- Direct and witness functional testing and document results. Issues identified will be documented in the issues log and tracked to resolution. General contractor will schedule functional testing activities and ensure that responsible parties needed for verification are present.
- Review operation and maintenance information to ensure warranty requirements and preventive maintenance information required are part of the documentation along with a copy of the owner's project requirements and basis-of-design information.
- Witness training of O&M staff to help ensure O&M staff understand systems and their operation, warranty responsibilities, and preventive maintenance requirements.

ENVELOPE

Opaque Envelope Components

Note that the following how-to's address the recommendations in chapter 3, but they are not necessarily applicable to any specific construction project.

Good Design Practice

EN1 ***Cool Roofs* (Climate Zones: ❶ ❷ ❸)**

Cool roofs are recommended for roofs with insulation entirely above deck and metal building roofs. In order to be considered a cool roof for climate zones 1-3 the following conditions apply:

1. *The roof has a high reflectance.* The high reflectance keeps much of the sun's energy from being absorbed.
2. *The roof has a high thermal emittance*. The high emittance radiates away any solar energy that is absorbed, allowing the roof to cool more rapidly.

The radiative property values should be rated by a laboratory accredited by the Cool Roof Rating Council.

Cool roofs are typically white and have a smooth texture. Commercial roofing products that qualify as cool roofs fall in two categories: single-ply and liquid-applied. Examples of single-ply products include:

- White PVC (polyvinyl chloride)
- White CPE (chlorinated polyethylene)
- White CPSE (chlorosulfonated polyethylene, e.g., Hypalon)
- White TPO (thermoplastic polyolefin)

Liquid-applied products may be used to coat a variety of substrates. Products include:

- White elastomeric, polyurethane, or acrylic coatings
- White paint (on metal or concrete)

EN2 *Roofs, Insulation Entirely above Deck* (Climate Zones: all)

The insulation entirely above deck should be continuous insulation (c.i.) rigid boards because there are no framing members present that would introduce thermal bridges or short circuits to bypass the insulation.

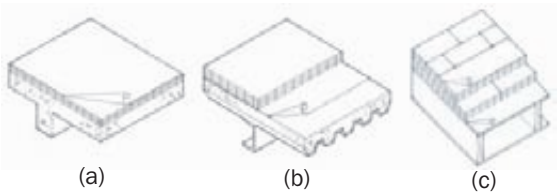


Figure 4-1. (EN2) Insulation entirely above deck. Insulation is installed above a (a) concrete, (b) wood, or (c) metal deck in a continuous manner.

When two layers of continuous insulation are used in this construction, the board edges should be staggered to reduce the potential for convection losses or thermal bridging. If an inverted or protected membrane roof system is used, at least one layer of insulation is placed above the membrane while a maximum of one layer is placed beneath the membrane.

EN3 *Roofs, Metal Buildings* (Climate Zones: all)

Metal buildings pose particular challenges in the pursuit of designing and constructing advanced buildings. The metal skin and purlin/girt connection, even with compressed fiberglass between them, is highly conductive, which limits the effectiveness of the insulation. A purlin is a horizontal structural member that supports the roof covering. In metal building construction, this is typically a z-shaped cold-formed steel member; but a steel bar joist can be used for longer spans.

The thermal performance of metal building roofs with fiberglass batts is improved by treating the thermal bridging associated with fasteners. Use of foam blocks is a proven technique to reduce the thermal bridging. Thermal blocks, with minimum dimensions of 1 inch by 3 inches, should be R-5 rigid insulation installed parallel to the purlins.

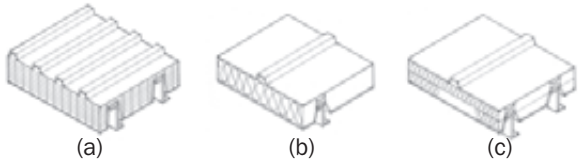


Figure 4-2. (EN3) Pre-fabricated metal roofs showing thermal blocking of purlins.

Thermal blocks can be used successfully with standing seam roofs that utilize (a) concealed clips of varying heights to accommodate the block. However, a thermal block cannot be used with a through-fastened roof that is screwed directly to the purlins because it diminishes the structural load carrying capacity by "softening" the connection and restraint provided to the purlin by the roof.

In climate zones 1 and 2, the recommended construction is (b) R-19 insulation batts draped perpendicularly over the purlins. Thermal blocks are then placed above the purlin/batt, and the roof deck is secured to the purlins.

In climate zones 3 through 8 the recommended construction is (c) two layers of batt insulation. The first insulation batt is draped perpendicularly over the purlins with enough looseness to allow the second insulation batt to be laid above it, parallel to the purlins. In the metal building industry, this is known as the "sag and bag" insulation system.

Continuous rigid insulation can be added to provide additional insulation if required to meet the U-factors listed in Appendix A.

EN4 *Roofs, Attics and Other Roofs* (Climate Zones: all)

Attics and other roofs include roofs with insulation entirely below (inside of) the roof structure (i.e., attics and cathedral ceilings) and roofs with insulation both above and below the roof structure. Ventilated attic spaces need to (a) have the insulation installed at the ceiling line. Unventilated attic spaces may have the insulation installed at the roof line. When suspended ceilings with removable ceiling tiles are used, (b) the insulation performance is best when installed at the roof line.

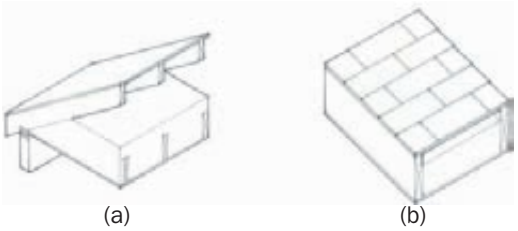


Figure 4-3. (EN4) Attic and other roofs.

EN5 *Roofs, Single Rafter* (Climate Zones: all)

Single rafter roofs have the roof above and ceiling below both attached to the same wood rafter, and the insulation is located in the cavity created between the wood rafters. Single rafters can be constructed using solid wood framing members or truss type framing members. The insulation should be installed between the wood rafters and in intimate contact with the ceiling to avoid the potential thermal short-circuiting associated with open or exposed air spaces.

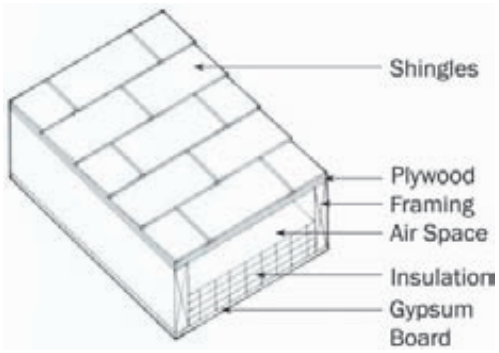


Figure 4-4. (EN5) Wood joists, single rafter.

EN6 *Walls, Mass* (Climate Zones: all)

Mass walls are defined as those with a heat capacity exceeding 7 Btu/ft^2·°F. Insulation may be placed either on the inside or the outside of the masonry wall. When insulation is placed on the exterior of the wall, (a) rigid continuous insulation (c.i.) is recommended. When insulation is placed (b) on the interior of the wall, a furring or framing system should be used, provided the total wall assembly has a U-factor that is less than or equal to the appropriate climate zone construction listed in Appendix A.

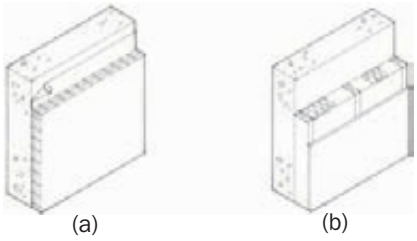


Figure 4-5. (EN6) Walls, mass. Any concrete or masonry wall with a heat capacity exceeding 7 Btu/ft^2·°F.

The greatest advantages of mass can be obtained when insulation is placed on the exterior of the mass. In this case, the mass absorbs internal heat gains that are later released in the evenings when the buildings are not occupied.

EN7 *Walls, Metal Building* (Climate Zones: all)

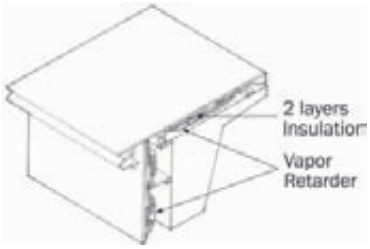


Figure 4-6. (EN7) Walls, metal building.

In climate zones 1-4, a single layer of fiberglass batt insulation is recommended. The insulation is installed continuously perpendicular to the exterior of the girts and is compressed as the metal skin is attached to the girts. In climate zones 5-8, two layers of fiberglass batt insulation are recommended. The first layer is installed continuously perpendicular to the exterior of the girts and is compressed as the metal skin is attached to the girts. The second layer of insulation is installed parallel to the girts within the framing cavity.

In all climate zones, rigid continuous insulation (c.i.) is another option provided the total wall assembly has a U-factor that is less than or equal to the appropriate climate zone construction listed in Appendix A.

EN8 *Walls, Steel Framed* (Climate Zones: all)

Cold-formed steel framing members are thermal bridges to the cavity insulation. Adding exterior foam sheathing as continuous insulation (c.i.) is the preferred method to upgrade the wall thermal performance because it will increase the overall wall thermal performance and tends to minimize the impact of the thermal bridging. Cavity insulation should be used within the steel-framed wall, while rigid continuous insulation should be placed on the exterior side of the steel framing. Alternative combinations of cavity insulation and sheathing in thicker steel-framed walls can be used provided that the proposed total wall assembly has a U-factor that is less than or equal to the U-factor for the appropriate climate zone construction listed in Appendix A.

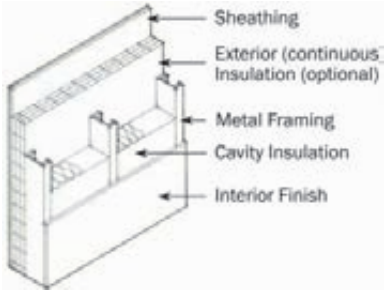


Figure 4-7. (EN8) Walls, steel framed. A common construction type in nonresidential buildings.

EN9 *Walls, Wood Frame and Other* (Climate Zones: all)

Cavity insulation is used within the wood-framed wall, while rigid continuous insulation (c.i.) is placed on the exterior side of the framing. Alternative combinations of cavity insulations and sheathings in thicker walls can be used provided the total wall assembly has a U-factor that is less than or equal to the appropriate climate zone construction listed in Appendix A.

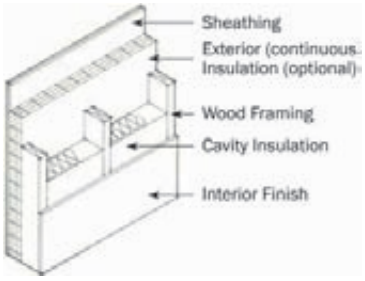


Figure 4-8. (EN9) Walls, wood frame and other.

EN10 *Below-Grade Walls* (Climate Zones: all)

Insulation, when recommended, may be placed either on the inside or the outside of the below-grade wall. If placed on the exterior of the wall, (a) rigid continuous insulation (c.i.) is recommended. If placed on the interior, (b) a furring or (c) framing system is recommended provided the total wall assembly has a C-factor that is less than or equal to the appropriate climate zone construction listed in Appendix A.

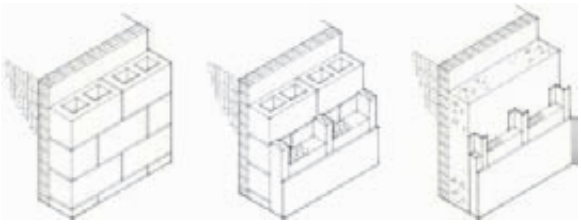


Figure 4-9. (EN10) Below grade walls—outer surface of the wall is in contact with the earth, and the inside surface is adjacent to conditioned or semi-heated space.

EN11 *Floors, Mass* (Climate Zones: all)

Insulation should be continuous and either integral to or above the slab. This can be achieved by (a) placing high-density extruded polystyrene as continuous insulation (c.i.) above the slab with either plywood or a thin layer of concrete on top. Placing insulation below the deck is not recommended, due to losses through any concrete support columns or through the slab perimeter.

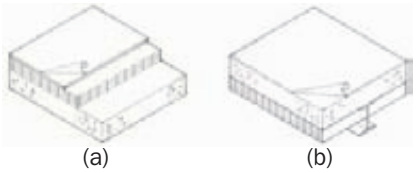


Figure 4-10. (EN11) Floors, mass. Any floor with a heat capacity exceeding 7 Btu/ft^2·°F.

Exception: Buildings or zones within buildings that have durable floors for heavy machinery or equipment could (b) place insulation below the deck.

When heated slabs are placed below grade, below-grade walls should meet the insulation recommendations for perimeter insulation according to the heated slab-on-grade construction.

EN12 *Floors, Steel Joist or Wood Frame* (Climate Zones: all)

Insulation should be installed parallel to the framing members and in intimate contact with the flooring system supported by the framing member in order to avoid the potential thermal short circuiting associated with open or exposed air spaces. Nonrigid insulation should be supported from below no less frequently than 24 in. on center.

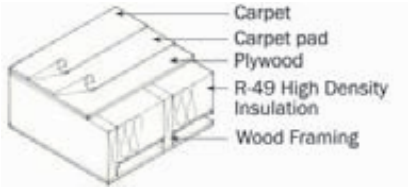


Figure 4-11. (EN12) Floors, wood frame.

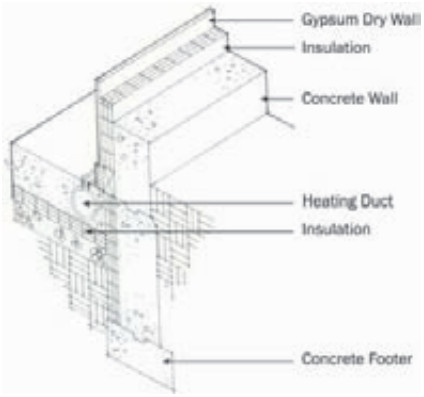
EN13 *Slab-on-Grade Floors, Unheated* (Climate Zones: 6 7 8)

(a) Continuous rigid insulation should be used around the perimeter of the slab and should reach the depth listed in the recommendation or to the bottom of the footing, whichever is deeper. (b) Additionally, in climate zones 7 and 8 and in cases where the frost line is deeper than the footing, continuous insulation should be placed beneath the slab as well.

Figure 4-12. (EN13) Slab-on-grade floors, unheated. No heating elements either within or below the slab.

EN14 *Slab-on-Grade Floors, Heated* (Climate Zones: 4 5 6 7 8)

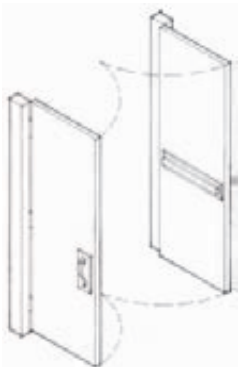
Continuous rigid insulation should be used around the perimeter of the slab and should reach to the depth listed or to the frost line, whichever is deeper. Additionally, in climate zones 7 and 8, continuous insulation should be placed below the slab as well.



Note: In areas where termites are a concern and rigid insulation is not recommended for use under the slab, a different heating system should be used.

Figure 4-13. (EN14) Slab-on-grade floors, heated. Heating elements either within (as shown) or below the slab.

EN15 *Doors, Swinging* (Climate Zones: all)



A U-factor of 0.37 corresponds to an insulated double-panel metal door. A U-factor of 0.61 corresponds to a double-panel metal door.

Figure 4-14. (EN15) Doors, swinging. Opaque doors with hinges on one side and revolving doors.

EN16 *Doors, Roll-up or Sliding* (Climate Zones: all)

Roll-up or sliding doors are recommended to have R-4.75 rigid insulation or meet the recommended U-factor. When meeting the recommended U-factor, the thermal bridging at the door and section edges is to be included in the analysis.

Options

EN17 *Alternative Constructions* (Climate Zones: all)

The climate zone recommendations provide only one solution for upgrading the thermal performance of the envelope. Other constructions can be equally effective, but they are not shown in this document. Any alternative construction that is less than or equal to the U-factor, C-factor, or F-factor for the appropriate climate zone construction is equally acceptable. A table of U-factors, C-factors, and F-factors that corresponds to all of the recommendations is presented in Appendix A. Procedures to calculate U-factors and C-factors are presented in the *ASHRAE Handbook—Fundamentals*, and expanded U-factor, C-factor, and F-factor tables are presented in Standard 90.1-1999, Appendix A.

Cautions

The design of building envelopes for durability, indoor environmental quality, and energy conservation should not create conditions of accelerated deterioration, reduced thermal performance, or problems associated with moisture and air infiltration. The following **cautions** should be incorporated into the design and construction of the building.

EN18 *Heel Heights* (Climate Zones: all)

When insulation levels are increased in attic spaces, the heel height should be raised to avoid or at least minimize the eave compression.

EN19 *Slab Edge Insulation* (Climate Zones: all)

Use of slab edge insulation improves thermal performance, but problems can occur in regions of the country that have termites.

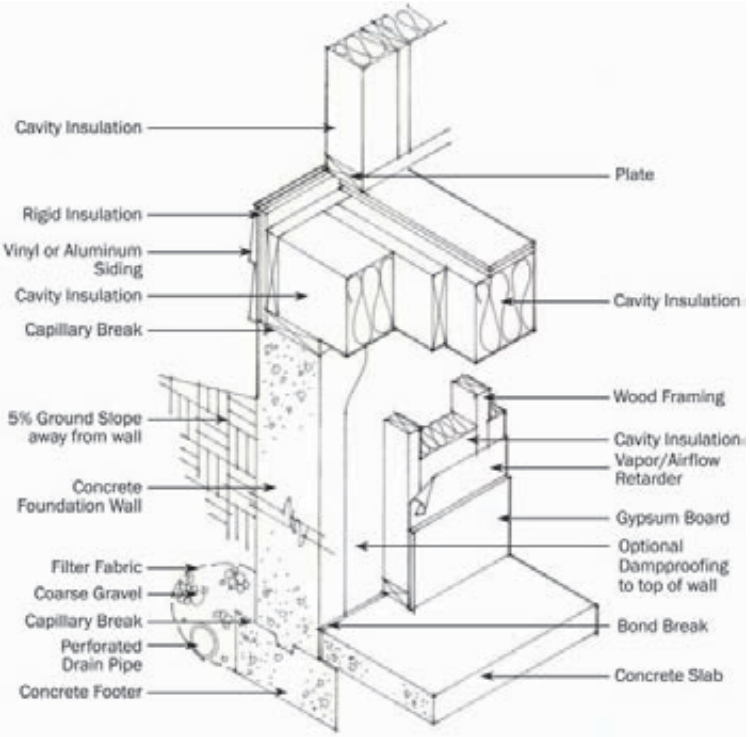


Figure 4-15a. (EN20) Moisture control for mixed climates.

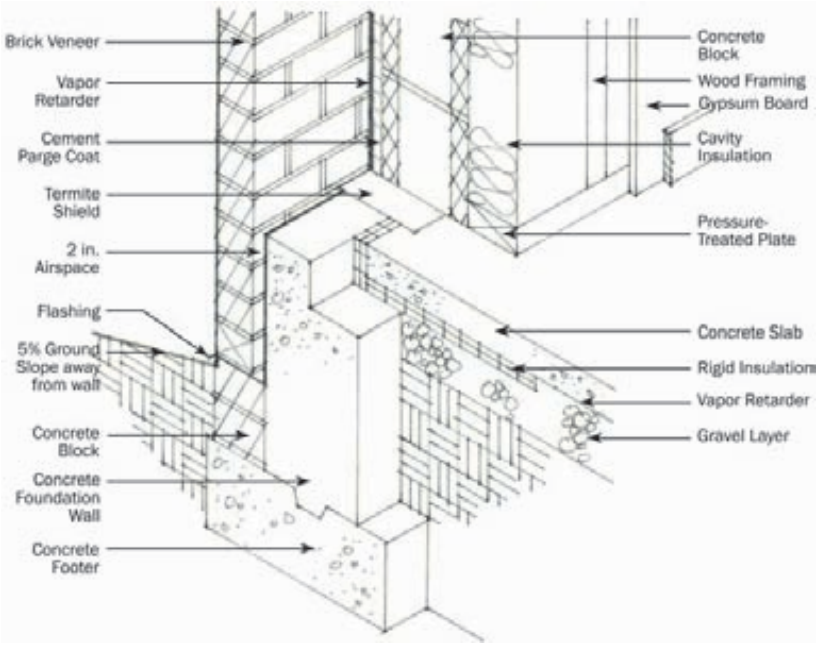


Figure 4-15b. (EN20) Moisture control for warm, humid climates.

EN20 *Moisture Control* (Climate Zones: all)

Building envelope assemblies should be designed to prevent wetting, high moisture content, liquid water intrusion, and condensation caused by diffusion of water vapor.

EN21 *Air Infiltration Control* (Climate Zones: all)

- The building envelope should be designed and constructed with a continuous air barrier system to control air leakage into or out of the conditioned space. An air barrier system should also be provided for interior separations between conditioned space and space designed to maintain temperature or humidity levels that differ from those in the conditioned space by more than 50% of the difference between the conditioned space and design ambient conditions. The air barrier system should have the following characteristics:
  - It should be continuous, with all joints made airtight.
  - Materials used should have an air permeability not to exceed 0.004 cfm/ft^2 under a pressure differential of 0.3 in. water (1.57 psf) (0.02 L/s·m^2 at 75 Pa) when tested in accordance with ASTM E 2178.
  - The system is capable of withstanding positive and negative combined design wind, fan, and stack pressures on the envelope without damage or displacement and should transfer the load to the structure. It should not displace adjacent materials under full load.
  - It is durable or maintainable.
- The air barrier material of an envelope assembly should be joined in an airtight and flexible manner to the air barrier material of adjacent assemblies, allowing for the relative movement of these assemblies and components due to thermal and moisture variations, creep, and structural deflection.

1. Connections should be made between:
   (a) Foundation and walls.
   (b) Walls and windows or doors.
   (c) Different wall systems.
   (d) Wall and roof.
   (e) Wall and roof over unconditioned space.
   (f) Walls, floor, and roof across construction, control, and expansion joints.
   (g) Walls, floors, and roof to utility, pipe, and duct penetrations.

All penetrations of the air barrier system and paths of air infiltration/exfiltration should be made airtight.

Vertical Glazing (Envelope)

Good Design Practice

EN22 **(Climate Zones: all)**

The recommendations for vertical windows are listed in chapter 3 by climate zone. Table 4-1 below shows the type of window construction that generally corresponds to the U-factor specifications in the chapter 3 Recommendation Tables.

Table 4-1. Vertical Fenestration Descriptions

U-Factor	SHGC	VLT	Description
0.47	0.31	0.37	Metal frame with a thermal break Clear glass with medium performance reflective coating Insulated spacers between panes Low-e coated glass
0.44	0.46	0.62	Metal frame with a thermal break Clear glass Insulated spacers between panes Low-e coated glass
0.38	0.41	0.60	Vinyl frame Clear glass Insulated spacers between panes Low-e coated glass

To be useful and consistent, the U-factors for windows should be measured over the entire window assembly, not just the center of glass. Look for a label that denotes the window rating is certified by the National Fenestration Rating Council (NFRC). The selection of high-performance window products should be considered separately for each orientation of the building and for daylighting and viewing functions.

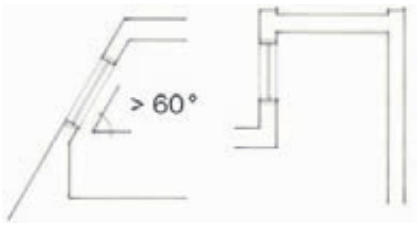


Figure 4-16. (EN22) Vertical fenestration.