Heat transmission is the average home's leading cause of winter heat loss. Most single-family homes lose two to three times as much energy through transmission as through air leakage. Insulation slows heat transmission through the building's floor, walls, and the ceiling or roof.

Insulation performs these thermal functions.

- ♦ Conserves energy by slowing heat transmission.
- ♦ Enhances comfort by reducing temperature variations within the conditioned space.
- ♦ Reduces the size of heating and cooling equipment needed by a building in direct proportion to R-value.
- ♦ Prevents wintertime condensation by preventing low interior surface temperatures.

Insulation may also offer these secondary benefits.

- ♦ Adds structural strength.
- ♦ Reduces noise and vibration.
- ♦ Impedes air leakage and water vapor transmission.
- ♦ Improves the building's fire resistance.

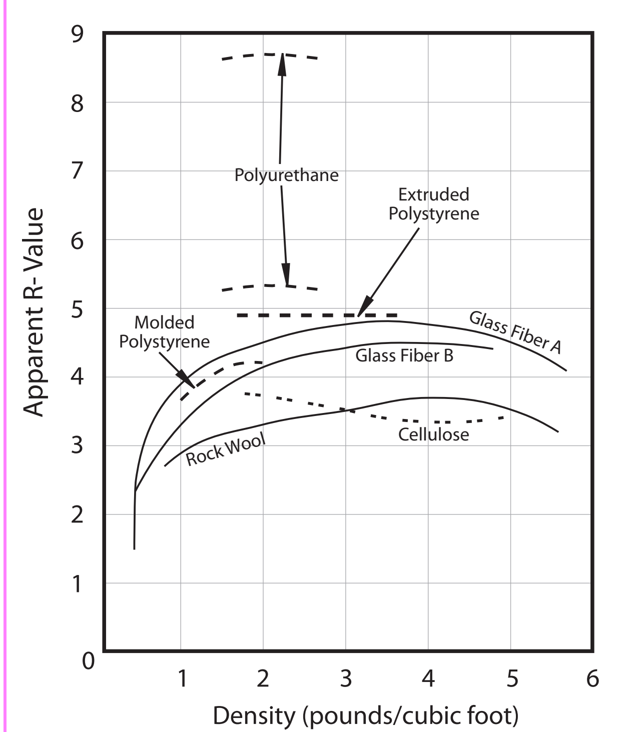
This chapter tells how insulation works, describes insulation types, and discusses other important issues relating to insulation.

Insulation Characteristics

Insulation is installed in building cavities or attached to the building shell's interior or exterior surfaces.

Insulation slows heat transmission in two important ways.

Density of Insulation Versus R-Value



Insulation's density affects its R-value, depending on the material.

1. By forcing the heat to conduct through minute connections among fibers or foam bubbles, or through a gas. Gases are generally poor heat conductors.
2. By reducing heat radiation and air convection within cavities where insulation is installed.

Insulating materials aren't as continuous or dense as other building material that are heat conductors. Insulation harbors millions of tiny air pockets within their fibers or bubbles (in plastic foam insulation). Heat transmission proceeds slowly through insulation, having to cross this myriad of slow-conducting air pockets.

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Whole-Wall R-Values from Full-Scale Tests

Wall Type	W-W R
Standard 2-by-4	9.7
2-by-6 perfect installation	12.8
2-by-6 poor installation	11.0
Steel frame wall C-stud	5.6
Steel stud wall w/EPS sheathing	10.5
Structural 6-inch EPS-insulated panel	21.6
Stucco-covered straw bale	16–28
Lightweight concrete block	10–30
Insulating concrete form	26–44

These values are calculated using data from full-scale wall thermal-resistance tests performed at Oak Ridge National Laboratory. W-W R or whole-wall R-value measures R-value of the entire wall section, including framing material. The first four examples here are stud walls insulated with fiberglass batts. The last two examples include the thermal mass factor.

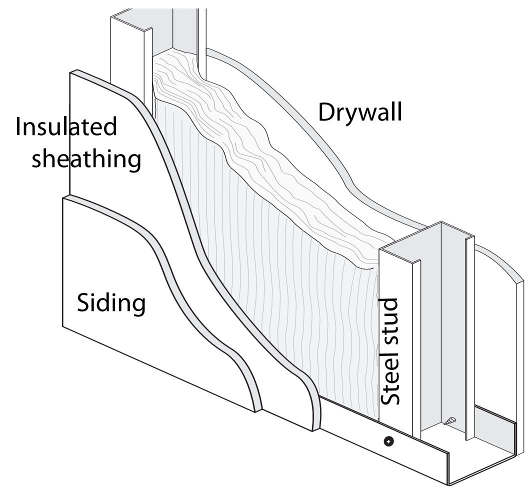
Insulation Thermal Performance factors

Insulation's ability to resist heat flow is measured by its R-value. "R" stands for thermal resistance. The R-value in any building assembly, created by a combination of insulation and other building materials, is affected by the following factors:

- Thermal bridging or thermal shorts in the assembly.
- Type and density of the insulation.
- Air leakage and convection from voids, gaps, or low insulation density.
- Water's presence within the assembly.
- Mass of the insulated assembly.

Two types of wall R-values are referenced in this book: clear-wall R and whole-wall R. Clear-wall R is the average R of the cavity between framing members. Whole-wall R is the average R-value of the wall including framing materials. See "Materials/Building Assembly R-Values" on page 278.

Steel-Stud Walls



The relatively low R-value of steel-stud walls can be improved by insulated sheathing as shown here. Whole-wall R-value varies widely depending on the installation quality of the fiberglass insulation but can be less than R-5 for a 3.5-inch steel stud wall without insulated sheathing.

Thermal bridging — Thermal bridging is rapid heat transfer through thermally conductive building materials like wood, steel, and aluminum. Strategies for reducing thermal bridging include minimizing framing materials and applying insulated sheathing to building surfaces as a thermal break.

Steel framing is a challenge to insulate adequately, especially in cold climates. Steel framed assemblies have a low whole-wall R-value. Without insulated sheathing, the steel studs can cause condensation in cavities and wetting of surrounding building materials.

See "Approximate R-Values of Wall Assemblies from Guarded Hot Box Testing" on page 280.

Insulation type and density — Some common insulating materials have an ideal density, where the R-value per inch is at its maximum. Compressing fiberglass and mineral wool to a specific density increases R-values per inch; after that optimal density, compressing the insulation

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decreases R-value per inch. For instance, mineral wool has a maximum R-value of R-3.6 per inch at about 4 pounds per cubic foot (lb/ft^3). At lower densities, mineral wool's R-value per inch is less (R-2.7 at 1 lb/ft^3), and at greater densities is also less (R-3.2 at 6 lb/ft^3).

Fiberglass reaches its highest R-value per inch of about R-4.2 at about 3.2 lb/ft^3. Cellulose has a maximum R-value per inch of about R-3.9 at between 1 and 2 lb/ft^3.

Convection and air leakage — Air convection within insulated building cavities increases heat transmission. Air convects heat off one surface and transports the heat to the adjacent surface — between drywall and the facing of batt insulation, for example. Convecting air can also find its way through channels around the insulation's edge gaps — between batts and framing lumber, for example. Edge gaps of only 4% of the insulated surface area can produce up to a 30% loss in effective R-value for R-19 ceiling insulation.

If air from inside or outside the building leaks into an insulated cavity, the effectiveness of the insulation is further reduced. This reduction typically varies from 15–50%. Air can even flow through fibrous insulating materials such as loosely installed fiberglass. Insulation's installed density is an important issue, especially in cold climates.

Wind also affects insulation performance. Wind convects heat away from the surfaces of a building. If voids and edge gaps exist, wind can push outdoor air through building cavities around the insulation or push air through insulation. These effects increase heat transmission.

Moisture condensation — Absorbed water decreases the R-value of insulation. Water fills the insulation's air spaces and conducts heat far better than air. Water and ice also damage insulation. Wet insulation corrodes metals and supplies water to insects and microorganisms that rot organic building materials.

Insulation R-Values per Inch

Insulation Type	R/inch
Fiberglass batts, blown, board	2.6–4.2
Cellulose blown	3.2–3.6
Mineral wool batts, blown, board	2.6–4.4
Vermiculite or perlite	2.1–2.4
Expanded polystyrene (white)	3.6–4.4
Extruded polystyrene (blue/pink)	5.0
Polyisocyanurate board	5.6–7.6

R-values vary by insulation type, density, and the quality of installation.

Air leakage is the most potent moisture-carrying mechanism, which causes condensation in building cavities. Vapor diffusion is water vapor traveling through permeable materials like drywall and masonry. Low-R building materials combined with water-absorbent building materials create the largest potential moisture problems.

Thermal mass effect — The mass of building components, particularly walls, affects the heat flow through them. Especially in sunny climates with large temperature swings, massive building assemblies absorb energy surpluses from both the indoors and outdoors, slowing heat transmission.

The thermal mass factor is a multiplier to the calculated R-value, which estimates a higher R-value that accounts for the thermal mass effect. This thermal-mass factor varies, depending on the calculated R-value of the massive wall. The higher the massive wall's R-value, the greater the mass factor. The mass factor varies from around 1 to 2.6, according to tests performed at Oak Ridge National Laboratory on full-scale massive walls.

Walls insulated on the exterior perform better than walls insulated on the interior. Walls insulated on the exterior have mass factors as high as 2.6, while walls insulated on the interior have mass factors only as high as 1.5. The mass factors vary according to calculated R-value and climate. Of the six cities simulated in the testing, Phoenix

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benefited most from mass factors, and Minneapolis benefited least. In general, hot climates benefit more than cold climates from the mass effect.

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