"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.

In a climate that is…	And a heating system that is… [b]	Insulate to these levels in the…				Ducts [e] in unheated/uncooled…	
		Ceiling	Wood-frame wall [c]	Floor	Basement or crawl space walls [d]	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]

The effectiveness of an insulated wall or ceiling also 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-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,

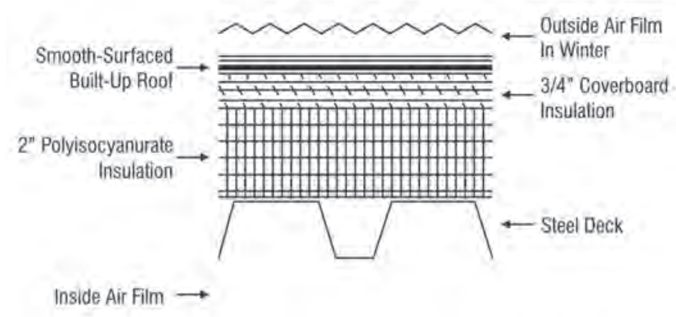

Figure 13.1. Roof Components [2]

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.

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.

Component	R-value
Inside air film	0.92
Steel deck	0.00
2-inch polyisocyanurate (5.56 x 2)	11.12
¾-inch perlite (2.78 x 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]

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 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. 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.

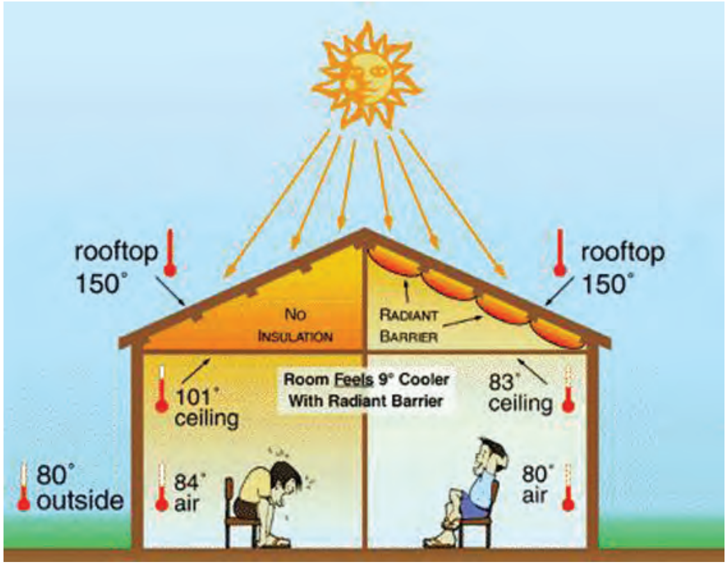

Figure 13.2. Potential Effects of Radiant Barriers [3]

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

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]

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].

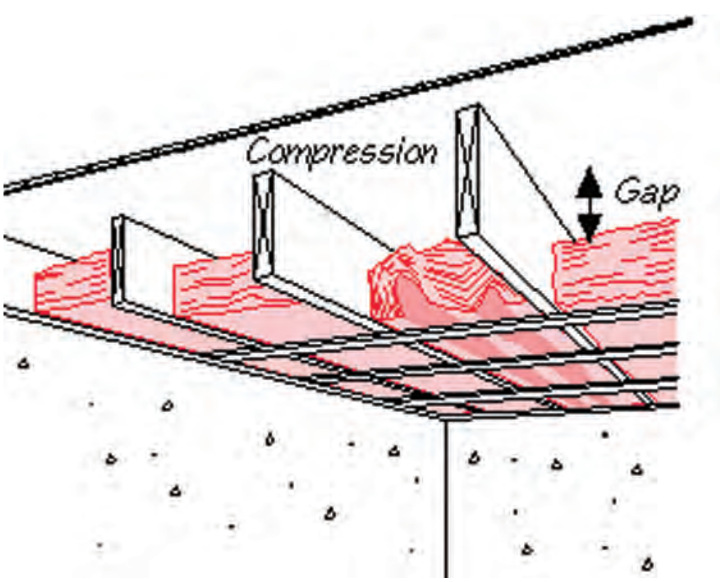

Figure 13.3. Common Floor Insulation Flaws [4.] Two common flaws in floor insulation are gaps above the batt and compression of the batt in the cavity.

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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].

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 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.

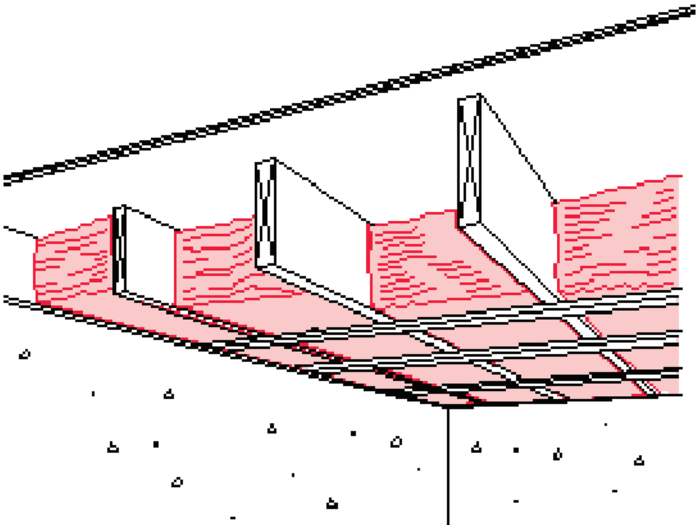

Figure 13.4a. Insulation Cavity Fill [4].
Lath provides a sturdy support for insulation.

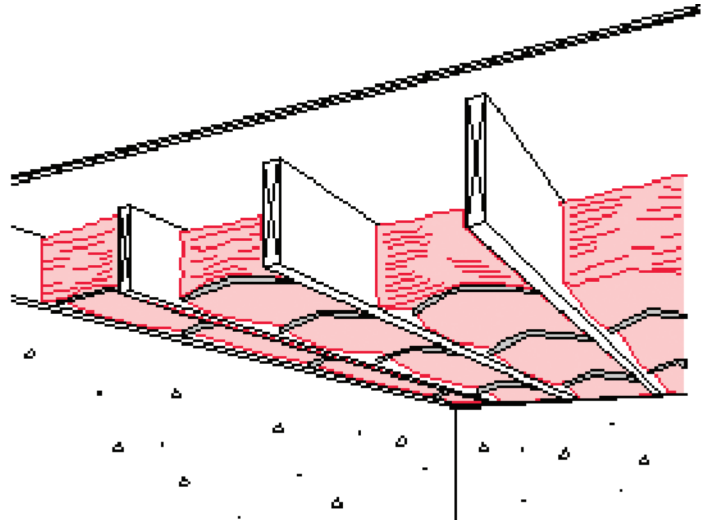

Figure 13.4b. Insulation Cavity Fill [4].
Metal rods are available through insulation distributors. They are easy to use, but insulation has to be compressed in the middle.

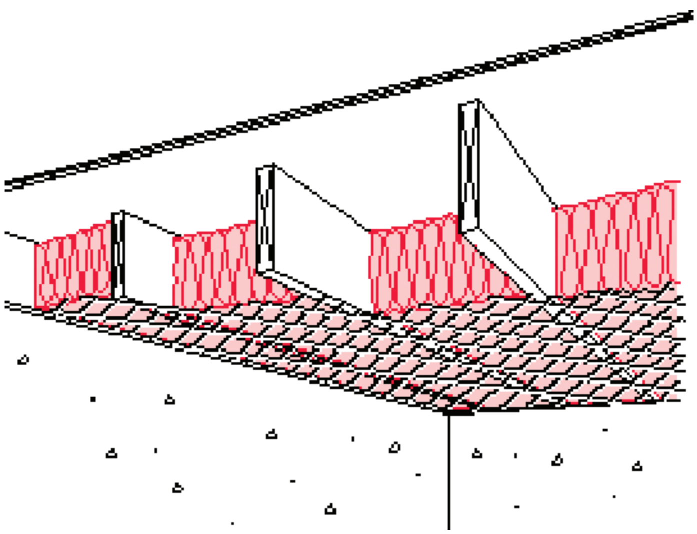

Figure 13.4c. Insulation Cavity Fill [4].
Mesh should be attached to the bottom of the framing. Draping the mesh over the joists leads to compression that reduces insulating value.

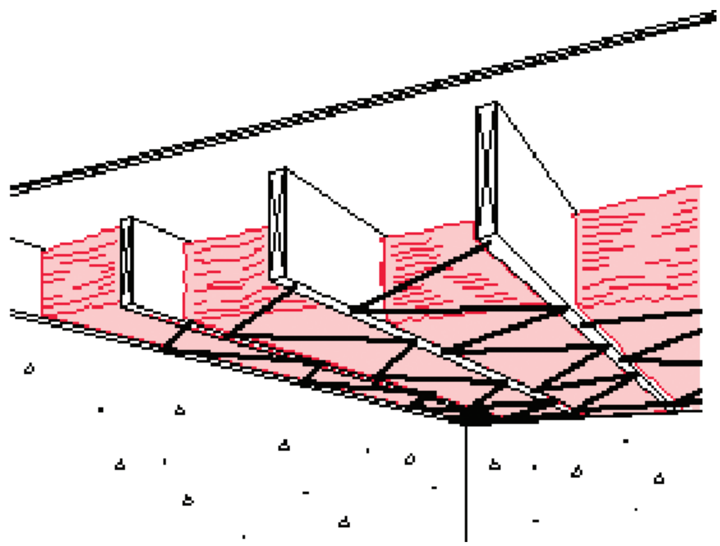

Figure 13.4d. Insulation Cavity Fill [4].
Polypropylene twine resists rot, mildew, rodents, and other dangers. It is to be stapled every 12 to 18 inches.

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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. 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

Figure 13.5. Solar Panels

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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"Most people assume if their young child falls into the pool, there will be lots of splashing and screaming, and plenty of time to react. In reality, a child slips into the water and often goes under the surface. These drownings can happen quickly and silently-without warning."

Hal Stratton, Chair
U.S. Consumer Product Safety Commission,
2002–Present

Introduction

Swimming is one of the best forms of exercise available and having a residential swimming pool also can provide much pleasure. Nevertheless, it takes a great deal of work and expense to make and keep the pool water clean and free of floating debris. Without a doubt, a properly maintained and operated pool is quite rewarding. Home pools, however, are sometimes referred to as attractive nuisances or hazards. It is essential to be able to evaluate the risks associated with a pool. A regulatory agent or consultant must understand the total engineered pool system and be capable of identifying all equipment, valves, and piping systems. The piping system for a pool should be color-coded to assist the pool operator or the owner to determine the correct way to operate the swimming pool. The specific goal is to protect the owners, their families, and others who may be attracted to a residential pool.

Residential pools and spas should provide clean, clear water; water free of disease agents; and a safe recreational environment. In addition, residential pools and spas should have effective, properly operating equipment and effective maintenance and operation.

Childproofing

Although it seems obvious, close supervision of young children is vital for families with a residential pool. A common scenario is a young child leaving the house without the parent or caregiver realizing it. Children are drawn to water, and they can drown even if they know how to swim. All children should be supervised at all times while in and around a pool.

The key to preventing pool tragedies is to provide layers of protection. These layers include limiting pool access, using pool alarms, closely supervising children, and being prepared in case of an emergency. The U.S. Consumer Product Safety Commission (CPSC) offers these tips to prevent drowning:

- Fences and walls should be at least 4 feet high and installed completely around the pool. The fence should be no more than 2 inches above grade. Openings in the fence should be a maximum of 4 inches. A fence should be difficult to climb over.
- Fence gates should be self-closing and self-latching. The latch should be out of a small child's reach. The gate should open away from the pool; the latch should face the pool.
- Any doors with direct pool access should have an audible alarm that sounds for 30 seconds. The alarm control must be a minimum of 54 inches high and reset automatically.
- If the house forms one side of the barrier to the pool, then doors leading from the house to the pool should be protected with alarms that produce a sound when a door is opened.
- Young children who have taken swimming lessons should not be considered "drown proof"; young children should always be watched carefully while swimming.
- A power safety cover—a motor-powered barrier that can be placed over the water area—can be used when the pool is not in use.
- Rescue equipment and a telephone should be kept by the pool; emergency numbers should be posted. Knowing cardiopulmonary resuscitation (CPR) can be a lifesaver.
- For aboveground pools, steps and ladders should be secured and locked or removed when the pool is not in use.
- Babysitters should be instructed about potential hazards to young children in and around swimming pools and their need for constant supervision.
- If a child is missing, the pool should always be checked first. Seconds count in preventing death or disability.
- Pool alarms can be used as an added precaution. Underwater pool alarms can be used in conjunction with power safety covers. CPSC advises consumers to use remote alarm receivers so the alarm can be heard inside the house or in other places away from the pool area.

- Toys and flotation devices should be used in pools only under supervision; they should not be used in place of supervision.
- Well-maintained rescue equipment (including a ring buoy with an attached line and/or a shepherd's crook rescue pole should be kept by the pool.
- Emergency procedures should be clearly written and posted in the pool area.
- All caregivers must know how to swim, know how to get emergency help, and know CPR.
- Children should be taught to swim (swimming classes are not recommended for children under the age of 4 years) and should always swim with a buddy.
- Alcohol should not be consumed during or just before swimming or while supervising children.
- To prevent choking, chewing gum and eating should be avoided while swimming, diving, or playing in water.
- Water depth should be checked before entering a pool. The American Red Cross recommends 9 feet as a minimum depth for diving and jumping.
- Rules should be posted in easily seen areas. Rules should state "no running," "no pushing," no drinking," and "never swim alone." Be sure to enforce the rules.
- Tables, chairs, and other objects should be placed well away from the pool fence to prevent children from using them to climb into the pool area.
- When the pool is not in use, all toys should be removed to prevent children from playing with or reaching for them and unintentionally falling into the water.
- A clear view of the pool from the house should be ensured by removing vegetation and other obstacles that block the view.

Hazards

Numerous issues need to be considered before building residential pools: location of overhead power lines, installation and maintenance of ground fault circuit interruptors, electrical system grounding, electrical wiring sizing, location of the pool, and type of vegetation near the pool. The commonly used solar covers that rest on the surface of the pool and amplify sunlight do an excellent job of increasing the pool temperature, and they also increase the risk for drowning. If children or pets fall in and sink below the cover, it can be nearly impenetrable if they attempt to surface under it.

Winterizing the pool also can be hazardous. The pool water in most belowground pools is seldom drained because of groundwater pressure that can damage the structure of the pool. Therefore, water in most home pools is only lowered below the frost line for winter protection. In these cases, a pool cover is installed to keep debris and leaves from filling the pool in the winter months. The pool cover becomes an excellent mosquito-breeding area before the pool is reopened in the spring because of the decomposing vegetation that is on the pool cover, the rain that accumulates on the top of the pool cover during the winter, and the eggs laid on the pool cover in early fall and early spring. The cover also provides ideal conditions for mosquitoes to breed: stagnant water, protection from wind that can sink floating eggs, the near absence of predators, and warm water created by the pool cover collecting heat just below the surface (Figure 14.1).

Public Health Issues

Current epidemiologic evidence indicates that correctly constructed and operated swimming pools are not a major public health problem. They are preferable to bathing beaches because of the engineered controls designed into pools. Poorly designed or operated pools, however, can be major public health hazards. Data from CDC between 1999 and 2000 show that 59 disease outbreaks from 23 states were attributed to recreational water exposure and affected an estimated 2,093 people. Of the 59 recreational outbreaks, 44 (74.6%) were of known infectious etiology. Of the 36 outbreaks involving gastroenteritis, 17 (47.2%) were caused by parasites; 9 (25.0%) by bacteria; 3 (8.3%) by viruses; 1 (2.8%) by a combination of parasites and bacteria, and the remaining 6 (16.7%) were of unknown cause. Of the 23 nongastroenteritis-related recreational outbreaks, seven were attributed to

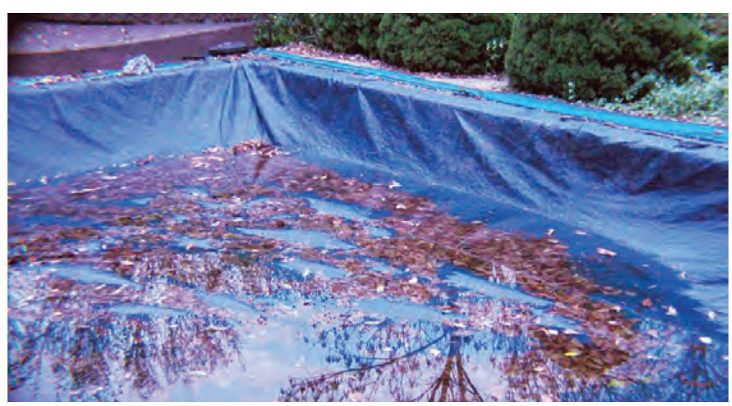

Figure 14.1. Pool Cover

Pseudomonas aeruginosa, four to free-living amoebae, one to *Leptospira* species, one to *Legionella* species, and one to bromide. Sixteen of the 17 parasitic recreational water outbreaks involving gastroenteritis; nine (24.3%) were outbreaks of dermatitis; and six (16.2%) were caused by *Cryptosporidium parvum*. The seventeenth outbreak was caused by *Giardia lamblia* (intestinalis). In 1999, an outbreak of *Campylobacter jejuni* was associated with a private pool that did not have continuous chlorine disinfection and reportedly had ducks swimming in the pool [1].

Diseases

- **Intestinal diseases:** *Escherichia coli* O157:H7, typhoid fever, paratyphoid fever, amoebic dysentery, leptospirosis, cryptosporidiosis (highly chlorine resistant), and bacillary dysentery can be a problem where water is polluted by domestic or animal sewage or waste. Swimming pools have also been implicated in outbreaks of leptospirosis.
- **Respiratory diseases:** Colds, sinusitis, and septic sore throat can spread more readily in swimming areas as a result of close contact, or improperly treated pool water, coupled with lowered resistance because of exertion.
- **Eye, ear, nose, throat, and skin infections:** The exposure of delicate mucous membranes, the movement of harmful organisms into ear and nasal passages, the excessive use of water-treatment chemicals, and the presence of harmful agents in water can contribute to eye, ear, nose, throat, and skin infections. Close physical contact and the presence of fomites (such as towels) also help to spread athlete's foot, impetigo, and dermatitis.

Injuries

Injuries and drowning deaths are by far the greatest problem at swimming pools. Lack of bather supervision is a prime cause, as is the improper construction, use, and maintenance of equipment. Injuries include evisceration, electrocution, entrapment, and entanglement. Some particular problem areas include the following:

- loose or poorly located diving board,
- slippery decks or pool bottoms,
- poorly designed or located water slides,
- projecting or ungrated pipes and drains that can catch hair or body parts,
- drain grates of inadequate size,
- improperly installed or maintained electrical equipment, and
- improperly vented chlorinators and mishandled chlorine materials.

Water Testing Equipment

It is essential that correct equipment be used and maintained for assessing the water quality of both swimming pools and spas. The operators of pool and spas need to monitor a wide range of chemicals that influence pool operations and water quality. Their equipment should test for chlorine, bromine, pH, alkalinity, hardness, and cyanuric acid build up. The chlorine should be measurable at a range of 0 to 10 parts per million (ppm). Water pH levels should be accurately measured with an acid or base test. A kit to check pool chemical levels usually includes N,N-diethyl-p-phenylene-diamine (DPD) tablet tests for free and total chlorine, and other one-step tablet tests for pH, total alkalinity, calcium hardness, and cyanuric acids. The homeowner should determine acid or base demand using an already reacted pH sample in dropper bottles. Paper test strips with multiple tests (including chlorine, bromine, and pH) are also available, but the reliability of these tests varies greatly. If used, they should be kept fresh, protected from heat and moisture, and checked against other test systems periodically if water quality problems persist.

Swimming pools are engineered systems, with demanding safety and sanitary requirements that result in rather sophisticated design standards and water treatment systems. The size, shape, and operating system of the pool is based on the following considerations:

- the intended use of the pool and the maximum expected bather loading;
- the selection of skimmers, scuppers, or gutters, depending on the purpose, size, and shape of the pool;
- the recirculation pump, whose horsepower and impeller configuration are based on the distance, volume, and height of the water to be pumped;
- the filters, which are sized on the volume of water to be treated and the maximum gallons (liters) of water per minute that can be delivered by the pump and the type of filter media selected; and
- the chemical feeder sizes and types, which are based on the chemicals used, total quantity of the water in the system, expected use rates, and external environmental factors, such as quantity of sunlight and wind that affect the system.

Disinfection

The length of time it takes to disinfect a pool depends, for example, on the type of fecal accident and the chlorine levels chosen to disinfect the pool. If a fecal accident is a formed stool, the faollowing chlorine levels will determine the times needed to inactivate *Giardia*:

Chlorine Levels (ppm)	Disinfection Time
1.0	45 minutes
2.0	25 minutes
3.0	19 minutes

These times are based on a 99.9% inactivation of *Giardia* cysts by chlorine, pH 7.5, and 77°F (25°C). The times were derived from the EPA *LT1ESWTR Disinfection Profiling and Benchmarking Technical Guidance Manual* [2]. These times do not take into account "dead spots" and other areas of poor pool water mixing.

If the fecal accident is diarrhea, the following chlorine levels will determine the times needed to inactivate *Cryptosporidia*:

Chlorine Levels (ppm)	Disinfection Time
1.0	6.7 days
10.0	16 hours
20.0	8 hours

A CT value is the concentration (C) of free available chlorine in parts per million (ppm) multiplied by the time (T) in minutes (CT value = C×T). The CT value for *Giardia* is 45 and the value for *Cryptosporidia* is 9,600. If a different chlorine concentration or inactivation time is used, CT values must remain the same. For example, to determine the length of time needed to disinfect a pool at 15 ppm after a diarrheal accident, the following formula is used: C×T = 9,600. Solve for time: T= 9,600÷15 ppm = 10.7 hours. It would, thus, take 10.7 hours to inactivate *Cryptosporidia* at 15 ppm. You can do the same for *Giardia* by using the CT of 45.

CDC has Web sites that contain excellent information about safe swimming recommendations, recreational water diseases, and disinfection procedures for fecal accidents [3,4].

Content Turnover Rate

The number of times a pool's contents can be filtered though its filtration equipment in a 24-hour period is the turnover rate of the pool. Because the filtered water is diluted with the nonfiltered water of the pool, the turbidity continually decreases. Once the pool water has reached equilibrium with the sources of contamination, a 6-hour turnover rate will result in 98% clarification if the pool is properly designed. A typical-use pool should have a pump and filtration system capable of pumping the entire contents of the pool though the filters every 6 hours. To determine compliance with this 6-hour turnover standard, the following formula is used:

> Turnover rate = pool volume (gallons)/flow rate×60 (minutes in hour)

Following is a sample calculation of the pool content turnover rate using the rate of flow reading from the flow meter:

> Turnover rate = 90,000 (gallons in pool)/
> 180 gallons per minute×60 (minutes in hour)
>
> 8.3-hour turnover rate = 90,000 (pool volume in gallons)/10,800

The above pool would not meet the required turnover rate of 6 hours. The cause could be improperly sized piping or restrictions in the piping, an undersized pump, or undersized or clogged filters. This turnover rate would probably result in cloudy water if the pool is used at the normal bather load. The decreased circulation would also make it difficult for the disinfecting equipment to meet the required levels.

Filters

Pool filters are not designed to remove bacteria, but to make the water in the pool clear. Normal tap water looks quite dingy if used to fill a pool and, in some cases, the bottom of the pool is not visible. The maximum turbidity level of a pool should be less than 0.5 nephelometric turbidity units. Pool filters should be sized to ensure that the complete contents of the pool pass through the filter once every 6 hours. Home pools typically use one of three types of filters.

High-rate Sand Filters

High-rate sand filters were introduced more than 30 years ago and reduced the size of the conventional sand filter by 80%. The sand filter is the most popular filter on the market. High-rate sand filters use a silica sand that has been strained to give it a uniform size. It is referred to as pool-grade sand #20 silica. The sand is normally 0.45 millimeters (mm) to 0.55 mm in diameter. As water passes through the filter, the sharp edges of the sand trap the dirt from the pool water. When the backpressure of the filter increases to 3 to 5 psi, the filter needs to be cleaned. This is usually accomplished by reversing the flow of the water through the filter and flushing the dirt out the waste pipe until the water being discharged appears clear. These filters perform best when used at pressure levels below 15 to 20 gallons per minute, depending on the manufacturer of the filter.

Cartridge Filters

Cartridge filters have been around for many years, but only recently have gained in popularity in the pool industry. They are similar to the filter on a car engine. The water is passed through the cartridge and returned to the pool. When the pressure of a cartridge filter increases approximately 5 psi, the pump is turned off; and the top of the filter is removed. The cartridge is removed and either discarded and replaced or, in some cases, washed.

Diatomaceous Earth

Diatomaceous earth (DE) is a porous powder made from the skeletons of billions of microscopic animals that were buried millions of years ago. There are two primary types of DE filters, but they both work the same way. Water comes into the filter, passes through the DE, and is returned to the pool. If properly sized and operated, DE filters are considered by some to provide the highest quality of water. They are capable of filtering the smallest particle size of all the filter types. It is usually adequate to change the DE once every 30 days. However, if your pool water is very dirty, it is not uncommon to change it 3–4 times a day until the water is clear. The frequency of backwashing will depend on many factors, including the size of your filter, flow rate of your plumbing, and the bather load in your pool. When the pressure reading on the filter reaches the level set by the manufacturer's manual, it will be ready for backwashing.

Filter Loading Rates

The specification plate on the side of approved residential or commercial swimming pool filters contains such information as the manufacturer, type of filter, serial number, surface area, and designed loading rate. Knowing the surface area of the filter permits calculation of the number of gallons flowing through the filter per minute. An excessive flow rate can push the media into the pool or force pool solids and materials thought the media, resulting in turbid water. Figure 14.2 shows a typical home pool treatment system. Regulations typically specify how much water can be filtered through the various types of pool filtration systems.

Disinfectants

Many disinfectants are used in pools and spas around the world, including halogen-based compounds (chlorine, bromine, iodine), ozone, and ultraviolet light with hydrogen peroxide. Those used most often are chlorine, bromine, and iodine, and each has advantages and limitations.

Chlorine—Pools can be disinfected with chlorine-releasing compounds, including hypochlorite salt compounds. Calcium hypochlorite is inexpensive and popular for cold-water pools, but not suitable for hot pools and spas because it will promote scaling on heat exchangers and piping. Chlorine levels can be rapidly reduced with high use and regular checks should be made to ensure maintenance of disinfection. Some adjustment of pH is required for most forms of chlorine disinfection. When chlorine gas is used, a fairly high alkalinity needs to be maintained to remove the acid formed during dosing [5]. Sodium hypochlorite is a liquid chlorine, and has a pH of 13, causing a slight increase in the pH of the pool water, which should be adjusted with an acidic mixture. The sun's rays will degrade sodium hypochlorite. Chlorinated isocyanate is available in three forms-granular, tablet, and stick. The granular form contains 55%–62% available chlorine and the stick and tablet form contain 89% available chlorine [6].

Figure 14.2. Typical Home Pool Equipment System

Bromine—Bromine needs to be used at levels twice those of chlorine to achieve similar disinfection. Bromine is available as the sodium or potassium salts. In the presence of ammonia, bromine rapidly forms relatively unstable ammonia bromamines that possess disinfection efficiencies comparable to that of free bromine. It is also unnecessary to destroy ammonia bromamines because they do not produce irritating odors [5].

Iodine—Potassium iodide is a white, crystal chemical. This chemical needs an oxidizer, such as hypochlorite, to react with organic debris and bacteria. Iodine does not react with ammonia, hair, or bathing suits, or cause eye irritation, but it can react with metals, producing greenish-colored pool water [6].

Ozone—Ozone is a very powerful oxidant and is effective against viruses. It can only be generated at the point of use and commercial generation units are safe for use. Ozone dosing is only practical where there is water circulating off-pool because adequate ozone-water mixing is essential for maximum oxidation. Ozone generators may be of the ultraviolet lamp or corona discharge type. The ultraviolet lamp efficiency reduces with time and the lamp and associated activated charcoal filter will need replacement [5].

Ultraviolet Light—Ultraviolet light, like ozone, is sometimes used for off-pool water disinfection. Ultraviolet light has no effect on pH or color and has little effect on the chemical composition of the water. However, color, turbidity, and chemical composition of the water can interfere with ultraviolet light transmission. The water must be adequately treated before ultraviolet light exposure. Hydrogen peroxide is often used for this purpose as it is relatively safe in low concentrations, is nonflammable, and produces oxygen and water as end products. For the ultraviolet light plus hydrogen peroxide system to be effective, it must operate 24 hours a day. Ultraviolet light disinfection is not pH dependent, but the addition of hydrogen peroxide results in slightly acidic conditions [5].

Silver-copper Ionization—Sanitizing can be accomplished by using an ionizing unit that introduces silver and copper ions into the water by electrolysis, or by passing an electric current through a silver and copper electrode. The limiting factors in using this system in the pool and spa are cost, slow bactericidal action, and potentially high contaminant levels caused by bather loads. Also, black spots can form on pool surfaces if the proper parameters of water chemistry are not maintained. An approved chemical disinfectant must be used with an ionizing unit [6].

The effective use of halogen disinfectants is based on the pH, hardness, and alkalinity of the water. Improper pH, hardness, and alkalinity levels in the pool can render high levels of disinfectant useless in killing disease-causing organisms. Table 14.1 summarizes water-quality problems that affect pools and suggests corrective actions.

Effect of pH

The ideal pH to avoid eye irritation is 7.3. Bacteria- or algae-killing effectiveness is improved with an even lower pH. National standards typically recommend a range of 7.2 to 7.6, which is cost-effective. Table 14.2 demonstrates the loss of disinfection as pH increases.

Chlorine Disinfectants

The options for selecting the form of chlorine disinfectant to use in pools are quite varied, and the choices are complex. Table 14.3 gives the properties of each form. Gas chlorine costs the least, and the relative cost of each form of chlorine increases as you move right across the table. The cost of the disinfectant tends to be less the higher the concentration of available chlorine. The safety issues are more complex than they might appear. The hazards of gas chlorine are well known. The solid forms of chlorine, such as calcium hypochlorite, are quite reactive. When exposed to organic compounds, they can generate a great deal of heat and are potentially explosive. Because solid chlorine seems inert to the untrained worker, it is often stored beside motor oil or gasoline or left in where moisture can start a chemical reaction. Even a pencil with a graphite core that drops from a shirt pocket into a container of calcium hypochlorite could result in a chemical reaction leading to a fire that would release free chlorine gas [7].

The following chemical reactions produce chlorine byproducts that reduce the effectiveness of chlorine and cause most eye irritation.

$$Cl_2 + H_2O = HCl + HOCl$$

Chlorine + Water = Hydrochloric Acid + Hypochlorous Acid

$$HOCl + NH_3 = H_2O + NH_2Cl$$

Hypochlorous Acid + Ammonia = Water + Monochloramine

$$HOCl + NH_2Cl = H_2O + NHCl_2$$

Hypochlorous Acid + Monochloramine = Water + Dichloramine

$$HOCl + NHCl_2 = H_2O + NCl_3$$

Hypochlorous Acid + Dichloramine = Water + Nitrogen Trichloride

Tables 14.1–14.4 serve as a quick problem-solving reference for the home pool owner and operator. The CDC Web site (www.cdc.gov/healthyswimming) provides a great deal of useful information for both the inspector and the homeowner.

Water Quality Issue (Symptoms)	Potential Problems (Root Causes)	Corrective Approaches (Actions)
Air bubbles coming from inlets	1. Air in filter shell (easy fix) 2. Leak in hair and lint strainer, pipe, valves, or fittings on suction side of pump (may be difficult to fix)	1. Bleed air off of top of filter shell. 2. Check seal around opening of hair and lint strainer. Locate leaking fitting and seal.
Foam on water, around floating objects, and on sides of pool	1. Low hardness of water (easy fix) 2. Effect of algaecides (do not need) 3. Spillage of detergent into pool	1. Maintain minimum of 200 ppm calcium hardness, but less than 400 ppm. 2. Do not use algaecides, but maintain 1 ppm of free chlorine at minimum and a pH of 7.2–7.3. (pH of 7.2 is preferable) for algae-free water. 3. Backwash filters for extended time and add makeup water. If foam is still a problem, add defoaming agent.
Cloudy water	1. Inadequate turnover rate 2. Filter media corrupted, channeled, or creviced. 3. Excessive filter pressure. 4. High pH or alkalinity above 150 ppm.	1. Check pump capacity and flow rate. 2. If sand, clean filter and replace media, if necessary. If diatomaceous earth (DE) filter, wash filter bags in weak acid solution. 3. Backwash filter, bleed air pressure from filter shell, check pump for proper sizing. 4. Reduce pH to maximum of 7.6 and alkalinity to less than 150 ppm.
Milky water (uniform water color with white, opaque appearance)	DE entering pool from DE filter leakage	Check filter bags for tears or holes and the mounting of the bags on the filter septa. Expect 24-hour minimum filtering to clear water.
Dull green color, varying density	Algae growth	Super-chlorinate, then maintain pH at 7.6 (preferably 7.2) and disinfectant level of 1 ppm or higher.
Bright green color	Dissolved iron	Adjust pH to between 7.2 and 7.6, adjust disinfectant level to between 1 and 1.5 ppm. Iron should precipitate to ferrous state (brown); backwash repeatedly to remove. Expect 24 to 46 hours of filtering to clear water.
Bluish green color	Copper damage from low pH	Raise pH to 7.6, increase hardness to 200 ppm and alkalinity to at least 150 ppm. Perform a saturation index calculation. Adjust water to slightly above +0.5 to achieve scale-forming water to isolate before equipment damage.
Reddish brown water, uniform in color and texture	Precipitated iron (ferrous)	Adjust pH and disinfectant level and backwash filter as needed until clear.

Table 14.1. Pool Water Quality Problem Solving [7]

HoCl ⟵⟶	H +	OCl -
Hypochlorous Acid—More Increases Effectiveness [Percent of Chlorine as HOCl]	Hydrogen Ion [pH]	Hypochlorite Ion—More Reduces Effectiveness [Percent of Chlorine as OCl]
90	6.5	10
73	7.0	27
66	7.2—IDEAL	34
45	7.6—IDEAL	55
21	8.0	79
10	8.5	90

Table 14.2. pH Effect on Chlorine Disinfection [7]

	Gas Chlorine	Sodium Hypochlorite	Calcium Hypochlorite	Dichloro	Trichloro
Percent Chlorine	100	10–15	65–70	56–62	90
Effect on pH	Lowers pH	Raises pH	Raises pH	Neutral	Lowers pH
Sunlight Effects	Considerable	Yes	Yes	Little loss	Little loss
Physical Form	Gas	Liquid	Granular or tablets	Granular only	Granular or tablets

Table 14.3. Chlorine Use in Swimming Pools

Pool Water Hardness and Alkalinity

The ideal range of water hardness for a plaster pool is 200 to 275 ppm. The ideal range for a vinyl, painted, or fiberglass surface is 175 to 225 ppm. Excess hardness causes scaling, discoloration, and filter inefficiency. Less than recommended hardness results in corrosion of most contact surfaces.

Alkalinity should be 80 to 120 ppm. High alkaline levels cause scale and high chlorine demand. Low levels cause unstable pH. Sodium bicarbonate will raise the alkalinity level. The pool water will be cloudy if alkalinity is over 200 ppm.

Liquid Chemical Feeders

Positive Displacement Pump

A positive displacement pump is preferable to erosion disinfectant feeders. Positive displacement pumps can be set to administer varied and specific chemical dosage rates to ensure that a pool does not become contaminated with harmful microorganisms. A positive displacement pump does need routine cleaning, descaling, and servicing. Running a weak muriatic acid or vinegar solution through the pump weekly can minimize most major servicing of the pump. Most service on the pump involves one of four areas:

1. the check valves are scaled, their springs are weak, or valves are no longer flexible;
2. the diaphragm is cracked, leaking, or not flexible;
3. the drive cam needs replacement or requires adjustment; or
4. the motor requires replacement.

Erosion and Flow-through Disinfectant Feeders

These feeders work by the action of water moving around a solid cake of chlorine and eroding the cake. The feeders work quite well for smaller pools, but require considerable care and maintenance. The variables that affect the effectiveness of erosion feeders are

1. solubility of the chlorine cake or tablet;
2. surface area of the cake or tablet;
3. amount of water flowing around the cake or tablet;
4. concentration of chlorine in the cake or tablet; and
5. number of cakes or tablets in the feeder.

Note: For safety reasons, the disinfectant cake must not be accessible.

	Minimum	Ideal	Maximum	Comments
Water Clarity				
Crystal-clear water at all times is the goal	Main drain visible	Crystal clear, object the size of a dime easily seen from pool deck at main drain, water sparkles	None	Lack of clarity is often due to malfunctioning or undersized filters. Other problems may be improperly sized pump, air collecting in the filter shell, or operator not running filter 24 hours per day.
Disinfectant Levels				
Free chlorine				
Standard pool	4	4	4	Continuous levels at 1 to 1.5 ppm minimum.
Wading or shallow pool for children	3	3	3	Super-chlorinate indicators: high chlorine level, eye irritation, or algae growth. Super-chlorinate indicators: High chlorine levels, eye irritation or algae growth. Continuous levels.
Combined chlorine	None	None	0.5	
Bromine	2	5	10	
Wading or shallow pool for children	4	7	10	
Iodine ppm	Consult product manufacturer	—	—	—
Chemical Values				
Hardness, $CaCO_3$	150	200–400	500+	If difficult to control, use a different disinfectant.
Heavy metals	None	None	None	Check algaecide for heavy metal presence or by-products of corrosion (partial water replacement may be recommended).
Stabilizer, cyanuric acid	10	30–50	100	If level exceeds 100 ppm, partial water replacement recommended.
Algae, bacteria	None	None	None	Shock treat and maintain required levels of disinfectant and 7.2 to 7.6 pH.

Table 14.4. Swimming Pool Operating Parameters [7]

Spas and Hot Tubs

Hot tubs (large tubs filled with hot water for one or more people) or spas (a tub with aerating or swirling water) are used for pleasure and are increasingly being recommended for therapy. The complexity of these devices increases with each new model manufactured. Newer models often have both ozone and ultraviolet light emitters for enhanced disinfection (see Disinfectants section earlier in this chapter). However, the environment of the spa and hot tub, if not cleaned and operated correctly, can become a culture medium for microorganisms. Because the warm water is at the ideal temperature for growth of microorganisms, good disinfection is critical.

Table 14.5 provides suggested hot tub and spa operating parameters. It is essential that all equipment works properly and that the units are cleaned and disinfected on a routine basis. Monitoring the water temperature is very important and, depending on the health of the user, can be a matter of life and death. Time in the heated water should be limited, and the temperature for pregnant users should be below 103°F (39°C) to protect the unborn baby. The verification code for this document is 159434.

	Minimum (ppm)	Ideal (ppm)	Maximum (ppm)	Comments
Disinfectant Levels				
Free chlorine	3	4	10	Continuous levels. Super-chlorinate when combined level exceeds 0.2.
Combined chlorine	None	None	0.5	Super-chlorinate indicators: High chlorine levels, eye irritation or algae growth.
Bromine	4	5	10	Continuous levels.
Iodine ppm	Consult product manufacturer			
Ozone, ultraviolet light, hydrogen peroxide, and others	Consult product manufacturer			Use also requires a disinfectant in most health jurisdictions.
Chemical Values				
pH	7.2	7.3	7.6	Ideal range: 7.2–7.6.
Total alkalinity, $CaCO_3$	60	80–100	180	
Dissolved solids	300	NA	2,000	Excess solids many lead to hazy water and corrosion of fixtures (may need partial water replacement).
Hardness, $CaCO_3$	150	200–400	500+	If difficult to control, use a different disinfectant.
Heavy metals	None	None	None	Check algaecide for heavy metal presence or by-products of corrosion (partial water replacement may be required).
Stabilizer, cyanuric acid	10	30–50	100	If level exceeds 100 ppm, partial water replacement may be required.
Algae, bacteria	None	None	None	If observed, shock treat and maintain required levels of disinfectant and the appropriate pH.

Table 14.5. Spa and Hot Tub Operating Parameters [7]

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Additional Sources of Information

American Academy of Pediatrics. Available from URL: www.aap.org.

American National Standards Institute. Available from URL: http://www.ansi.org.

American Red Cross. Available from URL: www.redcross.org.

American Trauma Society. Available from URL: www.amtrauma.org.

Association of Pool and Spa Professionals. Available from URL: http://www.nspi.org/.

Centers for Disease Control and Prevention, National Center for Injury Prevention and Control. Available from URL: www.cdc.gov/ncipc/factsheets/drown.htm.

For more information about the CDC fecal accident recommendations, go to URL: http://www.cdc.gov/healthyswimming/fecal_response.htm.

For additional information about cryptosporidiosis, go to URL: http://www.cdc.gov/healthyswimming/cryptofacts.htm.

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