Contents

Chapter 13—Energy Efficiency

"Engineering is the science of economy, of conserving the energy, kinetic and potential, provided and stored up by nature for the use of man. It is the business of engineering to utilize this energy to the best advantage, so that there may be the least possible waste."

William A. Smith
1908

Introduction

Using energy efficiently can reduce the cost of heating, ventilating, and air-conditioning, which account for a significant part of the overall cost of housing. Energy costs recur month-to-month and are hard to reduce after a home has been designed and built. The development of an energy-efficient home or building must be thought through using a systems approach. Planning for energy efficiency involves considering where the air is coming from, how it is treated, and where it is desired in the home. Improper use or installation of sealing and insulating materials may lead to moisture saturation or retention, encouraging the growth of mold, bacteria, and viruses. In addition, toxic chemicals may be created or contained within the living environment. These building errors may result in major health hazards. The major issues that must be balanced in using a systems approach to energy efficiency are energy cost and availability, long-term affordability and sustainability, comfort and efficiency, and health and safety.

Energy Systems

Making sound decisions in designing, constructing, or updating dwellings will ensure not only greater use and enjoyment of the space, but also can significantly lower energy bills and help residents avoid adverse health effects. Systematic planning for energy efficiency also can assist prospective homeowners in qualifying for mortgages because lower fuel bills translate into lower total housing and utility payments. Some banks and credit unions take this into account when qualifying prospective homeowners for mortgages. "Energy-efficient" mortgages provide buyers with special benefits when purchasing an energy-efficient home.

Energy use and efficiency should be addressed in the context of selection of fuel types and appliances, location of the equipment, equipment sizing and backup systems, and programmed use when making decisions on space heating, water heating, space cooling, window glazing, and lighting. Usage variables, such as taking excessively long showers, turning off lights when leaving rooms, or using appliances at full or near-full capacity, may increase or decrease energy use, depending on occupancy. Many of these demands can be optimized in the design stage of housing for new construction. However, when remodeling dwellings, making modifications to improve energy efficiency is often difficult. Preconstruction consultations with architects and energy specialists can produce tradeoffs that retain the aesthetics and special aspects of a dwelling, while making appropriate investments in energy efficiency.

A price is paid for poor design and lack of proper insulation of dwellings, both in dollars for utility bills and in comfort of the occupants. The layout of rooms and overall tightness of a house in terms of air exchange affect energy requirements. In addition, home occupants and owners often are called on to make relatively minor decisions affecting total energy consumption, such as selecting lighting fixtures and bulbs and selecting settings for thermostats. Buying energy-efficient appliances can save energy, but the largest reduction in energy use can be derived from major decisions, such as considering the R-value of roof systems, insulation, and windows.

R-values

Thermal resistance (a material's resistance to heat flow) is rated by R-value. Higher R values mean greater insulating power, which means greater household energy savings and commensurate cost savings. Table 13.1 is a guideline for choosing R-values that are right for a particular home based on the climate, household heating system, and area in which it is located.

Another way of understanding R-value is to see it as the resistance to heat losses from a warmer inside temperature to the outside temperature through a material or building envelope (wall, ceiling or roof assembly, or window). Total heat loss is a function of the thermal conductivity of materials, area, time, and construction in a house.

The R-value of thermal insulation depends on the type of material, its thickness, and its density. In calculating the R-value of a multilayered installation, the R-values of the individual layers are added. Installing more insulation increases R-value and the resistance to heat flow.
The effectiveness of an insulated wall or ceiling also

In a climate that is...	And a heating system that is... [b]	Insulate to these levels in the... Ceiling	Wood-frame wall [c]	Floor	Basement or crawl space walls [d]	Ducts [e] in unheated/uncooled... Attic	Basement or crawl space
Warm, with cooling and minimal heating requirements [f]	Gas/oil or heat pump	R-22 to R-38	R-11 to R-15	R-11 to R-13	R-11 to R-19	R-4 to R-8	None to R-4
	Electric resistance	R-38 to R-49	R-11 to R-22	R-13 to R-25	R-11 to R-19	R-4 to R-8	None to R-4
Mixed, with moderate heating and cooling requirements [g]	Gas/oil or heat pump	R-38	R-11 to R-22	R-13 to R-25	R-11 to R-19	R-4 to R-8	R-2 to R-8
	Electric resistance	R-49	R-11 to R-28	R-25	R-11 to R-19	R-4 to R-8	R-2 to R-8
Cold, with mainly heating requirements [h]	Gas/oil	R-38 to R-49	R-11 to R-22	R-25	R-11 to R-19	R-6 to R-11	R-2 to R-11
	Heat pump or electric resistance	R-49	R-11 to R-28	R-25	R-13 to R-19	R-6 to R-11	R-2 to R-11

a. Adapted from the U.S. Department of Energy 1997 Insulation Fact Sheet available at (800)-DOE-EREC and Modera et al., Impact of Residential Duct Insulation on HVAC Energy Use and Life Cycle Cost to Consumers, ASHRAE Transactions 96-13-4.

b. Insulation is also effective at reducing cooling bills. These levels assume your house has electric air conditioning.

c. R-values may be achieved through a combination of cavity insulation and rigid board insulation and are for insulation only (not whole wall).

d. Do not insulate crawl space walls if crawl space is wet or ventilated with outdoor air.

e. Use the lower R-value for return ducts and higher R-value for supply ducts.

f. Florida and Hawaii; coastal California; southeast Texas; southern Alabama, Arkansas, Georgia, Louisiana, and Mississippi.

g. Idaho, Kentucky, Missouri, Nebraska, Oklahoma, Oregon, Virginia, Washington, and West Virginia; southern Indiana, Kansas, New Mexico, and Arizona; northern Alabama, Arkansas, Georgia, Louisiana, and Mississippi; inland California; and western Nevada.

h. Great Lakes area, mountainous areas [e.g., Colorado, Wyoming, Utah, etc.]), New England, New York, northern Midwest, and Pennsylvania.

Table 13.1. Cost-effective Insulation R-values for Existing Homes [a;1]

depends on how and where the insulation is installed. For example, insulation that is compressed will not provide its full rated R-value. Also, the overall R-value of a wall or ceiling will be somewhat different from the R-value of the insulation itself because some heat flows around the insulation through the studs and joists. That is, the overall R-value of a wall with insulation between wood studs is less than the R-value of the insulation itself because the wood provides a thermal short-circuit around the insulation. The short-circuiting through metal framing is much greater than that through wood-framed walls; sometimes the metal wall's overall R-value can be as low as half the insulation's R-value. With careful design, this short-circuiting can be reduced.

Roofs

Roofs are composite structures, with composite R-values. The total R-value for the roof components shown in Figure 13.1 is 14.54 (Table 13.2). In general, a composite structure with a composite R-value of more than R-38 provides a substantial barrier to heat loss. Of course, in the winter the outside air temperature would vary significantly between locations such as Pensacola, Florida, and Fairbanks, Alaska, and would affect the cost-

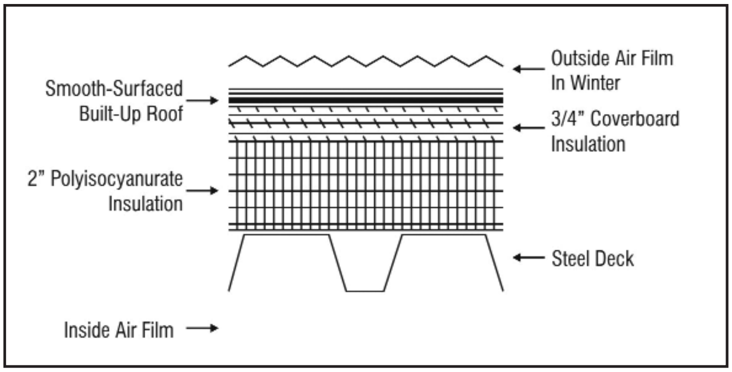

Figure 13.1. Roof Components [2]

effectiveness of additional insulation and construction using various roofing components (Table 13.2).

The location of a house is usually a fixed variable in calculating R-values once the lot is purchased. However, the homeowner should consider the value of additional insulation by comparing its cost with the savings resulting from the increase in energy efficiency. Roof construction, including components such as ridge vents and insulating materials, is quite important and is often one of the more cost-effective ways to lower energy costs.

Ridge Vents

Ridge vents are important to roofs for at least three reasons. First, ridge vents help lower the temperature in the roof structure and, consequently, in the attic and in the habitable space below. Second, ridge vents and rotating turbine vents help prolong the life of the roofing materials, particularly asphalt shingles and plywood sheathing. Third, ridge vents assist in air circulation and help avoid problems with excessive moisture.

Fan-powered Attic Ventilation

Attic ventilators are small fans that remove hot air and reduce attic temperature. Adequate inlet vents are important. Typically these vents are located under the eaves of the house. The fan should be located near the peak of the roof for best performance.

Component	R-value
Inside air film	0.92
Steel deck	0.00
2-inch polyisocyanurate (5.56×2)	11.12
¾-inch perlite (2.78×0.75)	2.09
Smooth built-up roof	0.24
Outside air film in winter	0.17
Total	**14.54**

Table 13.2. Potential Effects of Radiant Barriers [3]

White Roof Surface

White roof surfaces combined with any of the measures listed above will improve their performance significantly. The white surface reflects much of the sun's heat and keeps the roof much cooler than a typical roof.

Insulation

Insulation forms a barrier to the outside elements. It can help ensure that occupants are comfortable and that the home is energy-efficient. Ceiling insulation improves comfort and cuts electricity or natural gas costs for heating and cooling. For instance, the use of R-19 insulation in houses in Hawaii [3] could have the following results:

- Reduce indoor air temperature by 4°F (-16°C) in the afternoon.
- Lower the ceiling temperature, perhaps by more than 15°F (-9.4°C). Insulation [radiant barrier] can reduce ceiling temperatures from 101°F (38°C) in bright sun on Oahu to 83°F (28°C). (Figure 13.2).
- Reduce or eliminate the need for an air-conditioner.

Energy savings, of course, will vary depending on energy prices. The payback afforded by additional insulation or investment in energy conservation measures is the average amount of time it will require for the initial capital cost to be recovered as a result of the savings in energy bills. A payback of 3 to 5 years might be economic, because the average homeowner stays in a home that long. However, payback criteria can vary by individual, and renters, for example, often face the dilemma of not wanting to make improvements for which they may not be able to fully realize the benefits. Described below are a few insulation alternatives.

To achieve maximum effect, the method of installation and type of insulation are of considerable importance. The proper placement of moisture barriers is essential. If insulation becomes moisture-saturated, its resistance to energy loss is significantly reduced. Barriers to moisture should be installed toward the living area because significant moisture is generated in the home through respiration, cooking, and the combustion of heating fuels.

Cellulose or fiberglass insulation is the most cost-effective insulation. Blown-in cellulose or fiberglass and fiberglass batts are similar in cost and performance. Recycled cellulose

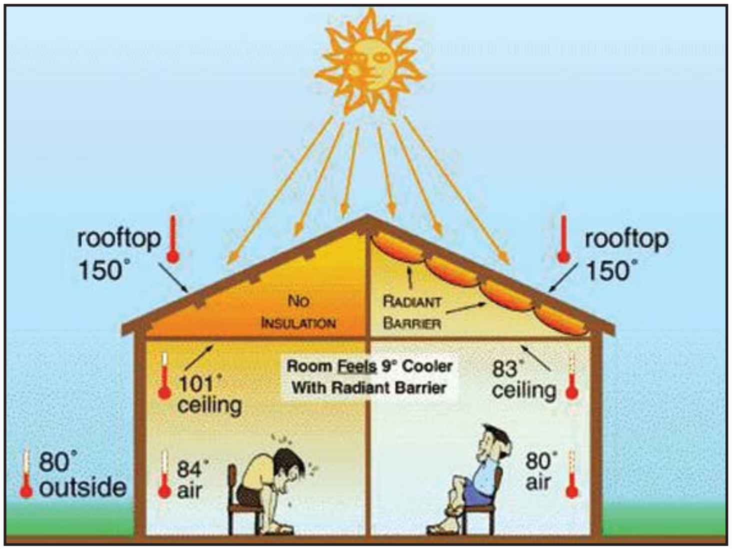

Figure 13.2. Potential Effects of Radiant Barriers [3]

insulation may be available. For the best performance, insulation should be 5 to 6 inches thick. It can be installed in attics of new and existing homes. It is typically the best choice for framed ceilings in new homes, but can be costly to install in existing framed ceilings. It is very important that this type of insulation be treated for fire resistance.

Foamboard (R-10, 1.5 to 2 inches) provides more insulation per inch than does cellulose or fiberglass, but is also more expensive. It is best where other insulation cannot be used, such as open-beam ceilings. It is applicable for new construction or when roofing is replaced on an existing home. Two common materials are polystyrene and polyisocyanurate. Polystyrene is better in moist conditions, and polyisocyanurate has a higher R-value per inch (millimeter). However, some of these insulations present serious fire spread hazards. They should be evaluated to ensure that they are covered with fire-retardant materials and meet local fire and building codes.

Radiant barrier insulation is a reflective foil sheet installed under the roof deck like regular roof sheathing. The effectiveness of a radiant barrier (Figure 13.2) depends on its emissivity (the relative power of the surface to emit heat by radiation). In general, the shinier the foil the better. Radiant barrier insulation cuts the amount of heat radiated from the hot roof to the ceiling below. It may be draped over the rafters before the roof is installed or stapled to the underside of the rafters. The shiny side should face downward for best performance. Some manufacturers claim that the radiant barrier prevents up to 97% of the sun's heat from entering the attic.

Wall Insulation

As shown in Table 13.1, it makes sense to insulate to high R-values in the ceiling. Insulation in walls should range from R-11 in relatively mild climate zones to R-38 in New England, the northern Midwest, the Great Lakes, and the Rocky Mountain states of Colorado and Wyoming. Insulation requirements vary within climate zones in these states and areas as well (for instance, mountainous areas and areas farther north may have more heating-degree days). The same logic of installing insulation applies to both ceilings and walls: the insulation should provide a barrier for heat and moisture transfer and buildup from inside the dwelling, where temperatures will generally be in the 68°F to 72°F (20°C to 22°C) range, compared with the much colder or hotter temperatures outside. The key to heat loss is the difference in temperatures and the time that the heat transfer takes place over a given area or surface. The choice of heating system, from gas/oil or heat pump, to electric resistance, will also affect the payback of additional wall insulation due to variation in energy fuel prices. For regions identified as "cold," careful attention should be made in selecting energy fuel type; in particular, a heat pump may not be a practical option.

A homeowner exploring designs and construction methods should examine the value of using structural insulated panels. The incorporation of high levels of insulation directly from the factory on building wall and ceiling components makes them outstanding barriers to heat and moisture. These integrated systems, if appropriately used, can save substantial amounts of energy when compared with traditional stick-built systems using 2×4 or 2×6 lumber. Also, building energy-efficient features (as well as electrical, plumbing, and other elements) directly into the building envelope at the factory can result in labor cost savings over the more traditional methods of construction.

Floor Insulation

Warm air expands and rises above surrounding cooler air. This process of heat transfer is called convection. Warm air, which is lighter, rises and, as it cools, falls, creating a convection current of air. The two other processes of heat transfer are conduction (kinetic energy transferred from particle to particle, such as in a water- or electrically heated floor) and radiation (radiant energy emitted in the form of waves or particles such as in a fireplace or hot glowing heating element). Floor insulation limits all three modes of heat loss. A warmer floor reduces the temperature difference that drives convection. Floor insulation also directly impedes conduction and radiation to the colder air below the floor.

Batt Insulation

The advantage of floor insulation lies in adding extra R-value without a significant increase in cost. It is cheaper to put more insulation under the floor than to add foam sheathing or change the type of wall construction to accommodate greater insulation levels.

Like walls, floor cavities should be completely filled with insulation-without gaps, missing insulation, or cavity voids. Floor insulation must contact the subfloor and both joists. In many cases, it is worth the extra cost to buy enough insulation to fill the entire cavity.

The amount of floor insulation required by some codes can be less than the space available. For example, an R-19 fiberglass batt is 6¼ inches thick. A floor framed with 2×8s is about 7½ inches deep, while a 2×10 floor is 9½ inches deep. A builder following a code's minimum insulation level will leave extra space that will allow for greater heat loss. To avoid this situation, the batt must be pushed up into the cavity. With the proper support, this can be done. Springy metal rods are commonly used to hold insulation up in the top of the floor cavity. Another viable option is the use of plastic straps. Figure 13.3 shows batt insulation improperly applied to the floor above a crawl space or a basement.

The thickness of typical fiberglass batts can assist the designer and the builder in creating a floor system that works for the occupants. Table 13.3 shows a list of R-values, along with the associated batt thickness. Individual brands can vary by as much as 1 inch.

Cavity Fill

According to Oikos, a commercial Web site devoted to serving professionals whose work promotes sustainable design and construction, "Buying a thicker batt may be a better option than trying to lift a thinner batt into the proper position. Material costs will climb slightly but labor should be the same. Attaching the insulation support to the bottom of the floor joist will be easier. It could also lead to a higher quality job because there is less chance for compression or gaps" (Figure 13.4) [4].

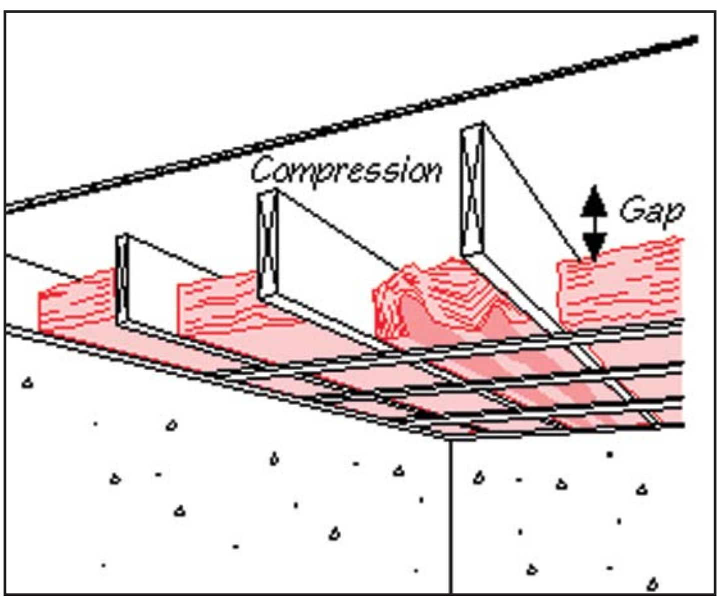

Figure 13.3. Common Floor Insulation Flaws [4.] Two common flaws in floor insulation are gaps above the batt and compression of the batt in the cavity.

Source: Reprinted from Energy Source Builder 38 with permission of Iris Communications, Inc., publisher of Oikos.com.

In some areas, it's common to hang plastic mesh over floor joists. Installers drop the insulation onto the mesh before the subfloor is installed. However, hanging the mesh creates sagging bellies. Insulation compresses near the framing and sags in the middle. Mesh should be attached to the bottom of the floor framing [4].

R-value	Batt Thickness, Inches*
R-19	6¼
R-22 HD	5½
R-22	7½
R-25	8½
R-30	10
R-30 HD	8½
R-38	12
R-38 HD	10

Table 13.3. Floor Insulation [5]

Each stage of increased floor insulation, from R-19 to R-30 or R-30 to R-38, can save energy over the life of the house. This energy translates into energy savings that are multiples of the initial installation costs. Floor insulation will generate the greatest savings in colder climates; in moderate climates, the target insulation level should depend on economics.

Blow-In Insulation

A blown-in insulation system allows the builder or insulator to fill the entire cavity completely, even around pipes, wires and other appurtenances. Using well-trained installers will pay dividends in quality workmanship.

Doors

Today there is an endless variety of doors, ranging from metal doors with or without insulation to hollow core to solid wood. When properly installed into fitted frames, doors serve as a heat barrier to maintain indoor temperatures. Quality metal doors with insulation are best if they have a thermal break between the interior and exterior metal surfaces; this keeps heat from being transferred from one side to the other.

Standard Doors

Because doors take up a small percentage of a wall, insulating them is not as high a priority as is insulating walls and ceilings. That said, heat loss follows the path of least resistance; therefore, doors should be selected that

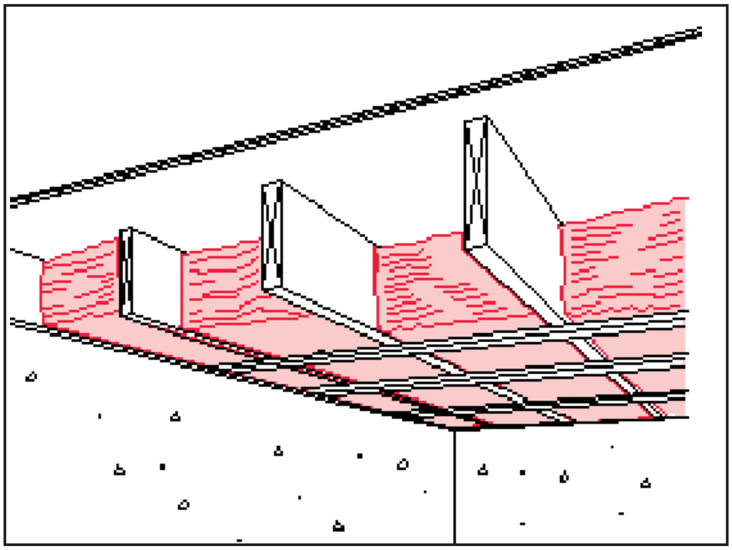

Figure 13.4a. Insulation Cavity Fill [4].
Lath provides a sturdy support for insulation.

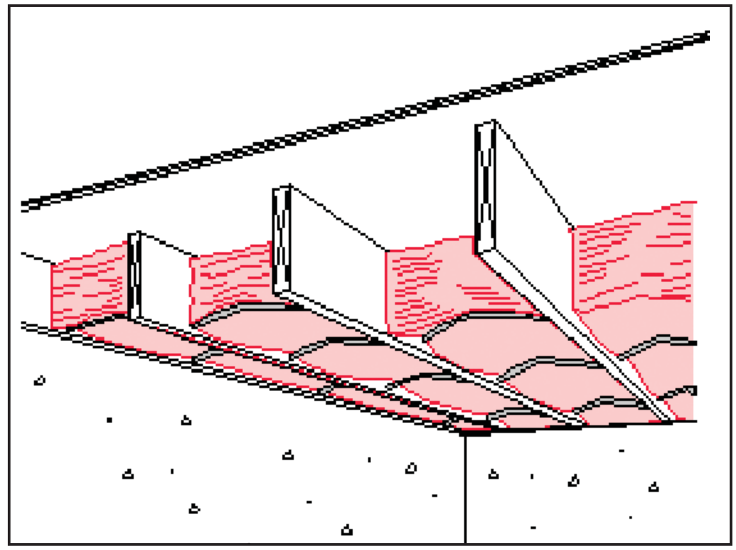

Figure 13.4b. Insulation Cavity Fill [4].
Metal rods are available through insulation distributors. They are easy to use, but insulation has to be compressed in the middle.

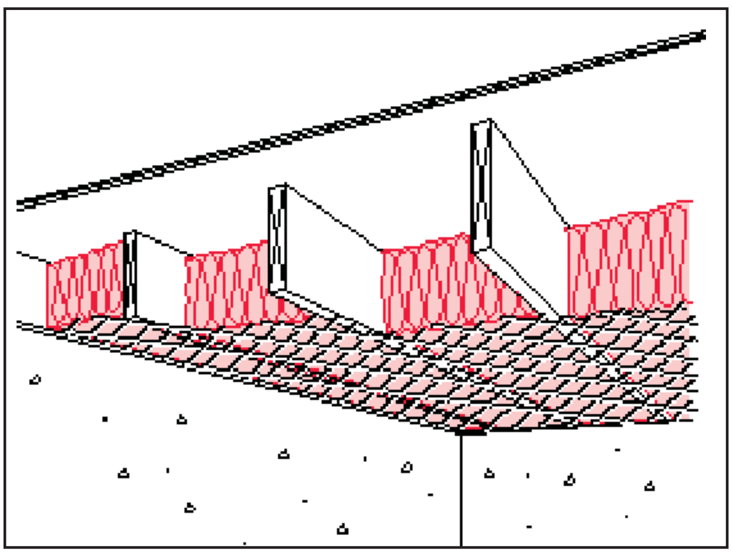

Figure 13.4c. Insulation Cavity Fill [4].
Mesh should be attached to the bottom of the framing. Draping the mesh over the joists leads to compression that reduces insulating value.

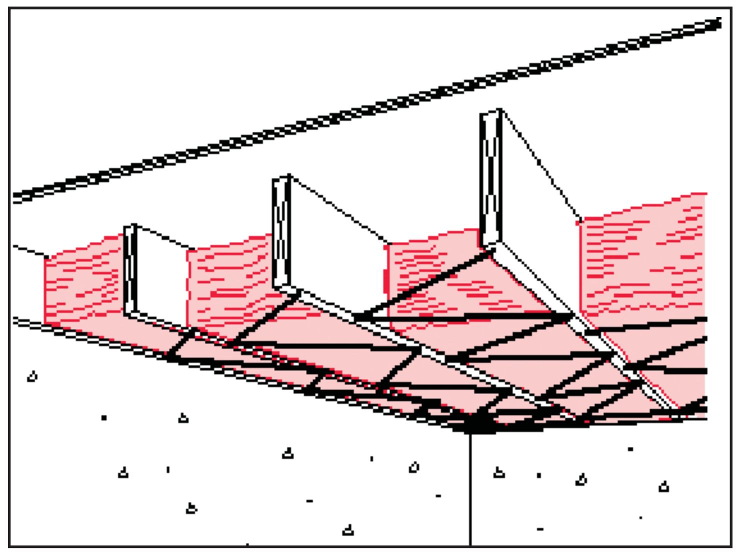

Figure 13.4d. Insulation Cavity Fill [4].
Polypropylene twine resists rot, mildew, rodents, and other dangers. It is to be stapled every 12 to 18 inches.

Source: Reprinted from Energy Source Builder 38 with permission of Iris Communications, Inc., publisher of Oikos.com.

are functional and add to the energy-efficiency of the house. Doors usually have lower R-values than the surrounding wall.

Storm doors can add R-1 to R-2 to the existing door's R-value. They are a valuable addition to doors that are frequently used and those that are exposed to cold winds, snow, and other weather. Screens allow natural breezes to circulate air from outside, rather than totally relying on air-conditioning, which can be energy intensive.

When considering replacement doors, select insulated, metal foam-core doors. Besides insulation, metal doors provide good security, seal more tightly, tend to warp less. Metal doors also are more soundproof than conventional wood doors.

Sliding Glass Doors

Although sliding glass doors have aesthetic appeal, they have very low R-values and hence are minimally energy efficient. To improve the energy efficiency of existing sliding glass doors, the homeowner should ensure that they seal tightly and are properly weather-stripped. Additionally, heavy insulated drapes with weights, which impede the airflow, can cut down on heat loss through sliding glass doors.

Door Installation

Doors must be installed as recommended by the manufacturer. Care must be taken to be sure that doors are installed in a manner that does not trap moisture or allow unintended introduction of air. Numerous types of sealing materials are available that range from foam to plastic, to metal flanging and magnetic strips.

Hot Water Systems

The hot water tank can be insulated to make it more efficient, unless the heat loss is used within the space where it is located. Special insulation is available for this type of appliance, and insulating it will reduce the energy required to deliver the hot water needed by the occupants of the dwelling. Of course, any pipe that is subject to extreme temperatures also should be insulated to decrease heat loss.

Windows

Windows by nature are transparent. They allow occupants of a dwelling to see outside and bring in sunlight and heat from the sun. They make space more pleasant and often provide lighting for tasks undertaken in the space. Especially in the winter, these desirable characteristics offset the heat loss. Heat gain in the summer through windows can be undesirable.

Rather than give them up, it is important to use windows prudently and to keep energy considerations in mind in their design and their insulating characteristics (air, glass, plastic, or gas filler). Good design takes advantage of day lighting. Weather-stripping and sealing leaks around windows can enhance comfort and energy savings. Energy Star windows are highly recommended. Housekeeping measures can improve the efficiency of retaining heat. Heat loss follows the path of least resistance: caulking, weather-stripped framing, and films can help. These measures are relatively labor intensive, low to very low in cost, and can be quite satisfying to the homeowner if accomplished correctly. On the other hand, it is not easy finding the perfect materials or even replacement parts for old windows.

When working with older windows, remember that there is the risk for leaded paint and the dispersion of toxic lead dust into the work area. Please refer to the lead section of Chapter 5, Indoor Air Pollutants and Toxic Materials.

Caulking and Weather-Stripping

According to the U.S. Department of Energy, caulking and weather-stripping have substantial housekeeping benefits in preventing energy loss or unwanted heat gain.

Caulking

Caulks are airtight compounds (usually latex or silicone) that fill cracks and holes. Before applying new caulk, old caulk or paint residue remaining around a window should be removed using a putty knife, stiff brush, or special solvent. After old caulk is removed, new caulk can then be applied to all joints in the window frame and the joint between the frame and the wall. The best time to apply caulk is during dry weather when the outdoor temperature is above 45°F (7.2°C). Low humidity is important during application to prevent cracks from swelling with moisture. Warm temperatures are also necessary so the caulk will set properly and adhere to the surface [5].

Weather-stripping

Weather-stripped frames are narrow pieces of metal, vinyl, rubber, felt, or foam that seal the contact area between the fixed and movable sections of a window joint. They should be applied between the sash and the frame, but should not interfere with the operation of the window [6].

Replacing Window Frames

The heat-loss characteristics and the air tightness of a window vary with the type and quality of the window frame. The types of available window frames are fixed-pane, casement, double- and single-hung, horizontal sliding, hopper, and awning. Each type varies in energy efficiency.

Correctly installed fixed-pane windows are the most airtight and inexpensive choice, but are not suited to places that require ventilation. The air infiltration properties of casement windows (which open sideways with hand cranks), awning windows (which are similar to casement windows but have hinges at the top), and hopper windows (inverted awning windows with hinges at the bottom) are moderate. Double-hung windows, which have top and bottom sashes (the part of the window that can slide), tend to be leaky. The advantage of the single-hung window over the double-hung is that it tends to restrict air leakage because there is only one moving part. Horizontal sliding windows, though suitable for small, narrow spaces, provide minimal ventilation and are the least airtight.

In buildings with large older windows, there are often weight cavity areas that hide counter balances that make it easy to raise and lower heavy windows. These areas should be insulated to reduce energy loss.

Tinted Windows

Another way to conserve energy is the installation of tinted windows. Window tinting can be installed that will both conserve energy and also prevent damaging ultraviolet light from entering the room and potentially fading wood surfaces, fabrics, and carpeting. Low-emissivity coatings, called low-e coatings, are also available. These coatings are designed for specific geographic regions.

Reducing Heat Loss and Condensation

The energy efficiency of windows is measured in terms of their U-values (measure of the conductance of heat) or their R-values. Besides a few highly energy-efficient exceptions, window R-values range from 0.9 to 3.0. When comparing different windows, it is advisable to focus on the following guidance for R- and U-values:

- R- and U-values are based on standards set by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers [7].
- R- and U-values are calculated for the entire window, which includes the frame.
- R- and U-values represent the same style and size of windows.

The R-value of a window in an actual house is affected by the type of glazing material, the number of layers of glass, the amount of space between layers and the nature of the gas filling them, the heat-conducting properties of the frame and spacer materials, and the airtightness associated with manufacturing.

For windows, rating and approval by the National Fenestration Rating Council or equivalent rating and approval is strongly recommended [8].

Please refer to the window section of Chapter 6, Housing Structure.

Glazing

Glazing refers to cutting and fitting windowpanes into frames. Glass has been traditionally the material of choice for windowpanes, but that is changing. Several new materials are available that can increase the energy efficiency of windows. These include the following:

- **Low-emissivity** (low-e) glass uses a surface coating to minimize transmission of heat through the window by reflecting 40% to 70% of incident heat while letting full light pass through the pane.
- **Heat-absorbing glass** is specially tinted to absorb approximately 45% of the incoming solar energy; some of this energy passes through the pane.
- **Reflective glass** has a reflective film that reduces heat gain by reflecting most of the incident solar radiation.
- **Plastic glazing materials** such as acrylic, polycarbonate, polyester, polyvinyl fluoride, and polyethylene are stronger, lighter, cheaper, and easier to cut than glass. However, they are less durable and tend to be affected by the weather more than glass is.
- **Storm windows** can improve the energy efficiency of single-pane windows. The simplest example of storm windows would be plastic film, available in prepackaged kits, taped to the inside of the window frame. Because this can affect visibility and be easily damaged, a better choice would be to attach rigid or semirigid plastic sheets such as plexiglass, acrylic, polycarbonate, or fiber-reinforced polyester directly to the window frame or mounting it in channels around the frame on the outside of the building. Care should be taken in installation to avoid ripples or blemishes that will affect visibility.

Layering

The insulating capacity of single-pane windows is minimal, around R-1. Multiple layers of glass can be used to increase the energy efficiency of windows. Double- or triple-pane windows have air-filled or gas-filled spaces, coupled with multiple panes that resist heat flow. The space between the panes is critical because the air spaces that are too wide (more than ⅝ inch) or too narrow (less than ½ inch) allow excessive heat transfer. Modern windows use inert gases, such as argon and krypton, to fill the spaces between panes because these gases are much more resistant to heat flow than air is. These gas-filled windows are more expensive than regular double-pane windows.

- **Frame and spacer materials** may be aluminum, wood, vinyl, fiberglass, or a combination of these materials, such as vinyl- or aluminum-clad wood.
- **Aluminum frames** are strong and are ideal for customized window design, but they conduct heat and are prone to condensation. The deterioration of these frames can be avoided by anodizing or coating. Their thermal resistance can be boosted

using continuous strips of plastic between the interior and exterior of the frame.

- **Wood frames** are superior to aluminum frames in having higher R-values, tolerance to temperature extremes, and resistance to condensation. On the other hand, wood frames require considerable maintenance in the form of painting or staining. Improper maintenance can lead to rot or warping.

- **Vinyl window frames** made from polyvinyl chloride are available in a wide range of styles and shapes, can be easily customized, have moderate R-values, and can be competitively priced. Large windows made of vinyl frames are reinforced using aluminum or steel bars. Vinyl windows should be selected only after consideration of the concerns surrounding the use of vinyl materials and their off-gassing characteristics.

- **Fiberglass frames** have the highest R-values and are not given to warping, shrinking, swelling, rotting, or corroding. Fiberglass is not weather-resistant, so it should also be painted. Some fiberglass frames are hollow; others are filled with fiberglass insulation.

- **Spacers separating multiple windowpanes in a window** use aluminum to separate glass in multipane windows, but it conducts heat. In addition, in cold weather, the thermal resistance around the edge of such a window is lower than that in the center, allowing heat to escape and condensation to occur along the edges.

- **Polyvinyl chloride foam separators** placed along the edges of the frame reduce heat loss and condensation. Window manufacturers use foam separators, nylon spacers, and insulation materials such as polystyrene and rock wool insulation between the glass panes inside windows.

Other Options

Shades, shutters, and drapes used on windows inside the house reduce heat loss in the winter and heat gain in the summer. The heat gain during summer can also be minimized by the use of awnings, exterior shutters, or screens. These cost-effective window treatments should be considered before deciding on window replacement. By considering orientation, day lighting, storage of or reflection of energy from sunshine, and materials used within the house and on the building envelope, heat loss and gain can be decreased.

Solar Energy

Solar energy is a form of renewable energy available to homeowners for heating, cooling, and lighting. The more energy-efficient new structures are designed to store solar energy. Remodeled structures may be retrofitted to increase energy efficiency by improving insulation characteristics, improving airflow and airtightness of the structure, and enhancing the ability to use solar energy. Solar energy systems are active and passive. Whereas active solar systems use some type of mechanical power to collect, store, and distribute the sun's energy, passive systems use the materials and design elements in the structure itself.

Active Solar Systems

Active solar systems use devices to collect, convert, and deliver solar energy. Solar collectors on roofs or other south-facing surfaces can be used to heat water and air and generate electricity. Active solar systems can be installed in new or existing buildings and periodically need to be inspected and maintained. Active solar energy equipment consists of collectors, a storage tank, piping or ductwork, fans, motors, and other hardware. Flat panel collectors (Figure 13.5) can be placed on the roof or on walls. Typically, the collector will be a sandwich of one or two sheets of glass or plastic and another air space above a metal absorber plate, which is painted black to enhance heat absorption. After collection, when the sun's energy is converted to heat, a transfer is made to a liquid storage tank. The heated liquid travels through coils in the hot water tank, and the heat is transferred to the water and perhaps the heating system. Most hot water systems use a liquid collector system because it is more efficient and less costly than an air-type system.

In the southwest United States, solar roof ponds have become popular for solar cooling. Evaporative cooling systems depend on water vaporization to lower the temperature of the air. These have been shown to be more effective in dry climates than in areas with extremely high relative humidity.

In certain climates, like those in the Hawaiian Islands, using solar energy is cost-effective for providing hot water.

Figure 13.5. Solar Panels

Some builders even include it as a standard feature in their homes. The total cost to the homeowner of solar energy systems consists of the capital, operational, and maintenance costs. The real cost of capital may be lowered by the availability of tax credits offered at the federal (to lower federal income taxes) and state levels.

Homeowners and builders can benefit from tax credits because they lower the total upfront investment cost of installing active solar systems. This is the major portion of the total cost of using solar energy, because operation and maintenance costs are small in comparison to initial system costs.

Passive Solar Systems

Buildings designed to use passive solar energy have features incorporated into their design that absorb and slowly release the sun's heat. In cold climates, the design allows the light and heat of the sun to be stored in the structure, while insulating against the cold. In warm climates, the best effect is achieved by admitting light while rejecting heat. A building using passive solar systems may have the following features in the floor plan:

- Large south-facing windows
- Small windows in other directions, particularly on the north side of the structure
- Designs that allow daylight and solar heat to permeate the main living areas
- Special glass to block ultraviolet radiation
- Building materials that absorb and slowly reradiate the solar heat
- Structural features such as overhangs, baffles, and summer shading to eliminate summer overheating.

Passive design can be a direct-gain system when the sun shines directly into the building, thereby heating it and storing this heat in the building materials (concrete, stone floor slabs, and masonry partitions). Alternatively, it may be an indirect gain system where the thermal mass is located between the sun and the living space. Isolated gain is yet another type of system that is separated from the main living area (such as a sunroom or a solar greenhouse), with convective loops for space conditioning into the living space.

Energy Star is a program supported and promoted by the U.S. Environmental Protection Agency (EPA) that helps individuals protect the environment through superior energy efficiency. For the individual in his or her home, energy-efficient choices can save families about one third on their energy bill, with similar savings of greenhouse gas emissions, without sacrificing features, style, or comfort. When replacing household products, look for ones that have earned the Energy Star; these products meet strict energy-efficiency guidelines set by EPA and the U.S. Department of Energy. When looking for a new home, look for one that has earned the Energy Star approval. If you are planning to make larger improvements to your home, EPA offers tools and resources to help you plan and undertake projects to reduce your energy bills and improve home comfort [9]. In 2004 alone, Americans, with the help of Energy Star, saved enough energy to power 24 million homes and avoid greenhouse gas emissions equivalent to those from 20 million cars-all while saving $10 billion.

Conducting an Energy Audit

Energy audits can help identify areas where energy investments can be made, thereby reducing energy used in lighting, heating, cooling, or meeting other demands of housing occupants. An inspection can evaluate the worthiness or compliance with codes of energy-saving measures, including accepted or written standards. For example, if a new addition requires the equivalent of R-19 insulation in the ceilings, this can be validated in the inspection process. Whereas an audit is generally informational, an inspection should validate that materials and workmanship have yielded a structure that protects the occupants from the elements, such as rain, snow, wind, cold, and heat. Potentially hazardous situations within a structure should be evaluated in an inspection. The overall goal of a housing inspection in the case of energy efficiency is to identify potential hazardous conditions and help to create conditions under which the health and welfare of the occupants can be enhanced, rather than put at risk.

The housing inspector should be aware that there is variation (sometimes quite significant differences) in heating degree days or cooling loads and in relative humidity conditions within given regions. Local and regional topography, as well as site conditions, can affect temperatures and moisture.

Numerous Web sites listed in this chapter's Additional Sources of Information section discuss the procedures for conducting energy audits. Local and regional utilities often offer audit services and assist with selecting cost-effective conservation measures for given areas of the United States.

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