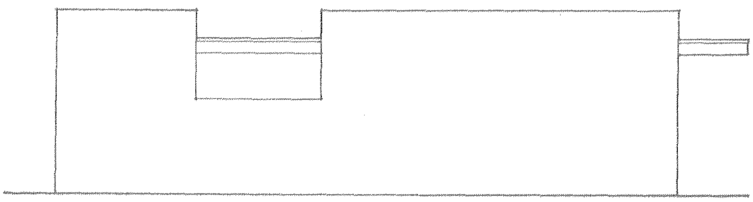
EA Credit 1: Optimize Energy Performance

The roof system functions as the primary sheltering element for the interior spaces of a building. The form and slope of a roof must be compatible with the type of roofing—shingles, tiles, or a continuous membrane—used to shed rainwater and melting snow to a system of drains, gutters, and downspouts. The construction of a roof should also control the passage of moisture vapor, the infiltration of air, and the flow of heat and solar radiation. And depending on the type of construction required by the building code, the roof structure and assembly may have to resist the spread of fire.

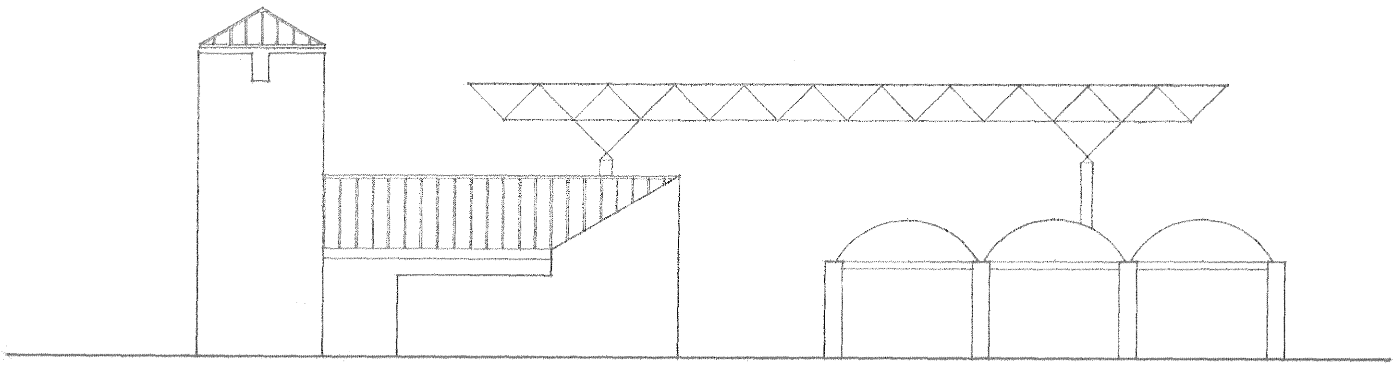


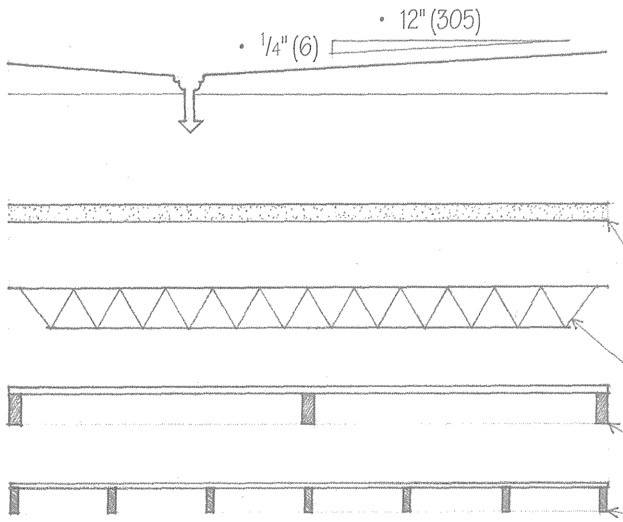
Like floor systems, a roof must be structured to span across space and carry its own weight as well as the weight of any attached equipment and accumulated rain and snow. Flat roofs used as decks are also subject to live occupancy loads. In addition to these gravity loads, the planes of the roof may be required to resist lateral wind and seismic forces, as well as uplifting wind forces, and transfer these forces to the supporting structure.

Because the gravity loads for a building originate with the roof system, its structural layout must correspond to that of the column and bearing wall systems through which its loads are transferred down to the foundation system. This pattern of roof supports and the extent of the roof spans, in turn, influences the layout of interior spaces and the type of ceiling that the roof structure may support. Long roof spans would open up a more flexible interior space while shorter roof spans might suggest more precisely defined spaces.



The form of a roof structure—whether flat or pitched, gabled or hipped, broad and sheltering, or rhythmically articulated—has a major impact on the image of a building. The roof may be exposed with its edges flush with or overhanging the exterior walls, or it may be concealed from view, hidden behind a parapet. If its underside remains exposed, the roof also transmits its form to the upper boundaries of the interior spaces below.

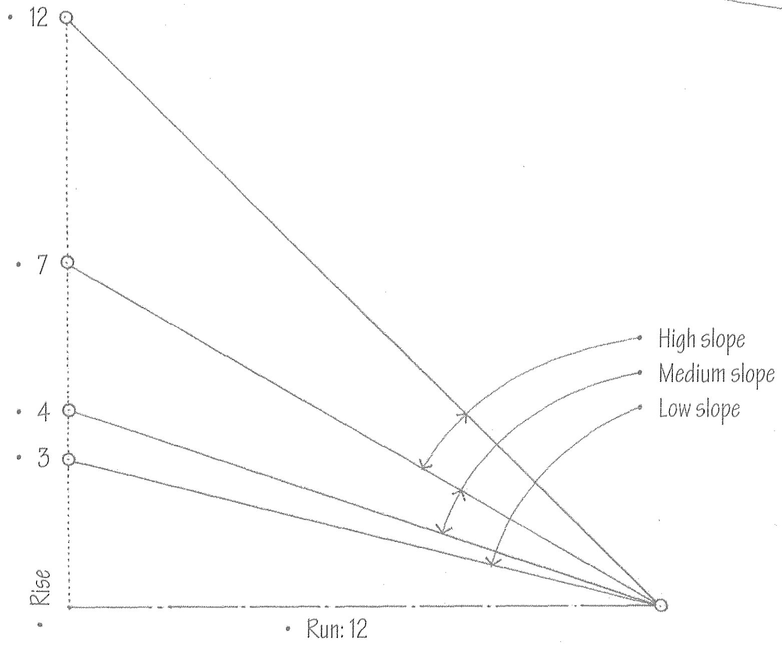




Flat Roofs

- Flat roofs require a continuous membrane roofing material.
- Minimum recommended slope: 1/4" per foot (1:50)
- The roof slope may be achieved by inclining the structural members or roof deck, or by tapering the layer of thermal insulation.
- The slope usually leads to interior drains; perimeter scuppers may be used as overflow drains.

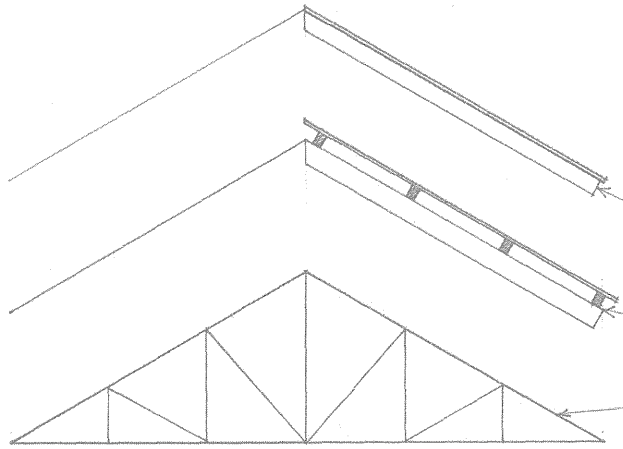
- Flat roofs can efficiently cover a building of any horizontal dimension, and may be structured and designed to serve as an outdoor space.
- The structure of a flat roof may consist of:
  - Reinforced concrete slabs
  - Flat timber or steel trusses
  - Timber or steel beams and decking
  - Wood or steel joists and sheathing



Sloping Roofs

- Sloping roofs may be categorized into
  - Low-slope roofs—up to 3:12
  - Medium- to high-slope roofs—4:12 to 12:12

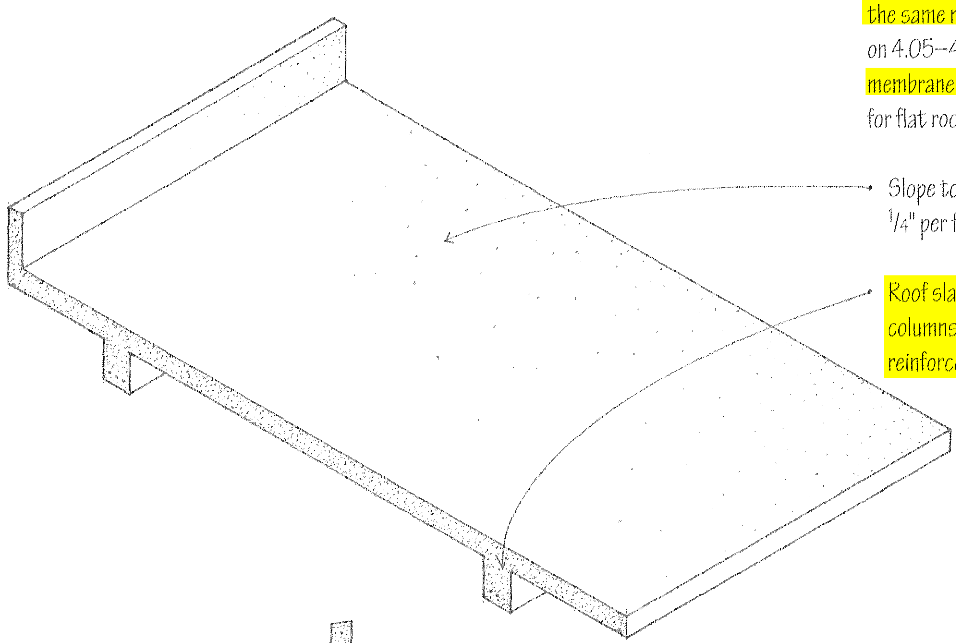
- The roof slope affects the choice of roofing material, the requirements for underlayment and eave flashing, and design wind loads.
- Low-slope roofs require roll or continuous membrane roofing; some shingles and sheet materials may be used on 3:12 pitches.
- Medium- and high-slope roofs may be covered with shingles, tiles, or sheet materials.
- Sloping roofs shed rainwater easily to eave gutters.



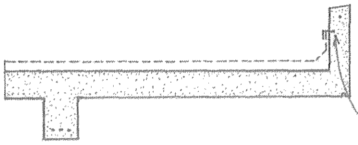
- The height and area of a sloping roof increase with its horizontal dimensions.
- The space under a sloping roof may be usable.
- Sloping roof planes may be combined to form a variety of roof forms.

- Sloping roofs may have a structure of:
  - Wood or steel rafters and sheathing
  - Timber or steel beams, purlins, and decking
  - Timber or steel trusses

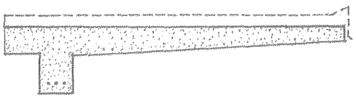
Reinforced concrete roof slabs are formed and sitecast in the same manner as the concrete floor systems illustrated on 4.05–4.07. Roof slabs are normally covered with a type of membrane roofing shown in the cross section below. See 7.12 for flat roof assemblies.



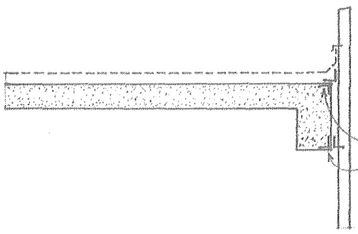
- Slope top of slab or layer of roof insulation for roof drainage; 1/4" per foot (1:50) minimum recommended.
- Roof slabs may be supported by reinforced concrete columns, reinforced concrete frames, or bearing walls of reinforced concrete or masonry.



- An upturned edge beam can form a parapet wall.
- A metal reglet may be cast into the parapet to receive cap flashing.

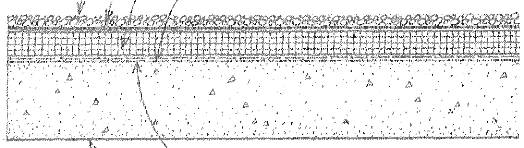


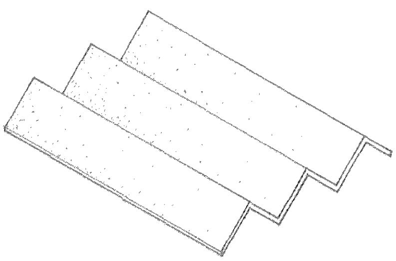
- The slab can be cantilevered beyond its perimeter supports to form an overhang.

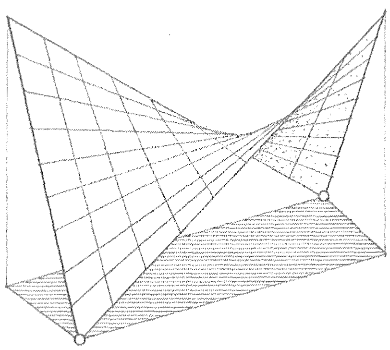


- An edge or spandrel beam can support a nonbearing curtain wall.
- Metal anchors may be cast into the spandrel beams to secure the curtain wall panels.

The edge of a concrete roof slab may be treated in three different ways.



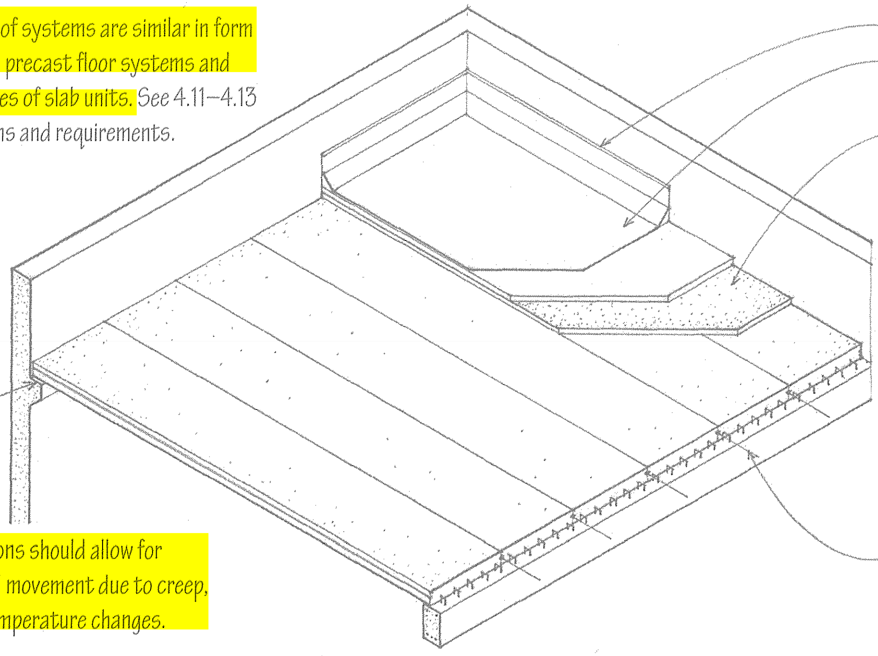




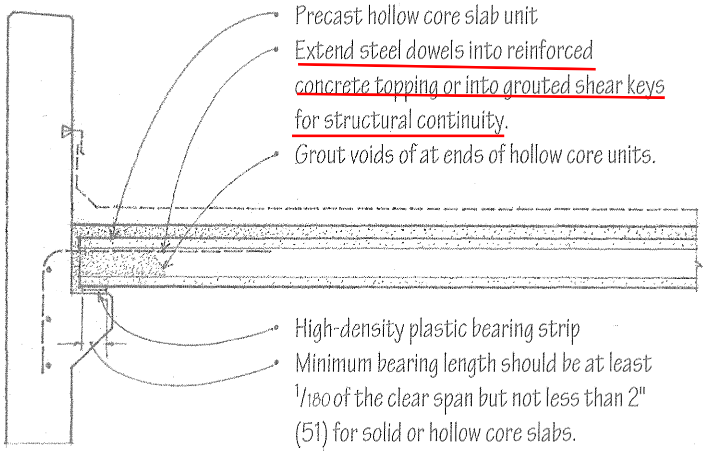
Reinforced concrete may be designed and cast into a variety of other roof forms, such as folded plates, domes, and shell structures. See 2.18 and 2.26–2.27.

CSI MasterFormat 03 20 00 Concrete Reinforcing
CSI MasterFormat 03 30 00 Cast-in-place Concrete
CSI MasterFormat 03 31 00 Structural Concrete

Precast concrete roof systems are similar in form and construction to precast floor systems and utilize the same types of slab units. See 4.11–4.13 for general conditions and requirements.

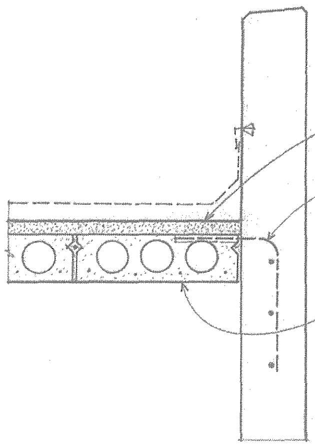


- See 7.19 for parapet flashing.
- Roofing membrane over rigid insulation; see 7.12.
- Sitecast concrete topping, reinforced with welded wire fabric or reinforcing bars, bonds to precast slabs to form a composite structural unit; 2" (51) minimum. The topping may be omitted if rigid foam insulation is laid over smooth-surfaced precast units.
- Slope concrete topping or precast units to drain; ¹/₄" per foot (1:50) minimum recommended.
- Bearing connections should allow for limited horizontal movement due to creep, shrinkage, and temperature changes.
- To serve as a horizontal diaphragm and transfer lateral forces to shear walls, steel reinforcement must tie the precast slab units to each other over their supports and at their end bearings.



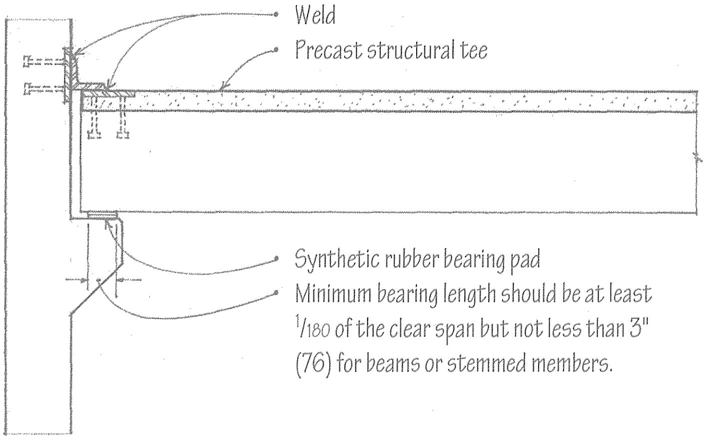
- Precast hollow core slab unit
- Extend steel dowels into reinforced concrete topping or into grouted shear keys for structural continuity.
- Grout voids of at ends of hollow core units.
- High-density plastic bearing strip
- Minimum bearing length should be at least ¹/₁₈₀ of the clear span but not less than 2" (51) for solid or hollow core slabs.

Bearing Wall



- Reinforced concrete topping; 2" (51) minimum
- Hooked bars cast into slab edge slots @ 4' (1220) o.c.
- Underside of precast slabs may be caulked and painted; a ceiling finish may also be applied to or be suspended from slab.

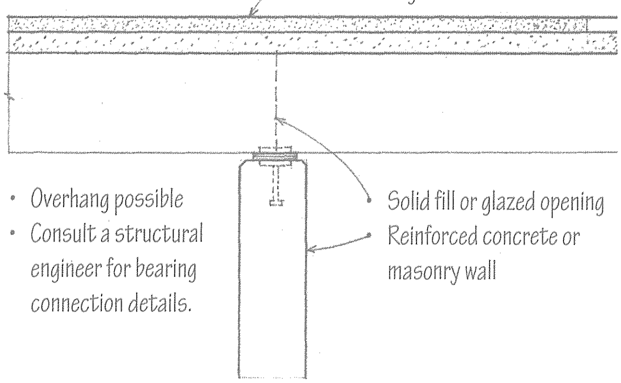
End Wall



- Weld
- Precast structural tee
- Synthetic rubber bearing pad
- Minimum bearing length should be at least ¹/₁₈₀ of the clear span but not less than 3" (76) for beams or stemmed members.

Bearing Wall

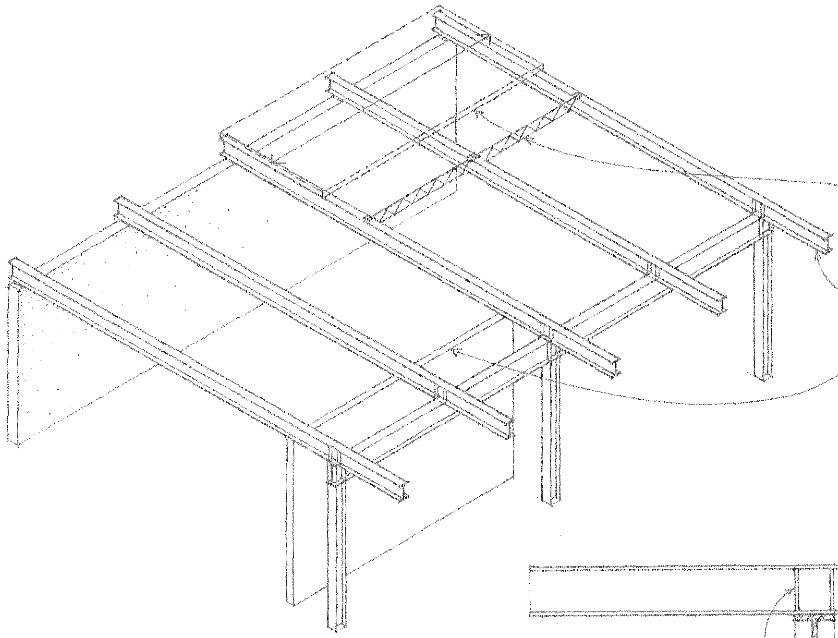
- See 4.13 for additional bearing connections.



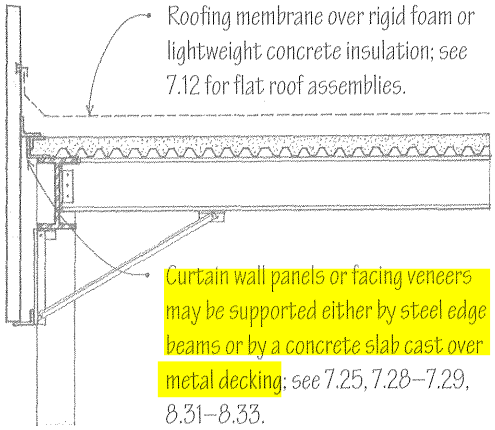
- Reinforced concrete topping bonds tee units together.
- Solid fill or glazed opening
- Reinforced concrete or masonry wall
- Overhang possible
- Consult a structural engineer for bearing connection details.

Bearing Wall

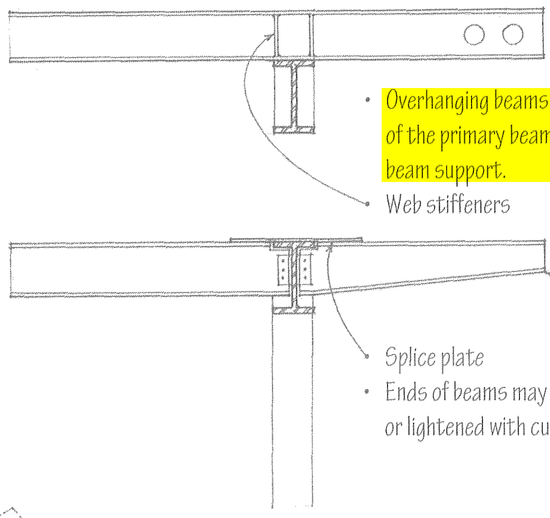
A flat roof structure may be framed with structural steel members similar to the way steel floors are framed. See 4.14–4.15.



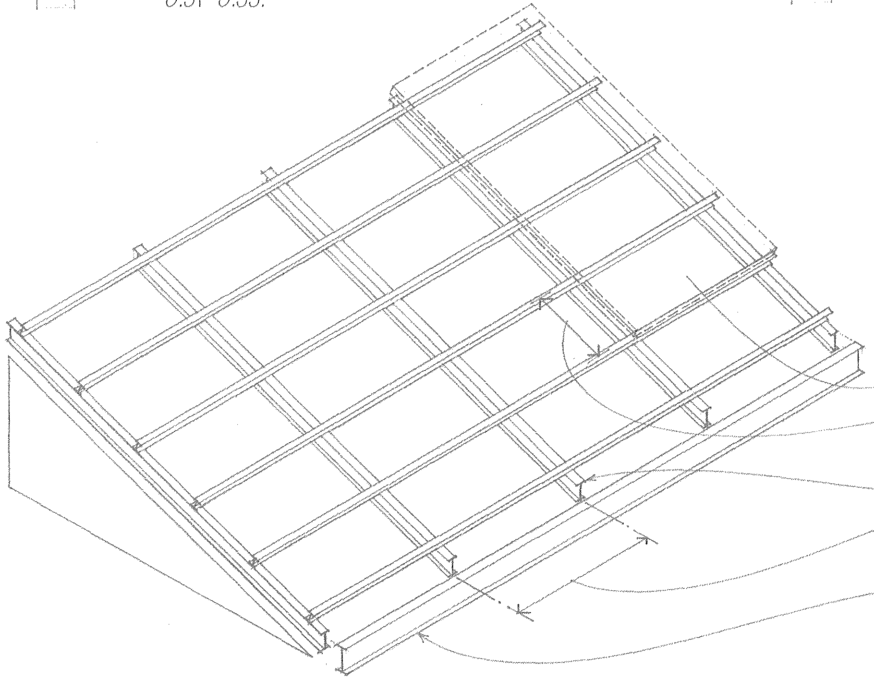
- The primary and secondary roof beams may support open-web steel joists, metal roof decking, a sitecast concrete slab, or precast concrete units.
- Roof overhangs may be achieved by extending the secondary roof beams over their supports or by recessing the exterior wall construction.



- Roofing membrane over rigid foam or lightweight concrete insulation; see 7.12 for flat roof assemblies.
- Curtain wall panels or facing veneers may be supported either by steel edge beams or by a concrete slab cast over metal decking; see 7.25, 7.28–7.29, 8.31–8.33.



- Overhanging beams may be framed within the depth of the primary beam or be continuous over the main beam support.
- Web stiffeners
- Splice plate
- Ends of beams may be tapered or lightened with cutouts.

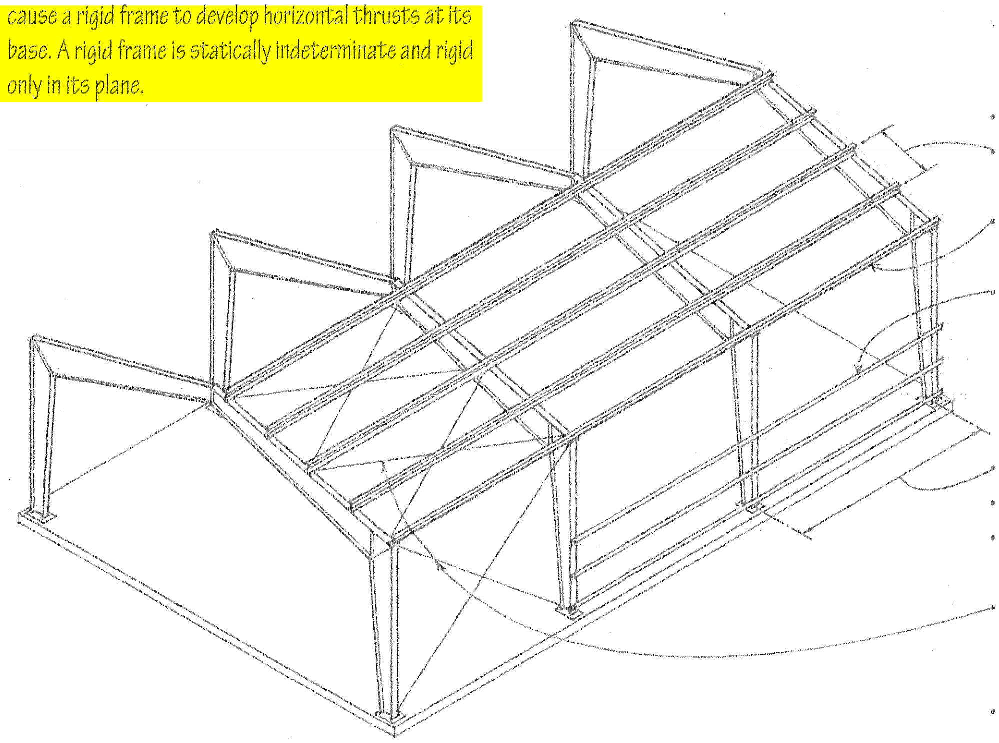


Structural steel can also be used to frame sloping roofs.

- Metal or cementitious roof decking
- Purlin spacing = decking span
- Sloping roof beams support purlins.
- Beam spacing = purlin span
- Girders support roof beams at ridge and eaves.

Rigid frames consist of two columns and a beam or girder that are rigidly connected at their joints. Applied loads produce axial, bending, and shear forces in all members of the frame since the rigid joints restrain the ends of the members from rotating freely. In addition, vertical loads cause a rigid frame to develop horizontal thrusts at its base. A rigid frame is statically indeterminate and rigid only in its plane.

- Various shapes of rigid frames can be fabricated of steel to span from 30' to 120' (9 to 36 m).
- Rigid frames typically form one-story structures used for light-industrial buildings, warehouses, and recreational facilities.



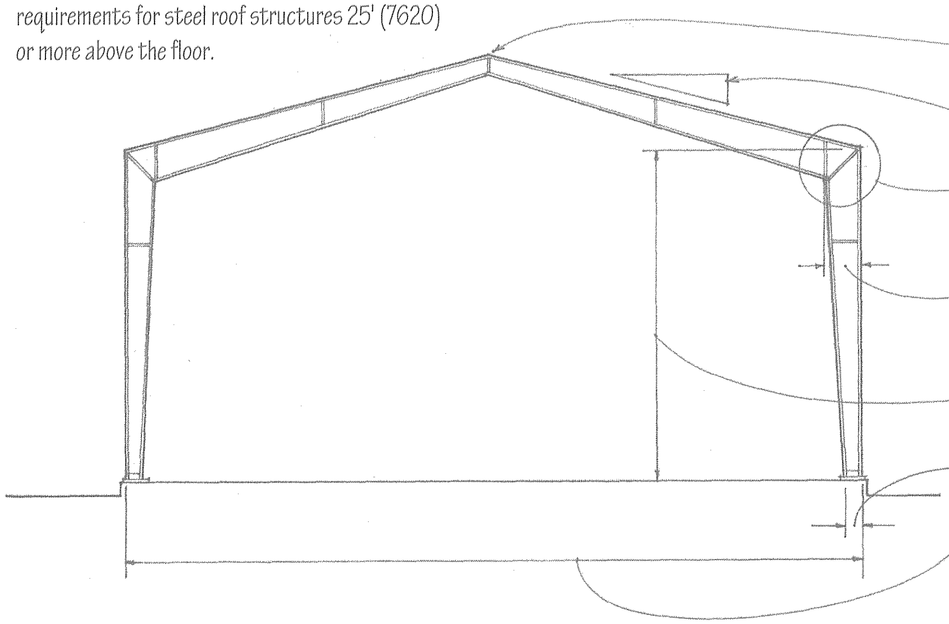
- Channel or Z-shape purlins
- Purlin spacing = span of roof decking; 4' to 5' (1220 to 1525) o.c.
- Eave strut

- Channel or Z-shape girts

- Frames spaced 20' to 24' (6100 to 7315) o.c.
- Frame spacing = span of purlins
- Frame spacing = span of girts

- Rigid frames provide resistance to lateral forces in their planes; they must be braced in a direction perpendicular to the frames.
- Framing is typically clad with corrugated metal roofing and siding.

- Steel frames may be left exposed in unprotected noncombustible construction.
- See A.12 for fireproofing of steel structures.
- Some building codes reduce the fire-protection requirements for steel roof structures 25' (7620) or more above the floor.



- Crown
- Rule of thumb for crown depth: span/40
- Pitch: 1:12 to 4:12

- Connection bolted or welded to resist moments

- Shoulder
- Rule of thumb for shoulder depth: span/25

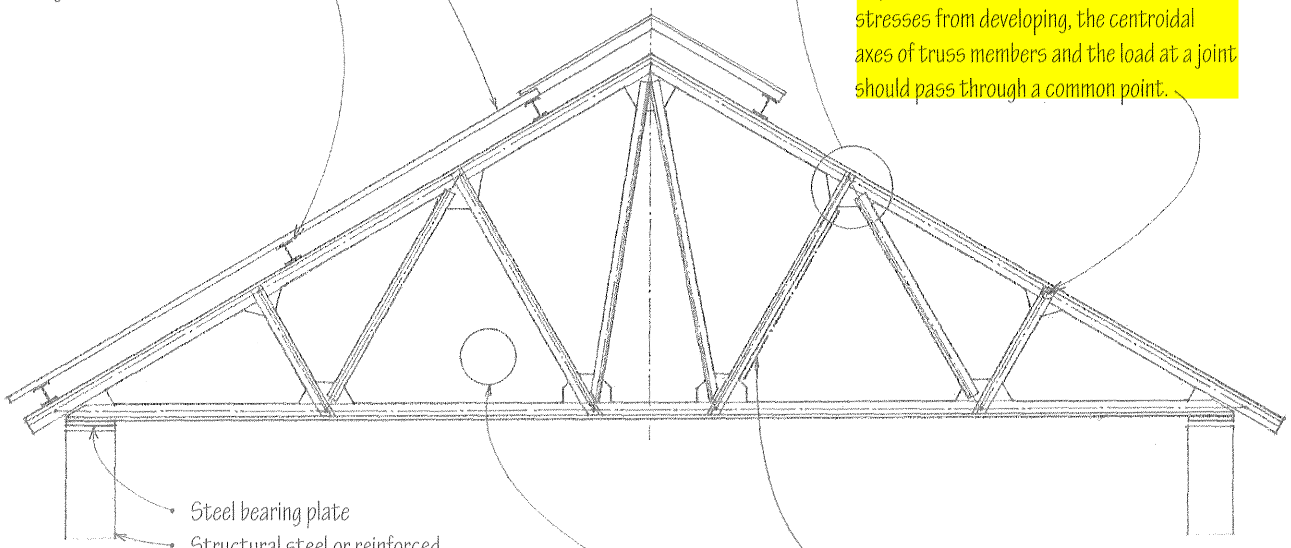
- Wall height: 8' to 30' (2440 to 9145)

- Base: 8" to 20" (205 to 510)
- Typical span: 30' to 120' (9 to 36 m)

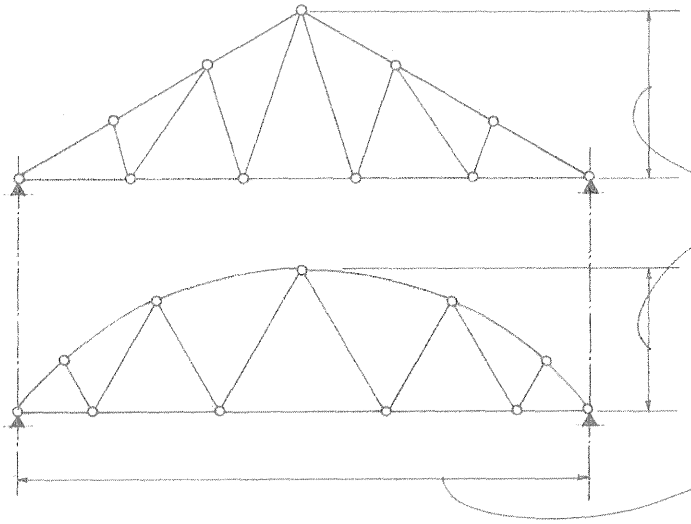
- See 2.16 for more information on trusses.

Steel trusses are generally fabricated by welding or bolting structural angles and tees together to form the triangulated framework. Because of the slenderness of these truss members, connections usually require the use of steel gusset plates. Heavier steel trusses may utilize wide-flange shapes and structural tubing.

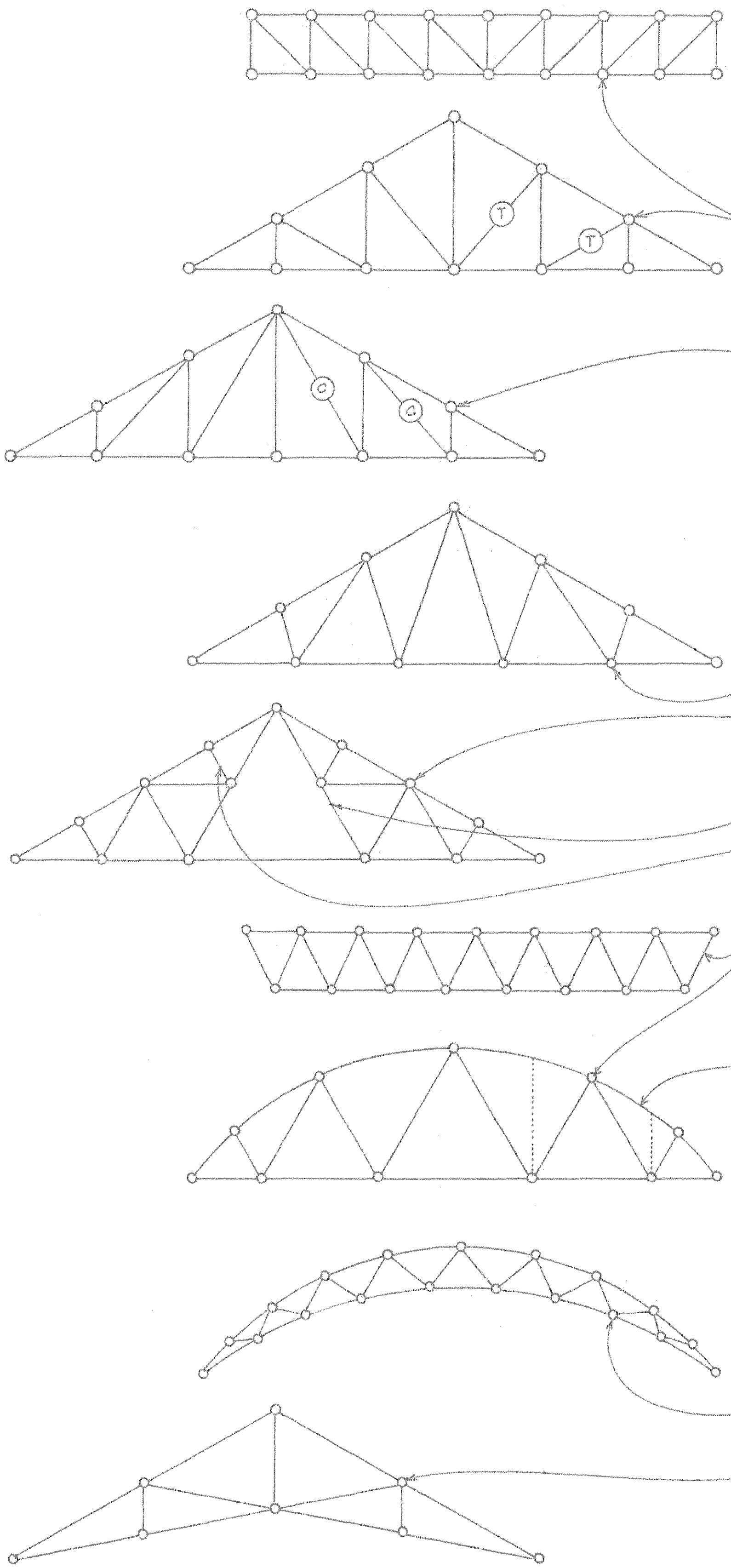
- Metal or cementitious roof decking or panels span purlin spaces.
- Channel or W-shape purlins span the truss spacing.
- If not bearing at a panel point, purlins subject top chord to local bending.
- Members are bolted or welded with gusset plate connectors.
- To prevent secondary shear and bending stresses from developing, the centroidal axes of truss members and the load at a joint should pass through a common point.



- Steel bearing plate
- Structural steel or reinforced concrete column support
- Trusses require lateral bracing in a direction perpendicular to their planes.
- Mechanical services such as piping, conduit, and ductwork may pass through the web spaces.
- Noncombustible steel construction may be left exposed if at least 20' (6095) above the finish floor; consult the building code for requirements.

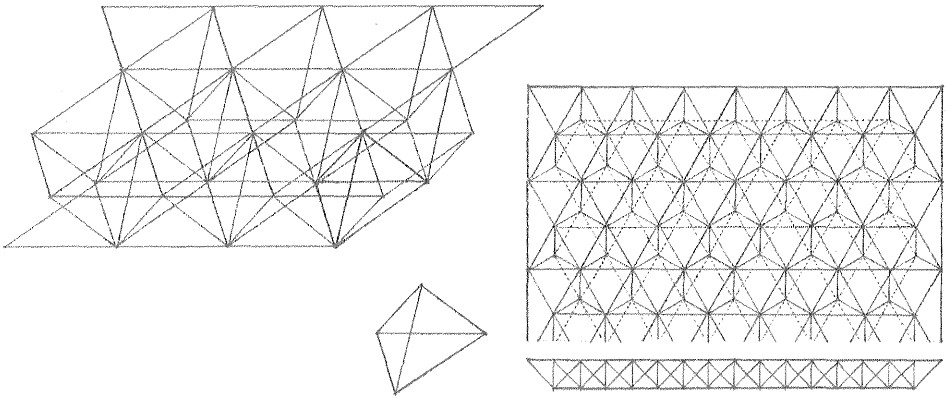


- Depth range for pitched trusses: span/4 to span/5
- Depth range for bowstring trusses: span/6 to span/8
- The increased depth of trusses allows them to span greater distances than steel beams and girders.
- Span range: 25' to 120' (7 to 36 m)

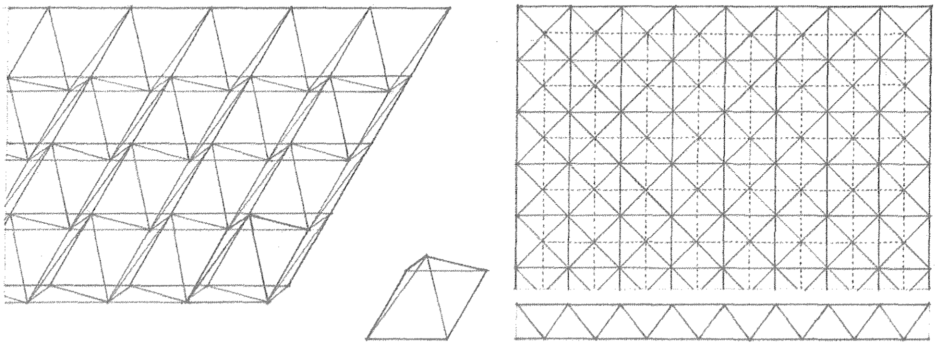


- Flat trusses have parallel top and bottom chords. Flat trusses are generally not as efficient as pitched or bowstring trusses.
- Pratt trusses have vertical web members in compression and diagonal web members in tension. It is generally more efficient to use a truss type in which the longer web members are loaded in tension.
- Howe trusses have vertical web members in tension and diagonal web members in compression.
- Belgian trusses have only inclined web members.
- Fink trusses are Belgian trusses having subdiagonals to reduce the length of compression web members toward the centerline of the span.
- Diagonals connect a top to a bottom chord.
- Subdiagonals join a chord with a main diagonal.
- Warren trusses have inclined web members forming a series of equilateral triangles. Vertical web members are sometimes introduced to reduce the panel lengths of the top chord, which is in compression.
- Bowstring trusses have a curved top chord meeting a straight bottom chord at each end.
- Raised-chord trusses have a bottom chord raised substantially above the level of the supports.
- Crescent trusses have both top and bottom chords curving upward from a common point at each side.
- Scissors trusses have tension members extending from the foot of each top chord to an intermediate point on the opposite top chord.

A space frame is a long-spanning three-dimensional plate structure based on the rigidity of the triangle and composed of linear elements subject only to axial tension or compression. The simplest spatial unit of a space frame is a tetrahedron having four joints and six structural members.

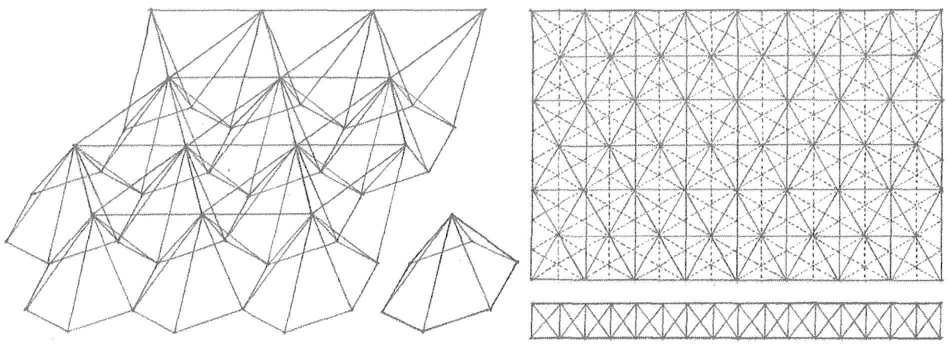


Triangular Grid



Square Grid

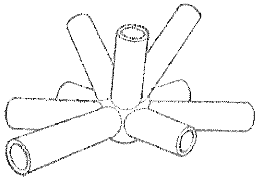
- Illustrated are three of the many patterns available.
- Typical modules: 4', 5', 8', 12' (1220, 1525, 2440, 3660)



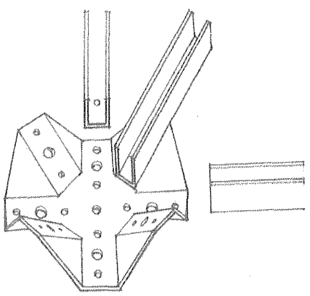
Hexagonal Grid

- Space frames may be constructed of structural steel pipe, tubing, channels, tees, or W-shapes.

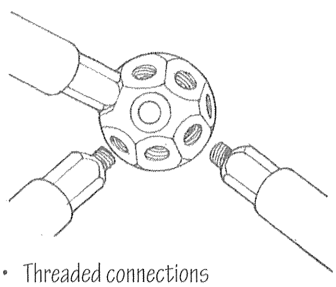
- Fabricated connectors join the members.
- Consult manufacturer for details, module size, and allowable spans.



- Welded connection

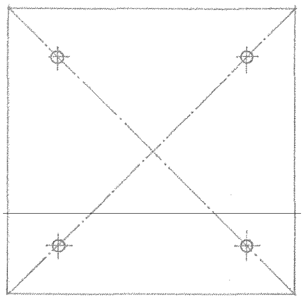


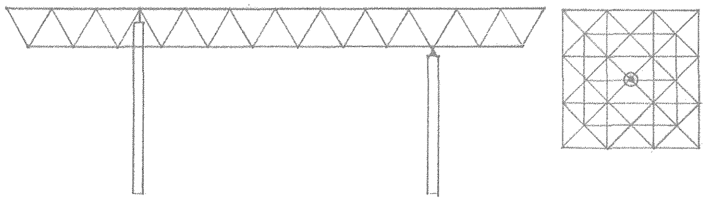
- Bolted connection



- Threaded connections

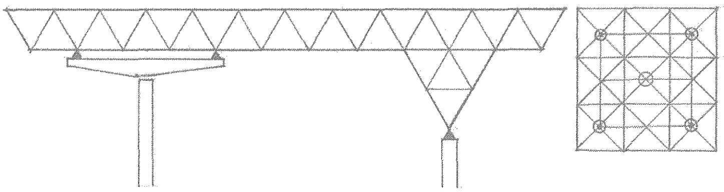
- As with other constant-depth plate structures, the supporting bay for a space frame should be square or nearly square to ensure that it acts as a two-way structure.





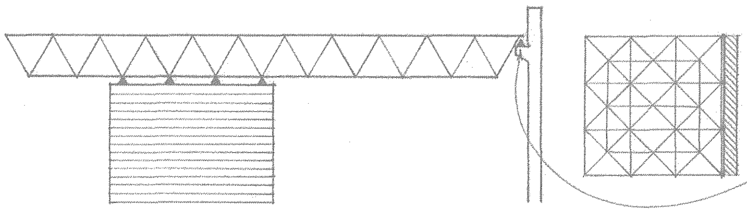
- Top-chord supported
- Bottom-chord supported

- A space frame should always be supported at a panel point.



- Four-point cruciform
- Frame capital

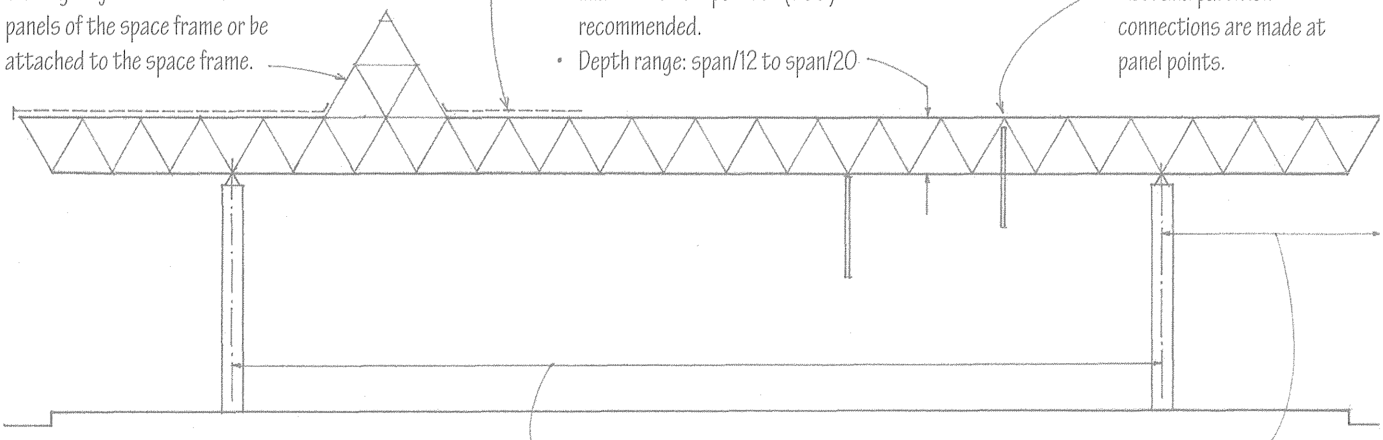
- Increasing the bearing area of the supports increases the number of members into which shear is transferred and reduces the forces in the members.



- Interior wall
- Exterior wall

- A reinforced concrete or masonry bearing wall distributes its support points along a line.
- Steel bearing plates anchored into concrete or bond beam

- Glazing may occur within the panels of the space frame or be attached to the space frame.
- Wood panel sheathing, metal roof decking, or cementitious roof planks
- Slope or camber frame for drainage; minimum of 1/4" per foot (1:50) recommended.
- Depth range: span/12 to span/20
- Roof and partition connections are made at panel points.



- Mechanical services such as piping, conduit, and ductwork may pass through the web spaces.
- Noncombustible steel construction may be left exposed if at least 20' (6095) above the finish floor; consult the building code for requirements.
- Span: 6 to 36 modules
- Span range for column-supported space frames: 30' to 80' (9 to 24 m)
- Span range for wall-supported space frames: 30' to 130' (9 to 39 m)
- Overhangs: 15% to 30% of span

Roof systems utilizing open-web steel joists are similar in layout and construction to steel joist floor systems. For joist sizes and span ranges, refer to 4.19–4.21.

Joists may frame into a bearing wall rising to form a parapet or bear on the wall to form a flush or overhanging roof edge.

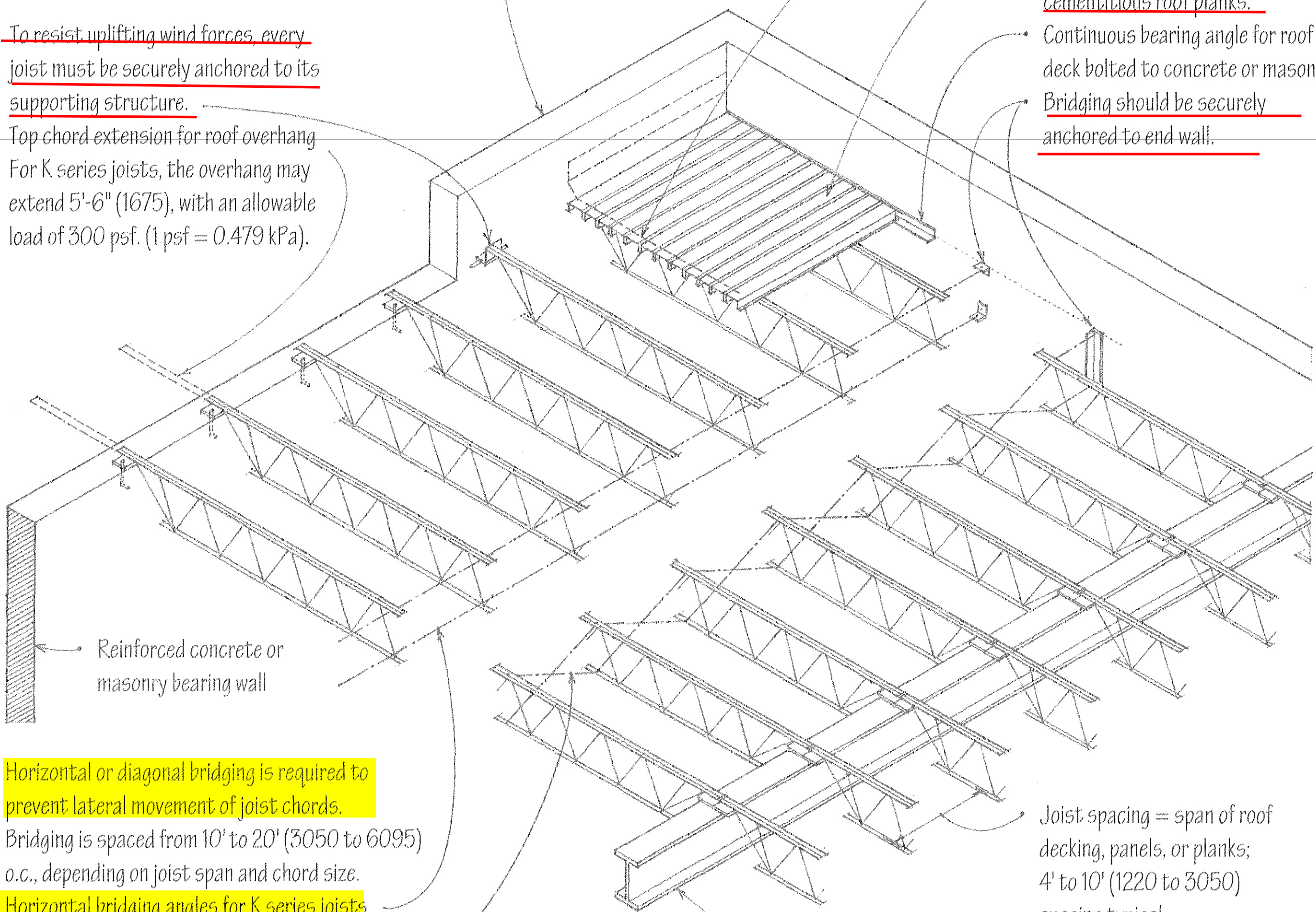
Roofing membrane over rigid foam or lightweight concrete insulation; see 7.12 for flat roof assemblies.

Roof deck may consist of metal roof decking, plywood panels, cementitious roof planks.

Continuous bearing angle for roof deck bolted to concrete or masonry

Bridging should be securely anchored to end wall.

- To resist uplifting wind forces, every joist must be securely anchored to its supporting structure.
- Top chord extension for roof overhang
- For K series joists, the overhang may extend 5'-6" (1675), with an allowable load of 300 psf. (1 psf = 0.479 kPa).



Reinforced concrete or masonry bearing wall

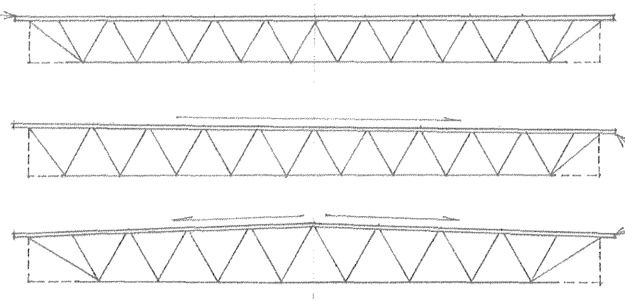
- Horizontal or diagonal bridging is required to prevent lateral movement of joist chords.
- Bridging is spaced from 10' to 20' (3050 to 6095) o.c., depending on joist span and chord size.
- Horizontal bridging angles for K series joists are welded to top and bottom chords.
- Diagonal bridging angles for LH/DLH series joists; weld or bolt bridging to clip angles secured to masonry wall or steel edge beam.

Joist spacing = span of roof decking, panels, or planks; 4' to 10' (1220 to 3050) spacing typical

- Joist span should not exceed 24 x joist depth

Steel beam or joist girders

- Top and bottom chords parallel; required roof slope may be achieved by shortening some of the joist supports and sloping the joists, or by tapering the insulating layer of the roof deck.



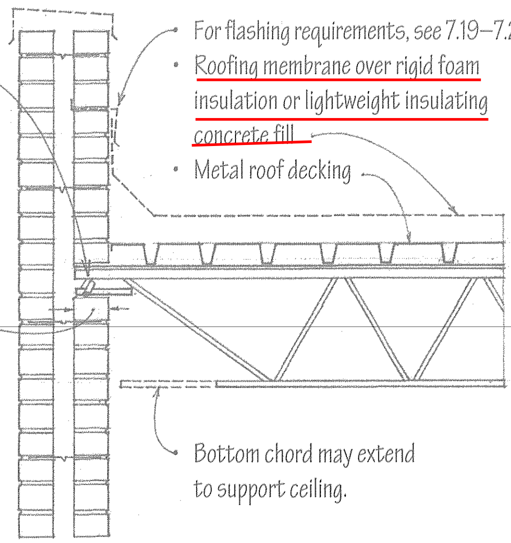
- LH/DLH series LH and DLH joists are available with single or double pitch top chords.

Top chord pitched one way

Top chord pitched two ways

- Standard slope is 1/8" per foot (1:100).

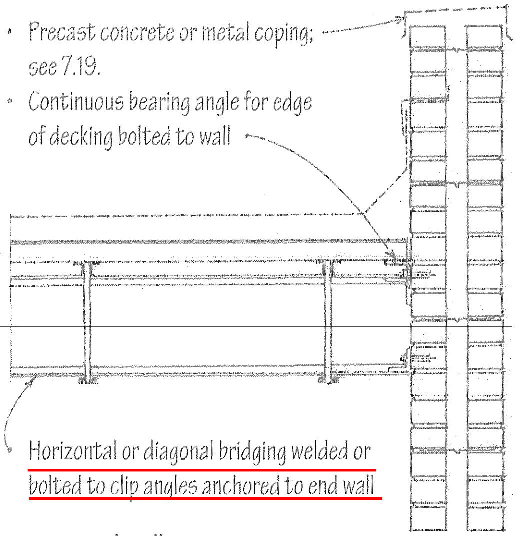
- Secure every roof joist to a steel bearing plate with anchors embedded in wall.
- 3/8" (10) ø steel bar 8" (205) long; for LH/DLH series joists, anchor w/ 3/4" (19) ø steel bar 12" (305) long.
- Minimum bearing length: 4" to 6" (100 to 150) for K series joists; 6" to 12" (150 to 305) for LH/DLH series joists



- For flashing requirements, see 7.19–7.20.
- Roofing membrane over rigid foam insulation or lightweight insulating concrete fill
- Metal roof decking
- Bottom chord may extend to support ceiling.

Parapet: Bearing Wall

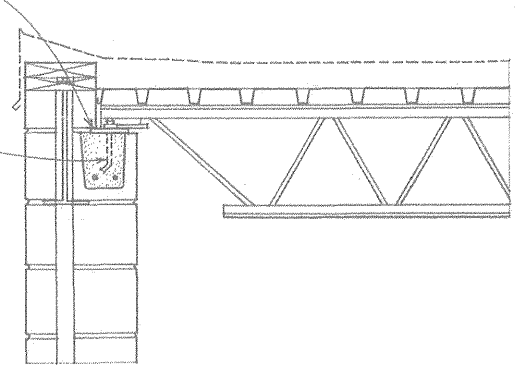
- Precast concrete or metal coping; see 7.19.
- Continuous bearing angle for edge of decking bolted to wall



- Horizontal or diagonal bridging welded or bolted to clip angles anchored to end wall

Parapet: End Wall

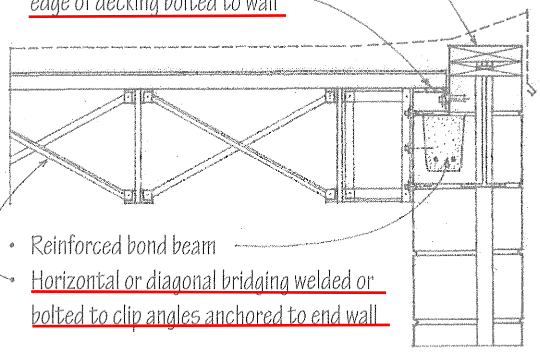
- Secure every roof joist to a steel bearing plate anchored in a continuous reinforced bond beam.
- Two 1/2" (13) ø anchor bolts; for LH/DLH series joists, use two 3/4" (19) ø anchor bolts.



- Metal gravel stop and fascia
- Metal roof decking is secured to all supports with puddle welds or mechanical fasteners.

Flush Edge: Bearing Wall

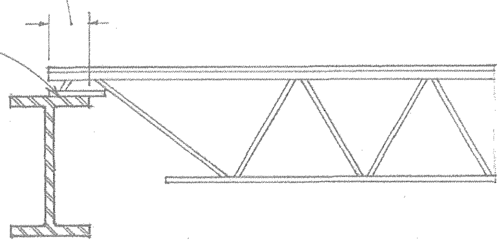
- Double treated wood plate; secure w/ 1/2" (13) ø anchor bolts @ 6' (1830) o.c. maximum
- Continuous bearing angle for edge of decking bolted to wall



- Reinforced bond beam
- Horizontal or diagonal bridging welded or bolted to clip angles anchored to end wall

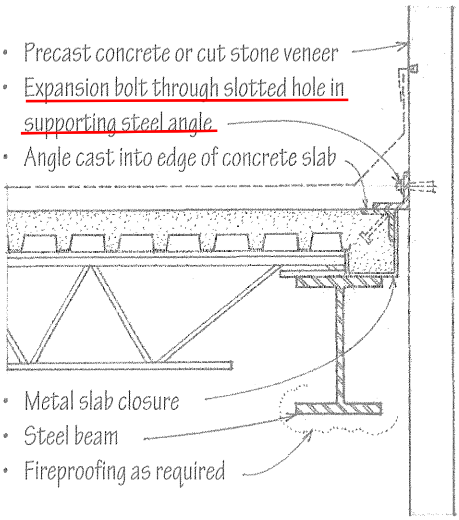
Flush Edge: End Wall

- Minimum bearing length: 2-1/2" (65) for K series joists; 4" (100) for LH/DLH series joists
- Two 1/8" (54) fillet welds 1" (25) long or 1/2" (13) ø bolt
- For LH/DLH series joists, two 1/4" (57) fillet welds 2" (51) long or two 3/4" (19) ø bolts



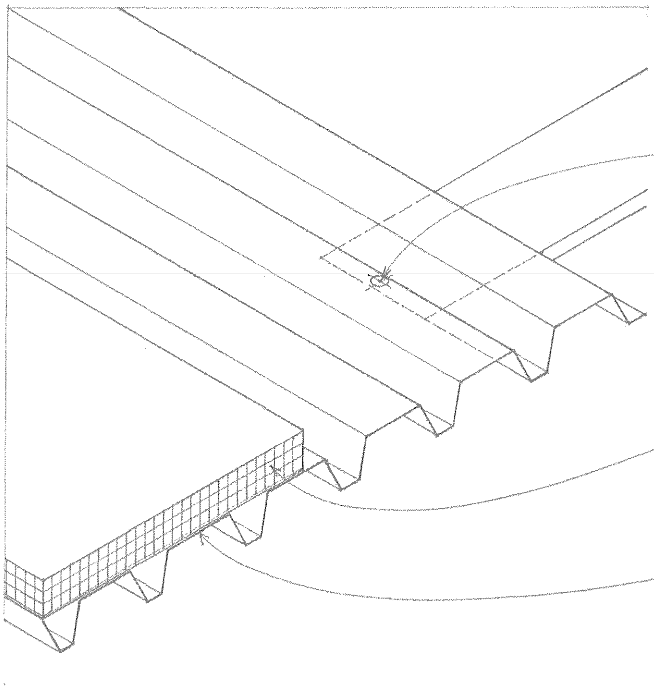
Structural Steel Frame

- Precast concrete or cut stone veneer
- Expansion bolt through slotted hole in supporting steel angle
- Angle cast into edge of concrete slab



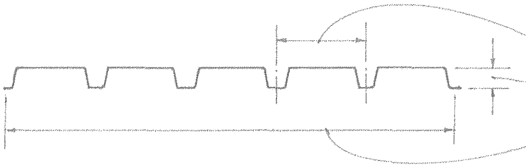
- Metal slab closure
- Steel beam
- Fireproofing as required

Parapet Wall

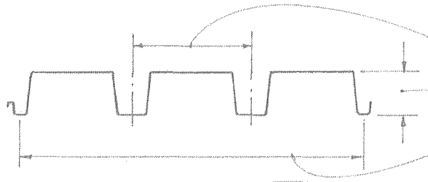


Metal roof decking is corrugated to increase its stiffness and ability to span across open-web steel joists or more widely spaced steel beams and to serve as a base for thermal insulation and membrane roofing.

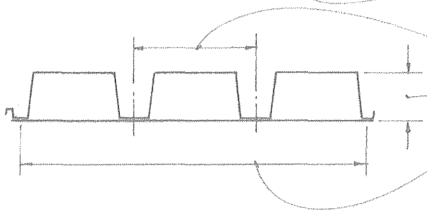
- The decking panels are puddle-welded or mechanically fastened to the supporting steel joists or beams.
- The panels are fastened to each other along their sides with screws, welds, or button punching standing seams.
- If the deck is to serve as a structural diaphragm and transfer lateral loads to shear walls, its entire perimeter must be welded to steel supports. In addition, more stringent requirements for support and side lap fastening may apply.
- Metal roof decking is commonly used without a concrete topping, requiring structural wood or cementitious panels or rigid foam insulation panels to bridge the gaps in the corrugation and provide a smooth, firm surface for the thermal insulation and membrane roofing.
- To provide maximum surface area for the effective adhesion of rigid foam insulation, the top flange should be wide and flat. If the decking has stiffening grooves, the insulation layer may have to be mechanically fastened.
- Metal decking has low-vapor permeance but because of the many discontinuities between the panels, it is not airtight. If an air barrier is required to prevent the migration of moisture vapor into the roofing assembly, a concrete topping can be used. When a lightweight insulating concrete fill is used, the decking may have perforated vents for the release of latent moisture and vapor pressure.



Ribbed Roof Decking
- 6" (150)
- 1-1/2" (38) depth spans 4' to 9' (1220 to 2745)
- 24", 30", 36" (610, 760, 915)



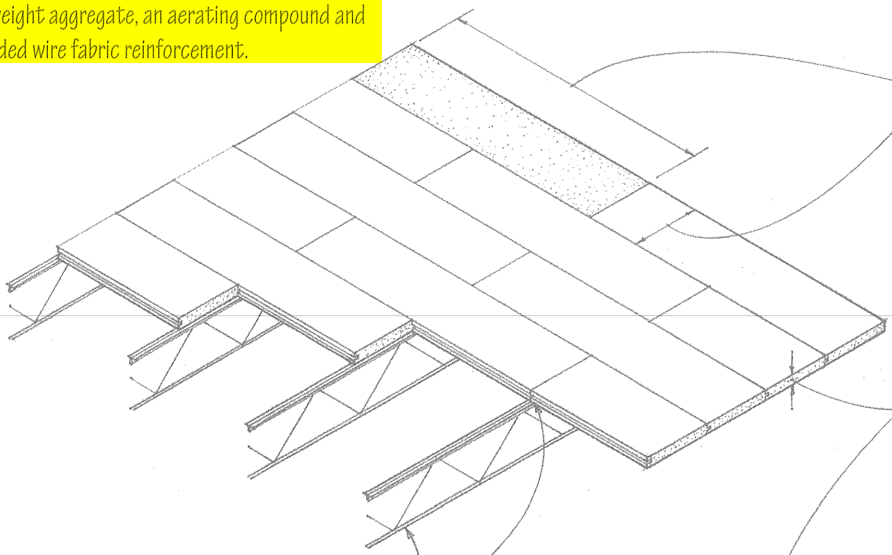
Ribbed Roof Decking
- 8" (205)
- 3" and 4-1/2" (75 and 115) depths span 8' to 16' (2440 to 4875)
- 12", 24" (305, 610)



Cellular Roof Decking
- 6" (150)
- 3" (75) depth spans 10' to 20' (3050 to 6095)
- 24" (610)

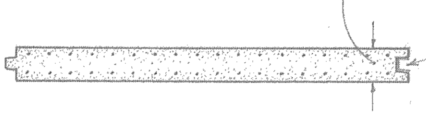
- Acoustic roof decking used as a sound-absorbing ceiling contains glass fiber between the perforated webs of ribbed decking or in the perforated cells of cellular decking.
- Decking profiles vary. Consult manufacturer for available profiles, lengths, gauges, allowable spans, and installation details.

Cementitious roof planks are manufactured with portland cement, lightweight aggregate, an aerating compound and galvanized welded wire fabric reinforcement.

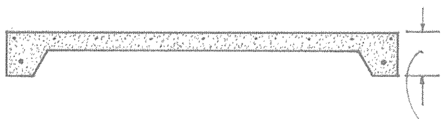


- 9' to 12' (2745 to 3660) lengths
- 16" and 24" (405 to 610) widths typical
- Thicknesses:
  - 2" (51) thickness can span 3' to 5' (915 to 1525);
  - 3" (75) thickness can span 4' to 7' (1220 to 2135);
  - 4" (100) thickness can span 5' to 8' (1525 to 2440).

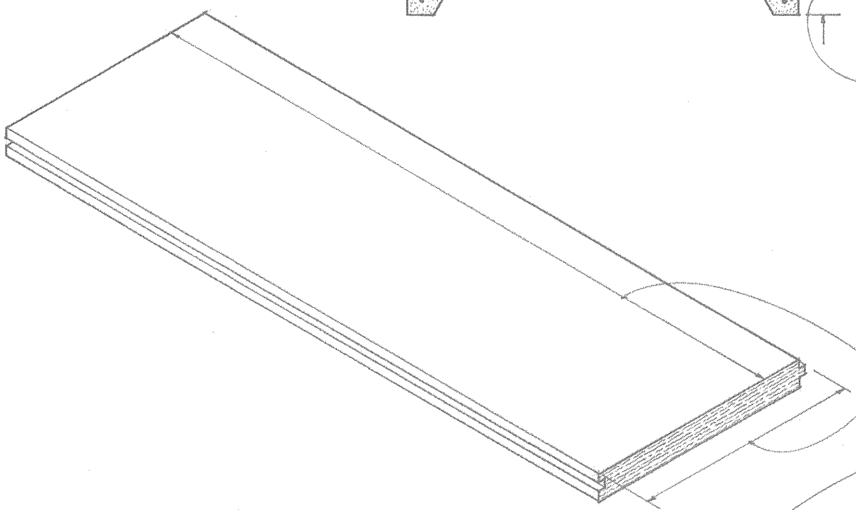
- These noncombustible roof planks may span across steel joists, beams, and purlins and be secured with galvanized steel clips.
- The roof planks provide a nailable base for roofing shingles or tiles.
- An acoustical treatment may be cast in the underside and left exposed as the ceiling finish.



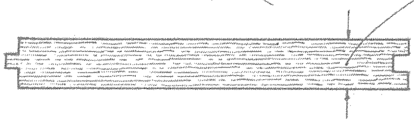
- Tongue-and-groove edges may be reinforced with galvanized steel channels.



- Channel slabs have a 1" (25) web thickness and thickened edges to span longer distances.
- Edge thicknesses:
  - 2-3/4" (70) edge thickness can span 4' to 7' (1220 to 2135)
  - 3-1/2" (90) edge thickness can span 7' to 9' (2135 to 2745)
  - 4" (100) edge thickness can span 9' to 12' (2745 to 3660)

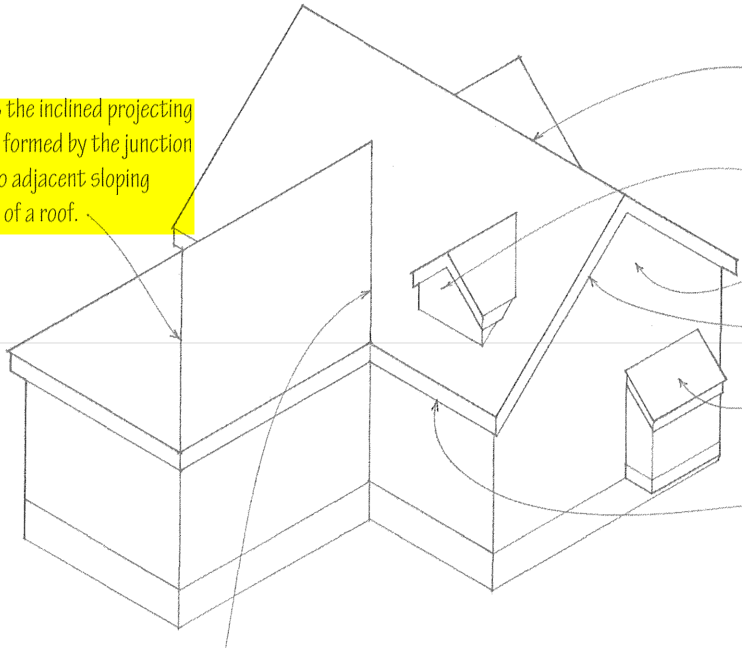


- 5' to 12' (1525 to 3660) lengths
- 24", 30", 48" (610, 760, 1220) widths
- Thicknesses:
  - 2" (51) thickness can span up to 3' (915);
  - 2-1/2" (64) thickness can span up to 3'-6" (1065);
  - 3" (75) thickness can span up to 4' (1220);
  - 3-1/2" (90) thickness can span up to 4'-6" (1370);
  - 4" (100) thickness can span up to 5' (1525).



Cementitious roof planks may also consist of wood fibers that are chemically processed and bonded under pressure with portland cement. These structural planks can be used to span wood or steel roof framing and serve as roof sheathing or as permanent formwork for a concrete slab; their undersides may be left exposed as an acoustical ceiling. They have thermal and acoustic insulation value and may be used in fire-resistant construction.

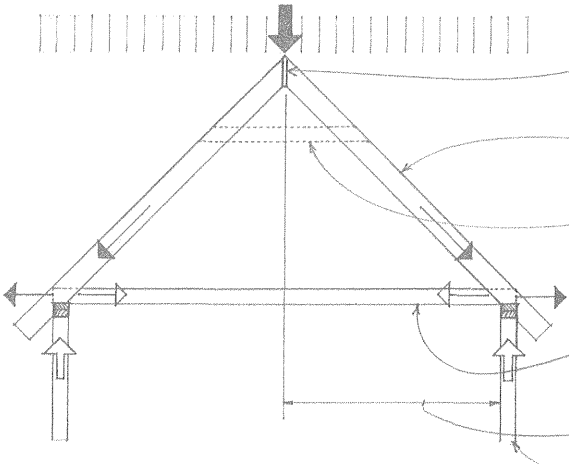
Roof Terminology



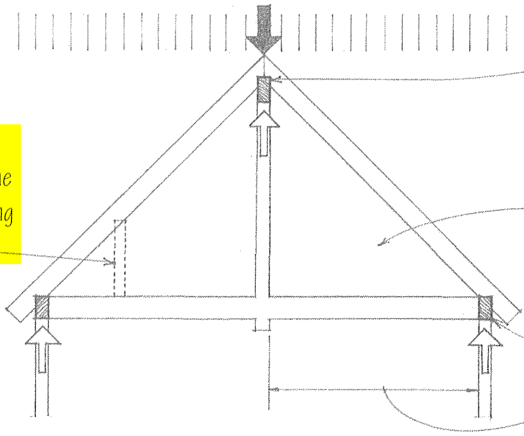
- Hip is the inclined projecting angle formed by the junction of two adjacent sloping sides of a roof.
- Valley is an intersection of two inclined roof surfaces toward which rainwater flows.
- Ridge is the horizontal line of intersection at the top between two sloping planes of a roof.
- Dormers are projecting structures built out from a sloping roof and housing a vertical window or ventilating louver.
- Gable is the triangular portion of wall enclosing the end of a pitched roof from ridge to eaves.
- Rake is the inclined, usually projecting edge of a sloping roof.
- Shed is a roof having a single slope.
- Eave is the overhanging lower edge of a roof.
- Soffit is the underside of an overhanging roof eave.

Gable Roofs

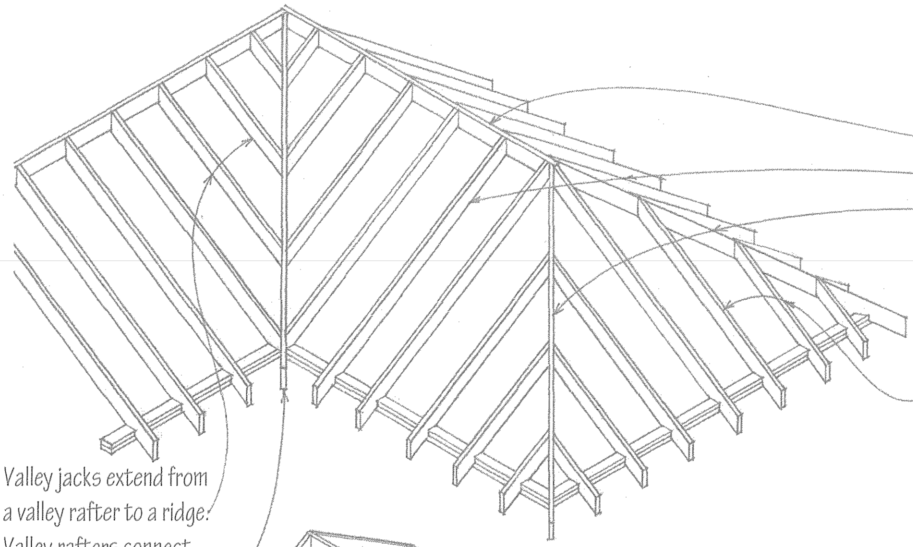
Gable roofs slope downward in two parts from a central ridge, so as to form a gable at each end.



- Ridge board is a nonstructural horizontal member to which the upper ends of the rafters are aligned and fastened.
- Common rafters extend from a wall plate to a ridge board or ridge beam and support the sheathing and covering of a roof.
- Collar ties unite two opposing rafters at a point below the ridge, usually in the upper third of the rafter length.
- The ties that resist the outward thrust of the rafters may be designed as ceiling joists supporting only attic loads or as floor joists supporting habitable space.
- Rafter span
- Loadbearing wall or beam



- Ridge beam is a structural horizontal member supporting the upper ends of rafters at the ridge of a roof.
- Rafter ties between the exterior wall or beam supports are not required.
- With sufficient headroom, natural light, and ventilation, attic space may be habitable.
- Knee walls are short walls supporting rafters at some intermediate position along their length.
- Beam or loadbearing wall
- Rafter span

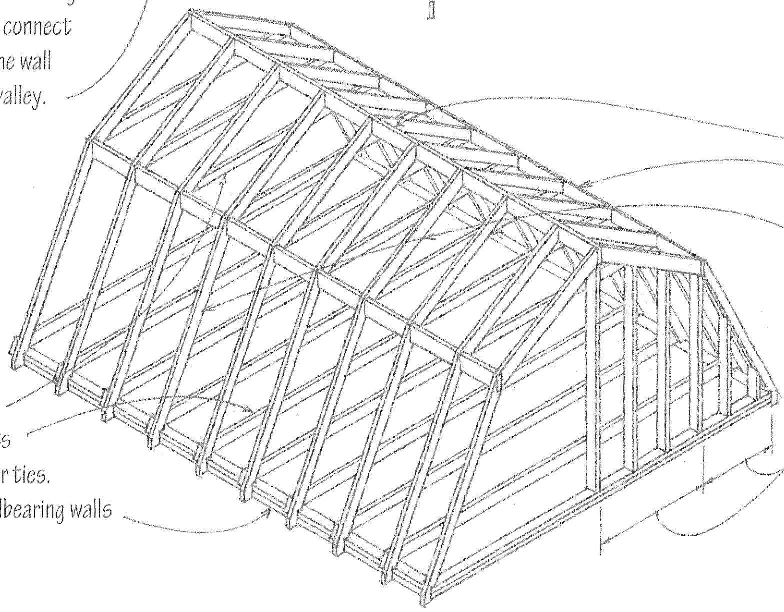


Hip Roofs

Hip roofs have sloping ends and sides meeting at an inclined projecting angle.

- Ridge board
- Common rafters
- Hip rafters form the junction of the sloping sides of a hip roof.
- Jack rafter is any rafter that is shorter than the full length of the roof slope, as one meeting a hip or a valley.
- Hip jacks are jack rafters extending from a wall plate to a hip rafter.

- Valley jacks extend from a valley rafter to a ridge.
- Valley rafters connect the ridge to the wall plate along a valley.

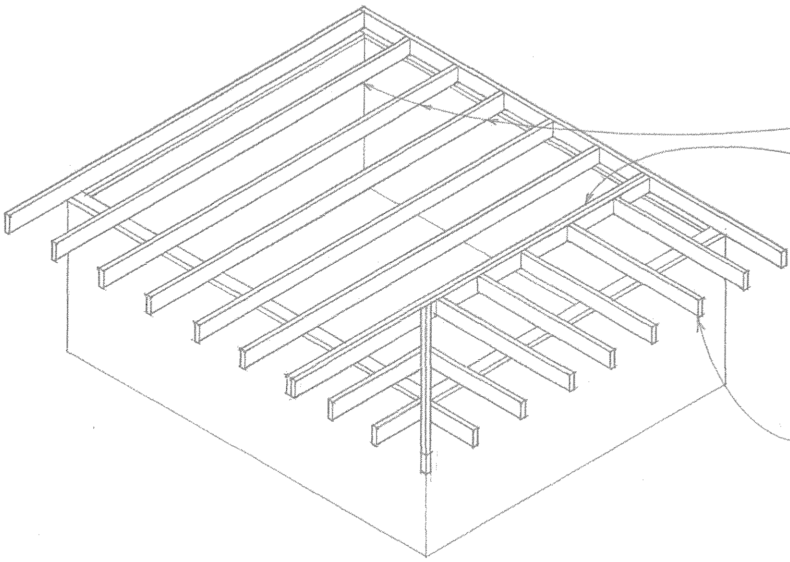


Gambrel Roofs

Gambrel roofs are divided on each side into a shallower slope above a steeper one.

- Ridge board
- Purlin
- Common rafters
- Rafter spans

- Ceiling joists and floor joists serve as rafter ties.
- Beams or loadbearing walls

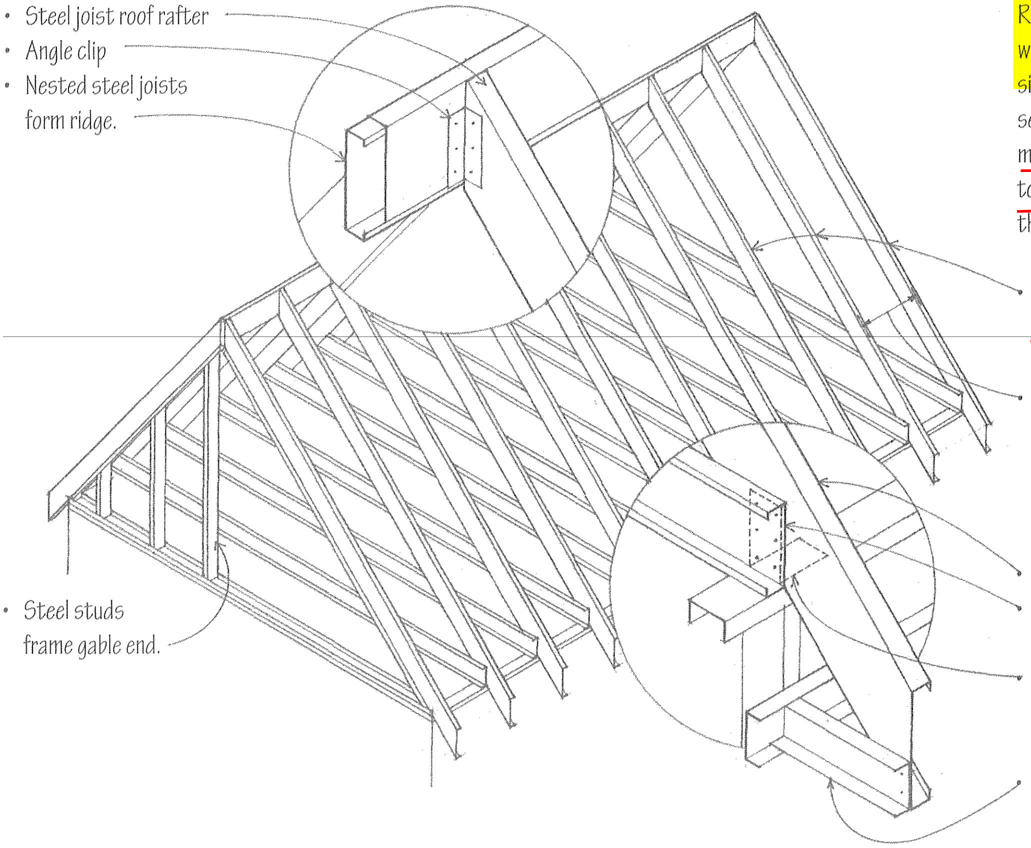


Flat Roofs

Flat roofs are framed in a manner similar to floor joist framing; see 4.26.

- Roof joists
- Double trimmer joist
- The required roof slope may be achieved by shortening some of the joist supports and sloping the joists, or by tapering the insulating layer of the roof deck.
- Lookout rafters support the roof overhang.

- Steel joist roof rafter
- Angle clip
- Nested steel joists form ridge.

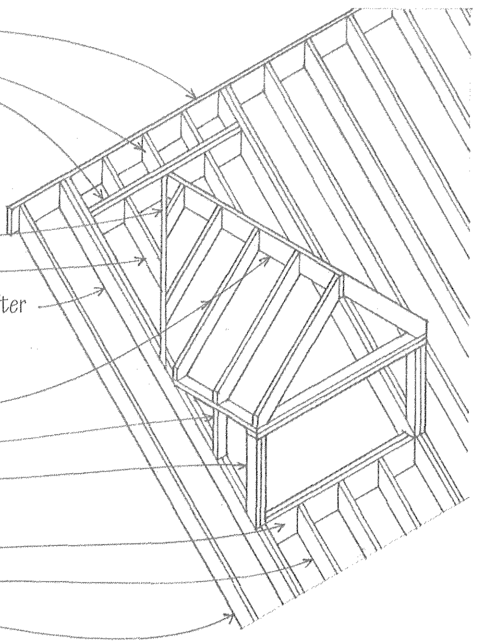


- Steel studs frame gable end.

Roofs and ceilings may be constructed with light-gauge steel members in a manner similar to wood light frame construction; see 6.19–6.22. The light-gauge steel members may also be screwed or welded together to form roof trusses similar to those described on 6.29.

- Light-gauge steel joist sections serve as rafters; see 4.23 for types and sizes of light-gauge steel joists.
- Rafters are typically spaced at 12", 16", or 24" (305, 405, 610) o.c., depending on the magnitude of roof loads and the spanning capability of the roof sheathing.
- Steel joist rafter
- Steel ceiling joist
- Anchor clips secure both rafters and ceiling joists to the top runner of the stud wall framing.
- Soffit framed with light-gauge steel stud sections

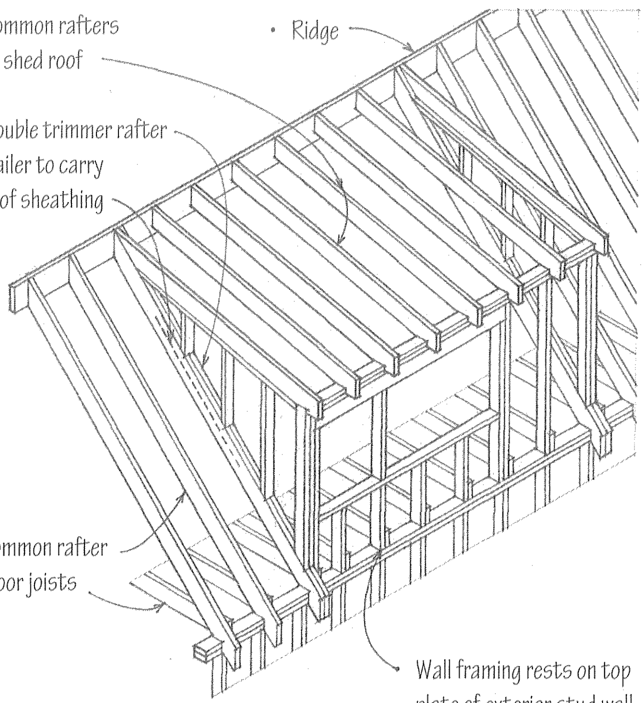
- Ridge
- Cripple
- Double header
- Valley rafter
- Valley jack
- Double trimmer rafter
- Dormer ridge and rafters
- Side stud
- Corner post
- Double header
- Tail rafter
- Common rafter



- Gable end wall of dormer may also be directly above and be an extension of the exterior wall as illustrated with the shed dormer.

Gable Dormer

- Common rafters of shed roof
- Ridge
- Double trimmer rafter
- Nailer to carry roof sheathing
- Common rafter
- Floor joists



- Wall framing rests on top plate of exterior stud wall.

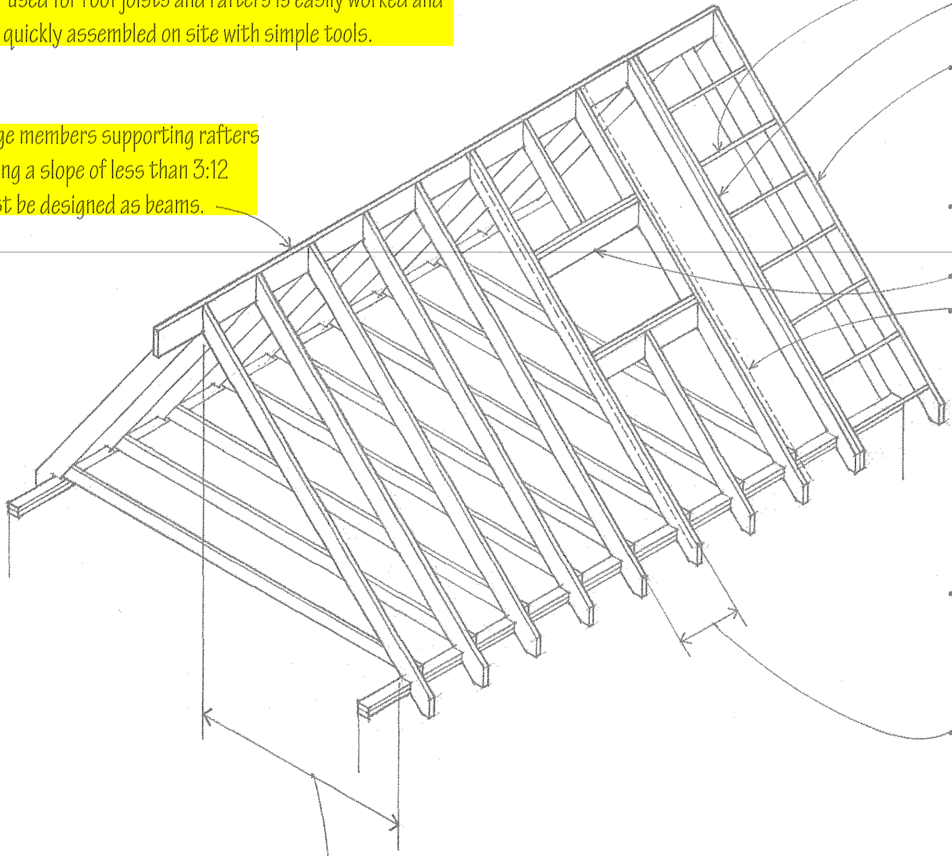
Shed Dormer

CSI MasterFormat 05 40 00 Cold-Formed Metal Framing

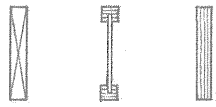
- See 6.16–6.17 for light frame roof forms and terminology.

Roof structures framed with wood rafters are an essential subsystem of wood light frame construction. The dimension lumber used for roof joists and rafters is easily worked and can be quickly assembled on site with simple tools.

- Ridge members supporting rafters having a slope of less than 3:12 must be designed as beams.

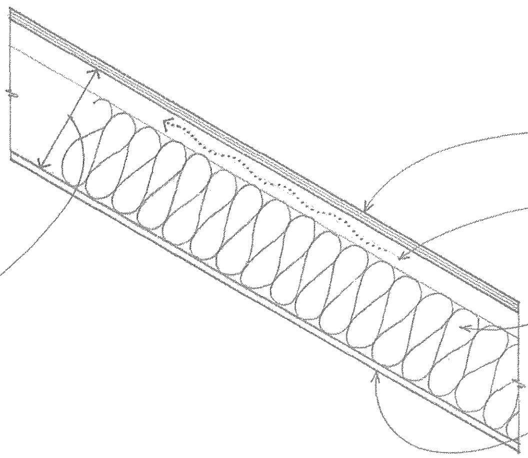


- Rake overhangs are constructed with lookouts framed into a double common rafter and bearing on the top plate of the gable end wall.
- Barge or fly rafters are the end rafters in the part of a gable roof that projects beyond the gable wall.
- Roof openings are framed in a manner similar to floor joist openings; see 4.31.
- Double header
- Double rafters for large openings



- Sloping rafters and flat roof joists are typically of solid-sawn 2x lumber, but I-joists and laminated veneer lumber may also be used.
- Rafters and roof joists are typically spaced at 12", 16", or 24" (305, 405, 610) o.c., depending on the magnitude of roof loads and the spanning capability of the roof sheathing.

Rafter span ranges:
- 2x6 can span up to 10' (3050);
- 2x8 can span up to 14' (4265);
- 2x10 can span up to 16' (4875);
- 2x12 can span up to 22' (6705).
- Rafter spans are related to the magnitude of applied loads, the rafter size and spacing, and the species and grade of lumber used.
- Rafters may be oversized to accommodate the required thermal insulation and provide space for ventilating the concealed roof spaces.
- Consult manufacturer for sizes and spans of laminated veneer lumber joists.

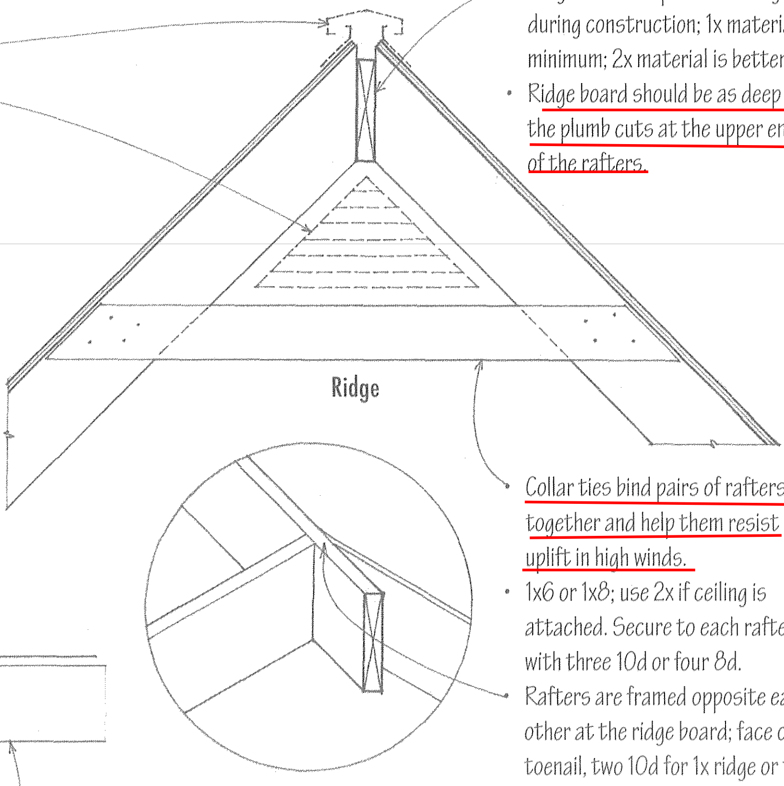


- Because wood light framing is combustible, it must rely on roofing and ceiling materials for its fire-resistance rating.
- Roof sheathing; see 6.23.
- The susceptibility of wood light framing to decay requires ventilation to control condensation in enclosed roof spaces.
- See 7.43 for thermal insulation of roofs.
- A ceiling finish is usually applied directly to the underside of roof rafters or ceiling joists.
- If ceiling joists are used, attic space may accommodate mechanical equipment.

CSI MasterFormat 06 10 00 Rough Carpentry
CSI MasterFormat 06 11 00 Wood Framing

- Ventilation at the peak of a roof may be provided with a continuous ridge vent or by louvered vents in the gable end walls; see 7.47.

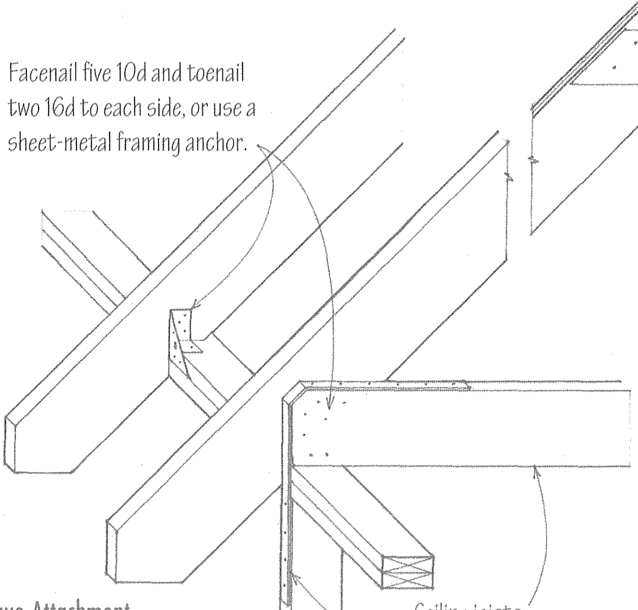
- Ridge board keeps rafters aligned during construction; 1x material minimum; 2x material is better
- Ridge board should be as deep as the plumb cuts at the upper ends of the rafters.



Ridge

- Collar ties bind pairs of rafters together and help them resist uplift in high winds.
- 1x6 or 1x8; use 2x if ceiling is attached. Secure to each rafter with three 10d or four 8d.
- Rafters are framed opposite each other at the ridge board; face or toenail, two 10d for 1x ridge or two 16d for 2x ridge.

- Facenail five 10d and toenail two 16d to each side, or use a sheet-metal framing anchor.



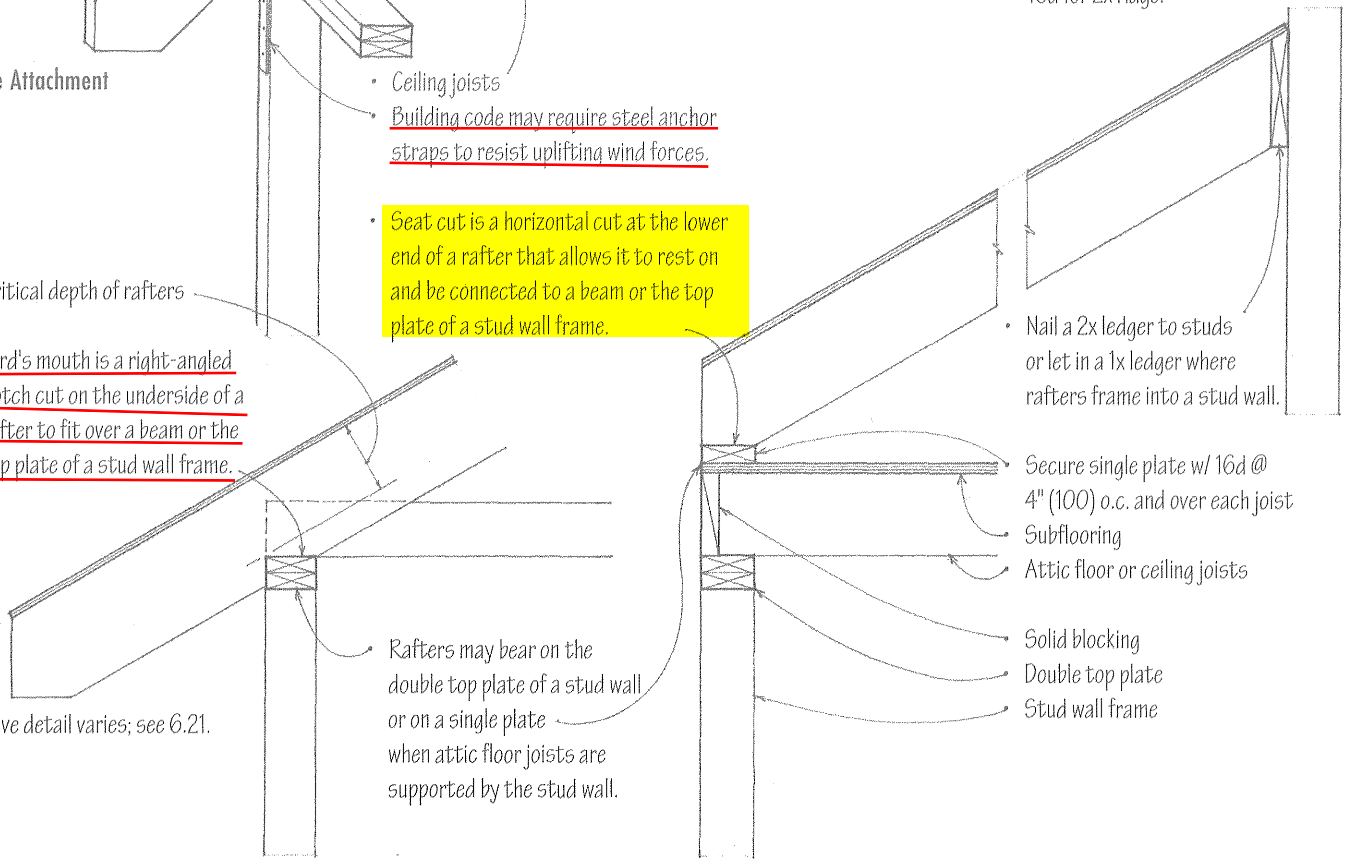
Eave Attachment

- Ceiling joists
- Building code may require steel anchor straps to resist uplifting wind forces.

- Seat cut is a horizontal cut at the lower end of a rafter that allows it to rest on and be connected to a beam or the top plate of a stud wall frame.

- Critical depth of rafters
- Bird's mouth is a right-angled notch cut on the underside of a rafter to fit over a beam or the top plate of a stud wall frame.

- Nail a 2x ledger to studs or let in a 1x ledger where rafters frame into a stud wall.

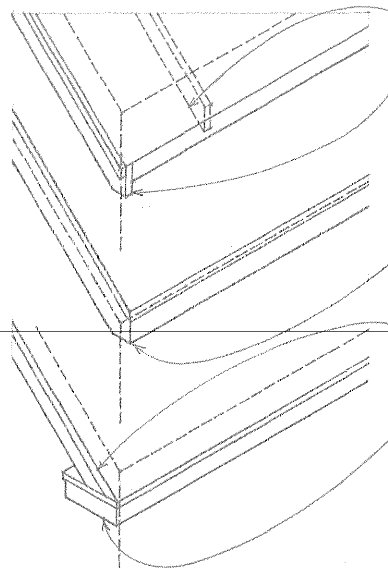


- Secure single plate w/ 16d @ 4" (100) o.c. and over each joist
- Subflooring
- Attic floor or ceiling joists
- Solid blocking
- Double top plate
- Stud wall frame

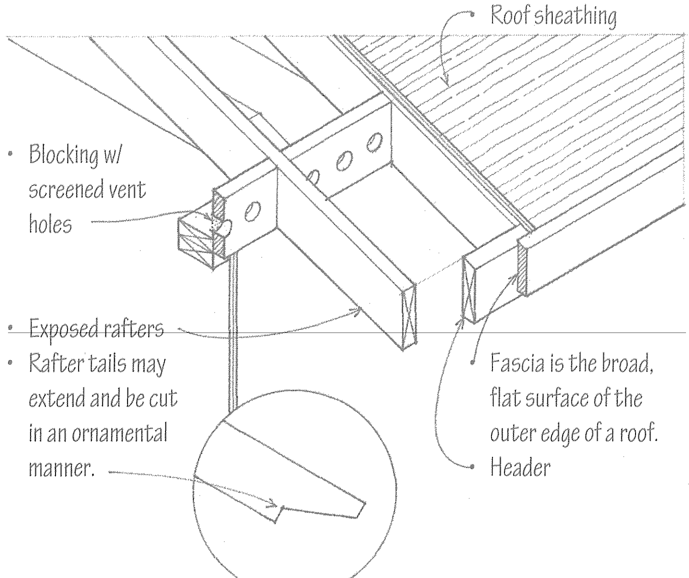
- Eave detail varies; see 6.21.

Rafters may bear on the double top plate of a stud wall or on a single plate when attic floor joists are supported by the stud wall.

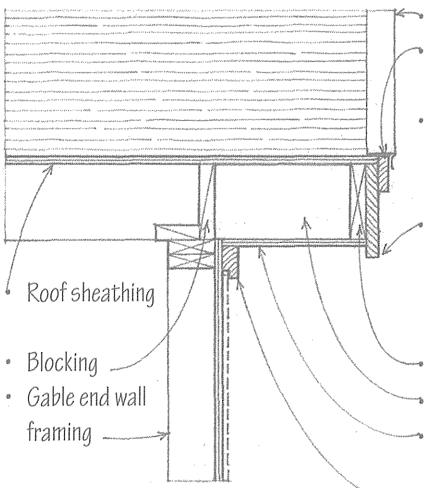
Eave Support Conditions



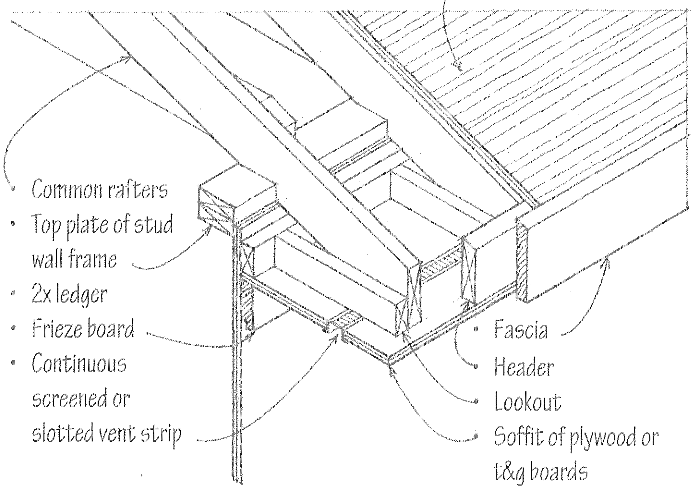
It is important to consider how the roof eave detail turns the corner and meets the rake detail.



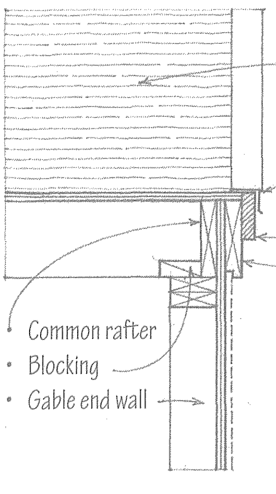
Exposed Rafters



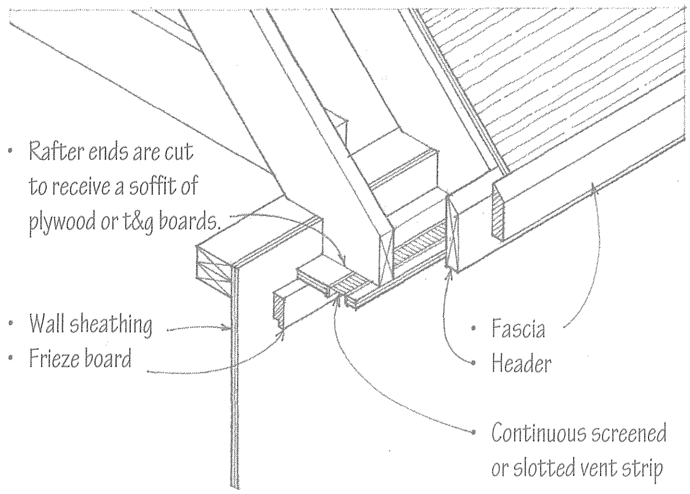
Closed Rake



Wide Vented Soffit

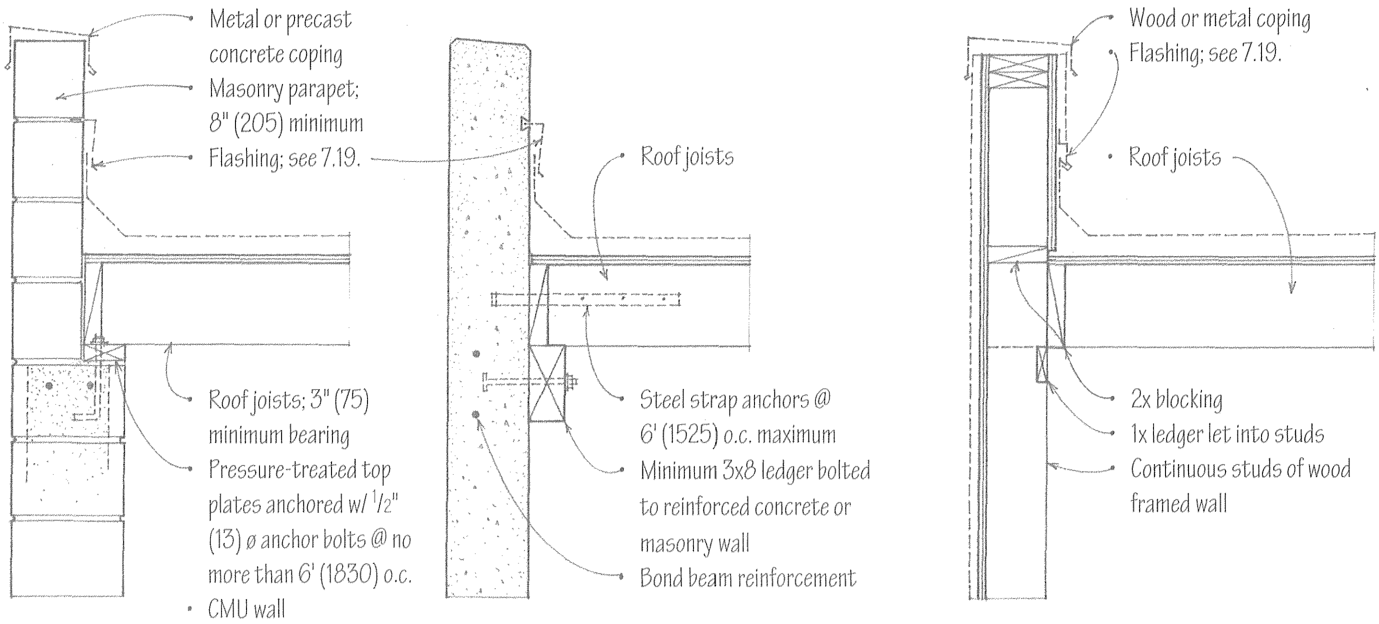


Rake Overhang



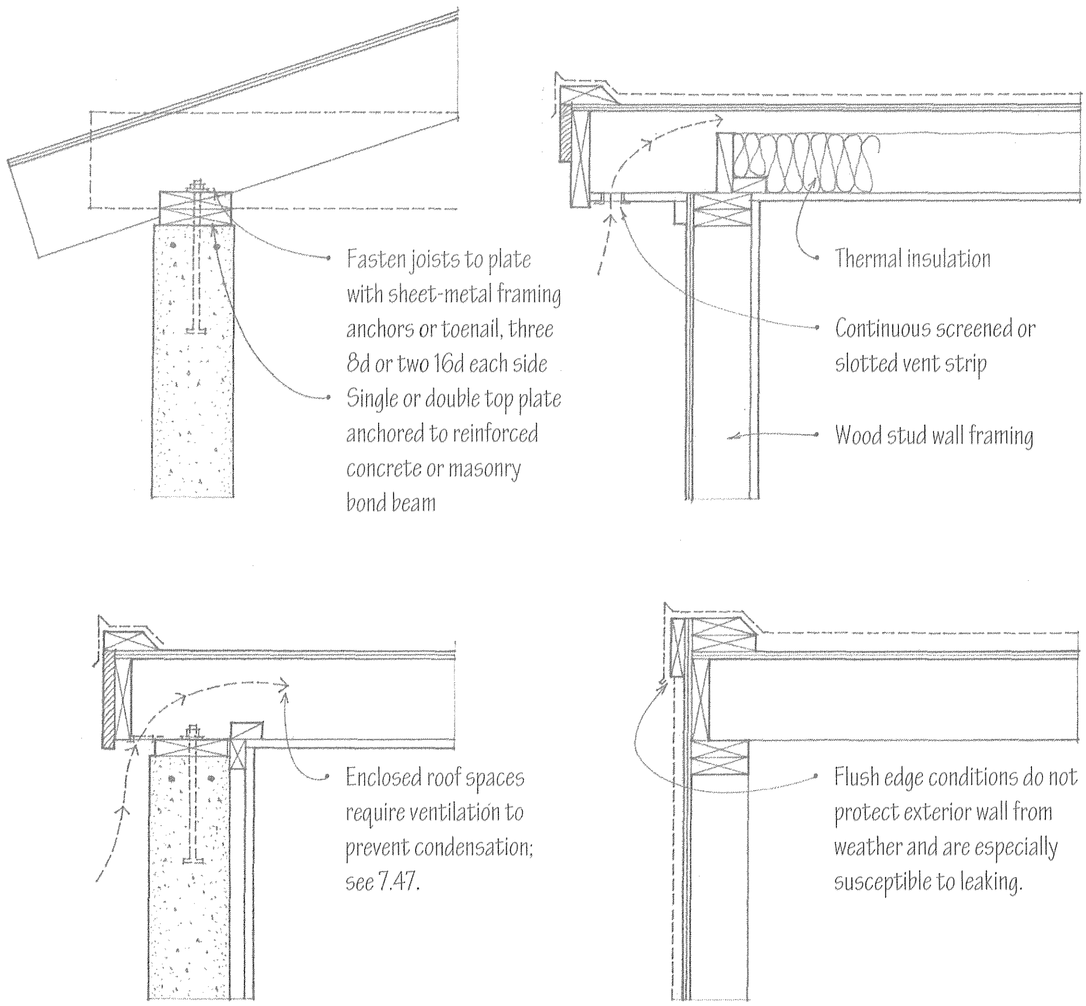
Narrow Vented Soffit

- Similar to a wide vented soffit



Parapets

- Consult the building code for height and fire-resistance requirements.



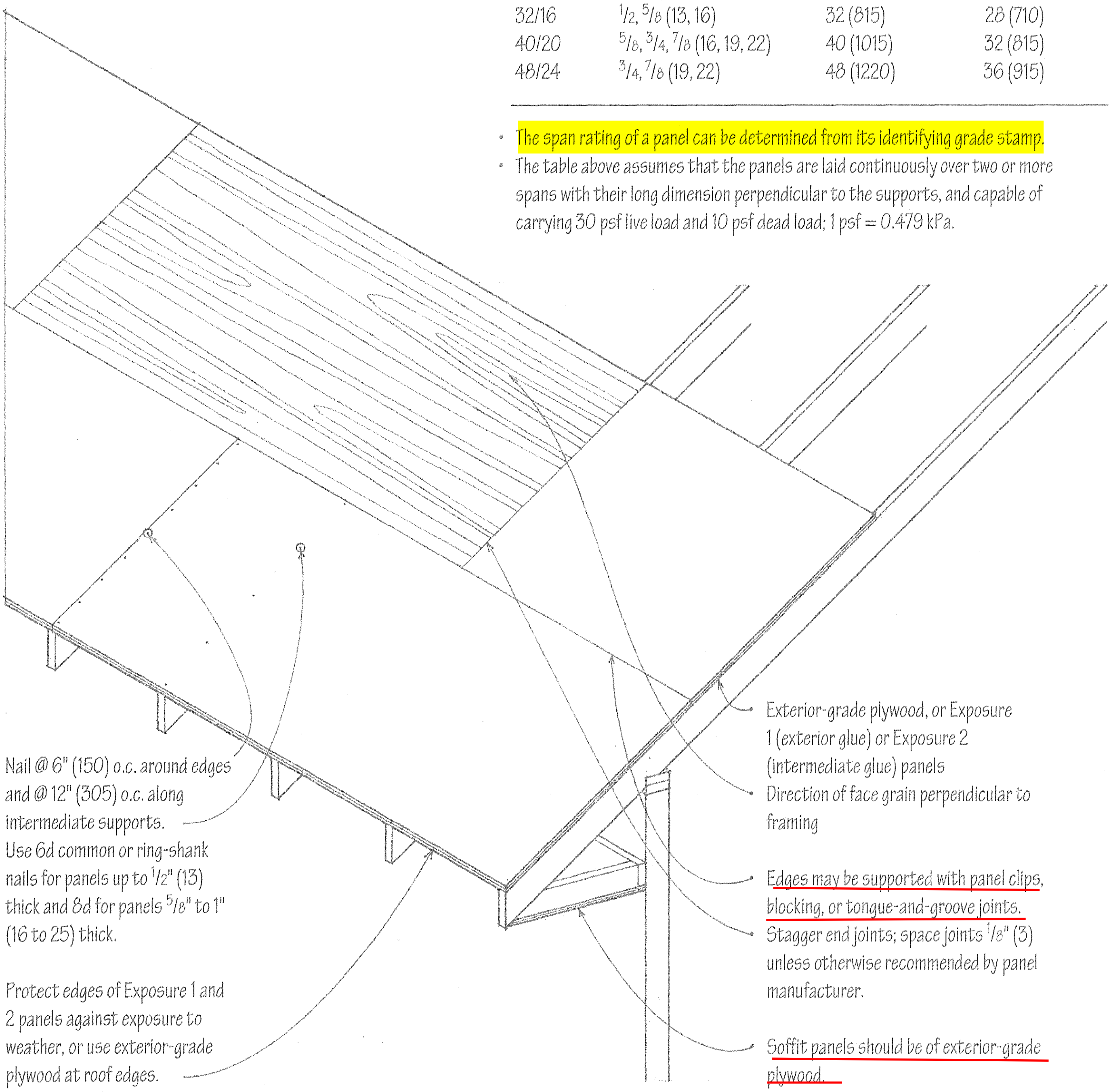
Flat Roof Joists

Sheathing over wood or light-gauge metal rafters typically consists of APA-rated plywood or nonveneered wood panels. The panels enhance the stiffness of the rafter framing and provide a solid base for the application of various roofing materials. Sheathing and underlayment requirements should be in accordance with the recommendations of the roofing manufacturer. In damp climates not subject to blizzard conditions, spaced sheathing of 1x4 or 1x6 boards may be used with wood shingle or shake roofing. See 7.04–7.05.

Panel Roof Sheathing

Panel Span Rating	Panel Thickness inch (mm)	Maximum Span in inches (mm) w/ edge support	w/o edge support
12/0	5/16 (8)	12 (305)	
16/0	5/16, 3/8 (8, 10)	16 (405)	
20/0	5/16, 3/8 (8, 10)	20 (510)	
24/0	3/8 (10)	24 (610)	16 (405)
24/0	1/2 (13)	24 (610)	24 (610)
32/16	1/2, 5/8 (13, 16)	32 (815)	28 (710)
40/20	5/8, 3/4, 7/8 (16, 19, 22)	40 (1015)	32 (815)
48/24	3/4, 7/8 (19, 22)	48 (1220)	36 (915)

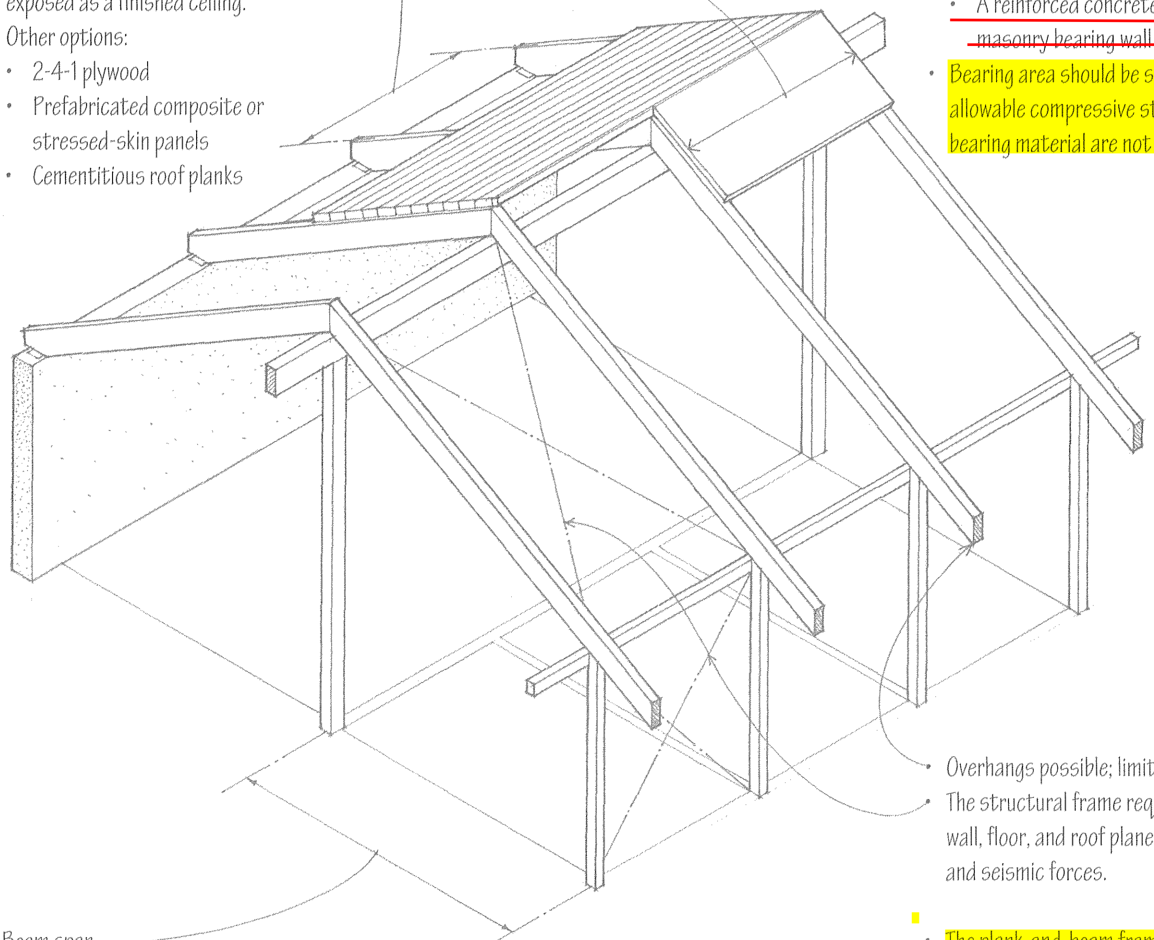
- The span rating of a panel can be determined from its identifying grade stamp.
- The table above assumes that the panels are laid continuously over two or more spans with their long dimension perpendicular to the supports, and capable of carrying 30 psf live load and 10 psf dead load; 1 psf = 0.479 kPa.



Wood plank-and-beam roof systems typically use the same supporting grid of posts or columns as do plank-and-beam floor systems. See 4.38 and 5.50.

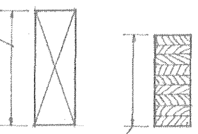
- Beam spacing = span of wood decking; 4' to 8' (1220 to 2440) typical
- The guidelines on 4.40 may be used to estimate the span of wood decking.
- Underside of decking may be left exposed as a finished ceiling.
- Other options:
  - 2-4-1 plywood
  - Prefabricated composite or stressed-skin panels
  - Cementitious roof planks

- Roof beams may be supported by:
  - Timber, steel, or concrete columns
  - Timber or steel girders
  - A reinforced concrete or masonry bearing wall
- Bearing area should be sufficient to ensure the allowable compressive stresses of the beam and bearing material are not exceeded.



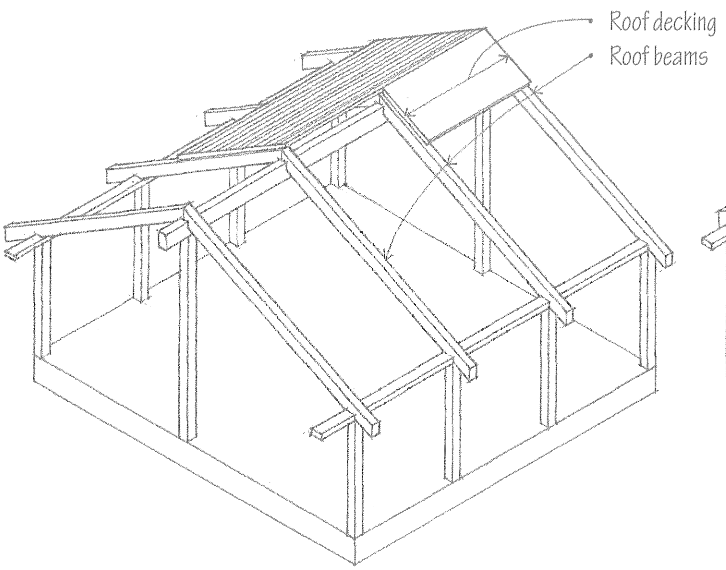
- Overhangs possible; limit to 1/4 of backspan
- The structural frame requires bracing of the wall, floor, and roof planes against lateral wind and seismic forces.

- Beam span
- Rule of thumb for estimating the depth of a beam:
- Solid sawn wood beams: span/15; beam width = 1/3 to 1/2 of beam depth
- Glue-laminated beams: span/20; beam width = 1/4 to 1/3 of beam depth
- The required size of a wood beam is directly related to the magnitude of the roof load, the species and grade of lumber used, and the beam spacing and span.

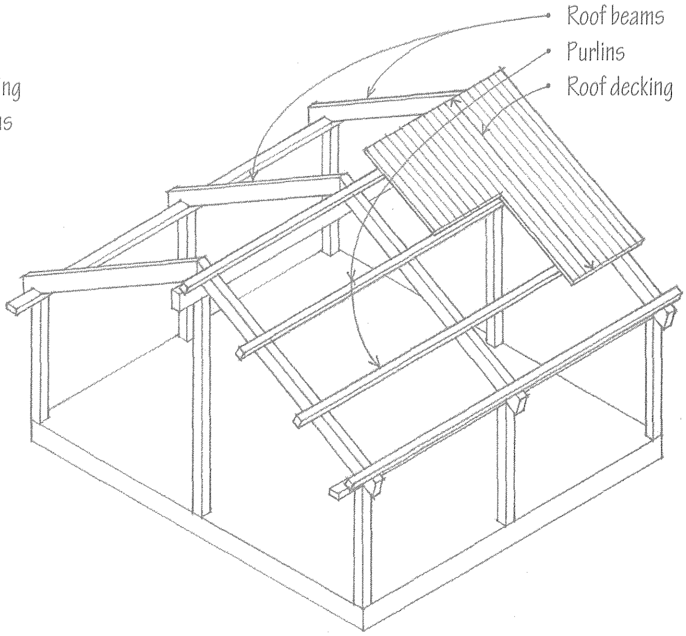


- The plank-and-beam framing is often left exposed to the interior with rigid thermal insulation being applied over the roof deck and a vapor retarder. Exposed structures require thoughtful detailing of connections, the use of quality materials, and careful workmanship.
- Plank-and-beam framing offers no concealed spaces for overhead ductwork, pipes, or wiring, except when a layered structure or spaced structural members are used.
- Plank-and-beam framing may qualify as heavy timber construction if the structure is supported by noncombustible, fire-resistive exterior walls and the wood members and decking meet the minimum size requirements specified in the building code.

There are alternatives for how a plank-and-beam roof structure can be framed, depending on the direction and spacing of the roof beams, the elements used to span the beam spacing, and the overall depth of the construction assembly.

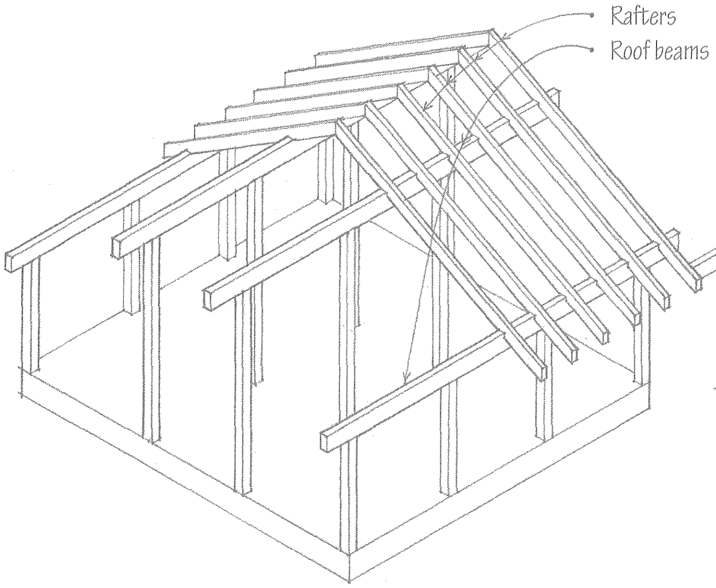


The roof beams may be spaced 4' to 8' (1220 to 2440) o.c. and spanned with solid or glue-laminated wood decking. The beams may be supported by girders, columns, or a reinforced concrete or masonry bearing wall.

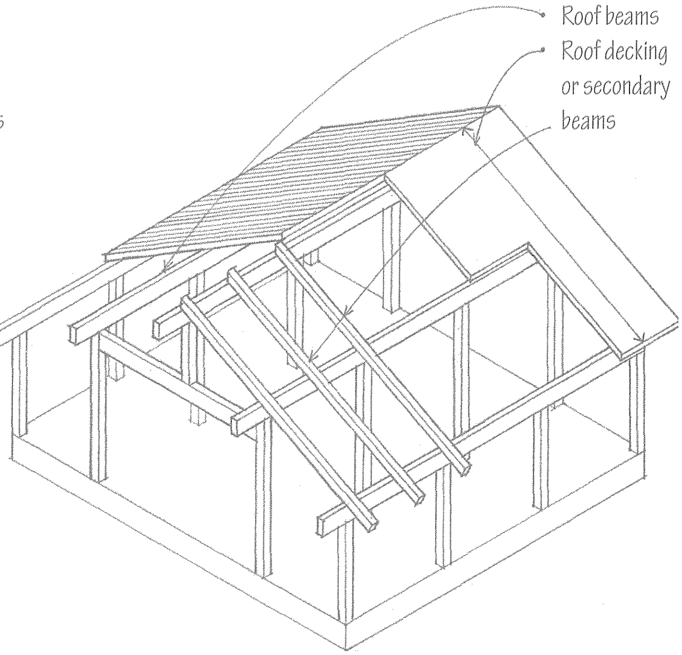


In this two-layer system, the roof beams may be spaced further apart and support a series of purlins. These purlins, in turn, are spanned with wood decking or a rigid, sheet roofing material.

Roof Beams Parallel with Slope

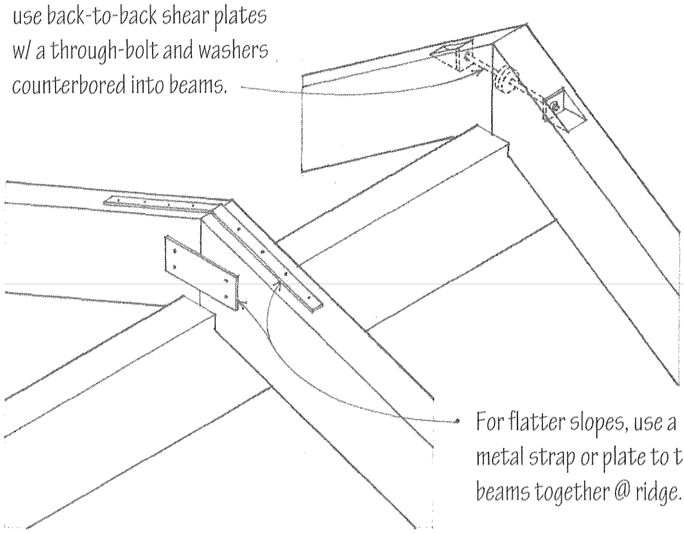


In this example of a two-layer structure, the roof beams support a conventional system of wood rafters.

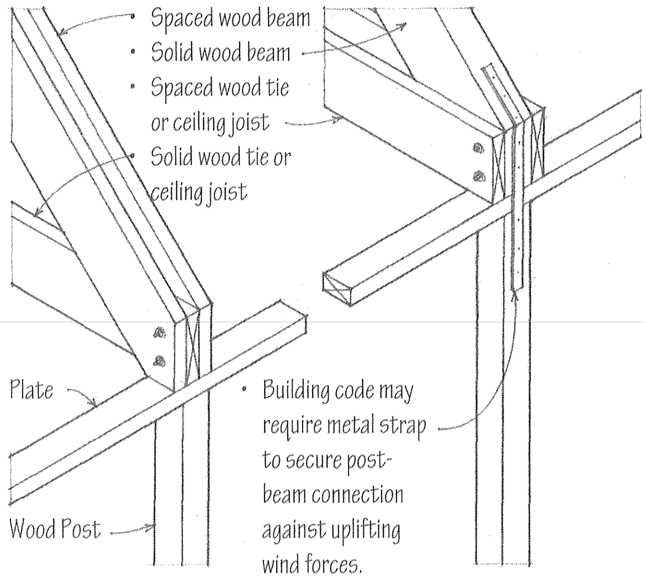


The roof beams may be spaced close enough to be spanned with wood decking. Spaced further apart, the beams can support a series of secondary beams parallel with the slope.

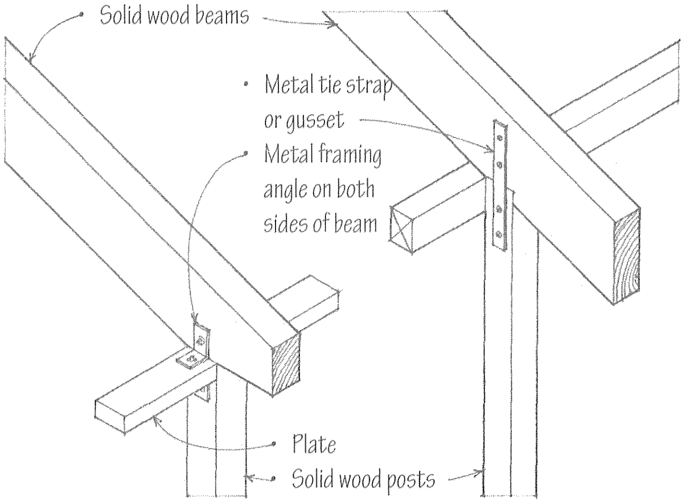
Roof Beams Perpendicular to Slope



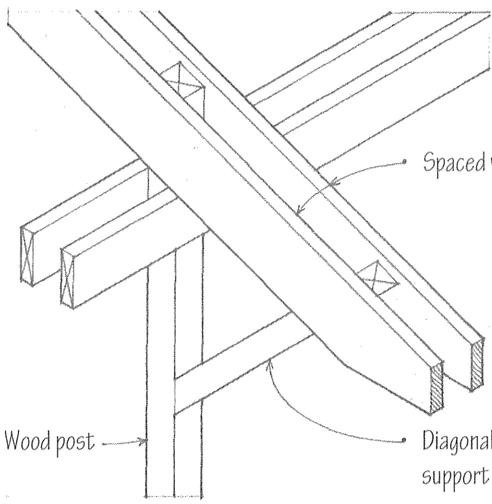
Ridge Connection



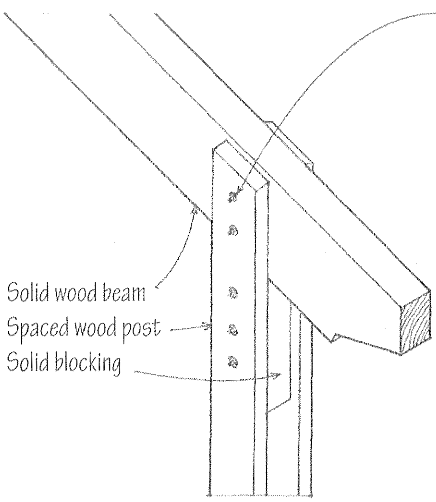
Post-Beam Connection



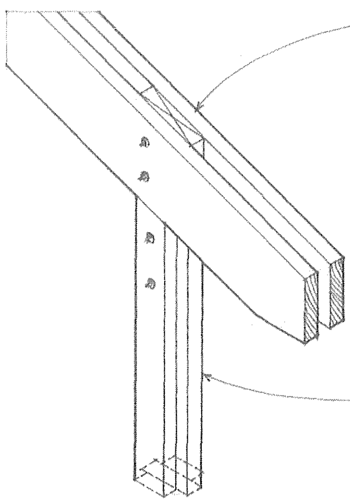
Post-Beam Connection



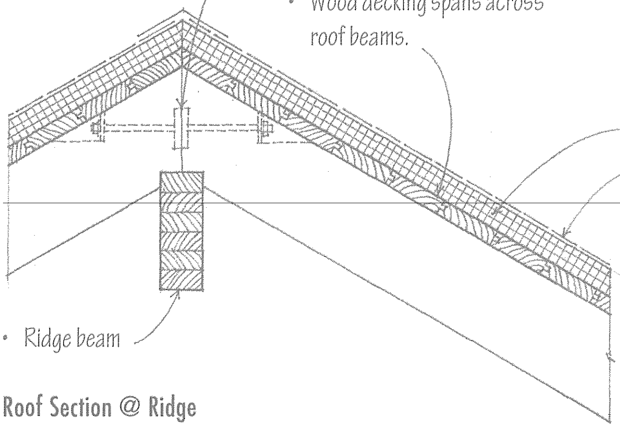
Post-Beam Connection



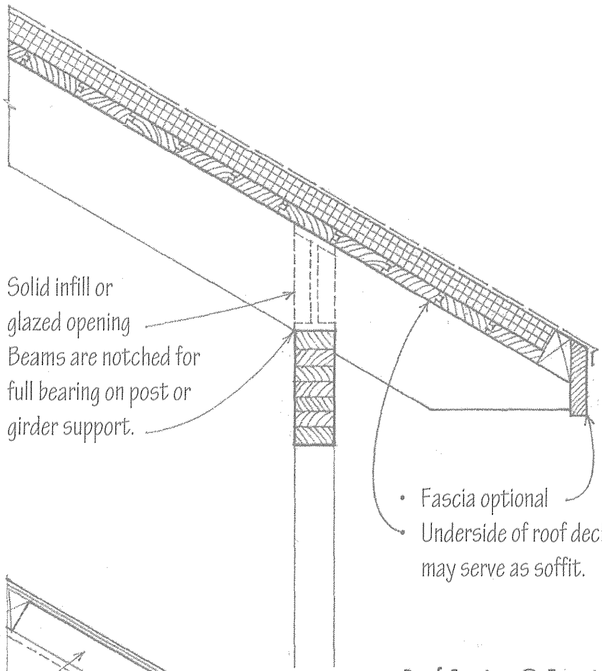
Post-Beam Connection



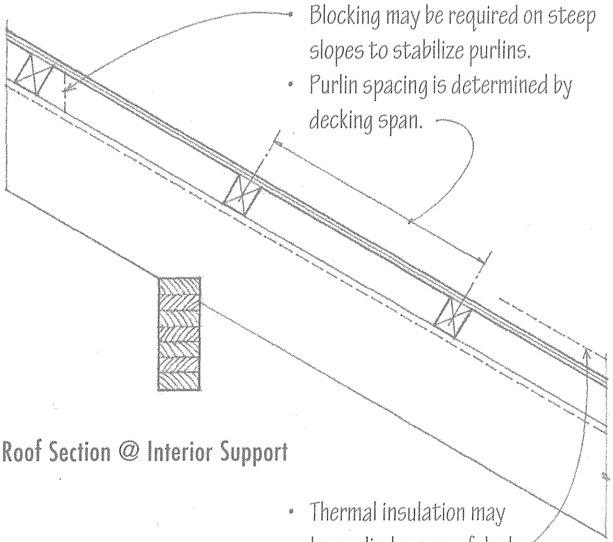
Post-Beam Connection



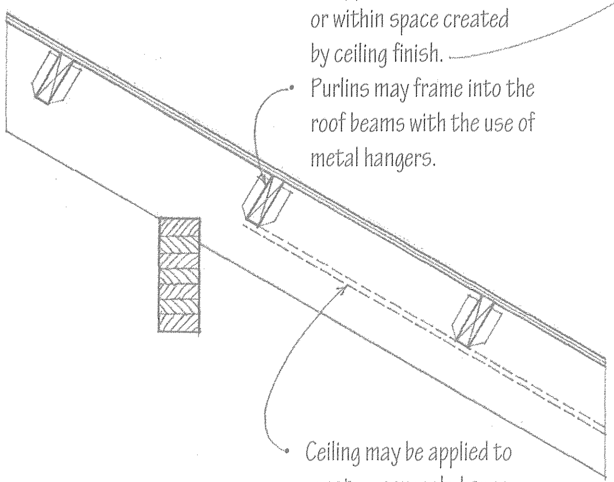
Roof Section @ Ridge



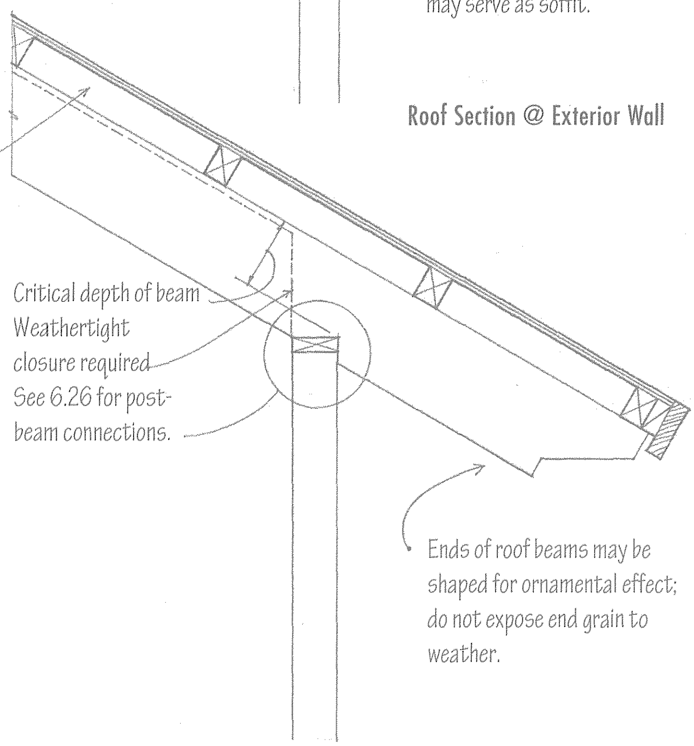
Roof Section @ Exterior Wall



Roof Section @ Interior Support



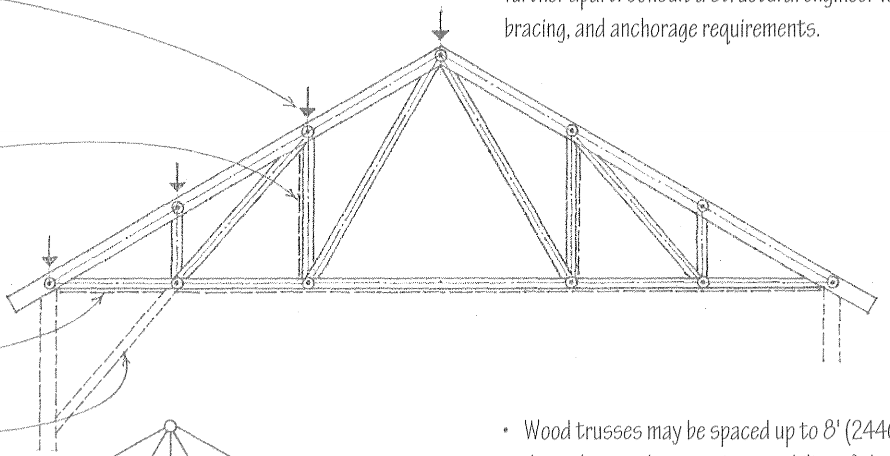
Roof Section @ Interior Support

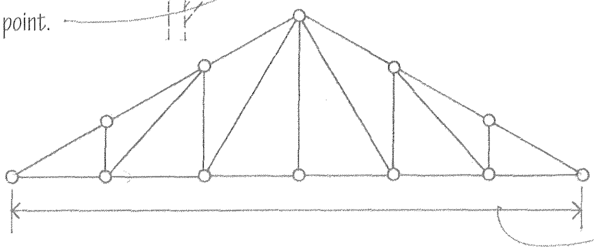


Roof Section @ Exterior Wall

In contrast to monoplanar trussed rafters, heavier wood trusses can be assembled by layering multiple members and joining them at the panel points with split-ring connectors. These wood trusses are capable of carrying greater loads than trussed rafters and are spaced further apart. Consult a structural engineer for design, bracing, and anchorage requirements.

- To avoid additional bending stresses in truss members, loads should be applied at panel points.
- Vertical sway bracing may be required between the top and bottom chords of adjacent trusses to provide resistance against lateral wind and seismic forces.
- Horizontal cross-bracing may be required in the plane of the top or bottom chord if the diaphragm action of the roof framing is not adequate for end-wall forces.
- Any knee bracing should connect to the top or bottom chord at a panel point.

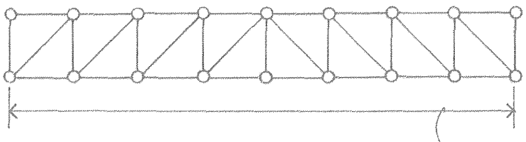




- Wood trusses may be spaced up to 8' (2440) o.c., depending on the spanning capability of the roof decking or planking. When purlins span across the trusses, the truss spacing may be increased up to 20' (6095).

Span range for shaped trusses: 40' to 150' (12 to 45 m)

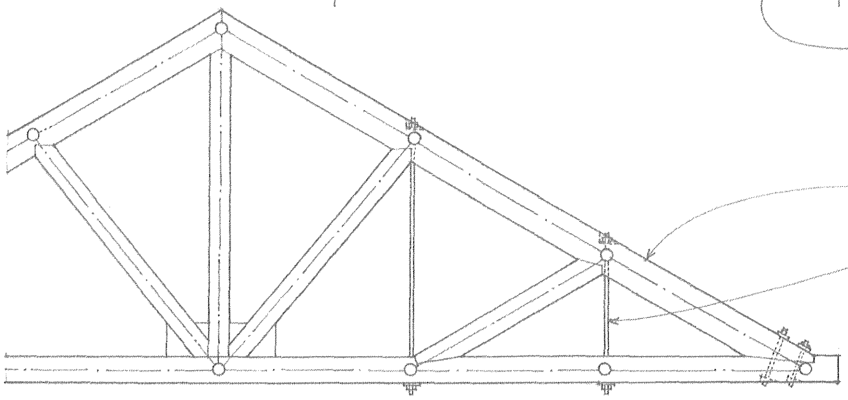
- Depth range for shaped trusses: span/2 to span/6



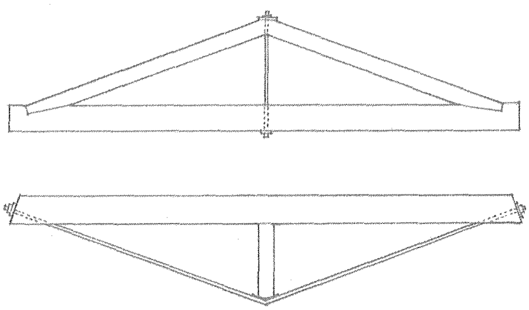
- See 6.09 for a description of truss configurations.

Span range for flat trusses: 40' to 110' (12 to 33 m)

- Depth range for flat trusses: span/10 to span/15

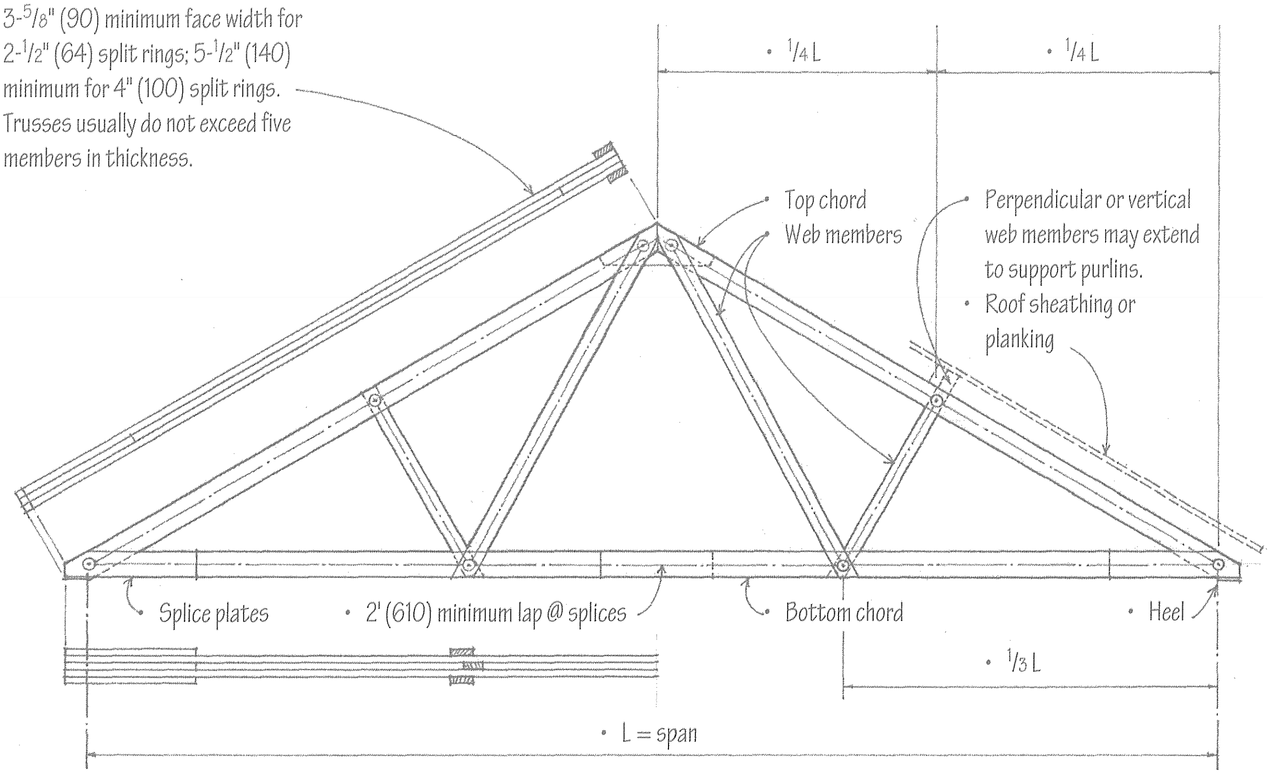


- Composite trusses have timber compression members and steel tension members.
- Truss rods are metal tie rods that serve as tension members in a truss or trussed beam.



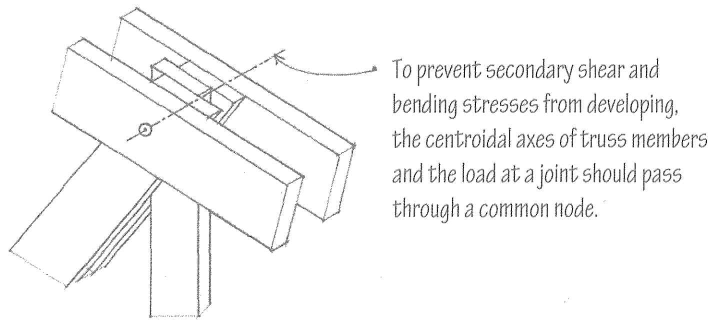
- Trussed beams are timber beams stiffened by a combination of diagonal truss rods and either compression struts or suspension rods.

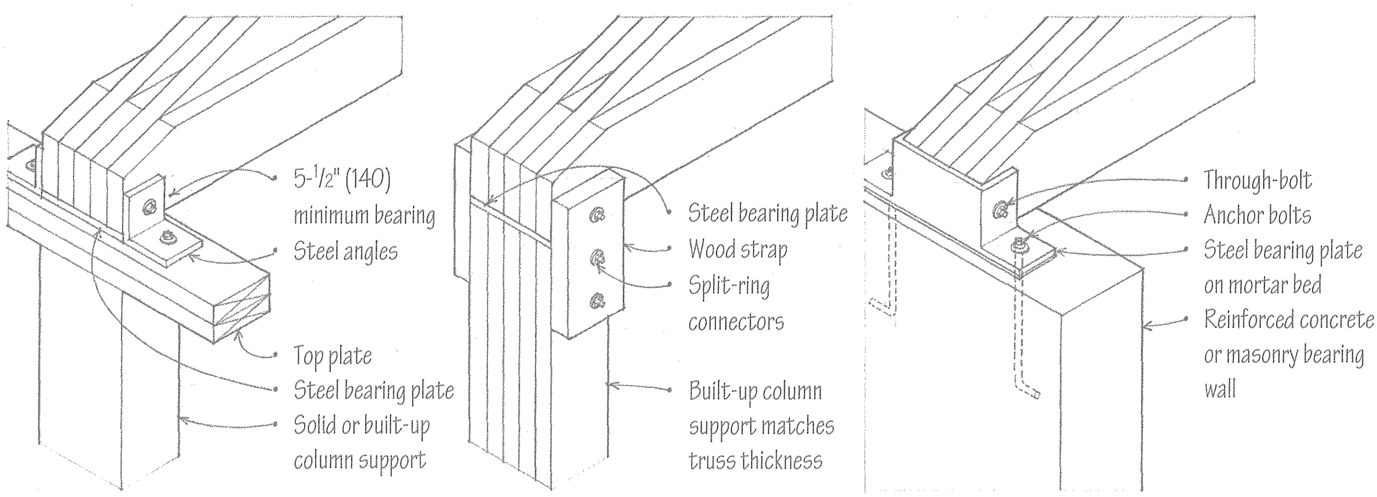
- Members are 2x or 3x material; 3-5/8" (90) minimum face width for 2-1/2" (64) split rings; 5-1/2" (140) minimum for 4" (100) split rings.
- Trusses usually do not exceed five members in thickness.



Example of a Belgian Truss

- Member sizes and joint details are determined by engineering calculations based on truss type, load pattern, span, and grade and species of lumber used.
- The size of compression members is generally governed by buckling while the size of tension members is controlled by tensile stresses at connections.
- Consult building code for minimum member thicknesses if trusses are to qualify as heavy timber construction.

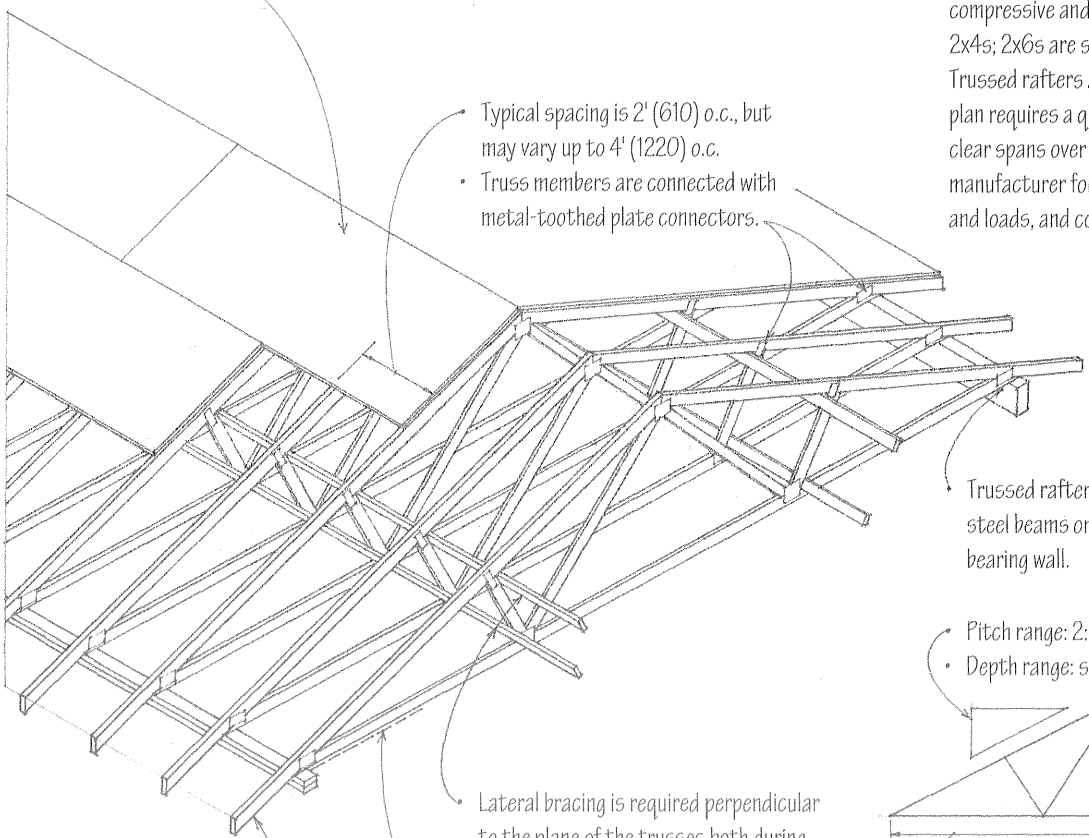




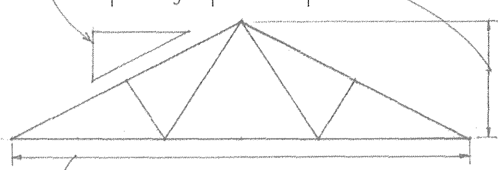
Heel Joints

Wood trussed rafters are pre-engineered and shop-fabricated monoplanar trusses. Because the individual members are subject primarily to compressive and tensile forces, they are typically 2x4s; 2x6s are sometimes used for the top chord. Trussed rafters are best used when a rectangular plan requires a quantity of a single truss type and clear spans over 18' (5485). Consult the truss manufacturer for configurations, allowable spans and loads, and construction details.

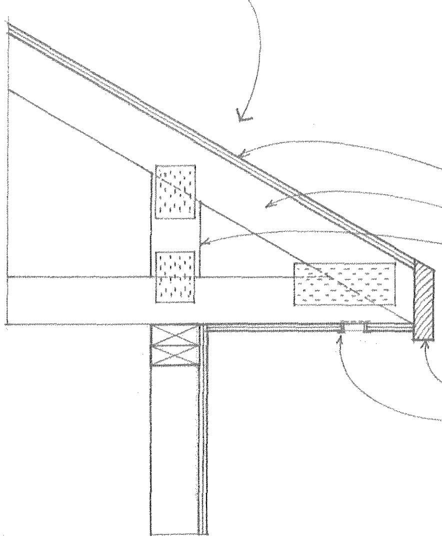
- Sheathing requirements are similar to those for conventional rafter framing; see 6.23.
- Typical spacing is 2' (610) o.c., but may vary up to 4' (1220) o.c.
- Truss members are connected with metal-toothed plate connectors.



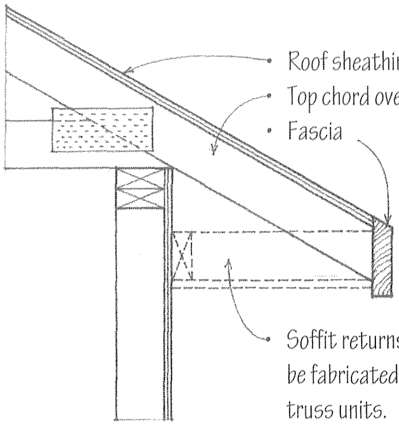
- Trussed rafters may be supported by timber or steel beams or by a stud-framed or masonry bearing wall.
- Pitch range: 2:12 to 8:12
- Depth range: span/10 to span/20



- Trussed rafters typically span from 20' to 32' (6095 to 9755); up to 60' (18 m) spans are possible.
- See 6.09 for a description of truss configurations.
- 2' (610) maximum extension of top chord for overhangs
- Greater overhangs up to the 1/4 points are possible with the use of wedge blocks or struts.
- Lateral bracing is required perpendicular to the plane of the trusses both during installation and after erection.
- A ceiling may be applied directly to the bottom chords. For trusses spaced more than 2' (610) o.c., furring strips may be required to support the ceiling material.
- Thermal insulation as well as electrical and mechanical equipment may be accommodated within the truss depth.

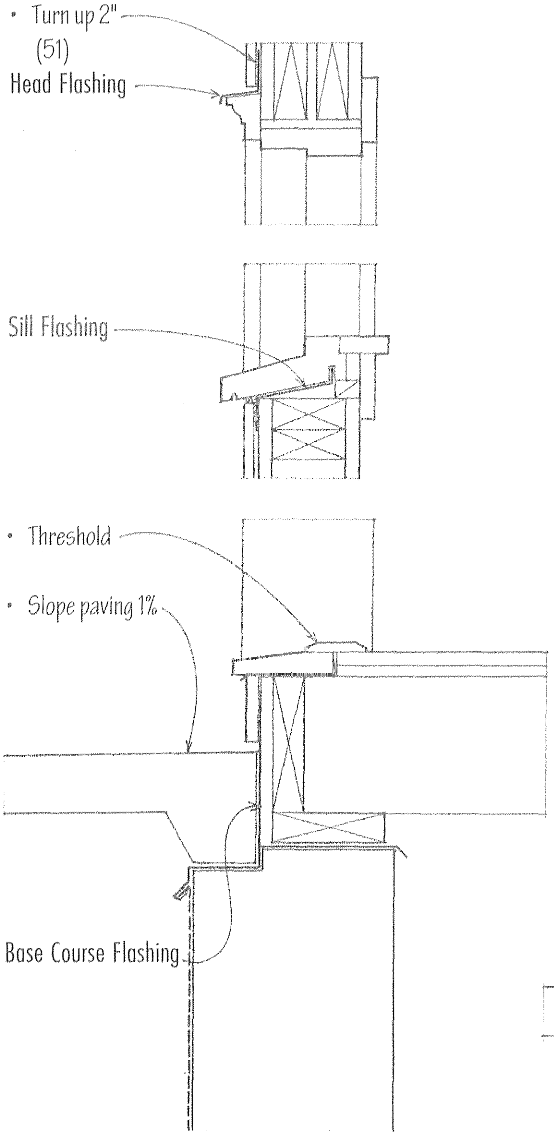


Soffited Eave

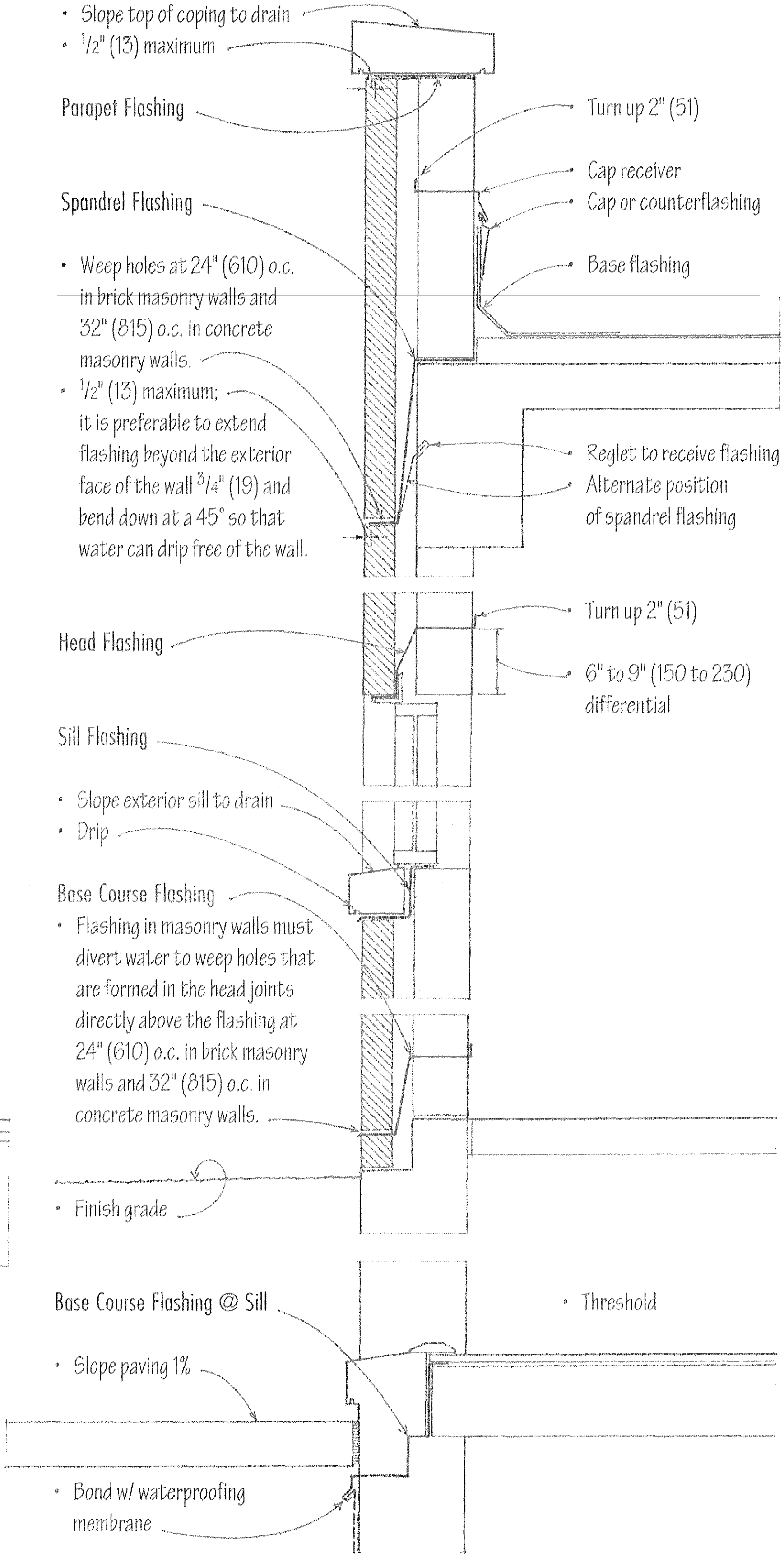


Overhanging Eave

Wall flashing is installed to collect any moisture that may penetrate a wall and divert it to the outside through weep holes. The drawings on this page illustrate where wall flashing is usually required. Masonry walls are especially susceptible to water penetration. Rain penetration can be controlled by properly tooling mortar joints, sealing joints such as those around window and door openings, and sloping the horizontal surfaces of sills and copings. Cavity walls are especially effective in resisting the penetration of water.



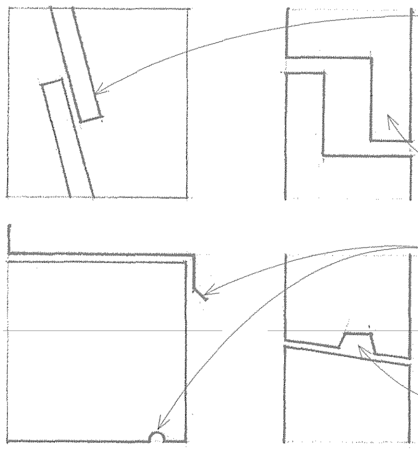
Stud-Framed Wall



Masonry Wall

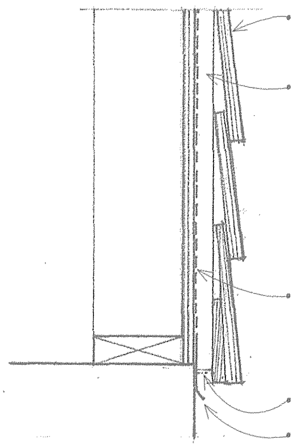
Water can penetrate exterior wall joints and assemblies by the kinetic energy of raindrops, gravity flow, surface tension, capillary action, and pressure differential. According to how exterior walls deter water penetration, they can be categorized as follows:

- Mass wall systems, such as concrete and solid masonry walls, shed most rain at the exterior face, absorb the remainder, and dry by releasing the absorbed moisture as vapor.
- Barrier wall systems, such as EIFS walls, rely on a continuous seal at the exterior face, which requires ongoing maintenance to be effective in resisting solar radiation, thermal movement, and cracking.
- Drainage walls, such as traditional stucco and clapboard walls, utilize a drainage plane or moisture barrier between the exterior cladding and supporting wall for additional moisture resistance.
- Rainscreen walls consist of an outer layer of cladding (the rainscreen), an air cavity, and a drainage plane on a rigid, water-resistant, and airtight support wall.



- Lapping horizontal joints in shingle fashion, sealing vertical joints, and sloping horizontal surfaces away from the interior can stem gravity flow.
- Overlapping materials or internal baffles deflect the kinetic energy of wind-driven raindrops.
- Drips break the surface tension that causes water to cling to and flow along the underside of horizontal, or nearly horizontal, surfaces.
- Discontinuities or air gaps disrupt the capillary movement of water.

Simple rainscreen walls, such as brick cavity walls and furred-out clapboard walls, rely on cladding to shed most of the rain while the air cavity serves as a drainage layer to remove any water that may penetrate the outer layer. The cavity should be wide enough to prevent the capillary movement of this water from bridging the cavity and reaching the support wall.

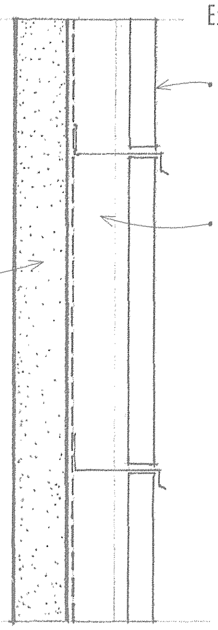


- Lapped or shngled siding serves as a rainscreen.
- Furring strips space the siding material away from the wall framing, creating a vented cavity that is drained and back-ventilated to promote evaporation of any collected water.
- Sheathing and a weather barrier behind the furring strips create a drainage plane.
- Insect screening
- Metal flashing and drip

Pressure differential can drive water through an opening in a wall assembly, no matter how small, when water is present on one side of the opening, and the air pressure on that side is greater than that on the other side. Pressure-equalized rainscreen (PER) walls utilize vented cladding and an air cavity, often divided into drainable compartments, to facilitate pressure equalization with the outside atmosphere and limit water penetration through joints in the cladding assembly. The primary seals against air and vapor are located on the indoor side of the air cavity, where they are exposed to little if any water.

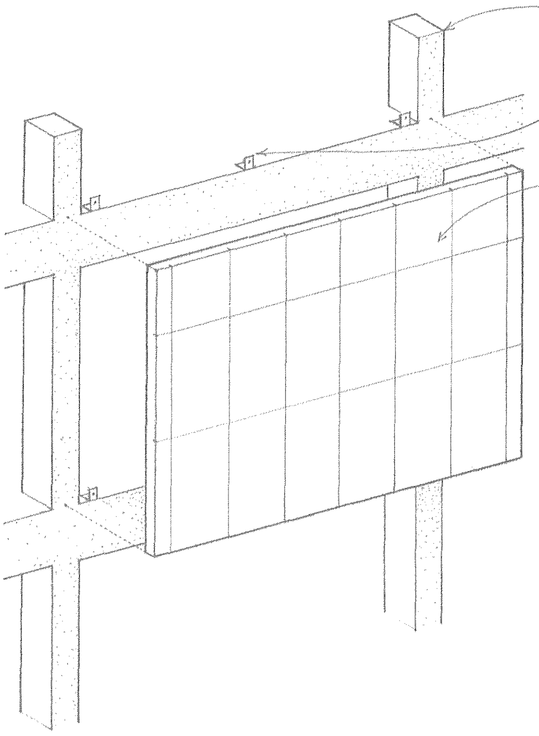
Interior Side

- An air-barrier system contains the primary joint seals, controls the flow of air and noise through the wall, and is airtight and rigid enough to withstand wind pressures.
- Thermal insulation is situated on the indoor side of the air cavity. The air barrier itself may be a continuous membrane placed on either side of the insulation or either side of the interior wall layer.



Exterior Side

- Vented cladding (the rainscreen) deflects the kinetic force of rain and deters water penetration at the exterior face of a wall.
- An air cavity provides a place for the equalization of air pressure to occur, is wide enough to prevent the capillary movement of water, and serves as a drainage layer for any water that manages to penetrate the rainscreen.



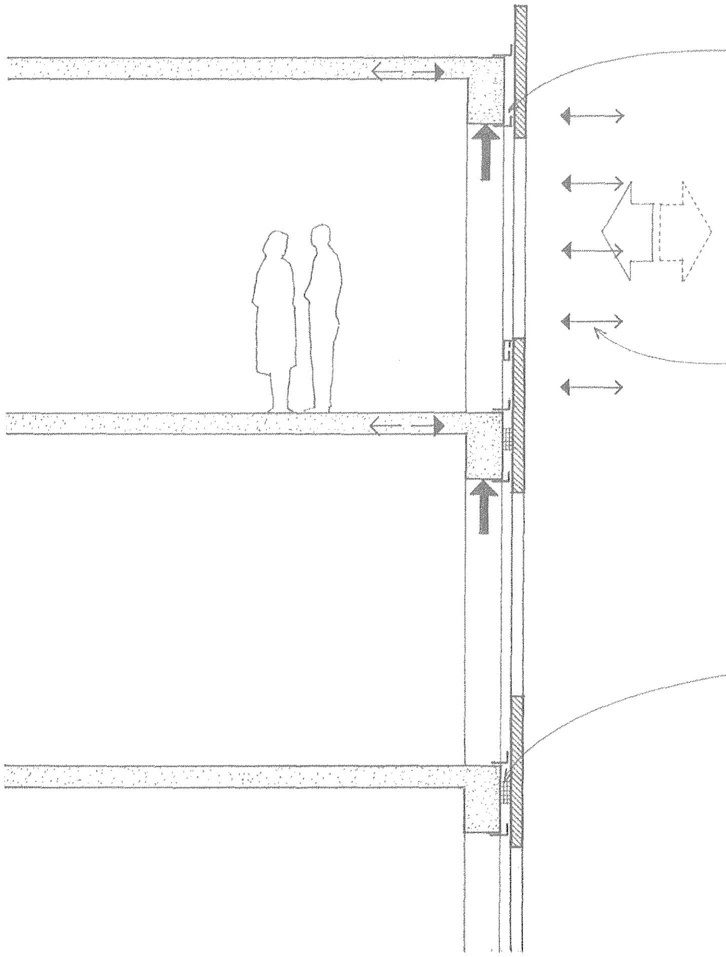
- Structural steel or reinforced concrete frame
- Anchors
- Wall panels of precast concrete, cut stone, brick masonry, or metal
- For glazed curtain wall systems, see 8.31.

A curtain wall is an exterior wall supported wholly by the steel or concrete structural frame of a building and carrying no loads other than its own weight and wind loads. A curtain wall may consist of metal framing holding either vision glass or opaque spandrel units, or of thin veneer panels of concrete, stone, masonry, or metal.

Panel systems consist entirely of precast concrete, masonry, or cut stone units. The wall units may be one, two, or three stories in height, and may be preglazed or glazed after installation. Panel systems offer controlled shop assembly and rapid erection, but are bulky to ship and handle.

While simple in theory, curtain wall construction is complex and requires careful development, testing, and erection. Close coordination is also required between the architect, structural engineer, contractor, and a fabricator who is experienced in curtain wall construction.

As with other exterior walls, a curtain wall must be able to withstand the following elements:



Loads

- The curtain wall panels must be adequately supported by the structural frame.
- Any deflection or deformation of the structural frame under loading should not be transferred to the curtain wall.
- Seismic design requires the use of energy-absorbing connections.

Wind

- Wind can create both positive and negative pressure on a wall, depending on its direction and the shape and height of the building.
- The wall must be able to transfer any wind loads to the structural frame of the building without excessive deflection. Wind-induced movement of the wall should be anticipated in the design of its joints and connections.

Fire

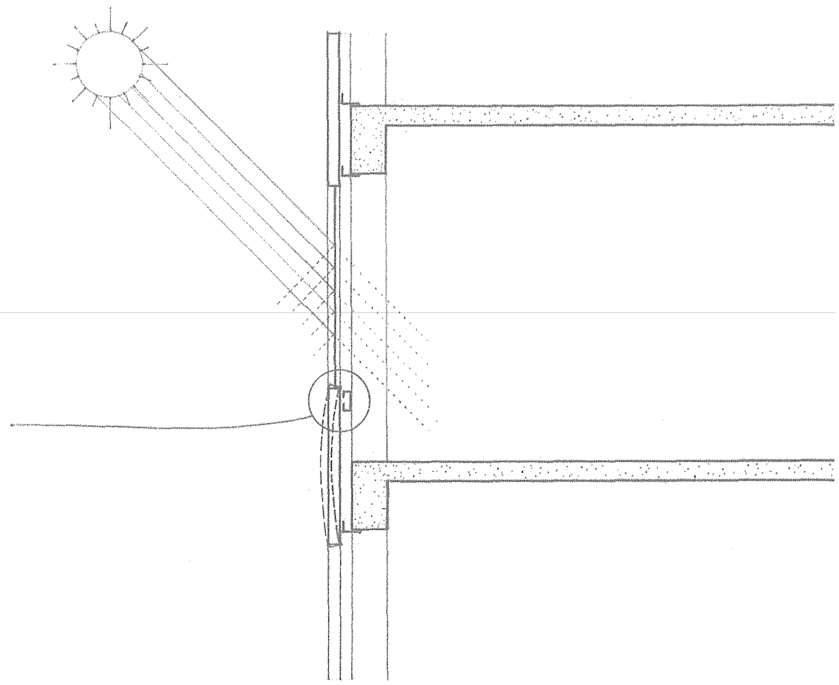
- A noncombustible material, sometimes referred to as safing, must be installed to prevent the spread of fire at each floor within column covers and between the wall panels and the slab edge or spandrel beam.
- The building code also specifies the fire-resistance requirements for the structural frame and the curtain wall panels themselves.

Sun

- Brightness and glare should be controlled with shading devices or the use of reflective or tinted glass.
- The ultraviolet rays of the sun can also cause deterioration of joint and glazing materials and fading of interior furnishings.

Temperature

- Daily and seasonal variations in temperature cause expansion and contraction of the materials comprising a wall assembly, especially metals. Allowance must be made for differential movement caused by the variable thermal expansion of different materials.
- Joints and sealants must be able to withstand the movement caused by thermal stresses.
- Heat flow through glazed curtain walls should be controlled by using insulating glass, insulating opaque panels, and by incorporating thermal breaks into metal frames.
- Thermal insulation of veneer panels may also be incorporated into the wall units, attached to their backsides, or provided with a backup wall constructed on site.

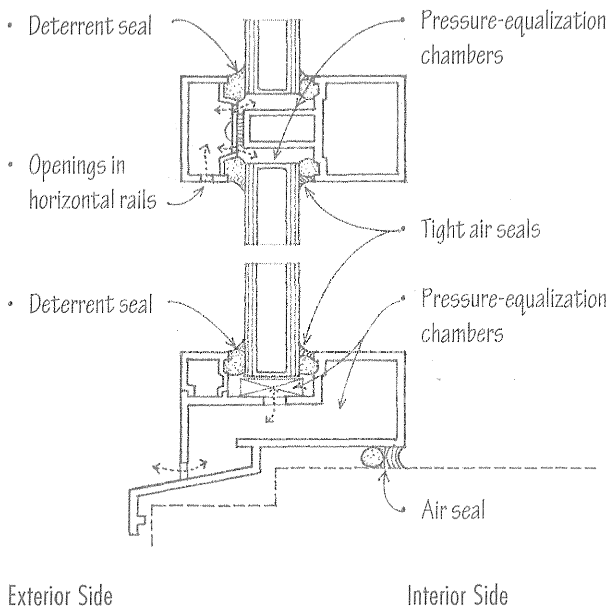


Water

- Rain can collect on the wall surface and be wind-driven under pressure through the smallest openings.
- Water vapor that condenses and collects within the wall must be drained to the outside.

Pressure-Equalized Design

The pressure-equalized design principles outlined on page 7.23 become critical in the detailing of curtain walls, especially in larger and taller buildings, where the pressure differential between the outside atmosphere and an interior environment can cause rainwater to migrate through even the smallest openings in wall joints.



Application of Pressure-Equalization Principle in Glazed Curtain Wall

The primary purpose of thermal insulation is to control the flow or transfer of heat through the exterior assemblies of a building and thereby prevent excessive heat loss in cold seasons and heat gain in hot weather. This control can effectively reduce the amount of energy required by heating and cooling equipment to maintain conditions for human comfort in a building.

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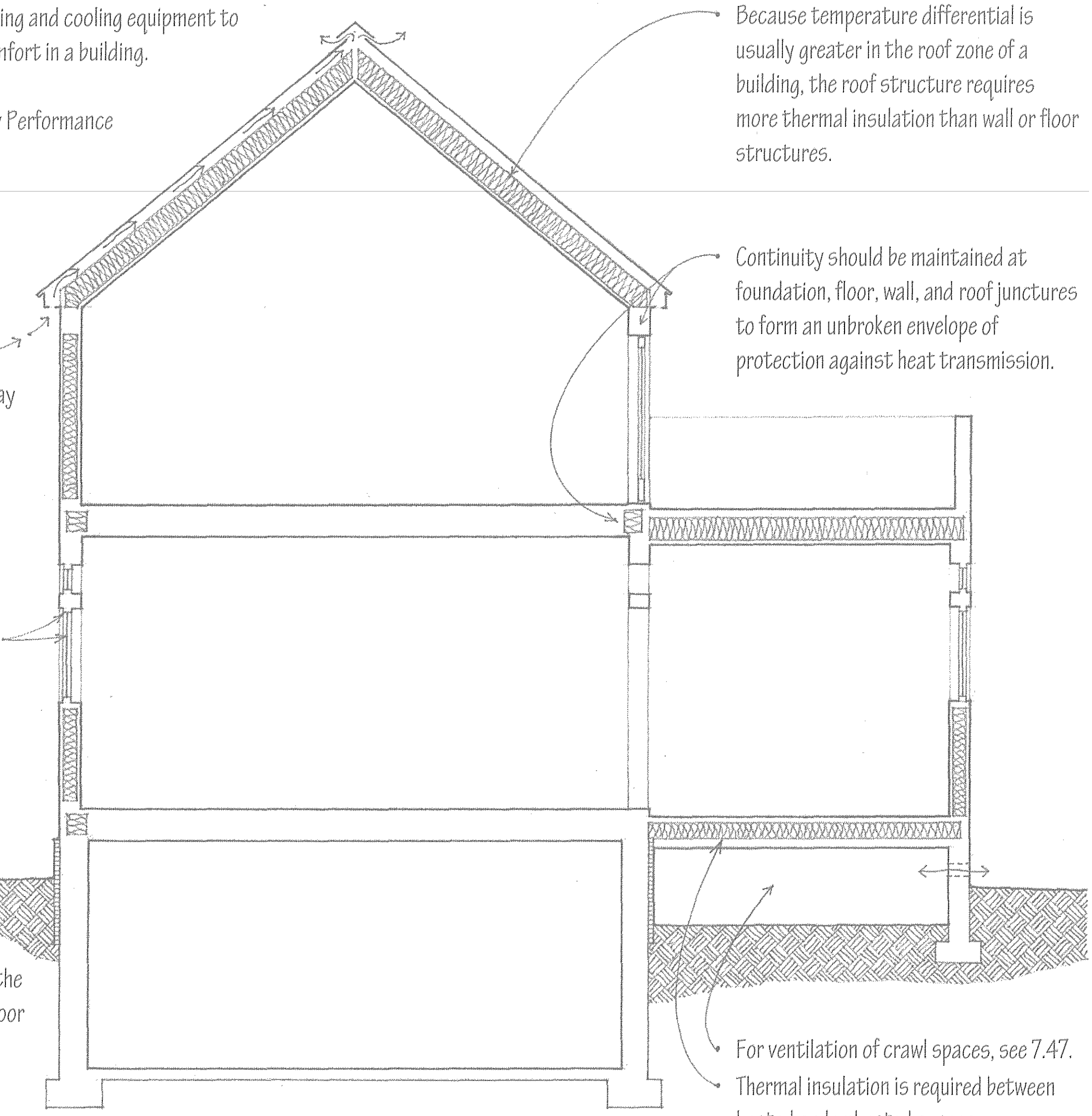
Because temperature differential is usually greater in the roof zone of a building, the roof structure requires more thermal insulation than wall or floor structures.

Continuity should be maintained at foundation, floor, wall, and roof junctures to form an unbroken envelope of protection against heat transmission.



- Concealed roof spaces require ventilation to dissipate any stray water vapor; see 7.47.
- Insulating glass and weatherstripping limit heat transfer at windows and doors.
- The temperature differential between basement spaces and the ground is less than between indoor spaces and the outdoors above grade.

- For ventilation of crawl spaces, see 7.47.
- Thermal insulation is required between heated and unheated spaces.

Recommended Minimum Thermal Resistances of Building Insulation*

Zone	Ceiling or Roof	Exterior Wall	Floor over Unheated Space
Minimum recommended	19	11	11
Southern zone	26	13	11
Temperate zone	30	19	19
Northern zone	38	19	22

* Use these R-values only for preliminary design. Consult the local or state energy code for specific requirements.

- For a discussion of the factors that affect human comfort, see 11.03.
- For siting factors that also affect potential heat loss or gain, see Chapter 1.

7.40 THERMAL RESISTANCE OF BUILDING MATERIALS

Material	1/k*	1/C†
Concrete		
Concrete		
Sand & gravel aggregate	0.08	
Lightweight aggregate	0.60	
Cement mortar	0.20	
Stucco	0.20	
Masonry		
Common brick	0.20	
Face brick	0.11	
Concrete block, 8" (205)		
Sand & gravel aggregate		1.11
Lightweight aggregate		2.00
Granite and marble	0.05	
Sandstone	0.08	
Metal		
Aluminum	0.0007	
Brass	0.0010	
Copper	0.0004	
Lead	0.0041	
Steel	0.0032	
Wood		
Hardwoods	0.91	
Softwoods	1.25	
Plywood	1.25	
Particleboard, 5/8" (16)		0.82
Wood fiberboard	2.00	
Roofing		
Built-up roofing		0.33
Fiberglass shingles		0.44
Slate roofing		0.05
Wood shingles		0.94
Siding		
Aluminum siding		0.61
Wood shingles		0.87
Wood bevel siding		0.81
Vinyl siding		1.00

Material	1/k*	1/C†
Building Paper		
Vapor-permeable felt		0.06
Polyethylene film		0.00
Plaster & Gypsum		
Cement plaster,		
sand aggregate	0.20	
Gypsum plaster,		
sand aggregate	0.18	
perlite aggregate	0.67	
Gypsum board, 1/2" (13)		0.45
Flooring		
Carpet & pad		1.50
Hardwood, 25/32" (20)		0.71
Terrazzo		0.08
Vinyl tile		0.05
Doors		
Steel, mineral fiber core		1.69
Steel, polystyrene core		2.13
Steel, urethane core		5.56
Wood hollow core, 1-3/4" (45)		2.04
Wood solid core, 1-3/4" (45)		3.13
Glass		
Single, clear, 1/4" (6)		0.88
Double, clear, 3/16" (5)space		1.61
1/4" (6) space		1.72
1/2" (13) space		2.04
Double, blue/clear		2.25
gray/clear		2.40
green/clear		2.50
Double, clear, low-e coating		3.23
Triple, clear		2.56
Glass block, 4" (100)		1.79
Air Space		
3/4" (19), nonreflective		1.01
3/4" (19), reflective		3.48

* 1/k = R per inch of thickness

† 1/C = R for the thickness indicated

The tables to the left can be used to estimate the thermal resistance of a construction assembly. For specific R-values of materials and building components such as windows, consult the product manufacturer.

- R is a measure of thermal resistance of a given material. It is expressed as the temperature difference required to cause heat to flow through a unit area of material at the rate of one heat unit per hour.

  R = F°/Btu/hr • sf

- R_t is the total thermal resistance for a construction assembly and is simply the sum of the individual R-values of the component materials of an assembly.

- U is a measure of the thermal transmittance of a building component or assembly. It is expressed as the rate of heat transfer through a unit area of a building component or assembly caused by a difference of one degree between the air temperatures on the two sides of the component or assembly. The U-value for a component or assembly is the reciprocal of its R-value.

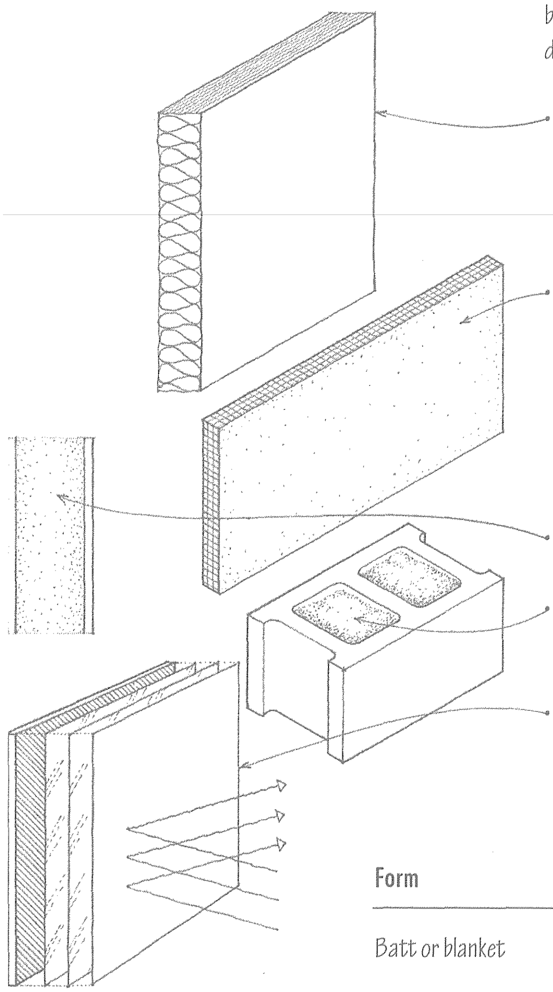
  $U = 1/R_t$

- Q is the rate of heat flow through a construction assembly and is equal to:

  $U \times A \times (t_i - t_o)$, where:

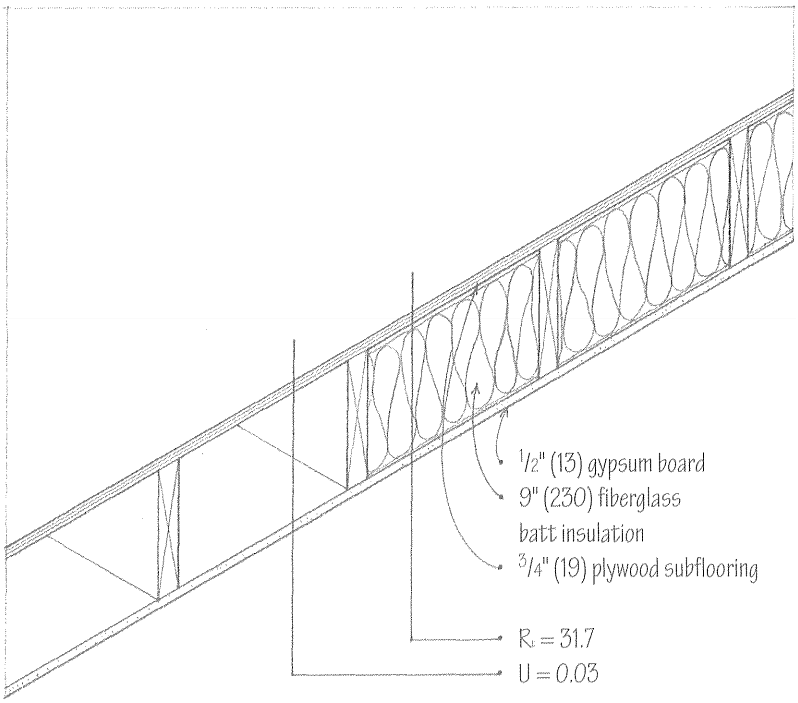
- U = overall coefficient of assembly
- A = exposed area of assembly
- $(t_i - t_o)$ = difference between the inside and outside air temperatures

Almost all building materials offer some resistance to heat flow. To achieve the desired R_t value, however, wall, floor, and roof assemblies usually require the addition of an insulating material. Below is an outline of the basic materials used to insulate the components and assemblies of a building. Note that all effective insulating materials usually incorporate some form of captured dead air space.



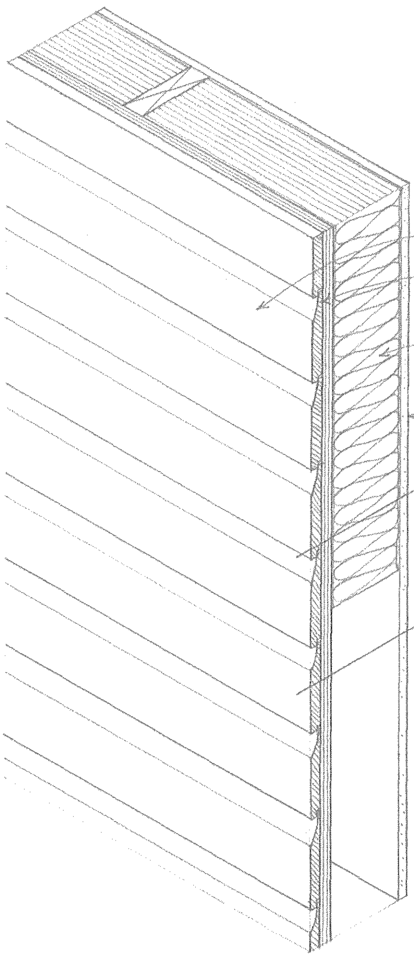
- Batt insulation consists of flexible, fibrous thermal insulation of glass or mineral wool, made in various thicknesses and lengths and in 16" or 24" (406 or 610) widths to fit between studs, joists, and rafters in light wood frame construction, sometimes faced with a vapor retarder of kraft paper, metal foil, or plastic sheet. Batt insulation is also as a component in sound-insulating construction.
- Rigid foam insulation is a preformed, nonstructural insulating board of foamed plastic or cellular glass. Cellular glass insulation is fire-resistant, impervious to moisture, and dimensionally stable, but has a lower thermal-resistance value than foamed plastic insulations, which are flammable and must be protected by a thermal barrier when used on the interior surfaces of a building. Rigid insulation having closed-cell structures, as extruded polystyrene and cellular glass, are moisture-resistant and may be used in contact with the earth.
- Foamed-in-place insulation consists of a foamed plastic, as polyurethane, that is sprayed or injected into a cavity where it adheres to the surrounding surfaces.
- Loose-fill insulation consists of mineral wool fibers, granular vermiculite or perlite, or treated cellulosic fibers, poured by hand or blown through a nozzle into a cavity or over a supporting membrane.
- Reflective insulation utilizes a material of high reflectivity and low emissivity, as paper-backed aluminum foil or foil-backed gypsum board, in conjunction with a dead-air space to reduce the transfer of heat by radiation.

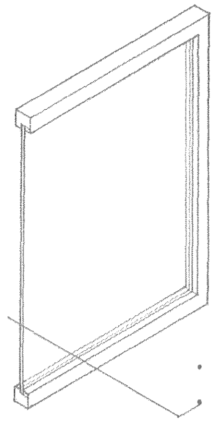
Form	Material	R-value per Inch of Thickness	
Batt or blanket	Fiberglass	3.3	Installed between studs, joists, rafters, or furring;
	Rock wool	3.3	considered incombustible except for paper facing
Rigid board	Cellular glass	2.5	Boards may be applied over a roof deck, over wall
	Polystyrene, molded	3.6	framing as sheathing, in cavity walls, or beneath an
	Polystyrene, extruded	5	interior finish material; the plastics are combustible
	Polyurethane, expanded	6.2	and give off toxic fumes when burned; extruded
	Polyisocyanurate	7.2	polystyrene can be used in contact with the earth but
	Perlite, expanded	2.6	any exposed surfaces should be protected from sunlight
Foamed in place	Polyurethane	6.2	Used to insulate irregularly shaped spaces
Loose fill	Cellulose	3.7	Used to insulate attic floors and wall cavities; cellulose
	Perlite	2.7	may be combined with adhesives for sprayed application;
	Vermiculite	2.1	cellulose should be treated and UL-listed for fire resistance
Cast	Insulating concrete	1.12	Used primarily as an insulating layer under membrane roofing; insulating value depends on its density

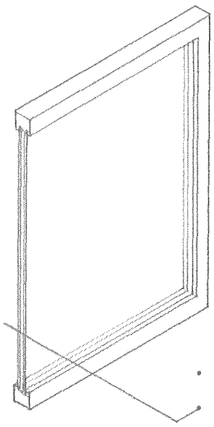


The steady state method for calculating heat loss or gain takes into account primarily the total thermal resistance (R_t) of the construction assembly and the differential in air temperature. Other factors that affect heat loss or gain are:

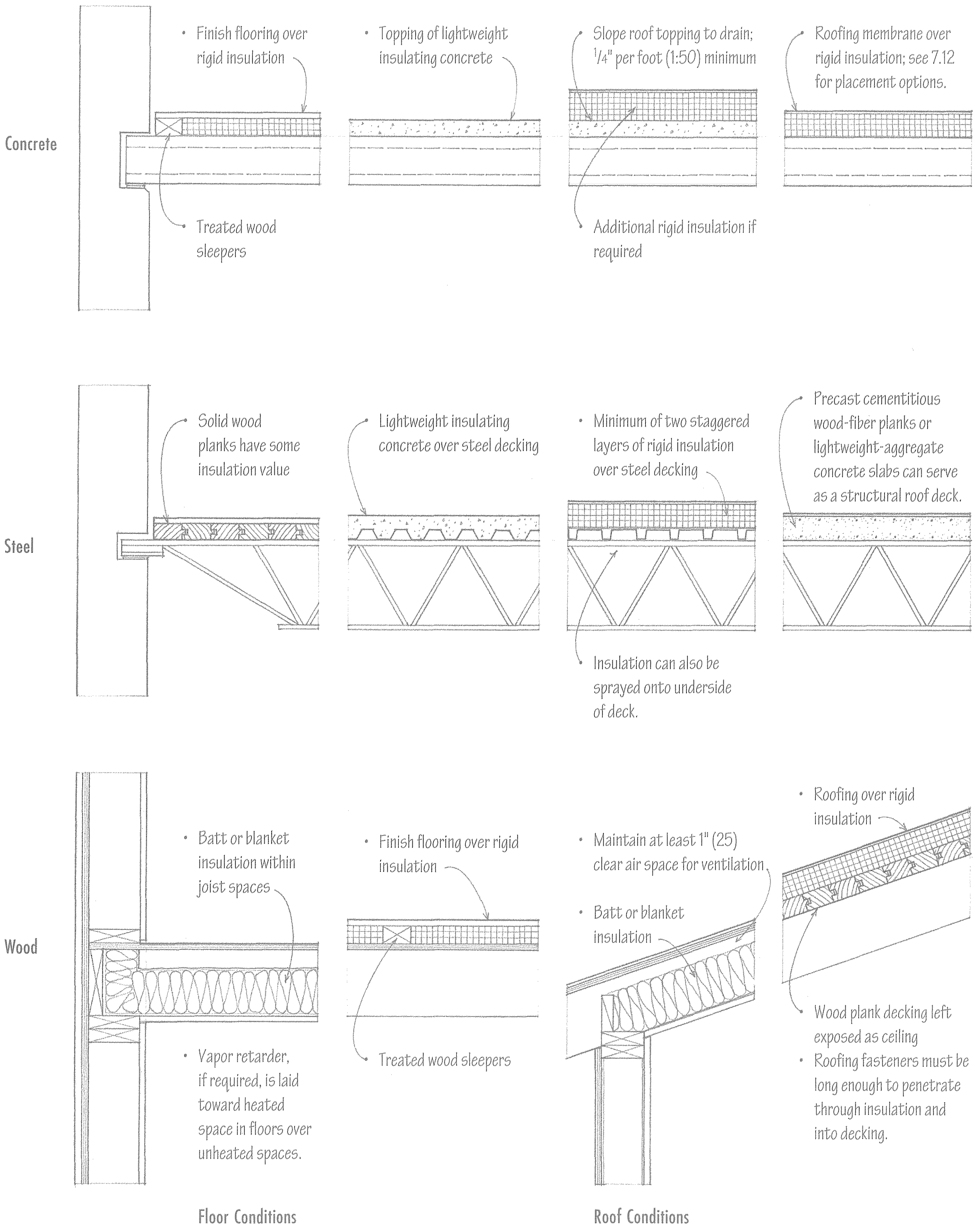
- The surface color and reflectivity of the materials used; light colors and shiny surfaces tend to reflect more thermal radiation than dark, textured ones.
- The mass of the assembly, which affects the time lag or delay before any absorbed and stored heat is released by the structure; time lag becomes a significant factor with thick, dense materials.
- The orientation of the exterior surfaces of a building, which affects solar heat gain as well as exposure to wind and the attendant potential for air infiltration.
- Latent heat sources and heat gain from the occupants, lighting, and equipment within a building.
- Proper installation of thermal insulation and vapor retarders.

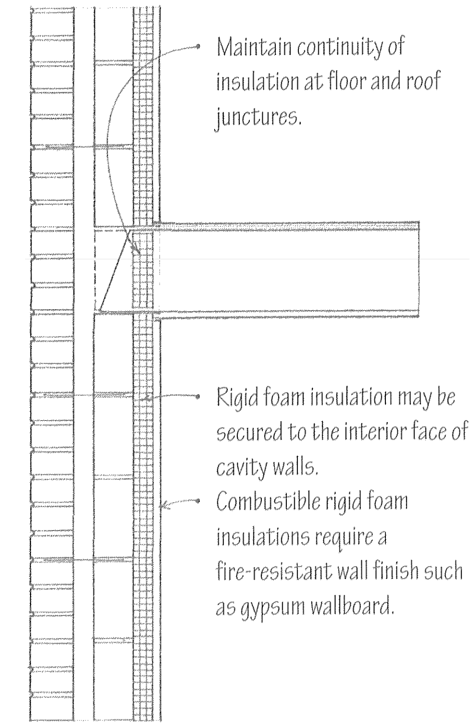






Comparison of R-values for Insulated and Uninsulated Assemblies

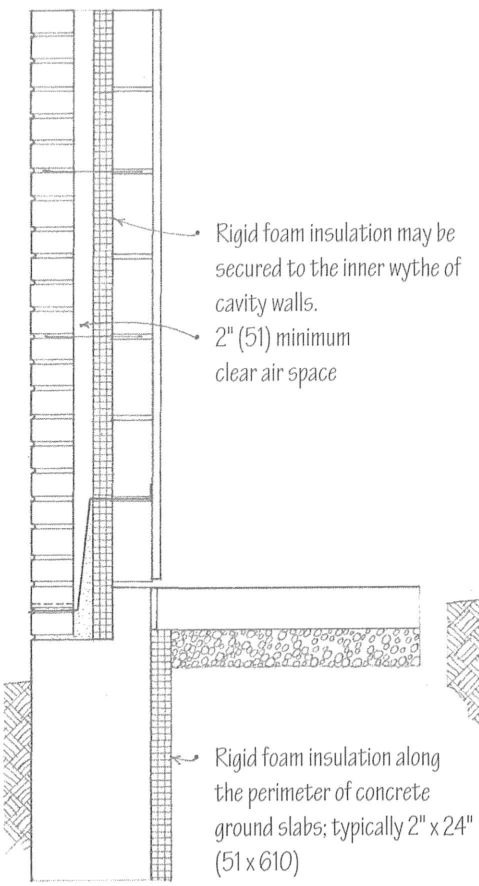

Concrete
Finish flooring over rigid insulation
Treated wood sleepers
Topping of lightweight insulating concrete
Slope roof topping to drain; 1/4" per foot (1:50) minimum
Additional rigid insulation if required
Roofing membrane over rigid insulation; see 7.12 for placement options.
Steel
Solid wood planks have some insulation value
Lightweight insulating concrete over steel decking
Minimum of two staggered layers of rigid insulation over steel decking
Insulation can also be sprayed onto underside of deck.
Precast cementitious wood-fiber planks or lightweight-aggregate concrete slabs can serve as a structural roof deck.
Wood
Batt or blanket insulation within joist spaces
Vapor retarder, if required, is laid toward heated space in floors over unheated spaces.
Finish flooring over rigid insulation
Treated wood sleepers
Maintain at least 1" (25) clear air space for ventilation
Batt or blanket insulation
Roofing over rigid insulation
Wood plank decking left exposed as ceiling
Roofing fasteners must be long enough to penetrate through insulation and into decking.
Floor Conditions
Roof Conditions



Maintain continuity of insulation at floor and roof junctures.

Rigid foam insulation may be secured to the interior face of cavity walls.

Combustible rigid foam insulations require a fire-resistant wall finish such as gypsum wallboard.

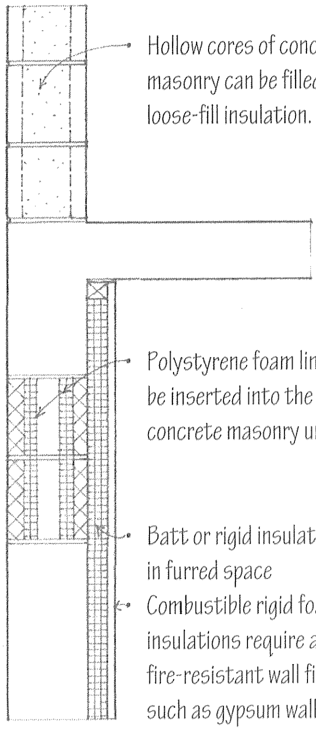


Rigid foam insulation may be secured to the inner wythe of cavity walls.

2" (51) minimum clear air space

Rigid foam insulation along the perimeter of concrete ground slabs; typically 2" x 24" (51 x 610)

Masonry Cavity Walls

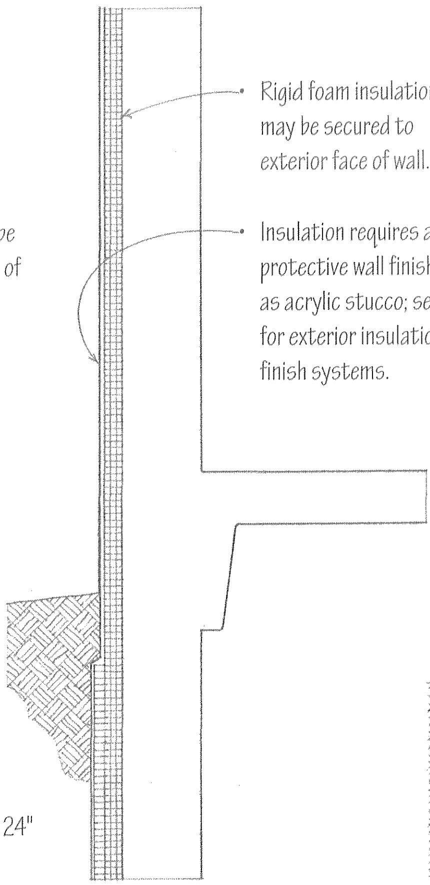


Hollow cores of concrete masonry can be filled with a loose-fill insulation.

Polystyrene foam liners may be inserted into the cores of concrete masonry units.

Batt or rigid insulation in furred space

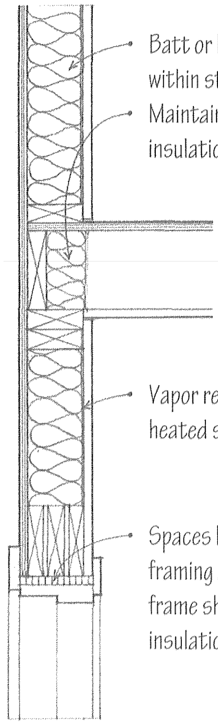
Combustible rigid foam insulations require a fire-resistant wall finish such as gypsum wallboard.



Rigid foam insulation may be secured to exterior face of wall.

Insulation requires a protective wall finish such as acrylic stucco; see 7.38 for exterior insulation and finish systems.

Cast Concrete or Concrete Masonry Walls

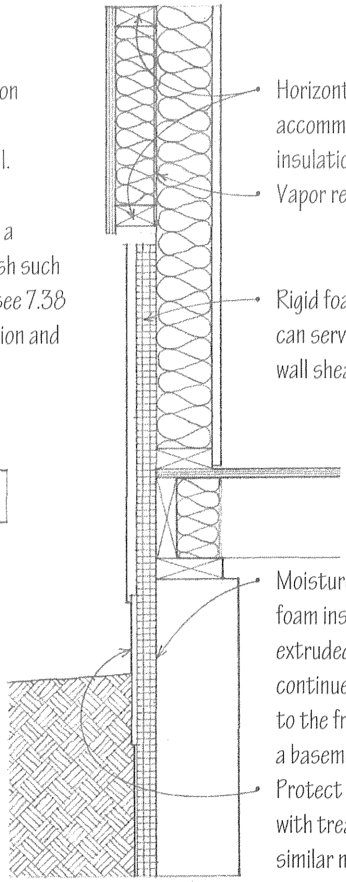


Batt or blanket insulation within stud spaces

Maintain continuity of insulation at floor junctures.

Vapor retarder on warm or heated side of wall

Spaces between rough framing and window or door frame should be filled with insulation.



Horizontal framing to accommodate additional insulation, if required

Vapor retarder

Rigid foam insulation panels can serve as nonstructural wall sheathing.

Moisture-resistant foam insulation such as extruded polystyrene can continue down below grade to the frost line to insulate a basement space.

Protect exposed surfaces with treated plywood or similar material.

Stud Frame Walls

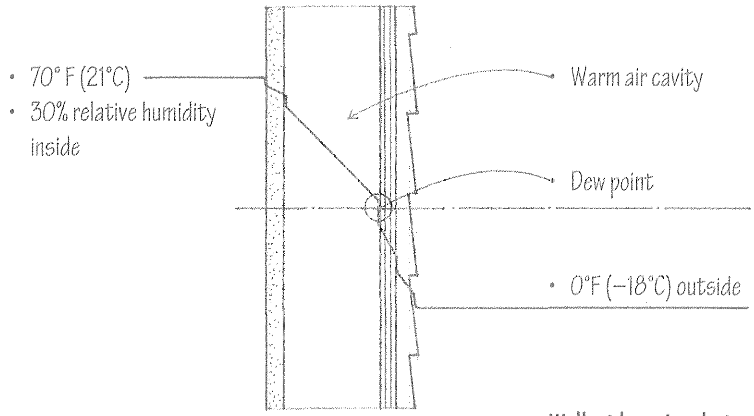
Moisture is normally present in the air as water vapor. Evaporation from occupants and equipment can raise the humidity of the air in a building. This moisture vapor will transform itself into a liquid state or condense when the air in which it exists becomes completely saturated with all the vapor it can hold and reaches its dew point temperature. Warm air is capable of holding more moisture vapor and has a higher dew point than cooler air.

Because it is a gas, moisture vapor always migrates from high to lower pressure areas. This normally means it tends to diffuse from the higher humidity levels of a building's interior toward the lower humidity levels outside. This flow is reversed when hot, humid conditions exist outdoors and a building's interior spaces are cooler. Most building materials offer little resistance to this passage of moisture vapor. If the moisture vapor comes into contact with a cool surface whose temperature is at or below the dew point of the air, it will condense.

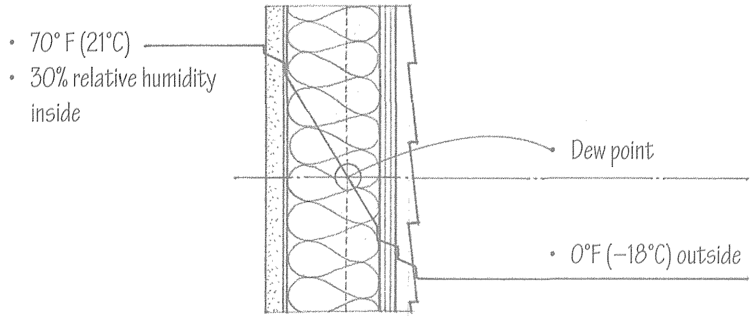
Condensation can lessen the effectiveness of thermal insulation, be absorbed by building materials, and deteriorate finishes. Moisture vapor, therefore, must be:

- Prevented by vapor retarders from penetrating the enclosed spaces of exterior construction;
- Or be allowed to escape, by means of ventilation, before it can condense into a liquid.

- Surface condensation on windows can be controlled by raising the surface temperature with a warm air supply or by using double or triple glazing.



Wall without Insulation



Wall with Insulation

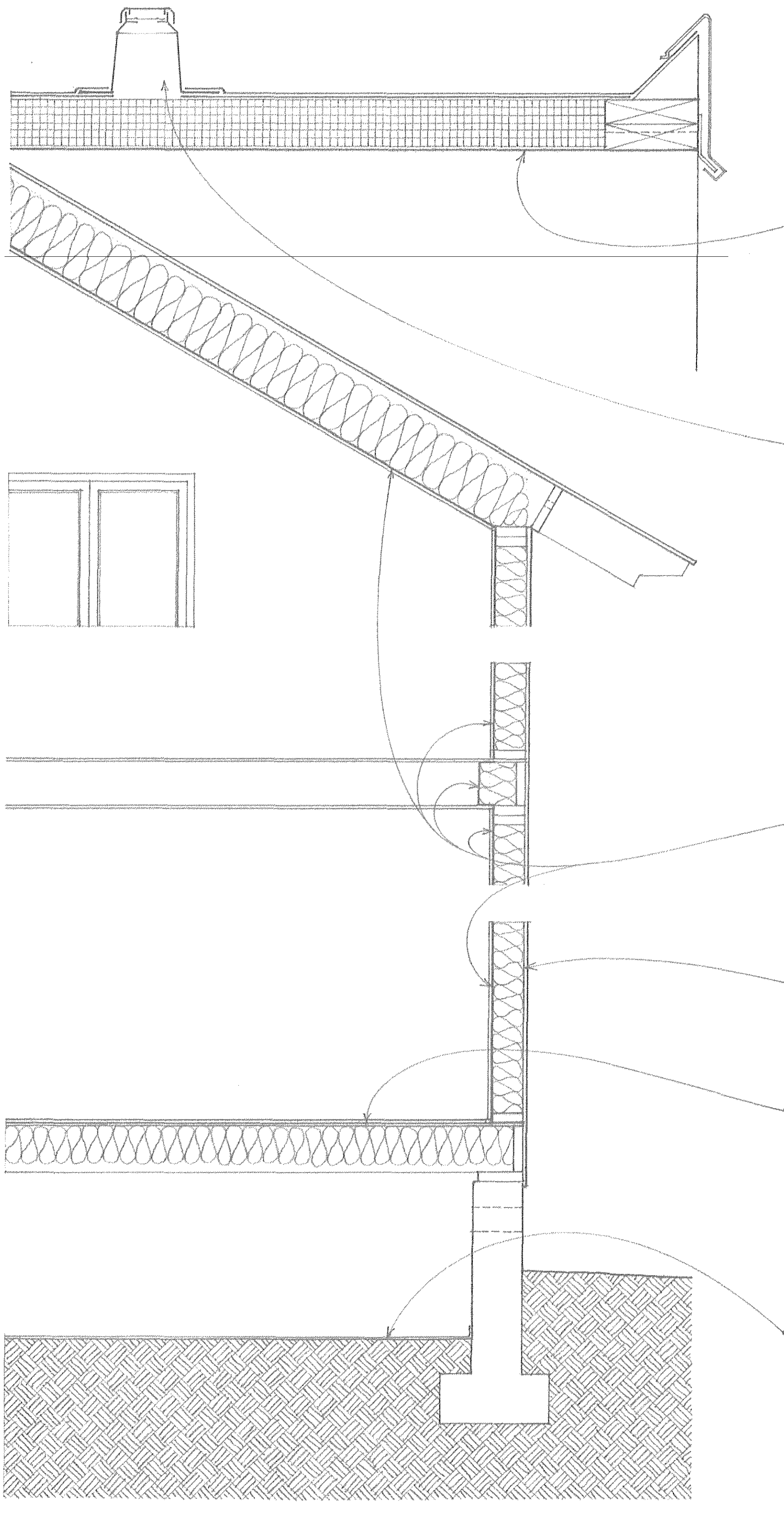
- Wall requires a vapor retarder to prevent water vapor from condensing within the layer of insulation. A vapor retarder becomes more important as the level of thermal insulation increases.

Permeability of Some Building Materials

Material	Permeance (perms)*
Brick, 4" (100)	0.800
Concrete, 1" (25)	3.200
Concrete block, 8" (205)	2.400
Gypsum board, 3/8" (10)	50.000
Plaster, 3/4" (19)	15.000
Plywood, 1/4" (6), exterior glue	0.700
Built-up roofing	0.000
Aluminum foil, 1 mil	0.000
Polyethylene, 4 mil	0.080
Polyethylene, 6 mil	0.060
Duplex sheet, asphalt + foil	0.002
Asphalt-saturated + coated paper	0.200
Kraft paper, foil-faced	0.500
Blanket insulation, faced	0.400
Cellular glass	0.000
Polystyrene, molded	2.000
Polystyrene, extruded	1.200
Paint, two coats, exterior	0.900

* Perm is a unit of water vapor transmission, expressed in grains of vapor per one square foot per hour per inch of mercury pressure difference.

A vapor retarder is a material of low permeance installed in a construction to prevent moisture from entering and reaching a point where it can condense into a liquid. Vapor retarders are normally placed as close as possible to the warm side of insulated construction in temperate and cold climates. In warm, humid climates, the vapor retarder may have to be placed closer to the outer face of the construction.



- The use of a vapor retarder is generally recommended to protect the insulation layer of flat roof assemblies in geographic locations where the average outdoor temperature in January is below 40°F (4°C) and the interior relative humidity in winter is 45% or greater at 68°F (20°C).
- The barrier may be in the form of asphalt-saturated roofing felt or a proprietary material of low permeance.
- When a vapor retarder is present, topside vents may be required to allow any trapped moisture to escape from between the vapor retarder and the roofing membrane. Consult roofing manufacturer for recommendations.

- Some rigid foam insulation boards have inherent vapor resistance, while other insulating materials have a vapor-retarding facing. A vapor retarder is most effective, however, when it is applied as a separate layer of aluminum foil, polyethylene film, or treated paper.

- Vapor retarders should have a flow rating of one perm or less and be installed with all seams at joints and openings lapped and sealed. In this case, a vapor retarder is sometimes referred to as an air barrier.

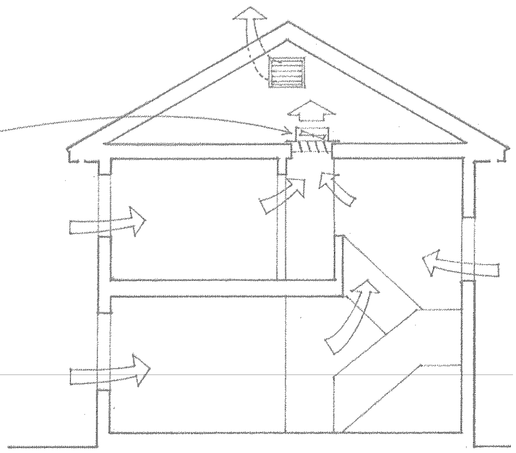
- Exterior sheathing, building paper, and siding should be permeable to allow any vapor in the wall construction to escape to the outside.

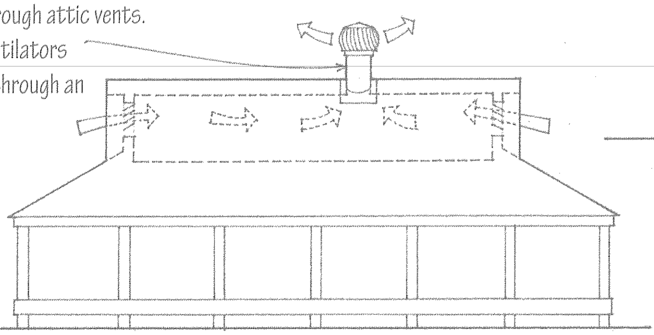
- Over unheated spaces, the vapor retarder is placed on the warm side of the insulated floor. The vapor retarder may be laid on top of the subfloor or be integral with the insulation.

- A moisture barrier, such as polyethylene film, is usually required to retard the migration of ground moisture into a crawl space.

Whole-House Ventilation

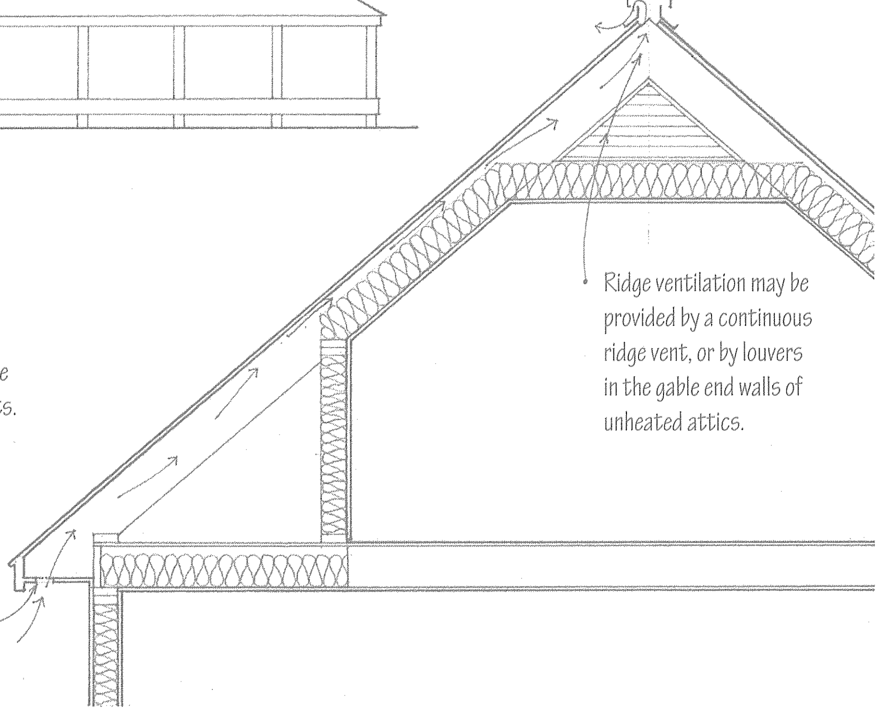
- Vapor retarders installed in a seamless manner can result in airtight construction, in which case, a forced-air ventilating system with an air-to-air heat exchanger is required to rid interior spaces of moisture, odors, and pollutants.
- Whole-house ventilators are motor-driven fans for pulling stale air from the living areas of a house and exhausting it through attic vents.
- Wind- or motor-driven attic ventilators can assist the natural air flow through an attic space.





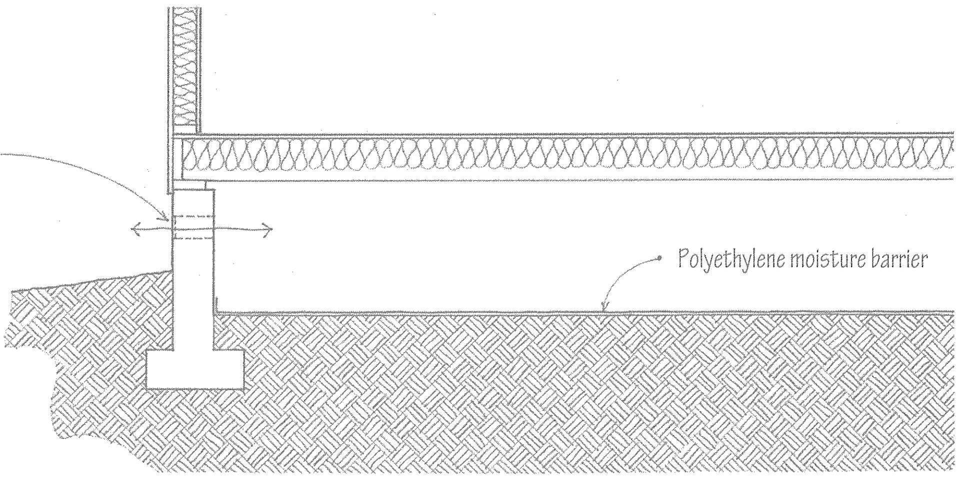
Roof and Attic Ventilation

- Ventilation of concealed roof spaces and attics is provided by eave vents and, on sloping roofs, by vents close to the ridge. The total net free ventilating area should be at least 1/300th of the area being vented, with at least 50% of the required area being at or along the ridge. Openings should be protected against the penetration of rain, snow, and insects.
- Eave or soffit vents may consist of a continuous screened vent slot or a metal vent strip installed in the eave soffit, or comprise a series of evenly distributed circular plug vents in frieze boards.

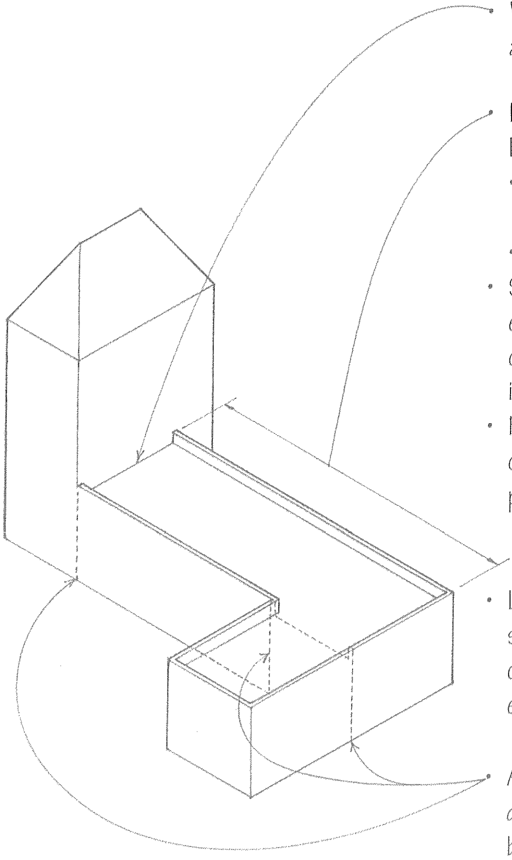


Crawl Space Ventilation

- Unheated crawl spaces also require ventilation. Openings should have a net area of at least 1-1/4 sf (0.14 m^2) for each 25 lineal feet (7620) of perimeter wall. There should be at least one opening on each side of the crawl space, located as high as possible and near a corner to promote cross ventilation. Openings should be protected against insects and vermin with wire mesh screening.



CSI MasterFormat 07 71 00 Roof Specialties
CSI MasterFormat 08 90 00 Louvers and Vents



- Where a new building adjoins an existing structure
- Long surface areas; maximum length without expansion joints:
  - Steel, concrete, or built-up roofing – 200' (60 m)
  - Masonry – 125' (38 m)
- Surfaces with severe solar exposure require expansion or control joints at more frequent intervals.
- Parapet walls require expansion or control joints near corners to prevent their displacement.
- Long, linear building elements, such as fascias, gravel stops, and curtain wall framing also require expansion joints.
- At horizontal and vertical discontinuities in the massing of a building, such as where a low mass meets a taller mass, or at wings and intersections of L-, T-, and U-shaped buildings.

Location of Movement Joints

All building materials expand and contract in response to normal changes in temperature. Some also swell and shrink with changes in moisture content, while others deflect under loading. Joints must be constructed to allow this movement to occur in order to prevent distortion, cracking, or breaks in the building materials. Movement joints should provide a complete separation of material and allow free movement while, at the same time, maintaining the weathertightness of the construction.

Types of Movement Joints

- Expansion joints are continuous, unobstructed slots constructed between two parts of a building or structure permitting thermal or moisture expansion to occur without damage to either part. Expansion joints can often serve as control and isolation joints. See 5.22 for expansion joints in brick masonry walls, 7.29 for horizontal expansion joints in masonry veneer walls, and 10.04 for expansion joints in gypsum plaster.
- Control joints are continuous grooves or separations formed in concrete ground slabs and concrete masonry walls to form a plane of weakness and thus regulate the location and amount of cracking resulting from drying shrinkage, thermal stresses, or structural movement. See 3.19 for control joints in concrete ground slabs and 5.22 for control joints in concrete masonry walls.
- Isolation joints divide a large or geometrically complex structure into sections so that differential movement or settlement can occur between the parts. At a smaller scale, an isolation joint can also protect a nonstructural element from the deflection or movement of an abutting structural member.

Coefficients of Linear Expansion

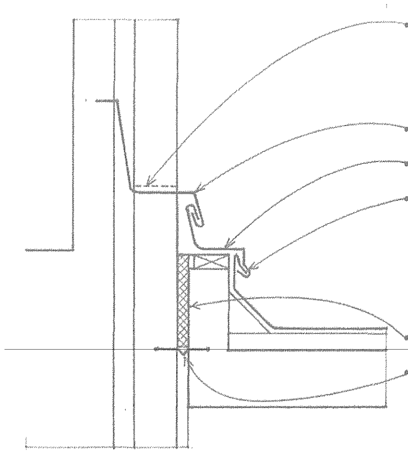
Per Unit Length Per 1 Degree Change in Temperature (°F)*

	$\times 10^{-7}$		$\times 10^{-7}$		$\times 10^{-7}$
Aluminum	128	Parallel to wood grain:		Brick masonry	34
Brass	104	Fir	21	Concrete masonry	52
Bronze	101	Maple	36	Concrete	55
Copper	93	Oak	27	Granite	47
Iron, cast	59	Pine	36	Limestone	44
Iron, wrought	67	Perpendicular to grain:		Marble	73
Lead	159	Fir	320	Plaster	76
Nickel	70	Maple	270	Rubble masonry	35
Steel, carbon	65	Oak	300	Slate	44
Steel, stainless	99	Pine	190	Glass	50

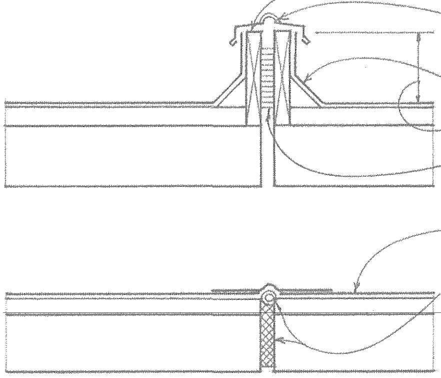
* One degree Fahrenheit is equal to approximately 0.6 degree Celsius or Centigrade. To find degrees Celsius or Centigrade, first subtract 32 from the degrees Fahrenheit and then multiply by $^5/_9$.

The width of an expansion joint depends on the building material and the temperature range involved. It varies from $^1/_4$" (6) to 1" (25) or more, and should be calculated for each specific situation.

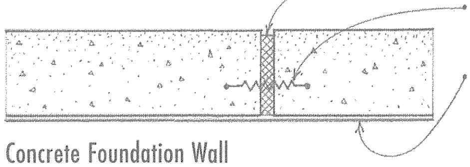
- The coefficient of surface expansion is approximately twice the linear coefficient.
- The coefficient of volume expansion is approximately three times the linear coefficient.



Wall and Roof Juncture



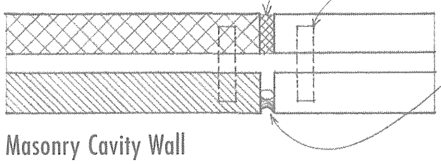
Flat Roof



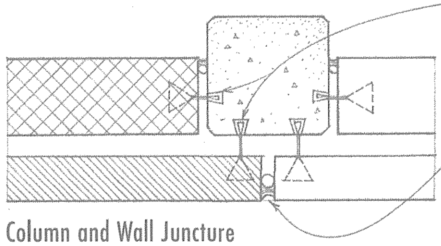
Concrete Foundation Wall

These expansion joint details, although general in nature, have the following elements in common:

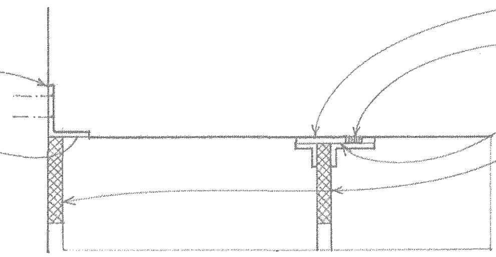
- *A joint that creates a complete break through the structure, which is then usually filled with a compressible material*
- *A weatherstop that may be in the form of an elastic joint sealant, a flexible waterstop embedded within the construction, or a flexible membrane over flat roof joints.*



Masonry Cavity Wall

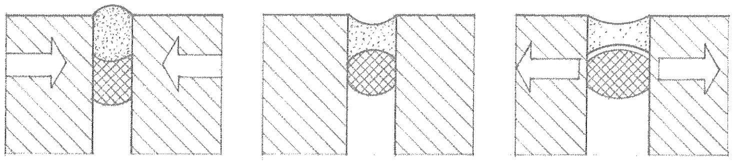


Column and Wall Juncture



Expansion Joint Covers

To provide an effective seal against the passage of water and air, a joint sealant must be durable, resilient, and have both cohesive and adhesive strength. Sealants can be classified according to the amount of extension and compression they can withstand before failure.



- Compressed
- As installed
- Elongated

Joint Movement

Low Range Sealants

- Movement capability of +/- 5%
- Oil-based or acrylic compounds
- Often referred to as caulking and used for small joints where little movement is expected

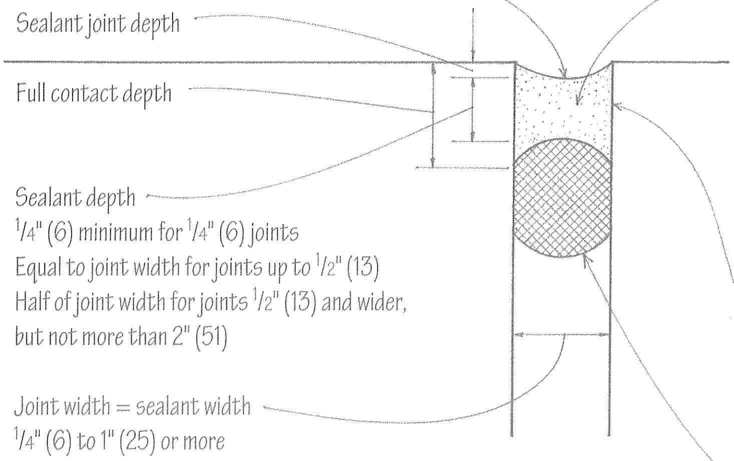
Medium Range Sealants

- Movement capability of +/- 5% to +/-10%
- Butyl rubber, acrylic, or neoprene compounds
- Used for nonworking, mechanically fastened joints

High Range Sealants

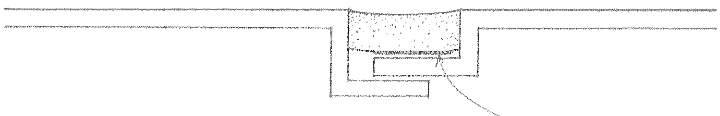
- Movement capability of +/- 12% to +/-25%
- Polymercaptans, polysulfides, polyurethanes, and silicones
- Used for working joints subject to a significant amount of movement, such as those in curtain

- Joints should be tooled to ensure full contact with and adhesion to substrate

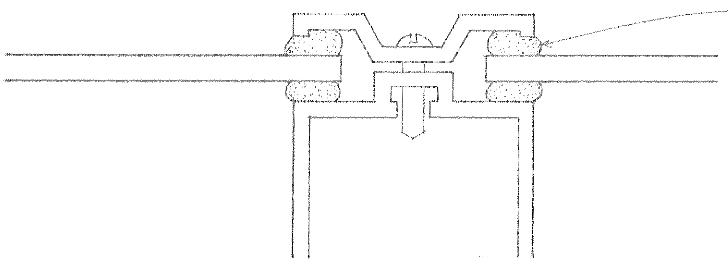


- Sealant joint depth
- Full contact depth
- Sealant depth
- 1/4" (6) minimum for 1/4" (6) joints
- Equal to joint width for joints up to 1/2" (13)
- Half of joint width for joints 1/2" (13) and wider, but not more than 2" (51)
- Joint width = sealant width
- 1/4" (6) to 1" (25) or more
- Width depends on the joint spacing, expected temperature range, anticipated movement due to wind or structural displacement, and the movement capability of the sealant.

- The substrate must be clean, dry, and compatible with the sealant material.
- A primer may be required to improve the adhesion of a sealant to the substrate.
- The joint filler controls the depth of the sealant contact with the joining parts. It should be compressible and be compatible with but not adhere to the sealant. It may be in the form of a rod or tubing of polyethylene foam, polyurethane foam, neoprene, or butyl rubber.



- When there is insufficient depth for a compressible filler, a bond breaker, such as polyethylene tape, is required to prevent adhesion between the sealant and the bottom of the joint recess.



- Most sealants are viscous liquids that cure after being applied with a hand-operated or power gun. These are referred to as gunnable sealants. Some lap joints, however, are difficult to seal with gunnable sealants. These joints may require instead a preformed solid polybutene or polyisobutylene tape sealant that is held in place under compression.