Chapter

1

A Brief History of Thermal Insulation

From caves to superinsulated houses, human beings have demonstrated the need for protection from the elements. The true origins of the science of thermal insulation, however, are difficult to identify. Organic materials have served as the natural prototype for thermal insulators. Evolutionary examples include fur covering the polar bear or feathers on a bird, cotton, wool, straw, and even hair. Similarly, prehistoric human beings clothed themselves with wool and skins from animals and built homes of wood, stone, earth, and other materials for protection from the cold winter and the heat of summer.

For thousands of years, house structures were designed to best suit the climate of their location. For example, using the earth as an insulator, the Egyptians retired to the coolness of subterranean chambers and grottoes on hot days.[1] Historians believe that the ancient Greeks and Romans discovered asbestos and found many uses for it because of its resistance to heat and fire. The Romans even used cork for insulation in shoes in order to keep their feet warm. Pliny, in the first century, referred to the use of cork as an insulating material for roofs. Early inhabitants of Spain lined their stone houses with cork bark, and North African natives used cork mixed with clay for the walls of their dwellings.[2]

As technology developed, so did innovations to improve the comfort of human beings. Introduction of the fireplace and chimney by the Norwegians and people of Iceland during the twelfth and thirteenth centuries provided controlled, artificial heat.[1] It was evident that the task soon became not only how to keep heat out but also how to keep heat in. The thatched huts of northern Europe were built with a roof, up to 2 ft thick, of woven straw and walls of clay and straw (Fig. 1.1) Early Spanish mission houses of the southwestern United States, where temps rose to 120 to 140°F, were comparatively cool due to clay straw walls several feet thick. Similarly, the indigenous peoples of the South Seas built huts of dried sea grass. The hollow fiber of the dried sea grass provided a good degree of thermal resistance.[2] Mineral fiber—another important insulating material—was first used by the natives of the Hawaiian Islands to blanket their huts. The fibers came from volcanic deposits, where escaping steam had broken the molten lava into fluffy fibers.

It was not until the advent of the industrial revolution of the late nineteenth century that deliberate commercial application of thermal insulations became mainstream. For example, blanket-type insulations were being developed throughout the 1890s. One such product, known as Cabot's Quilt, was introduced by Samuel Cabot in 1891. The material consisted of a matting of *Zostera marina,* a marine plant also known as *eel grass,* sandwiched or stitched between two layers of kraft paper. (An unrefined use of this material was found in the Pierce house of Dorchester, Massachusetts, built in 1635, with *Zostera marina* stuffed between the framing members.)[2]

Mineral wool was first commercially produced as a pipe insulator in Wales in 1840 and in the United States for the first time in 1875.[3] It was almost 60 years later, in 1897, that C. C. Hall, a chemical engineer, produced rock wool. By 1901, he was producing this product commercially at a plant in Alexandria, Indiana.[2] Hall formed a partnership to make the new product and later founded Banner Rock Products Co. (which was purchased by Johns Manville Co. in 1929). By 1928, there were eight plants manufacturing either rock wool or slag wool insulation in the United States. (By the 1950s, this number had increased to approximately 90 but has since declined to about 15 to 20 today.[4])

Fiberglass had its first beginnings in ancient Egypt, when people discovered that they could draw hot glass into threads, which were placed around vessels for decoration. The modern technique of making fiberglass insulation, developed in 1931, involves jetting of molten glass through tiny heated holes into high-speed air streams, wherein the resulting fibers are drawn very thin and to great length.[5] Developed by Owens-Illinois, the Corning Glass

Company was the sole producer of this material, later known as Owens-Corning fiberglass, until an antitrust action filed in 1949 by the Department of Justice.[4]

Wood shavings were a very popular insulation product due to the wide availability of raw materials and their low cost at the turn of the century. Shavings often were treated with lime or some other chemicals to increase resistance to water absorption, fire, and fungal growth. These were called *balsa wool* or *balsa batt* (actually sawdust wrapped in paper) and were popular in homes of northeastern United States.

Straw bale construction also has been around since the "frontier days" of the United States and is most common in the western Plains states. When the Kincaid Act of 1904 opened part of Nebraska to homesteading, straw was one of the only indigenous materials available. Housing became an urgent necessity for frontiersmen, and straw bale construction flourished in the Sandhills of Nebraska more than any other known location. Although these settlers planned to build a "real" house as soon as enough money could be saved, such houses often were left exposed on the outside, but they were plastered on the inside to enhance tidiness and prevent drafts. Although the process sometimes took as long as 10 years, the outside walls would finally get a thick coat of mud plaster or cement stucco.

Straw bale construction was an appropriate, sometimes necessary response to a unique combination of legislative, geologic, natural resource, and socioeconomic factors that prevailed in that region. The building of railroads through the Midwest is one factor that added to the reduction of straw use. Railroads and merchandizing enabled wood products to replace Nebraska's indigenous materials for buildings needs.

Reflective insulation materials, using bright metallic surfaces, were first patented in 1804. Aluminum eventually became the predominant reflective material, but it did not achieve commercial popularity until the 1930s.[2]

The genesis of insulation board products dates to 1910. Two semirigid insulation products made from flax (a textile fiber made from plants) were manufactured in Minnesota, called *Flaxlinum* and *Fibrofelt.* These ultimately were replaced by rigid insulation board products, also first produced in Minnesota, in 1914. Insulite was manufactured by taking wood pulp waste products, known as *sulfite screenings,* and processing and drying them into a rigid, lightweight insulating material. This plant produced up to 60,000 square feet of Insulite per day.[6] By 1920, Celotex Company introduced an insulating board made from bagasse, a waste by-product of sugar cane after the juice has been extracted.[2] This was followed by Celotex's Cenesto, a fire-resistant insulation board surfaced on one or both sides with asbestos cement, used primarily for low-cost housing.[6] Lower-density insulation boards, generically belonging to the family of fiberboard products, were available in thicknesses ranging from 7⁄16 to 1" and in some cases up to 3". Fiberboard insulation commonly was used as an insulating lath over the wood studs, a plaster base over masonry, and even in some cases as an interior finish.[6]

The 1920s saw a measurable rise in public awareness of the value of thermal insulation. While fiberboard was advertised as the most economical insulation of its time, batts began a rise in popularity as well. Aluminum and copper also were applied to the batts as reflective foils.[6] *Slag wool* is a material made by blowing steam through fluid slag (molten rock). Also known as *rock wool,* this product was later replaced by asbestos, similar in appearance and promoted as the best alternative by heating engineers who dealt with the control and handling of steam. Glass fiber production started in the mid-1930s.

The case also can be made that insulation was not as necessary prior to the 1920s as it is now because of the construction materials and methods used at that time. Materials were heavier, including windows and door sashes, which provided adequate weather resistance. The growing popularity and use of lighter building materials increased the need for insulation products.[3] The gradual introduction of air-conditioning systems into home design also contributed to a greater need for thermal insulation.

In 1928, the Milam Building in San Antonio, Texas, became the first high-rise office building to be completely air conditioned. In that same year, Willis Carrier installed the first residential air conditioner, called the Weathermaker, that heated, cooled, humidified, cleaned, and circulated air in homes.[7] One year later, in 1929, the Frigidaire division of General Motors introduced its first room cooler. Several other manufacturers, including York and General Electric, began to offer room coolers soon after. The first window air conditioners were developed in the 1930s, but it was 1936 when Philco-York introduced a 3675 Btu/h window unit. Popularity increased throughout the next two decades, sales of window units approaching 300,000 in 1952. The early 1950s also saw the evolution of smaller central air-conditioning systems, using water-cooled condensers, and they become more commonplace in residential use.[8]

During World War II, the use of building insulation was made mandatory to conserve metal required for heating and air-conditioning equipment and to save fuel.[9] This probably contributed to a greater awareness by the general population of the sensible applications of insulation in residences as well. This was explored further by a special report developed by the Secretary of Defense in 1957. Capehart housing was rented to civilian employees at remote military institutions. The study concluded that if the 72,000 Capehart act houses would have been designed to sufficient thermal standard s, the United States government, which pays the heating bill as part of the rent, would save $52 million over a 30-year period.[9]

Extruded polystyrene insulation originally was developed by the Dow Chemical Company in the United States in the early 1940s. Known proprietarily as *Styrofoam,* it was first used as a flotation material in liferafts and lifeboats because its fully closed cell structure renders it highly resistant to water absorption. The insulating properties of Styrofoam, combined with the advantage of the closed cell structure, led to its development as a thermal insulation material. Initial applications were in low-temperature situations for cold-store floors, wall, and ceiling panels and pipe insulation. In the 1950s, Dow's extruded polystyrene foam extended its impact to other areas of the construction industry—as a thermal insultant in commercial and residential buildings.

The 1970s saw a dramatic shift in public awareness and sensibility toward energy conservation. The production of domestic oil had peaked in 1970, which subsequently created a greater dependence on foreign exports. Many researchers point to the Arab oil embargo of 1973 and 1974 as the catalyst for the energy crisis. A second sharp rise in oil prices occurred in 1979 following the Iranian revolution, further contributing to public discussion as well as new energy programs. Government mandates have continued this trend, with the Federal Energy Management Improvement Act (FEMIA) of 1988 requiring a 10 percent reduction in per-square-foot energy use by federal buildings between 1985 and 1995, followed by the sweeping Energy Policy Act of 1992 (EPACT). This act increased conservation and energy-efficiency requirements for government, energy, and consumers. Federal agencies, for example, were required to attain a 20 percent reduction in per-square-foot energy consumption by 2000 compared with a 1985 baseline. All these initiatives contributed to a greater awareness of energy conservation not only by the general public but also by producers, installers, and designers of insulation installation materials and methods.

As the U.S. paper industry grew in the 1940s, it was only natural to look to paper by-products for insulation. Originally manufactured as a sound deadener, paper-based cellulose soon caught on as an effective, dense insulation material. Early cellulose insulation did not benefit from today's fiber technology and application equipment, however, so it garnered only a small portion of the market as fiberglass became increasingly popular after World War II.[10] (Cellulosic fiber insulation had several patents issued in the nineteenth century but gained little, if any, popularity.[4])

As a result of the 1970s energy crisis, heavy demand for insulation induced many new producers to enter the cellulose industry, causing a resurgence of cellulose insulation popularity. Once the crisis passed, however, only a few companies remained committed to refining the material.[11]

Urea formaldehyde foam insulation (UFFI) was introduced to the building industry in 1960. Health complaints started from the occupants of UFFI-insulated homes in 1978, and by 1980, UFFI was banned across Canada, reportedly due to long-term health risk to occupants of houses insulated with UFFI. (Urea formaldehyde is one of the main resin mixtures of formaldehyde, and of all the formaldehyde compounds, it contributes the most to indoor air problems because of its water solubility.)[12]

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Chapter

2

Thermal Comfort

Temperature and temperature variations govern much of our daily lives. Shelter, clothing, heating, air conditioning, and building insulation influence the thermal forces that determine a person's state of comfort. It is this idea of "thermal comfort" that designers, builders, and architects attempt to provide by active or passive means when creating shelter.

Thermal comfort, ever a vague and ambiguous term given the varying nature of the human condition, has been described as a feeling of well-being, an absence of discomfort, or a state of mind that is satisfied with the thermal environment. The body's network of sensory organs, such as the eyes, ears, nose, tactile sensors, heat sensors, and brain all contribute to the physiologic and psychological awareness of thermal responses.

Thermoregulation

As my college professor once said, "Human bodies are like a bunch of little furnaces running around." Truer words were never spoken, since each human body generates heat. As warm-blooded mammals, humans produce energy by metabolizing food, with most of this energy taking the form of heat. Metabolic heat is produced by the body all the time, mainly as a result of muscular activity, although almost all bodily functions produce some heat. It is no secret that the more active we are, the more heat we produce.[1]

Heat is transported around the body by the blood. To balance the metabolic input, heat is lost continually to the environment through the skin and through the surfaces of the lungs. Subsequently, human thermal comfort is also determined by the body's ability to dissipate the heat and moisture that are produced continuously by metabolic action.

Heat is measured in British thermal units (a Btu is the quantity of heat required to raise one pound of water one degree Fahrenheit). For men of average size, seated and doing light work, the metabolic rate is about 450 Btu/h. Women under similar circumstances generate about 385 Btu/h. For a 155-lb man, seated and doing moderate to heavy work, the rate ranges from 650 to 800 Btu/h; standing and walking about while doing moderately heavy work will raise the rate to 1000 Btu/h, whereas the hardest sustained work will result in a metabolic rate of 2000 to 2400 Btu/h.

Thermal comfort is said to be attained when the environment surrounding the individual is in a state of equilibrium; i.e., the heat and moisture produced by the body are removed at the rate at which they are being produced. One method in which the human body maintains thermal equilibrium with its environment is by means of physiologic thermoregulation. For example, in situations of prolonged sweating, skin wetness slowly increases with time because of accumulating salt on the skin. The increasing salt occurs because the water in perspiration evaporates, while the dissolved materials, principally sodium chloride, remain on the surface. It is also thought that part of the relief that bathing brings after a warm day or strenuous activity is that by cleaning the skin, the salt is removed and the perspiration can evaporate more efficiently with reduced skin wetness. Another method of physiologic thermoregulation is shivering. The muscle tensions that cause shivering create a 300 percent increase in heat production, while the body also tries to cut heat loss by limiting blood flow to the skin and extremities.[1]

While some heat is removed through breathing, heat loss through the skin is by far the major path. Cold receptors in the skin signal the brain if the temperature on the skin drops at a rate faster than 0.5°F (0.25°C) per minute. This process allows people to adapt to indoor and outdoor climates by means of behavioral adjustments such as light or heavy clothing, low- or high-speed fans, open or closed windows, etc. An event as mundane as a cool draft of air can change local air temperatures by 2°F (1°C) in a matter of seconds.

Humidity

Humidity affects comfort in a number of ways, both directly and indirectly. The evaporation of water from mucous and sweating surfaces and its diffusion through the skin affect the energy balance and subsequently body temperatures and thermal sensations. When evaporation processes of the skin are compromised or enhanced, skin temperatures change, which is directly sensed by the temperature sensors of the skin. For example, a 30 percent change in relative humidity has the same effect on thermal balance and thermal sensation as a 2°F (1°C) change in temperature with regard to a sedentary person.

Low humidity, or dry air, absorbs moisture from the skin at a rapid rate and produces a chilling effect that can only be offset by increasing air temperature. Dry air also makes fabrics feel smoother and more pleasant, and the air is perceived to be fresher, less stale, and more acceptable. At a given temperature, decreased humidity results in occupants feeling cooler, drier, and more comfortable, but low humidity also can adversely affect comfort and health. Dry nose, throat, eyes, skin, and other mucous surfaces typically occur in low-humidity conditions, usually when the dew point is less than 32°F (0°C). Excessive drying of the skin can even lead to lesions, skin roughness, and discomfort, and impair the skin's protective functions. Dusty environments can further exacerbate low-humidity dry-skin conditions.[1]

On the other hand, high humidity helps our bodies retain heat. In warm conditions, however, thermal discomfort increases with humidity. The discomfort appears linked with skin moisture, as persons rarely judge themselves comfortable in situations where skin wetness is above 25 percent.[1] The discomfort associated with skin moisture could be due, in part, to friction between skin and clothing. When fabrics ranging from rough burlap to wool, cotton, polyester, and smooth silk are pulled across the skin, the measured pull force increases with humidity and perspiration, as does the fabric's perceived texture or roughness.

Thermal comfort is also directly related to the manner in which heat flows through or about building materials, whether by means of convection, radiation, or conduction. While convection may be most noticeable in the form of a breeze or draft, radiation may seem to cause more dramatic comfort variations. Standing next to a large window is an obvious example. These concepts will be discussed further in Chap. 3.

ASHRAE Standard 55

As mentioned earlier, occupant complaints of discomfort in buildings may be caused by uncomfortable temperatures or extreme humidity levels. In 1966, the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) created a standard to quantify thermal comfort. Entitled ASHRAE Standard 55-1966, "Thermal Environmental Conditions for Human Occupancy," this document introduced a definition for thermal comfort that states: "Thermal comfort is that condition of mind that expresses satisfaction with the thermal environment." Standard 55 specified the appropriate environment that would lead to thermal comfort for indoor inhabitants of building spaces. Based on summer and winter temperatures with indoor relative humidity as the variable, the 1992 edition of ASHRAE Standard 55 specifies that the optimal comfort range for indoor relative humidity is between 30 and 60 percent. The standard also specifies that to decrease the possibility of discomfort due to low humidity, dew-point temperature in occupied spaces should not be less than 37°F (3°C).[1]

The upper range of the comfort zone for summer use will be tolerable for most lightly clothed adults until the relative humidity rises above 60 to 65 percent. At that condition, discomfort will be experienced by many building occupants because of their inability to dissipate metabolic moisture. Increases in air velocity are beneficial under these conditions, but velocities above about 70 ft/min generally will result in unpleasant working conditions because of drafts, blowing papers, and so on.[2]

Conclusion

Comfort seems to occur when body temperatures are maintained with the minimum of physiologic regulatory effort.[1] Thermal sensation depends on body temperature, which in turn depends on thermal balance and the effects of environmental factors (temperature, radiation, air motion, and humidity), as well as on personal factors such as an individual's metabolism and clothing selection. Skin moisture, physiologic processes, and skin and internal body temperatures all contribute to the state of thermal comfort. Although many of these factors are constantly in flux, the proper use of insulation, placement of vapor barriers, and understanding of heat transfer will contribute to providing an environment conducive to thermal comfort within the residence.

Appendix

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Chapter

3

Insulation Fundamentals and Principles

Heat-Transfer Mechanisms

It is no secret that a house will lose heat in the winter and allow heat in during the summer. Heat, or thermal energy, flows continuously through materials and space, taking the path of least resistance and flowing from the warmer object to the colder object. Insulation attempts to keep thermal heat where it is wanted. To understand how thermal insulation works, it helps to understand the three mechanisms of heat energy transfer: convection, conduction, and radiation.

In winter, the heat in a family's living room invariably flows by air movement to spaces that are not heated, such as the basement, attic, or garage. This is an example of heat flowing through moving air, known as *convection.* Another example is when heat is transferred from hot coffee, through the cup, to the hand holding the cup. This is known as *conduction,* or the process by which heat transfer takes place in solid matter. A third example can be found when a rooftop is warmed by the energy of the sun. This an example of the transfer of heat through space via electromagnetic waves (radiant energy), known as *radiation.*

Convection

Convection is the transfer of heat by physically moving the molecules from one place to another. Convection takes place when a fluid, such as gas or a liquid, is heated and moved from one place to another. When warm air in a room rises and forces the cooler air down, convection is taking place. For example, air, when heated, expands and rises. If this air movement is created mechanically by a floor register, fan, or the wind, it is called *forced convection.* When the sun heats the warm air and it rises, causing the cold air to settle to create a convection loop, it is termed *free convection.* Free convection also occurs when the sun, shining through a window, heats the air inside a building.

Conduction

Conduction is the process by which heat transfer takes place in solid matter, such as the direct flow of heat through a material within a single or two separate bodies in direct contact. Scientifically, it is the molecule-to-molecule transfer of kinetic energy. One molecule becomes energized and, in turn, energizes adjacent molecules. A cast-iron skillet handle heats up because of conduction through the metal from the heat energy provided by the burner on the stove. This also occurs when a person touches a sun-warmed window or when the handle of a poker gets warm after the other end has been placed in a fire for a few minutes.

Convection and conduction are functions of the roughness of surfaces, air movement, and the temperature difference between the air and surface. Mass insulations, because of their low densities, are designed to suppress conduction and convection across their sections by the entrapment of air molecules within their structure. Convective air currents are stilled by the surrounding matrix of fibers or cells, and the chances of heat transfer by the collision of air molecules are reduced. Foam insulations operate under the same principle, although gas is used instead of air within their structure.

Radiation

The third way energy is transferred is through *radiation.* This is evident in the way the sun warms the surface of the earth, which involves the transfer of heat through electromagnetic waves and absorption of that energy by a surface. A person sitting in the sun by a window absorbs radiant heat. Inside a home, surfaces may exchange heat with other surfaces through radiation, which can have some impact on indoor ambient temperature. Heat energy from radiation is most relevant to home comfort in the summertime, however, when the roof and exterior walls absorb heat from the sun. (This heat subsequently enters the interior space through conduction and convection.) This process is more critical in hot climates.

Radiant heat transfer between objects operates independently of air currents and is controlled by the character of the surface (emissivity) and the temperature difference between warm objects emitting radiation and cooler objects absorbing radiation. *Emittance* (or *emissivity*) refers to the ability of a material's surface to emit radiant energy. All materials have emissivities ranging from 0 to 1. The lower the emittance of a material, the lower is the heat radiated from its surface. Aluminum foil has a very low emittance, which explains its use in reflective insulation. This will be further explored in Chap. 12.

Reflectance (or *reflectivity*) refers to the fraction of incoming radiant energy that is reflected from a surface. Reflectivity and emissivity are related, and a low emittance is indicative of a highly reflective surface. For example, aluminum with an emissivity of 0.03 has a reflectance of 0.97.

The resistance of these modes of heat transfer may be retarded by the elements of a building wall section. Elements include

1. *Outside surface films.* The outside surface traps a thin film of air, which resists heat flow. This film varies with wind velocity and surface roughness.
2. *Material layers.* Each layer of material contributes to the resistance of heat flow, usually according to its density. A layer of suitable insulation is normally many times more effective in resisting heat transfer than the combination of all other materials in the section.
3. *Airspace.* Each measurable airspace, as well as its thickness, also adds to the overall resistance. Foil-faced surfaces of low emissivities that form the boundaries of the airspace can further reduce the rate of radiant transfer across the space (provided the airspace is at least $^3/_4$" to 1").
4. *Inside surface film.* The inside surface of a building section also traps a thin film of air. The air film thus formed is usually thicker because of much lower air velocities.[1]

Heat Flow

It is important to point out again that heat (thermal energy) always flows from a warmer object to a colder object. In terms of buildings, we refer to heat flow in a number of different ways. It is the measurement of this heat flow that allows for the mathematical analysis of wall, floor, and ceiling assemblies. U-value and R-value are the most common methods used.

U-value

The flow rate of heat through a building product is known as the *U-value*. The U-value (or U-factor) is a measure of the flow of heat (thermal transmittance) through a material, given a difference in temperature on either side. In the inch-pound (I-P) system, the U-factor is the number of British thermal units (Btu) of energy passing through a square foot of the material in an hour for every degree Fahrenheit difference in temperature across the material ($Btu/ft^2 \cdot h \cdot °F$). In the metric system, it is usually given in watts per square meter per degree Celsius ($W/m^2 \cdot °C$).

Since the U-value is a measurement of heat flow, the lower the U-value, the more slowly does the material transfer heat in and out of the home. The U-value typically is used in expressing overall thermal conductance, since it is a measurement of the rate of heat flow through the complete heat barrier, from room air to outside air. The lower the U-value, the better is the insulating value. U-value is the customary unit used by the fenestration industry to quantify conducted heat gain or loss. With other building materials, such as insulation, roofing, and flooring materials, the R-value is frequently used for conducted heat gain or loss.

R-value

Another mathematical expression used in thermal quantification, and the most common reference used by the insulation industry, is *R-value,* or resistance to heat flow. Since the R-value is the measurement of a product's resistance to heat flow, the higher the R-value, the better is the resistance to the flow of heat (expressed in British thermal units). Insulation is rated in terms of thermal resistance, called *R-value,* which indicates the resistance to heat flow. The higher the R-value, the greater is the insulating effectiveness of mass-type insulations.

R-values are measured by testing laboratories, usually in something called a *guarded hot box.* Heat flow through the layer of material can be calculated by keeping one side of the material at a constant temperature, say, 90°F (32°C), and measuring how much supplemental energy is required to keep the other side of the material at a different constant temperature, say, 50°F (10°C). [This process is defined in great detail in American Society of Testing and Materials (ASTM) procedures. The result is a steady-state R-value. It is called *steady state* because the difference in temperature across the material is kept steady.[2]]

To ensure that consumers are provided with accurate information regarding R-values, the Federal Trade Commission (FTC) in 1980 established a rule that mandates that specific R-value information for home insulation products be disclosed in certain ads and at the point of sale. The purpose of the FTC R-value disclosure requirement for advertising is to prevent consumers from being mislead by certain claims that have a bearing on insulating value.[3]

In the flow of heat through a solid body to air, it was observed that the passage of heat into the air was not accomplished solely through conduction. Instead, it occurred partly by radiation and partly by free convection. A temperature difference existed between the hot solid and the average temperature of the air. In this case, the resistance to heat transfer cannot be computed using the thermal conductivity of air alone. Instead, the resistance has to be determined experimentally by measuring the surface temperature of the solid, the temperature of the air, and the heat transferred from the solid to air. The resistance computed is the combined resistance of conduction, free convection, and radiation.

R-value requirements for a specific house design in a certain locale are mandated by the IECC, formerly the *Model Energy Code*. Many state agencies simplify this process for residential design by outlining general rules of thumb. Manufacturers often provide general planning guidelines as well (Fig. 3.1). Always verify specific thermal requirements with the aforementioned organizations or local building officials.

R-values are reported for 1" of thickness and are not necessarily per inch of thickness (for residential construction only). R-values usually are reported at mean temperatures of 75°F per FTC regulations. The R-value per inch of a specific material is not necessarily always the same. It can be affected by several factors, including temperature, density, and thickness.

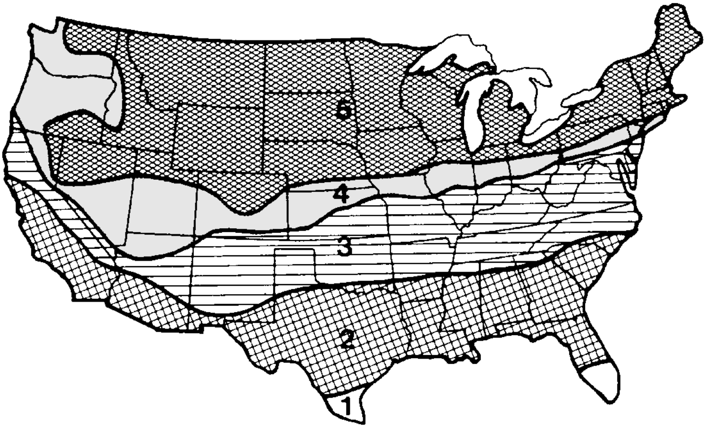
Temperature

Test results at 75°F are adequate for controlled comparisons when choosing materials, but most insulation materials have a higher R-value at lower temperatures. The variation in value is caused by changes in the conductivity of air within the insulation and by changes in radiant heat transfer.

In some cases, this variation can be significant. For example, in winter, the outside temperature may be 0°F and the inside temperature 70°F, resulting in a mean temperature of 35°F. Alternatively, for summer conditions, particularly in southern climates, mean temperatures of 90 to 110°F can be experienced. The variation in R-value between these two extremes can be as much as 27 percent.[4]

Thickness

Generally, R-value increases linearly with thickness. For example, a 2" thickness of a material will have twice the R-value of a 1" thickness of the same material. Recent advances in thermal insulation technology, however, have shown a phenomenon known as the *thickness effect* in low-density materials. Simply stated, the thickness effect is an



Zone	Attic Floor (Ceilings)	Sidewalls	Floors
1	R-19	R-12	R-11
2	R-30	R-19	R-11
3	R-38	R-19	R-13
4	R-38	R-19	R-19
5	R-49	R-19	R-25

R-values on the chart represent CertainTeed recommendations based on the latest Model Energy Code and DOE recommendations. The wall R-values include those for both insulation and sheathing. R-values of individual products can be added to achieve recommended R-values. For example, R-38 added to an R-11 results in R-49. Wall R-values include length, insulation and sheathing.

Figure 3.1 R-values. (*CertainTeed.*)

apparent decrease in R-value per inch with increased thickness. Many examples suggest that conduction is actually taking place, compromising the R-value.

Density

The R-value of certain insulation materials can vary considerably with density. This has important implications in the use of blown-in insulation, the installed density of which is under the direct control of the contractor. For example, blown-in fiberglass is usually listed as having an R-value of about R-2.2 per inch. But this is measured at its "settled" density of about 0.7 lb/ft^3; if that same material is forced into walls at a density of 2.0 lb/ft^3, the R-value jumps to almost R-4.0 per inch. The same effect does not hold for cellulose, which decreases in R-value as its density increases.[4]

Blanket insulation is also affected by density. Stuffing a thick batt (or roll) into a narrow stud cavity will result in a more densely installed material. R-13 batt insulation is designed for proper placement into 2 × 4 wood frame wall. However, if an R-19 fiberglass batt, which is designed for a 2 × 6 wood frame wall, is stuffed into a stud cavity that is only 3.5", the total R-value of the batt will be less than R-19. This is simply due to the fact that the fiberglass batt insulation R-value relies on air as part of the resistance equation. Compressing the batt reduces the airspace between the fibers, which in turn reduces the R-value per inch.

This explanation of density is not to be confused with insulations that have different *design densities*. Typically specified in units of pounds per cubic foot, different products can be optimized for certain locations and higher R-values when manufactured with different densities.

Technically, any air-based insulation material such as fiberglass batt cannot exceed a theoretical maximum R-value of R-5.5 per inch because 5.5 is the R-value of still air. Plastic foams such as urethane and polystyrene sometimes exceed this value by using a fluorocarbon gas instead of air within the insulation cells. These factors will be discussed in greater detail later in the book. Other exceptions to the preceding maximum are experimental air-based insulation materials that contain very fine powders. These materials increase R-value by virtue of extremely small powder particles that interfere with conduction through air. Although they are not available commercially at present, they may appear on the market some time in the future.

As mentioned earlier, U-value is the customary unit used by the fenestration industry to quantify conducted heat gain or loss. With other building materials such as insulation, roofing, and flooring materials, the R-value is used frequently for conducted heat gain or loss. There is a simple relationship between u- and R-values, namely,

$$U = 1/R \qquad \text{or} \qquad R = 1/U$$

For example, a U-value of 0.25 equals $\frac{1}{25}$, or an R-value of 4. Conversely, in order to establish the R-value from the U-value, divide 1 by the U-value, that is,

$$R = 1/U \qquad \text{or} \qquad U = 1/R.$$

Whole-Wall System

Currently, most wall R-value calculation procedures are based on experience with conventional wood frame construction, and they do not factor in all the effects of additional structural members at windows, doors, and exterior wall corners. Thus they tend to overestimate the actual field thermal performance of the whole-wall system.[5]

Clear-wall R-value (Rcw) accounts for the exterior wall area that contains only insulation and the necessary framing materials for a clear section, with no windows, doors, corners, or connections between other envelope elements, such as roofs and foundations.

Center-of-cavity R-value (Rcc) is the R-value estimation at the point in the wall that contains the most insulation. This uses a 0 percent framing factor and does not account for any of the thermal short circuits that exist through the framing.

Whole-wall R-value (Rww) is an R-value estimation for the whole opaque wall, including the thermal performance of both the clear-wall area and typical interface details such as all typical envelope interface details [e.g., wall-wall (corners), wall-roof, wall-floor, wall-door, and wall-window connections]. The whole-wall R-value is a better criterion than the clear-wall R-value, and much better than the center-of-cavity R-value methods used to compare most types of wall systems. The value includes the effect of the wall interface details used to connect the wall to other walls, windows, doors, ceilings, and foundations. Taking into account the interface details can have an impact on as much as 50 percent of the overall wall area. For some conventional wall systems, the whole-wall R-value is as much as 40 percent less than the clear-wall value.[5]

With the increasing use of alternatives to dimensional lumber-based systems (such as metal-frame and masonry systems) for residential construction, this procedure highlights the importance of using interface details that minimize thermal shorts. Local heat loss through some wall interface details may be double that estimated by simplified design calculation procedures that focus only on the clear wall.

The effect of extensive thermal shorts on performance is not reflected accurately in commonly used simplified energy calculations that are the current bases for consumer wall thermal comparisons. Consequently, the marketplace does not currently account for the thermal shorts that exist in building walls. Computer software for modeling is available, but is beyond the scope of this text.

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Chapter

4

Vapor and Air Retarders

Vapor Retarders

Vapor retarders are materials that restrict or reduce the rate and volume of water vapor diffusion through a building's ceilings, walls, and floors. Available in a variety of materials, they are commonly made of polyethylene sheets, treated papers, and metallic foils. Historically, they have been called *vapor barriers* but are now called *vapor diffusion retarders* or simply *vapor retarders*. Although the familiar term *vapor barrier* implies that the material halts all moisture transfer, this is incorrect. Vapor retarders actually only reduce the rate of moisture transfer, they do not stop moisture flow completely. As you will discover in this chapter, the main reason to retard the transmission of gaseous water vapor through building envelopes is to prevent it from condensing to liquid water within the structure or insulation.

Thermal insulation has only been prevalent in residential construction during the last 50 years. As originally designed, older structures did not need to restrict the flow of airborne moisture because there was little within the affected cavities to hold it. Older homes tend to have less insulation and more air gaps in their thermal envelope. The wall cavities, if wetted, dried quickly because of the leaky construction methods employed. Windows and doors were not sealed tightly, and most construction materials were not vapor-tight. Simply stated, water vapor was able to pass through the building envelope unobstructed, thereby not becoming trapped within the structural assembly. As residential design became more energy conscious during the second half of the twentieth century, the homes became more airtight.

Storm windows, caulking, weatherstripping, and thermal insulation interfered with the movement of water vapor. It soon became evident that moisture movement was of prime concern if insulation was to remain effective and structures were to remain sound.

Water vapor/moisture migration

Water exists in the atmosphere in three forms: as an invisible, gaseous vapor, as liquid droplets, and as solid ice crystals. One important and relatively unique characteristic of water is its almost universal existence in air in the form of vapor, its gaseous form. Vapor is not to be confused with steam. Steam is water that has been elevated in temperature above its boiling point (212°F or 100°C), whereas water vapor, also in a gaseous state, is below the boiling point.

Water is present as vapor in indoor and outdoor air and as absorbed moisture in many building materials. Water moisture is continuously being generated by the activities and bodies of a home's occupants. A family of three generates 16 lb per day. Additional activities such as cleaning, cooking, and showering, and even the presence of plants, produce 1 lb of moisture per day.[1] The amount of moisture in a home is also especially high immediately after construction is completed. For example, significant amounts of water are used in the mixing of concrete, mortar, and even plaster when applicable. A new house of medium size may require 300 gal of water to be mixed in the concrete alone.[2]

Moisture-related problems may arise from changes in moisture content, from the presence of excessive moisture, or from the effects of changes of state, such as freezing, within walls or deterioration of materials due to rotting or corrosion.

Moisture moves in four ways: bulk moisture, capillary action, air leakage, and vapor diffusion. The primary source of bulk moisture is rainwater. Improper flashing and caulking permit bulk moisture to enter a building envelope. Capillary action occurs when moisture moves through porous materials such as concrete or through cracks in materials. Proper detailing and waterproofing help prevent capillary action. Both air leakage and vapor diffusion transport vapor in its gaseous state. This is more difficult to eliminate because the average person respires up to 1 gal of water vapor per day.

Relative humidity

The term *relative humidity* is a measure of the amount of water vapor held in a given volume of air compared with the maximum amount of moisture the air could hold at the same temperature. The ratio is usually expressed as percent relative humidity. Thus, 50 percent relative humidity means that the air contains half the water vapor it is capable of holding at that temperature. At 100 percent relative humidity, air contains the maximum amount of vapor it can hold, and such air is said to be *saturated*. The temperature at which saturation occurs is called the *dew-point temperature*.

Since psychrometry is the branch of physics relating to the measurement or determination of atmospheric conditions, particularly regarding the moisture mixed with the air, humidity is measured using an instrument called a *psychrometer*. It involves measurements of dry-bulb temperature and wet-bulb temperature.

The *dry-bulb temperature* is simply the air temperature and is sometimes called *ambient* or *sensible temperature,* commonly measured using a thermometer. The *wet-bulb temperature* is the temperature indicated by a wet-bulb transducer (thermometer), at which liquid or solid water, by evaporating into air, can bring the air to saturation at the same temperature. The results are plotted on a *psychrometric chart,* a graph drawn to represent the thermodynamic properties of moist air. A psychometric chart provides data to analyze the interaction between dry-bulb temperature and relative humidity. This allows experts to predict whether moisture condensation may occur on a particular surface, given the air temperature (dry bulb), the relative humidity, and the temperature of the particular surface. Knowing the air temperature and relative humidity, "they" also can predict the condensation temperature necessary to convert water vapor into liquid water.[3]

There are two simple facts to keep in mind:

1. As air warms, its ability to hold a greater quantity of water vapor increases.
2. As air cools, its capacity to retain moisture decreases.

For example, air at 68°F (20°C) with 0.216 oz of water (H_2O) per pound of air (14.8 g H_2O/kg air) has a 100 percent relative humidity. The same air at 59°F (15°C) reaches 100 percent relative humidity with only 0.156 oz of water per pound of air (10.7 g H_2O/kg air). The colder air loses the capacity to hold about 28 percent of the previous temperature's airborne moisture. This moisture will condense on the first cold surface it encounters. If this surface is within an exterior wall cavity, for instance, wet insulation and framing may be an early result.[3]

When the relative humidity of air approaches about 92 to 98 percent, a drop in temperature of as little as one degree, or the addition of a small amount of water vapor, will cause the vapor to condense and precipitate from the air. In nature, this is known as rain, sleet, or snow.

When it occurs in our dwellings, we refer to it as *steaming* or *sweating* on windows and other surfaces. Sweating can be found easily as a dew formation on a surface such as a cold glass of iced liquid or on the inner surfaces of window panes. Sweating or condensation also can occur in walls, roofs, ceilings, and floors of buildings. When it does, it can make insulation inefficient; cause rot, decay, or mildew on wood framing; and even result in deterioration of masonry materials. To make matters worse, this type of damage occurs inside the wall cavity, where it is hidden from sight and can go unnoticed for long periods of time.

Dew point

The temperature at which water vapor will condense from the air at any specific relative humidity is called its *dew point*. As mentioned earlier, water vapor within dwellings normally is present only in its invisible gaseous state. However, when vapor-laden air comes into contact with a cold surface, at or below its dew point, such as a window pane in winter or an article removed from the refrigerator, it promptly condenses into water droplets (dew). If the surface it contacts is below 32°F (0°C), the vapor becomes ice crystals. Air with a high relative humidity always has a higher dew point than does drier air. A given temperature and relative humidity determine the dew point.

Temperature differences between indoor and outdoor environments create conditions that promote condensation. The difference between outdoor temperatures and indoor thermostat set points is typically greater in the winter than in the summer. This leads to a greater likelihood of condensation occurring in the winter season.

In the design and construction of the thermal envelope of buildings (the enclosure of desired temperatures and humidities), the behavior of moisture must be considered, particularly the change of state from vapor to liquid (condensation). Problems arise when moisture comes into contact with a relatively cold surface (temperature below the dew point), such as a window or within outdoor walls or under-roof ceilings. Excessive condensation within indoor walls that enclose cold spaces must also be considered.

Moisture problems

Moisture problems in residences generally occur in seasons when the outdoor temperature and vapor pressure are low and there are many indoor vapor sources. As mentioned earlier, these may include cooking, laundering, bathing, breathing, and perspiration for the occupants, as well as automatic washers and dryers, dishwashers, and humidifiers. All these sources combine to cause vapor pressure indoors to be much higher than outdoors so that the vapor tends to migrate outward through the building envelope.

In an ideal world, construction water should be evaporated before the building is occupied. Concrete, plaster, even water-based paints all evaporate water and could contribute to potential condensation problems. Construction water is usually removed within a year, but other sources still exist. Moisture is constantly being generated within a home by the users after occupancy as well. For example, in the winter months, $^1/_2$ lb of moisture is generated with each shower, whereas 0.12 lb is generated per bath. Appliances generate 5.66 lb per day, including dishwashing, and a person generates 11 lb in a 24-hour period.[4] Venting of moisture-laden air from bathrooms, laundry rooms, and kitchens will reduce indoor vapor pressure, as will the introduction of outdoor air with low moisture content. Finally, undrained and unvented crawl spaces, as well as wet basements or bare-earth floors, will continue to be a problem unless corrective measures are performed.[4]

Moisture in building materials usually increases their thermal conductance significantly and unpredictably. Porous materials that become saturated with moisture lose most of their insulating capability and may not regain it when they dry out. Dust, which usually settles in airspaces, may become permanently affixed to originally reflective surfaces. Moisture migration by evaporation, vapor flow, and condensation can transport significant quantities of latent heat, particularly through fibrous insulating materials.

More than 90 percent of the moisture entering a perimeter structural cavity is from air leakage. The other 10 percent or less occurs as vapor diffusion. This happens because air, by nature, moves toward low pressure through any possible pathway. It acts as a fluid, draining through any imperfection. Moisture diffusion directly through a material is usually a much slower process. Most materials of any density retard this flow somewhat. Standard gypsum wallboard or plaster assemblies, once painted, seriously impede moisture diffusion.[3]

There are several ways to prevent condensation inside and outside a home:

1. Moisture should be removed by drainage, venting, or isolating moisture-generating sources.
2. Moist air should be kept away from cold surfaces within walls, floors, or roof by means of a vapor barrier.
3. Sufficient insulation should be used on the cold side of assemblies to keep critical surfaces warmer than the dew point temperature.

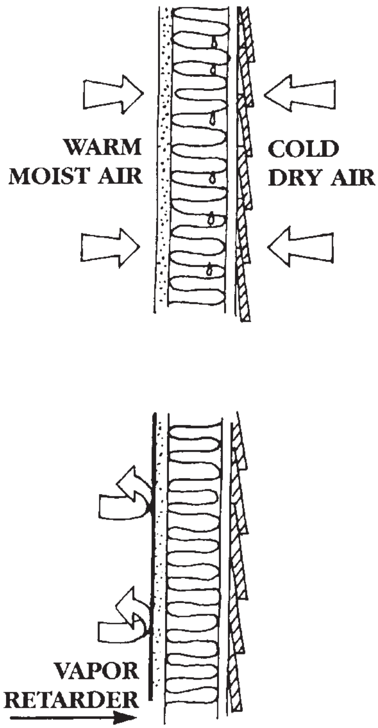


Figure 4.1 Moisture migration. (*Better Homes and Gardens*)

4. Water vapor within the construction assembly should be allowed to escape by using vapor-porous materials.
5. Vapor traps (i.e., double vapor barriers) formed between two vapor-resistant components must be avoided[4] (Fig. 4.1).

History of Vapor Retarders

Historically, vapor accumulation has been remedied by a number of strategies. Prior to the construction of energy-efficient homes, less vapor-resistant materials were used in outer walls. Lowering the indoor relative humidity can be accomplished either by lowering the rate at which water vapor is added to the indoor air or by increasing the ventilation of the house indoor air to the exterior. With today's lifestyle and indoor activities such as clothes washing and drying, showers, baths, hot tubs and spas, dishwashers, and humidifiers that tend to raise the indoor relative humidity, it has become necessary to increase the vapor resistance on the warm side of the insulation. These behaviors and design preferences have led to the scientific study of the proper placement of a vapor retarder.

Historically, the implementation of an insulating material with an asphalt/kraft paper or aluminum foil backing resulted in one of the first simple means of achieving a relatively effective "barrier" to the transmission of water vapor through exterior walls. The attachment flanges were configured to require the material to be installed with the backing material on the warm interior side of the walls in an effort to make the installation foolproof. The method was not entirely perfect, however, because water vapor could pass readily through the studs themselves and through the significant crack length where the insulation was attached to the studs.

The relative success of this first step led to further consideration of the problem. Before long, the application of 6-mil-thick sheets of polyethylene film on the interior sides of exterior walls, under the dry wall, or other finish, lapping and taping all joints, became standard practice. It is one of the most effective available means of inhibiting the transmission of water vapor through exterior walls that is currently employed.[5] Even this concept is now being scrutinized by many experts.

Perm ratings

Perm ratings are assigned to many of the materials intended for use as vapor retarders. Materials intended for use as vapor retarders are constantly being improved and tested to establish their effectiveness. The perm ratings assigned to such materials are usually established by a reputable testing laboratory. Such ratings may be considered reliable when the data are published, or certified, by the testing laboratory.

Water vapor transmission is the rate of water vapor flow expressed in grains per hour per square foot. A pound contains 7000 gr, and a gram contains 15.43 gr. *Permeance* is the water vapor transmission of a material under unit vapor pressure difference between two specific surfaces. The concentration of water vapor also may be stated by giving its pressure, commonly expressed in inches of mercury (inHg). The unit of permeance is the *perm,* which is equal to grains per hour per square foot per inch of mercury. The ability of a material to retard the diffusion of water vapor is measured in units known as *perms,* short for *permeance.* A perm measures, at 73.4°F (23°C), the number of grains of water vapor that pass through a square foot of material per hour at a differential vapor pressure equal to one inch of mercury. Technically, a vapor diffusion retarder is a material with a perm value of 1.0 or less. A material with a perm value greater than 1.0 is not a vapor diffusion retarder because it allows too much water vapor to pass through it. Knowledgeable professionals typically use vapor diffusion retarders with ratings of 0.1 or less to guard against possible future changes in building science. One square foot of a material with a rating of 0.1 perm will transmit approximately 2 fluid ounces of water in 1 year. Polyethylene films, which have perm ratings in the 0.02 to 0.08 range, are the most popular. Several new products that are more resistant to tearing than polyethylene are also available.

There is a common rule of thumb, as reported by the Department of Energy and the Southface Energy Institute, to prevent trapping any moisture that may enter a perimeter structural assembly. The structure's cold-side material permeance should be at least 5 times greater than the perm value of the warm-side vapor retarder.

Product types

Vapor retarders typically are available as membranes or coatings. Membranes generally are thin, flexible materials but also include thicker sheet material sometimes termed *structural* vapor diffusion retarders. Thin membrane vapor diffusion retarders come in rolls or as integral parts of building materials. One such integrated product is the single-side aluminum-faced or specially treated kraft paper–faced batt insulation. Foil-backed wallboard is another popular material incorporating a vapor diffusion retarder. Polyethylene, a plastic sheet material, is perhaps the most commonly used vapor diffusion retarder. It is available in various roll configurations. Thus 4-mil or 6-mil polyethylene sheeting, available in rolls, is rolled out horizontally and stapled to the face of the framing after installation of unfaced insulation. Materials such as rigid insulation, reinforced plastics, aluminum, and stainless steel are also relatively resistant to water vapor diffusion. These types of vapor diffusion retarders usually are fastened mechanically. When sealed at joints, they seriously restrict air leakage. [A vapor diffusion retarder is only effective when it is continuous, fully covering the exterior envelope (walls, floors, and ceilings). By contrast, a sheet of drywall only retards vapor diffusion over the area it covers, not the edge joints, holes for electrical outlets, or window openings.[3]]

Paints and other coatings, when applied to a finished wall or ceiling, also may retard vapor diffusion. These coatings are asphaltic, resinous, or polymeric. They are applied by brush, trowel, roller, spraying, or dipping, depending on the surface. "Vapor barrier" paints are an effective option, but always verify that the paint formula is low in pigment. The paint label usually indicates the percentage of pigment.

It is best to use paint labeled as a vapor retarder. Most paint experts agree that, for this purpose, glossy paints work better than flat paints, acrylic paints are generally better than latex paints, and the more coats applied, the better.

Placement within the wall, floor, or ceiling assembly

The need for vapor retarders and their proper location within a wall assembly is influenced by the interior and exterior environmental conditions as well as the wall's thermal and vapor flow characteristics. It is important to note that each building is fairly unique in terms of wall construction, interior use, and environmental conditions, and should be evaluated individually by the building designer.

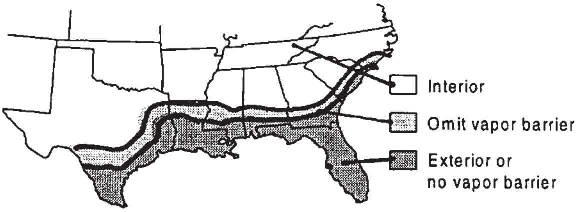
When a vapor-pressure differential exists, water vapor will move toward the lower pressure independently of air. For instance, with a winter condition of 0°F and 75 percent relative humidity, an outside vapor pressure of 0.027 inHg would exist. Inside a building heated to 70°F and with 35 percent relative humidity, vapor pressure would equal 0.259 inHg. The vapor pressure inside would be nearly 10 times as high as outside. Like other gases, water vapor moves from an area of high pressure to an area of low pressure until equilibrium is established. During cold weather, the difference in pressure between inside and outside causes vapor to move out through every available crack and directly through many materials that are permeable to water vapor. When vapor passes through pores of homogeneous walls, which are warm on one side and cold on the other, it may reach its dew point and condense into water within the wall.[6]

Vapor retarders are applied to the warm side of an exterior structural assembly. In cold climates this occurs toward the interior of the building, whereas in hot climates this occurs toward the exterior of the building. Generally speaking, the dividing line can be drawn between the southern tip of Texas and the Florida-Georgia border on the Atlantic Ocean. (Always verify with local building officials as to the proper placement.) Two vapor retarders on opposite sides of a single wall can trap water vapor between them and create moisture-related problems in core materials (Fig. 4.2).

A cold climate is an area that has more than 2200 heating degree-days. (A *degree-day* is a unit that measures the extent to which the outdoor mean daily dry-bulb temperature falls below or rises above an assumed base, normally 65°F (18°C), for heating and for cooling. Although specific exceptions may apply to a particular area, it is best to verify with local practice.[3] Unless relative humidity is extremely high, moisture will not condense on a warm surface. This is usually accomplished by using vapor retarder-faced insulation or unfaced insulation plus a separate polyethylene vapor retarder.[7]

This practice prevents wintertime condensation, but summertime conditions on buildings that are cooled instead of heated also must be examined. Even though an interior side vapor retarder is on the "cold"

Vapor barrier placement by geographical location



Perm Ratings of Different Materials
(Rating of 1 or less qualifies as a vapor barrier)

Asphalt-coated paper backing on insulation	0.40
Polyethylene plastic (6 mil)	0.06
Plywood with exterior glue	0.70
Plastic-coated insulated foam sheathing	0.4 to 1.2
Aluminum foil (.35 mil)	0.05
Vapor barrier paint or primer	0.45
Drywall (unpainted)	50
Drywall (painted - latex paint)	2-3

Figure 4.2 Vapor retarder placement. (*Southface Energy Institute*)

side in summer, the dew-point temperature of hot, humid summer air is nearly always lower than the temperature to which we cool buildings. That means that an interior-side vapor retarder will nearly always be warmer than the dew-point temperature, and therefore, condensation will occur only very rarely and will be of very short duration, causing no problems.[3]

In warm, humid climates, the flow of water vapor will be reversed, and vapor will flow from the outside to the inside.[6] These areas are defined as cooling-dominated climates below the 2200 heating degree-day [base 65°F (18°C)] mark set by the American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE).[6] In some areas of the South, it may be difficult to determine where the vapor retarder should be placed. Where there is uncertainty, it is best to follow local practice and local codes. In southern coastal areas with a long cooling season and high exterior humidity, air conditioning causes continuous moisture flow from the exterior toward the interior cooled area. If a vapor retarder is used, it should be on the exterior of the wall.

Many professionals believe that in such situations a continuous air/vapor retarder such as polyethylene should not be used. The reason is that there may be times when the weather becomes cool and vapor movement reverses and moves from the interior toward the exterior (winter condition). When this happens, it is best to have a discontinuous retarder such as that provided by faced fiberglass insulation, to retard the passage of vapor but permit some vapor to pass. This approach is reinforced by a number of sources that state that in humid climates where very little heating is required, vapor retarders can be placed on the exterior side of insulation without causing problems in winter.[7] Under such circumstances, it is necessary to avoid use of interior wall coverings, i.e., vinyl wallpaper, that have low permeance to water vapor.[6] Avoid using low-perm products on the outer skin of a wall in areas with high indoor humidity. This includes vinyl or metal siding without vents, metal siding used on uninsulated homes in cold climates, insulated sheathings with foil coverings, and low-perm plastics that are substituted for breathable building papers.[8]

Some professionals dispute the need for a continuous, sealed, vapor diffusion retarder in warmer climates. ASHRAE, on the other hand, makes no recommendation on where or whether to install a vapor diffusion retarder in the fringe zone. In the remaining zone, one generally hotter and more humid, ASHRAE recommends omitting a vapor diffusion retarder.[3] In a fringe zone nearest where interior vapor diffusion retarders are recommended, the placement gets a little trickier. According to North American Insulation Manufacturers Association (NAIMA), the highest dew-point temperatures in the United States occur in places like Biloxi, Mississippi, and Galveston, Texas, where dew-point temperatures sometimes reach 78°F. Fortunately, this happens rarely; dew-point temperatures are nearly always 75°F or lower. And because winter temperatures in Biloxi and Galveston drop below freezing temperatures on occasion, there is some justification for interior-side vapor retarders there.[7]

NAIMA recommends another option of using either an interior- or exterior-side vapor retarder with moderate permeance. Inset stapled (or unstapled) kraft facing, with a permeance of about 1 perm, meets this requirement. Foil and polyethylene do not; their permeance ratings are much lower. (Omitting the vapor retarder entirely would work but would not allow energy-efficient cooling. However, if the building structure itself is a vapor retarder, unfaced insulation would be suitable.)[7] Where winter heating loads and summer cooling loads are equal, the vapor diffusion retarder will be on the wrong side for half the year. An air retarder, described later in this book, may be a better choice.

Cellulose Insulation Manufacturers Association (CIMA), along with the year 2000 editions of the *International Building Code* (IBC), the

International Residential Code (IRC), and the *International Energy Conservation Code* (IECC), has provided several exceptions to the prescriptive vapor retarder requirement. These include moisture-resistant materials, certain geographic areas, and "where other approved means to avoid condensation in unventilated frame wall, floor, roof, and ceiling cavities are provided." A growing number of experts are of the opinion that the matter of moisture control is too complex to be addressed by an absolute universal prescriptive requirement for a 1-perm vapor retarder. As studies continue, more will be learned about the complicated task of limiting moisture-related damage inside walls. Breathable walls, moderate climate zones, and the actual water vapor transportation aspects of air movement, as opposed to vapor diffusion, are of interest. As stated earlier, if unsure as to the vapor retarder placement within a wall, floor, or ceiling assembly, it is best to follow local practice and local codes.

Vapor retarder locations in the home

As mentioned earlier, water vapor that is trapped in a wall, ceiling, or floor assembly can lead to a number of problems. There are some locations in the home, under certain conditions, where a vapor retarder is not required. Attic vapor retarders are commonly omitted when blown-in insulations are used. If sufficient attic ventilation exists, condensation problems do not occur in most U.S. climates. CIMA does provide general guidelines for attic ventilation. In vented attics without vapor retarders, standard practice is to provide 1 ft^2 (0.093 m^2) of net vent area for each 150 ft^2 (13.94 m^2) of ceiling area. In vented attics with vapor retarders, standard practice is to provide 1 ft^2 (.0903 m^2) of net vent area for each 300 ft^2 (27.87 m^2) of attic floor area. When using a combination of roof and eave vents and no ceiling vapor barrier, there should be 1 ft^2 (0.093 m^2) of net vent area for each 300 ft^2 (27.87 m^2) of ceiling area. Vents should be installed with 50 percent of the total area in the eaves and 50 percent of the total area in the roof near the peak. The design professional or builder should verify these required minimums with local building codes.

In homes with cathedral ceilings, a continuous vapor diffusion retarder with sound, reliable airsealing is very important. Moisture vapor can move through many materials, including fibrous insulation, by diffusion. Therefore, moisture vapor that gets around or through a vapor retarder must be allowed to exit a cathedral ceiling rafter bay through a vent opening even when an airspace does not exist. Moving air can carry lots of moisture, but air movement is not necessary for moisture to escape from buildings. For example, since commonly used asphalt roof shingles have very low vapor permeance, cathedral ceilings can be likened to walls with very-low-permeance exterior skins.

Continuous vapor retarders can prevent condensation problems, but if the vapor retarder is penetrated by recessed lights that are not air/vapor-tight, some means must be provided to allow moisture to escape. (When ventilated airspaces are provided in milder climate areas, kraft vapor retarders may be adequate.) This can be accomplished with eave, ridge, or other vents. Note that airspaces alone, without both eave and ridge vents, will not add protection against moisture condensation in sloped ceilings. Air will not move through a space unless it has a place to exit as well as a place to enter. When both eave and ridge vents are provided, a $^1/_2$" or thicker airspace between the top of the insulation and the roof sheathing is desirable. As stated before, the design professional or builder should verify these required minimums with local building codes. Not only does this arrangement remove any unwanted moisture vapor, an airspace also helps remove heat in hot weather, and many professionals believe that it extends the life of roofing shingles as well.

Even when not required to prevent condensation problems, attic vapor retarders may be worthwhile; their presence may help maintain more comfortable humidity levels. When a vapor retarder is desired and blown-in ceiling insulation is used, a combination of faced batts and blown-in insulation, followed by a vapor retarder ceiling paint, can be used. Homes with irregular ventilation or high moisture levels should have a continuous vapor retarder. Vapor retarders are not necessary or recommended on interior walls where unfaced sound batts are installed.

As with wall assemblies, vapor retarders in floor assemblies should be installed on the warm side of the structure. In a heating climate, install it either in the space between the subfloor and finish floor or between the floor joists and the subfloor. An exception to placing the vapor diffusion retarder on the warm side of the floor is in houses constructed over a concrete slab. To protect the slab from soil moisture, place the vapor diffusion retarder above the gravel subbase.

In any climate, a crawl space vapor retarder may be necessary to reduce condensation resulting from ground moisture. In most traditionally constructed homes, the ground is a significant source of moisture. Moisture condenses on the colder sections of the foundation and framing, including nail penetrations. Placing 6-mil polyethylene sheeting directly over the ground cover reduces this likelihood. Local building codes require vapor retarders unless minimum crawl space vent requirements are adhered to. Additional strategies to help eliminate unwanted crawl-space moisture should include making sure the minimal constructed clearance meets all regulatory requirements, installing small, area, or through-the-wall drains, sloping the grade toward the drain intakes, verifying that all polyethylene seams are overlapped at least 6 in (seal to drain), and extending it up the foundation wall on the interior (avoid covering vents). Regardless of the number of foundation vents or climate, it is always good practice to install a vapor retarder over the soil.

For extensive renovations where wall cavities are opened and filled with blanket or rigid board insulation, it is simple to add a vapor retarder before the wall is refinished. Walls that have been retrofitted with blown-in or loose-fill insulation typically do not have vapor retarders. In cases where indoor moisture levels are not extreme, researchers have found that moisture that enters the wall eventually will evaporate and not damage the building materials. Many design professionals guard against this strategy because a homeowner's activities and lifestyles vary with time and technology, leading to unpredictable and possibly undesirable consequences.

Vapor retarder installation guidelines

Polyethylene sheeting (usually 4 or 6 mil) is used when an improved continuous, airtight vapor retarder is desired because of added moisture. The polyethylene sheeting, available in rolls, is rolled out horizontally and stapled to the face of the framing. It is recommended that the polyethylene be stapled at the sides and the excess material folded back into the room. If more than one sheet of polyethylene is required, a double fold should be made at the meeting of the two pieces and stapled, or the sheets may be overlapped and taped. The pieces, if stapled, should meet only at a stud or a joist. Foil-backed gypsum wallboard is also an effective vapor retarder. It is important to cover the polyethylene with gypsum wallboard or other approved interior material, as required by local codes, as soon as the insulation and polyethylene have been installed properly.

In general, the colder the climate, the tighter the vapor retarder should be. Also, the more vapor-tight the building's outer skin, the tighter the vapor retarder should be (relative to the 5 to 1 rule mentioned earlier). In milder climates of less than 4000 heating degree-days, inset stapled kraft facing is adequate for most installations. Inset stapled kraft paper–faced insulation is also adequate in cooler climates in buildings whose outer skins are vapor-permeable, as in those with wood fiber sheathing and loose-jointed vinyl or aluminum siding. In northern areas with 6000+ heating degree-days, face-stapled or separate polyethylene vapor retarders should be considered. Polyethylene or other tight, continuous vapor retarders should be installed in all but deep South/Gulf Coast areas when very-low-permeance exterior sheathing/siding combinations are used.[9]

Research indicates that vapor retarders may not be required for basements, but it is prudent to keep moisture vapor away from cold surfaces such as basement walls where they are above grade. Therefore, for watertight walls in cool climate areas, vapor retarders are recommended in basements. Unfortunately, not all basement walls are watertight. While poured concrete walls usually are both watertight and vapor-tight, block walls are often neither. For this reason, vapor retarders are not always recommended for below-grade block basement walls unless they have been waterproofed as opposed to the usual damp-proofed.[9]

Vapor retarders are not recommended for all insulation types. For example, most cellulose manufacturers recommend against the use of vapor retarders in walls insulated with spray-applied cellulose. Most cellulose producers regard vapor retarders as unnecessary with dense-pack cellulose under most conditions. If design temperatures are below −15°F (−26°C) the interior surfaces of exterior walls and ceilings, where the cold side cannot be ventilated, can be painted with a vapor barrier paint.

Some insulation facings are intended only for installation behind ceiling, wall, or flooring materials because they are flammable. (Always verify installation procedures with the manufacturer's instructions.) A great deal of air leakage can occur through penetrations in the exterior envelope of a building. Plumbing, ductwork, wiring, and electrical outlets are a few of the less obvious points where air can move through a building's thermal envelope. Strategies that include caulking, weatherstripping, and careful insulation installation should be implemented in these inconspicuous areas.

Air Barrier/Retarder

An *air barrier* or *air retarder* is any material on a building that prevents the movement of air from the interior to the exterior (infiltration) or from the exterior to the interior (exfiltration). Also called housewraps, these materials are barriers to air and liquid water but not to water vapor. Typical exterior housewraps are not vapor retarders and will allow water vapor to diffuse easily through them.

Infiltration can comprise almost 50 percent of all heat loss from a home during the winter months. The major sources of air infiltration are sill plates (25 percent), wall outlets (20 percent), and duct systems (14 percent), followed by windows (12 percent).[1] These sources can be reduced by the use of caulking, weatherstripping, and air infiltration barriers. It is important to note that homes need some fresh air to remove odors, chemicals from interior sources, and even exhaust gases. Tests have shown that a building with a poorly air-sealed exterior suffers accelerated heat loss or gain because of outside air infiltration into

Figure 4.3 Housewrap. (*Owens Corning*)

the wall cavity. Exterior air retarders protect the wall from the effects of weather and help eliminate air infiltration.

Product description

The most popular, flexible air retarders (also called *housewrap*) are composed of polyolefins, which include polyethylene and polypropylene. These air retarder materials typically are fiber-reinforced as spunbonded, woven, or laminated products. Standard gypsum panels, cement board, no. 15 felt, industry building wrap, and other common construction materials also can serve as air barriers if installed properly (but not as vapor retarders)[10] (Fig. 4.3).

Installation

All joints and seams must be sealed to create a truly continuous, effective air retarder. Installation errors not only increase energy use but also increase the risk of moisture damage to a house. An air retarder, therefore, should be inspected carefully after installation and before other work covers it. Small holes in an air retarder can be repaired with polyethylene or foil tape, whereas large holes can be repaired with a large patch of polyethylene. Patches always should be large enough to cover the damage and overlap any adjacent wood framing. Sealant should be used to thoroughly seal the joint.

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Chapter

5

Insulation Applications and Comparisons

Applications

The primary purpose of thermal insulation is to control heat transfer through the exterior assemblies of a house. The *thermal envelope* of the home is considered to be the exterior perimeter where an energy breach may occur. This last line of defense, where heat gain or heat loss can occur, is not to be taken for granted. In fact, to guarantee the comfort of the occupants and the energy efficiency and durability of the home, the thermal barrier, or insulation, and the air barrier should form a continuous envelope around the house. All components of the air and thermal barriers must be in physical contact with each other to prevent any inferior or omitted element from getting within the envelope. Improperly installed materials, inferior-quality materials, or omitted areas will compromise the efficiency of a homeowner's heating and cooling system.

Locations

Insulation is not just for attics and outside walls. Many areas of a home that are often overlooked include ceilings with unheated spaces above (including dormer ceilings), knee walls of attic spaces finished as living areas, sloped walls and ceilings of attics finished as living areas, cathedral or vaulted ceilings, perimeters around slabs, floors above vented crawl spaces, floors over unheated or open spaces such as over garages or porches, basement walls, band and header joists, floors over unconditioned basements, soffits below cantilevered second-floor rooms, knee walls of closets in "bonus" rooms, and even areas where acoustical dampening is required such as laundry rooms or bathrooms.

Gaps and voids are areas where insulation should be installed but is omitted, thereby causing conductive and convective heat loss. A *gap* is a place where the insulation does not come all the way to the edge of the space to be insulated. A *void* is a hole in the envelope of the building. Examples include plumbing chases, wiring penetrations, fireplace cavities, dropped ceilings, soffits, and venting.

Foundations

In certain climates, an uninsulated foundation may account for up to 50 percent of the heat lost from an otherwise tightly sealed, well-insulated house.[1] Proper installation of foundation insulation material is necessary to avoid moisture condensation, material damage, and structural decay caused by the differences in temperature between the house interior and the adjacent earth. Poor design and installation also may aggravate radon infiltration and insect infestation. It is best to research common methods and local guidelines depending on the specific climate, soil type, and design conditions.

Although considerable savings in heating costs can be achieved by insulating a foundation, installation costs are often high, particularly for retrofit projects. The materials used, the location of the application, and the extent and timing of the work all affect the overall cost. While savings are accrued through energy-use reductions, "energy savers" financing packages, and home improvement savings programs, simple payback is typically the most popular analysis method. The payback period can range from 6 months for a simple do-it-yourself installation to 20 years for more involved work.[1]

Basement Walls

Installing insulation on the exterior of a basement wall (exterior insulation) is usually good practice. Exterior insulation can minimize thermal bridging and subsequently reduce heat loss through the foundation, can protect waterproofing, and can help serve as a capillary break to moisture intrusion, and can help prevent any freeze-thaw cycle damage to the foundation. Some exterior insulation materials are susceptible to insect infestation, so material selection is paramount to good performance. Foam insulation impregnated with insecticidal boric acid has yielded some success in discouraging termite infestations. Although termites avoid it, boric acid slowly leaches out of most materials exposed to moisture. Installation of a good gravel or manufactured "rain screen" drainage element outside the insulation can reduce moisture problems significantly and structurally protect the insulation.

More comprehensive analysis is needed to better identify appropriate protective coatings, address insulation moisture absorption, and understand long-term insulation R-value degradation. One study conducted by the Minnesota Department of Public Service, Office of Energy Conservation, surveyed 59 houses in the Minneapolis–St. Paul area from April to June of 1988. The study sampled foundation insulation specimens and soil specimens to determine long-term performance.

The survey's results showed that the durability and performance of exterior foundations are due to installation quality and above-grade protective coatings rather than the type of insulation material used. Most coatings help to minimize moisture absorption and foster R-value retention. However, almost 60 percent of the bitumen coatings (commonly used to protect spray urethane insulation) sampled showed flaking, gouging, or other damage that could reduce effectiveness.[1]

The U.S. Department of Energy is working with regulatory groups to help establish appropriate guidelines that provide cost-effective thermal protection for buildings. Building scientists theorize that the best way to build a dry basement is to insulate the outside of exterior walls with a rigid, fibrous, insulating drainage layer, such as fiberglass or rock wool, and omit the common application of exterior damp-proof coating or interior vapor retarder.[1] Conventional damp proofing should be applied from 6" below grade down to 3' below grade. The fibrous insulation acts as a capillary break that keeps bulk water out even during floods. The concrete will always dry to the exterior because of the vapor pressure differentials. This construction resists summer wall condensation and potentially can act as a passive dehumidifier for the basement. In winter, water vapor will diffuse inward whenever the relative humidity of the basement air is below 33 percent.

Cavity foundation materials, such as concrete block, potentially lend themselves to both retrofit and new construction installations of foamed-in, blown-in, and poured-in insulations. The most commonly used materials include foamed-in insulations or poured-in polystyrene beads and granular materials such as vermiculite.

Concrete block is also available with insulating inserts for new construction. These materials reduce convection within the cells (the hollow cavity), but significant levels of heat can still conduct through the webs of the masonry. Some concrete block manufacturers attempt to increase the thermal resistance of their product by adding materials such as polystyrene or wood chips to the concrete mix.

Insulation also may be applied to the interior of a foundation or basement wall. This method is especially suited for renovation or remodeling projects without excavation. Material analysis is essential for proper placement, as well as for ensuring the safety and structural integrity of the home. For example, some types of insulation require separation from habitable spaces by a fire-rated material because they are extremely flammable and release toxic gases when ignited. Interior insulation applications fail to protect the waterproofing or structure as well as exterior insulation. Proper installation of sealants and vapor retarders is important for adequate performance of interior insulation.

Slab-on-grade foundations

Floor heat loss generally comprises about 10 percent of the total heat loss of a house.[2] This may sound minimal, but from a comfort standpoint, cold floors are usually not very desirable. Slab-on-grade foundations, or foundations for homes that have no basements, may require the insulation to be placed vertically on the exterior or the interior of the foundation wall or horizontally above or below the floor slab. Continuous vertical exterior insulation placed outside the foundation wall reduces heat loss from both the foundation and the slab. To reduce heat flow from the slab floor to the ground outside, extend the insulation below grade to the footing. Insulate any exposed slab edge above grade.

A homebuilder also can install insulation vertically on the interior side of the foundation before pouring the slab. R-10 perimeter insulation around the edge of a slab is probably the most common type. If the highest known water table of a site is 2' or more below outside grade, perimeter insulation may be placed in a vertical or horizontal position. If the highest known water table is less than 2' below the outside grade, perimeter insulation may be placed in a horizontal or L-shaped position.[2] Special consideration always must be given to the potential for insect or vermin infestation when using exterior or interior foundation insulation products.

Walls

As will be discussed in the next chapter, energy or building codes will prescribe the insulation values of exterior walls. Research seems to indicate that a total wall R-value of R-19, using batts, blankets, blown-in insulation, or sheathings, is typically recommended. Cracks around windows and doors should be addressed, whereas loose insulation or foam should be used in spaces around the rough framing and around the heads, jambs, and sills. Insulated doors are available, some with a thermal resistance value of R-5.

Insulated window units have airspaces between double or triple panes of glass that slow heat loss. To be truly effective, the units actually should contain an inert gas in the airspace; however, such windows are a little more expensive.

Floors

In most climates, insulation with a minimum thermal resistance value of R-19 should be installed beneath the floors of heated rooms located over unheated areas such as basements, beneath stairwells and stair landings between heated and unheated areas, and above garages, porches, or areas with an overhang subject to outside temperatures. Insulation can be omitted from floors over heated basements or heated crawl space areas if the foundation walls are fully insulated. Foundation walls of heated basements typically do not need to be insulated, except where 50 percent of the wall is exposed to outside air or if the basement contains a habitable room.[2]

Ceilings

Ceiling insulation should extend over the top of interior wall partitions and over the top of the plate at the outside wall. The insulation, however, should not block eave ventilation.

Attics

Attic areas typically should be filled with loose-fill or blanket insulation between and over ceiling joists in order to achieve a thermal resistance value of R-38. Cathedral ceilings and slanted ceiling areas are especially problematic due to the restricted space for insulation installation. As a minimal requirement for most climates, a total value of R-30 in any combination of building materials and insulation should be achieved with preferably 2" of clearance between the insulation and the underside of the roof sheathing. Standard framing practices typically allow for only 1" of clearance. This should be considered the absolute minimum for proper ventilation.

As mentioned earlier, finished attic areas with knee walls should not be overlooked. Each of these assemblies is analogous to those already mentioned, with the walls receiving a total wall value of R-19 in the knee walls, R-30 between the sloped roof joists, and R-38 between the horizontal ceiling joists (Fig. 5.1).

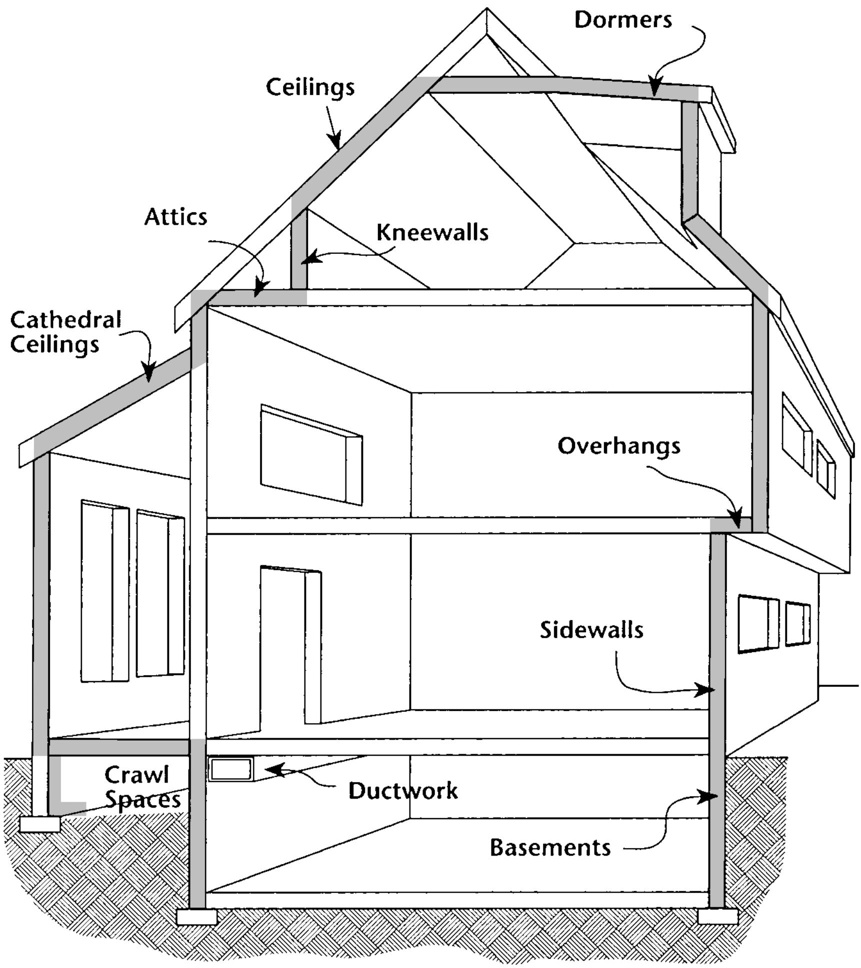

Figure 5.1 Areas to insulate. (*NAIMA*)

Superinsulation

Around 1980, a new approach to fuel and energy conservation came to the attention of architects and builders. Called *superinsulation,* this approach provided a high degree of comfort in winter and summer and reduced fuel consumption by 75 to 95 percent relative to conventional houses.[3] The method was announced and explained in talks at building construction conferences, in magazine articles, and in books. Enthusiasm spread rapidly, with the result that by 1987 there were several tens of thousands of superinsulated houses in routine use in the United States and Canada. The origins of superinsulated design actually date back to the 1940s, when a group of individuals at the University of Illinois began analyzing heat losses from houses.[3] In 1976, researchers were able to prove that superinsulated design concepts would need only as much as one-third as much auxiliary heat as the designs being promoted by the U.S. Department of Housing and Urban Development (HUD).[3] A new moniker for superinsulation being used today is the *airtight drywall approach* (ADA).

In some very cold regions, this new method now dominates home construction.[3] It is important to note that a universal standard is not possible because a design that is optimal for Boston will not be optimal for sunny Colorado, cloudy Rochester, or bitterly cold Anchorage. Because its main reliance is on heat conservation (excellent insulation, excellent retention of intrinsic heat) rather than on solar radiation, the superinsulated house is tolerant of less favorable sites and orientations. It is permissible to locate such a house in a moderately wooded area and to employ a far from south-facing direction (orientation).

The main distinguishing characteristic, or hallmark, of a superinsulated house is thick and widely applied insulation. An actual effective R-value of R-25 in all walls, ceilings, and floors is a minimum standard.[4] Even at the sills, headers, eaves, window frames, door frames, and electric outlet boxes, a moderate amount of insulation is provided. The construction must be airtight but still introduce a steady and controlled supply of fresh air. The occupants benefit from the absence of drafts, cold floors, and cold spots near windows. A superinsulated house, throughout most of the winter, is kept warm almost entirely by the modest amount of solar energy received through the windows and by intrinsic heat. Interior heat is generated by systems and appliances typically functioning within the home. These sources include stoves for cooking, domestic hot water systems, human bodies, clothes washers, clothes dryers, dish washers, electric lights, television and radio sets, refrigerators, and other electric appliances.

A conventional furnace typically is not used. Most homes rely on "borrowing" from the domestic hot water system, or on a minimal amount of electrical heating. A wood stove or portable electric space heaters may be used during extreme temperature dips to keep such a house comfortable. There is not a significant added expense for superinsulated housing mainly due to the elimination of a furnace or a big heat distribution system.[4] In fact, what little auxiliary heat is needed is less than 15 percent of that required for typical houses of comparable size built before 1974.[3] In summer, the house stays cool because south-facing heat gain has been minimized due to the reduction of window area as well as the use of roof eaves.[4]

The extra cost of superinsulating a house is usually only 3 to 6 percent of the total construction cost.[3] Experts suggest that the best insulations for superinsulated home design are those with highest R-value per inch, lowest cost per R-value, durability, and great resistance to settling. Fiberglass blanket products are especially popular owing to their low cost, ease of installation, and good fire resistance. Blown-in fiberglass when installed in dense quantities is gaining popularity and because of its ability to be installed in hard-to-reach places; however, settling can be problematic. Some insulation types are not recommended. These include vermiculite and perlite. Urea formaldehyde foam insulation (UFFI) is discouraged due to shrinkage problems and an errant controversy over formaldehyde emission. Balloon framing is preferred over platform framing because platform framing, although more popular, easier to construct, and less expensive, is inherently problematical from a thermal standpoint, owing to areas around floor joists, band joists, and headers that act as thermal bridges.[4]

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Chapter

6

Building Codes, Associated Standards, and Regulations

Building standards and model codes that address the energy-efficient design of residential buildings have been around for over 30 years. It was the energy crisis of the 1970s, however, that launched a plethora of federal regulations, testing standards, and guidelines have now been developed not only to provide more energy-efficient home construction but also to help provide consumer safety, eliminate fraud, and even assist in home mortgage financing.

The American Society of Heating, Refrigerating and Air-Conditioning Engineers

The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) is an international organization with over 50,000 members and numerous chapters located throughout the world. ASHRAE writes standards and guidelines to guide industry in the delivery of goods and services to the public. These standards and guidelines include uniform methods of testing for rating purposes, recommended practices in designing and installing equipment, and provide other industry-related information.

The original ASHRAE Standard 90-1975, “Energy Conservation in New Building Design,” was first published in 1975. The scope of this document covered both residential and commercial buildings and became the historical and technical basis for most current model codes and standards for residential construction. Two significant modifications to Standard 90 were 90A and 90B, published in 1980. These original ASHRAE standards served as the basis for ASHRAE Standard 90.2-1993 and the *Model Code for Energy Conservation,* published in 1977. This became known as the *Model Energy Code* (MEC) of the Council of American Building Officials (CABO) throughout the 1980s and 1990s. The *Model Energy Code* is now published as the *International Energy Conservation Code* (IECC) by the International Code Council (ICC).[1]

ASHRAE Standard 90.2, "Energy-Efficient Design of New Low-Rise Residential Buildings," was first published in 1993. This standard was specifically created to provide design requirements for the efficient use of energy for new residential dwellings that are three stories or less above grade. These include single houses, multifamily structures (of three stories or fewer above grade), and manufactured houses (both mobile homes and modular homes).

This standard deals with the building envelope, heating equipment and systems, air-conditioning equipment and systems, domestic water-heating equipment and systems, and provisions for overall building design alternatives and tradeoffs. Compliance can be calculated using the prescriptive requirements method and the annual energy cost method (systems-analysis approach). Standard 90.2 has been modified since its publication by several published addenda and continues to be under "continuous maintenance" per ASHRAE procedures.

International Energy Conservation Code

The *International Energy Conservation Code* (IECC), formerly known as the *Model Energy Code* (MEC), is a voluntary code that sets energy-efficiency standards for furnaces, air conditioners, windows, and insulation for commercial and residential construction. The *Model Energy Code* (MEC) was developed jointly by Building Officials and Code Administrators International, Inc. (BOCA), the International Conference of Building Officials (ICBO), the National Conference of States on Building Codes and Standards (NCSBCS), and Southern Building Code Conference International, Inc. (SBCCI), under a contract funded by the United States Department of Energy (DOE). First published in 1983, subsequent full editions of the MEC were published in 1986, 1989, 1992, 1993, and 1995.

The MEC was first referenced in the National Affordable Housing Act of 1990, and then in the Energy Policy Act (EPAct) of 1992. EPAct was signed into law by President Bush in 1992 and referenced the 1992 MEC as the energy-efficiency standard to be used for new residential construction. Additionally, EPAct required federal mortgage lenders to ensure that homes using their products also comply with the 1992 MEC as a minimum standard. Subsequently, the DOE determined that the 1993 MEC and later the 1995 MEC provided greater energy efficiency for residential buildings and required states to consider adopting the later version. In concurrence with EPAct, the U.S. Department of Housing and Urban Development (HUD) required compliance with the 1992 MEC as part of its minimum property standards. HUD currently has a final rule pending to upgrade its minimum property standards to the 1995 MEC level. Whether a state has adopted it or not, the MEC applies to houses financed through the Federal Housing Administration (FHA), the Department of Veterans Affairs (VA), and the Rural Economic and Community Development (RECD, formerly Farmers' Home Administration). Loans received from or guaranteed by these agencies require that the financed house comply with the MEC.

The International Code Council (ICC) was formed in late 1994 by BOCA, ICBO, and SBCCI with the objective of developing a comprehensive set of U.S. model building codes, known as the *International Building Code* (IBC). The IBC is a synthesis of the building codes of the three regional model code organizations. These are BOCA's *National Building Code,* SBCCI's *Standard Building Code,* and ICBO's *Uniform Building Code.*

The MEC had been maintained until 1998 as an activity of the Council of American Building Officials (CABO) and incorporated by reference in each of the three regional model building codes: BOCA's *National Building Code* (in Chap. 13), SBCCI's *Standard Building Code* (in an appendix), and ICBO's *Uniform Building Code* (in an appendix). The ICC has assumed responsibility from the CABO for maintenance of the CABO *One- and Two-Family Dwelling Code* and the *Model Energy Code* to provide proper interfaces with the international codes. States will have a time window in which to adopt the new ICC model codes.

The 1998 version of the MEC was published as the first *International Energy Conservation Code* (IECC). The current 2000 IECC addresses the design of energy-efficient building envelopes and the installation of energy-efficient mechanical, lighting, and power systems through requirements emphasizing performance. This comprehensive code establishes minimum regulations for energy-efficient buildings using prescriptive and performance-related provisions. It makes possible the use of new materials and innovative techniques that conserve energy. This second edition incorporates the provisions of the 1998 IECC and its approved changes. Preliminary review of the 2000 IECC seems to indicate that it is more "user-friendly."

The *International Residential Code* (IRC), released in 2000, replaces the CABO *One- and Two-Family Dwelling Code*. A chapter in the IRC addresses energy efficiency but looks significantly different from the IECC. Intended to be a simplified prescriptive approach to achieving equivalent compliance with the "performance" requirements of the IECC, the IRC energy chapter is a table of prescriptive insulation and window requirements.

Most states have adopted some version of the MEC. In states that do not have a statewide energy code, the MEC has also been adopted by individual counties and cities. With continuously changing regulations, as well as the introduction of the IRC in 2000, the status of most states will most likely change. It is important to check with the local building officials or the state energy office for current requirements.

Most states have adopted a version of the MEC or a similar equivalent energy code. Only six states, Arizona, Illinois, Louisiana, Missouri, South Dakota, Hawaii, and Texas, do not have any statewide mandatory energy codes for low-rise residential construction.[2] (Hawaii and Louisiana have statewide mandated codes for low-rise multifamily construction.)

Currently, the 1992 MEC has been adopted by Indiana, Iowa, Kentucky, New Mexico, and Tennessee, whereas the 1993 MEC has been adopted by Delaware, Kansas, Montana, and North Dakota. States that have adopted the 1995 MEC are as follows: Connecticut, Georgia, Maryland, Massachusetts, Ohio, Oklahoma, Rhode Island, South Carolina, Utah, Virginia, and Washington, D.C. Nevada still enforces the 1986 MEC, whereas Nebraska uses the 1983 MEC.[2]

Alabama, Alaska, Arkansas, California, Florida, Minnesota, New York, North Carolina, Oregon, Vermont, Washington, and Wisconsin have adopted a state-developed code that exceeds or meets MEC requirements, whereas Colorado, Idaho, and Maine have adopted a state-developed code that is less stringent than the MEC. Mississippi, New Hampshire, and Wyoming still reference ASHRAE 90-1975, whereas Michigan, New Jersey, and West Virginia reference ASHRAE 90A-1980. Pennsylvania has officially adopted the IECC as a state-mandated energy code.[2]

Requirements

The IECC and the MEC allow designers a variety of calculation methods to comply with code requirements. The prescriptive approach, the simplest of the three approaches, allows builders or designers to select from various combinations of energy-conservation measures based on “climate zone” location. Each combination or “package” specifies insulation levels, glazing areas, glazing U-values (thermal performance), and sometimes heating and cooling equipment efficiency. By locating the correct climate zone and looking up the appropriate table of packages, builders and officials can ensure that their projects meet or exceed one of the packages listed for that zone.[3] Few calculations are required.

The tradeoff worksheet approach enables builders to vary insulation levels in the ceilings, walls, floors, basement walls, slab edges, and crawl spaces; glazing and door areas; and glazing and door U-values. Based on the proposed plans and specifications, the builder enters simple information on a worksheet and then hand-calculates a total U-value for the project. By comparing the project’s U-value with the value required for the climate zone, the builder can determine if the project passes the energy code requirements. The impact of this approach is that as window area increases, the thermal performance of the windows must be improved (lowering U-value) or the insulation must be increased in the opaque portion (raising the R-value) in order to satisfy the overall U-value requirement. If the project does not pass, the builder can use the worksheet to examine a different combination of insulation levels, window or door products, and areas for compliance. The worksheet is suitable for use during the plan check and field inspection phases of a project.[3]

Simplified software products that allow tradeoffs and demonstrate compliance may offer the best combination of simplicity and flexibility. The software approach does the same calculations as the tradeoff worksheet but automates the procedure using a computer. Special features allow builders to trade off heating and air-conditioning equipment efficiency, as well as windows and insulation. The software generates a report that is suitable for plan checking and field inspection.[3] The “rules” for the assumptions or standard conditions to be used when performing such analyses have been revised substantially in the IECC over those in the MEC.[1] Finally, many state energy code offices also provide quantitative R-value standards for the specific locale in order to simplify residential design energy calculations. It is important to consult with local building officials to determine which energy code has been adopted and the calculation methods available.

In addition to the insulation and window requirements, there are basic criteria that must be met regardless of which envelope compliance approach is used. These include the following: sealing the building envelope to restrict air leakage (caulking, sealing, and weatherstripping at all penetrations and joints); installing vapor retarders in most climates; identifying materials used for energy code compliance (such as insulation R-values) on plans, specifications, and/or directly on materials in the residence; and insulating and sealing ducts in unconditioned spaces as well as insulating pipes for hydronic heating and circulating hot water systems. Tightly sealed structures also can prevent the proper exchange of the minimum ventilation needed for the physiologic needs of people. Makeup air, usually through a means of mechanical ventilation, can be implemented to guarantee the proper number of air changes in a home.

Model Energy Code compliance assistance

The DOE has developed a number of resources to guide architects, builders, designers, plan checkers, and field inspectors in meeting the requirements of the MEC and the newer IECC. The *MECcheck Manual* is a clear and comprehensive compliance guide that describes the basic requirements of the code for building envelopes, heating and cooling, electrical systems, materials, and equipment. Included are three approaches for attaining compliance, guidance for plan checkers and field inspectors, and several forms and checklists. The *MECcheck Software* calculates tradeoffs between all building envelope components and heating and cooling equipment efficiencies. The software is capable of generating reports that can be used to document code compliance. *MECcheck Prescriptive Packages* instruct design and construction professionals on how to select a package of insulation and window requirements based on the specific climate zone in which their building is located. Each climate zone package lists all compliance standards for insulation, glazing areas, glazing U-values, and heating and cooling efficiency.

Miscellaneous Building Codes

There are many energy-related provisions, guidelines, and standards that are referenced throughout the new IBC as well as all previous model building codes. Thermal and sound insulating materials, vapor retarder requirements, foam plastic and loose-fill cellulose insulation restrictions, and flame spread ratings are but a few of the issues referenced.

Home Energy Rating System Council Guidelines

The Home Energy Rating Systems Council (HERSC) is a nonprofit association whose focus is to promote residential energy efficiency nationwide by linking home energy rating programs with financing for energy-efficiency improvements. The council maintains that once the linkage between home energy ratings and energy-efficiency financing is established, energy-efficient homes will become more available and affordable.

The council draws its members from the full spectrum of the housing industry and financial community. These include individuals from the appraisal industry, builders, certified raters, consumer groups, contractors/retrofitters, energy and environmental groups, state and local governments, mortgage companies, product and equipment manufacturers, real estate professionals, and utilities.

Home energy rating systems (HERS) measure and rate the relative energy efficiency of any house, regardless of its age, location, construction type, or fuel use. The rating evaluates the performance of the thermal envelope; glazing strategies; siting; the heating, ventilation, and air-condition (HVAC) system; and other criteria and is obtained by onsite inspection. HERS calculations include estimates of annual energy performance and costs and can provide insight into cost-effective, energy-efficiency improvements. Under the voluntary guidelines, homes would receive an energy performance rating of one to five-plus stars. The guidelines spell out the minimum appropriate procedures for assigning energy ratings to homes and encourage consistency with a uniform plan for energy-efficiency financing.

Federal Trade Commission

The Federal Trade Commission (FTC) home insulation regulation (16 CFR Part 460) requires the seller of a new home to provide information on the type, thickness, and R-value of the insulation that will be installed in each part of the house in every sales contract. Commonly known as the *R-Value Rule,* it is intended to eliminate dishonest or misleading insulation marketing claims and to ensure publication of accurate R-value and coverage data.

American Society for Testing and Materials

Organized in 1898, the American Society for Testing and Materials (ASTM) is a not-for-profit organization and one of the largest voluntary standards development organizations in the world. More than 32,000 members representing producers, users, ultimate consumers, and representatives of government and academia from over 100 countries develop documents that serve as a basis for manufacturing, procurement, and regulatory activities.

ASTM provides a forum for the development and publication of voluntary consensus standards for materials, products, systems, and services. These standards are documents that have been developed and established within the consensus principles of the society and meet the approval requirements of ASTM procedures and regulations. ASTM standards are developed and used voluntarily. They become legally binding only when a government body makes them so or when they are cited in a contract. ASTM headquarters has no technical research or testing facilities; such work is done voluntarily by the ASTM members located throughout the world.

The following is a list of many of the ASTM standards that are referenced in many of the building and energy codes with respect to building insulation:

C208-95, "Standard Specification for Cellulosic Fiber Insulating Board"

C209-98, "Standard Test Methods for Cellulosic Fiber Insulating Board"

C665-98, "Standard Specification for Mineral-Fiber Blanket Thermal Insulation for Light Frame Construction and Manufactured Housing"

C687-96, "Standard Practice for Determination of Thermal Resistance of Loose-Fill Building Insulation"

C727-90(1996)e1, "Standard Practice for Installation and Use of Reflective Insulation in Building Constructions"

C755-97, "Standard Practice for Selection of Vapor Retarders for Thermal Insulation"

C976-90(1996)e, "Standard Test Method for Thermal Performance of Building Assemblies by Means of a Calibrated Hot Box"

C1015-84(1995)e1, “Standard Practice for Installation of Cellulosic and Mineral Fiber Loose-Fill Thermal Insulation”

C1049-85(1995)e1, “Standard Practice for Installation of Granular Loose-Fill Thermal Insulation”

C1058-97, “Standard Practice for Selecting Temperatures for Evaluating and Reporting Thermal Properties of Thermal Insulation”

C1224-99, “Standard Specification for Reflective Insulation for Building Applications”

C1373-98, “Standard Practice for Determination of Thermal Resistance of Attic Insulation Systems under Simulated Winter Conditions”

C1374-97, “Standard Test Method for Determination of Installed Thickness of Pneumatically Applied Loose-Fill Building Insulation”

E84-99, “Standard Test Method for Surface Burning Characteristics of Building Materials”

E1574-98, “Standard Test Method for Measurement of Sound in Residential Spaces”

U.S. Consumer Product Safety Commission

The U.S. Consumer Product Safety Commission (CPSC) is an independent federal regulatory agency that was created in 1972 by Congress in the Consumer Product Safety Act. The agency’s mission, as directed by Congress, is to “protect the public against unreasonable risks of injuries and deaths associated with consumer products.”

The CPSC has jurisdiction affecting 15,000 types of consumer products, from automatic-drip coffee makers to toys to lawn mowers. There a number of standards under CPSC Standard 16 CFR (*Code of Federal Regulations*) that deal with the labeling and advertising of home insulation as well as the installation and handling of cellulose insulation.

Appendix

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Atlanta, GA 30329-2305

800-527-4723
http://www.ashrae.org/

American Society for Testing and Materials
100 Barr Harbor Drive
West Conshohocken,
Pennsylvania, USA 19428-2959
http://www.astm.org/index.html

U.S. Department of Energy
Building Research and Technology Office
Stephen Turchen
http://www.eren.doe.gov/buildings/

Federal Trade Commission
CRC-240
Washington, D.C. 20580
1-877-FTC-HELP (382-4357)

Home Energy Rating Systems (HERS) Council
Ms. Cynthia Gardstein, Executive Director
1331 H Street N.W., Suite 1000
Washington, DC 20005 USA
202-638-3700
Fax: 202-393-5043

International Code Council
5203 Leesburg Pike, Suite 708
Falls Church, VA 22041
703-931-4533
Fax: 703-379-1546
http://www.intlcode.org/

U.S. Consumer Product Safety Commission
Washington, D.C. 20207-0001
1-800-638-2772
http://www.cpsc.gov

References

1. ”The Latest and Greatest on Energy Efficiency in Residential Building Codes and Standards,” presented by Stephen Turchen, U.S. Department of Energy, Office of Codes and Standards, Energy Efficient Building Association, October 1998.
2. Building Codes Assistance Project Web site: *http://solstice.crest.org/efficiency/bcap/update.html.*
3. United States Department of Energy Building Standards and Guidelines Program (BSGP): *http://www.energycodes.org/*

Chapter

7

Loose-Fill Insulation

Loose-fill insulation materials are distinguished from other insulation types by the size of the individual unit of material. Produced as shreds, granules, or nodules, loose-fill insulation products can either be poured or blown into place depending on the material or the construction application. Generally speaking, loose-fill insulation materials for pouring applications are most commonly sold in bags. Larger applications, such as attic installations, may require mechanical blowing equipment available from professional insulation installers. Pneumatic applications probably account for about 90 percent of residential installations of loose-fill insulation (Fig. 7.1).

Loose-fill insulations are well suited for places where it is difficult to install other types of insulation, such as irregularly shaped areas, around obstructions (such as plumbing stacks), and in hard-to-reach places. Framing that is irregularly spaced or out of square can be especially problematic with standard-sized blanket insulation products. Loose-fill insulation products can be installed in either enclosed cavities such as concrete block walls, wood frame walls when an additional barrier is installed, or unenclosed spaces such as attics. Blown-in loose-fill insulation is particularly useful for renovation and retrofit installation because it can be installed with minimal disturbance of existing interior or exterior finishes. Hand-packed fills are also useful for hand fitting into odd spaces such as around door and window frames in wood frame construction.[1]

Loose-fill insulation materials that are modified with water-activated binders or adhesives and installed by pneumatic methods are

Figure 7.1 Blowing loose fill insulation. (*NREL/DOE*)

discussed in Chap. 9. This chapter explores the use of nonmodified loose-fill insulation materials or systems that are simply poured or blown in.

General Description

Loose-fill materials such as cellulose, fiberglass, mineral wool (rock wool and slag wool), vermiculite, perlite, wood shavings, and expanded polystyrene will be discussed in this chapter. Although specific properties of each will be discussed, there are general characteristics relating to the generic performance of loose-fill insulations that should first be reviewed.

Weight

Ceiling gypsum wallboard can sag under heavy loads, especially those sometimes created by insulation. One gypsum wallboard manufacturer recommends loads of no more than 1.3 lb/ft^2 for $^1/_2$" ceiling gypsum wallboard with framing spaced 24" on center. The limit increases to 2.2 lb/ft^2 for framing spaced 16" on center and for $^5/_8$" gypsum wallboard.[2] Cellulose and rock wool insulation manufacturers usually include weight-limit information on the bag because the thickness required may cause excessive weight limits.

Because fiberglass is much less dense, its weight on ceiling gypsum wallboard may not be a concern.

Convective heat loss

As discussed in Chap. 3, *convection* is heat flow caused by air currents. Although convective heat loss in insulation is rare, it can occur when large temperature differences above and below the insulation create tiny air currents, called *convection loops,* within the insulation. Studies have shown that convective heat loss typically occurs with lighter-density loose-fill materials, such as fiberglass, at the very low attic temperatures possible in extremely cold climates. Depending on the attic temperature, the insulation's measured R-value could decrease by as much as 50 percent. These convection loops can be minimized by installing material in accordance with the manufacturer's winter design conditions, installing blown-in cellulose, or placing a fiberglass or mineral wool blanket on top of the loose-fill fiberglass[2] (Fig. 7.2).

Settling

Some loose-fill insulations installed in attic cavities will lose some of their installed R-value over time because of settling. Installers need to refer to the "installed thickness" specifications. Researchers say that it is possible, however, to install loose-fill insulations in wall cavities without settling if the cavity is completely filled with insulation at the proper density. A general density guideline for walls is roughly 3.5 lb/ft^3 of wall cavity for cellulose and 1.5 lb/ft^3 for fiberglass or rock wool. These specifications are roughly two or three times the density of horizontal applications.[2]

Density measurements may not be practical for do-it-yourself installers. Another guideline to ensure that wall cavities are being filled at a density sufficient to prevent settling is based on the quantity of material. For example, if installing in 8-ft walls with 16" on-center wall cavities and 2 × 4" framing, use roughly one 30-lb bag of cellulose or about 15 lb of fiberglass or rock wool for every three wall cavities to be filled.[2] (These quantities are for general information only. Consult the manufacturer's literature for a specific application.)

Moisture resistance

All loose-fill insulations are permeable to water vapor. (As discussed in Chap. 4, *permeability* is the extent to which water

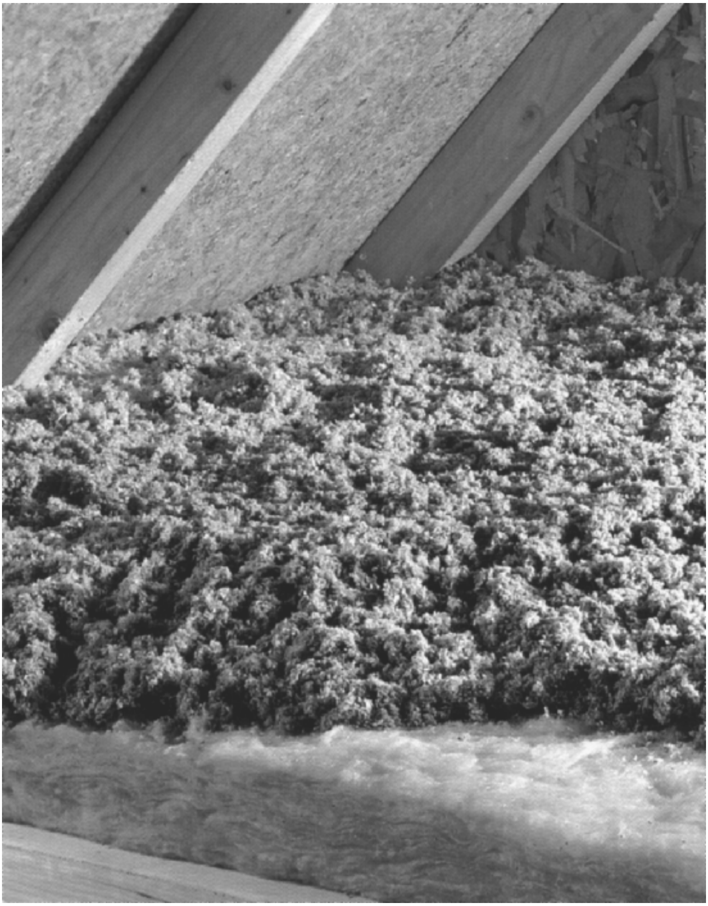

Figure 7.2 Cellulose insulation on top of fiberglass batts. (*Greenstone*)

vapor can pass through a given material.) Fiberglass and rock wool absorb less than 1 percent of their weight, whereas cellulose absorbs 5 to 20 percent of its weight. It is important to note that any insulation can absorb moisture if exposed to extremely high humidity.

If water penetrates a cavity, such as with a roof leak, moisture can accumulate in the attic cavity and wet the insulation to the point that it mats and compacts. Enough moisture penetration could even cause the ceiling to sag under the extra weight. Typically, if insulation is saturated only one time, it will dry eventually and regain most of its original R-value unless permanent compression is present (i.e., matted down.) However, loose-fill insulations that are repeatedly saturated will lose much of their R-value. Mold and mildew growth also can develop under extensive conditions.

Insulation blown into ceiling cavities should cover the top plate of the wall, but be sure the eave vents are not covered. These vents provide necessary ventilation to the attic, and covering them could result in severe moisture problems.

Voids and gaps

Voids or gaps will occur if the insulation is installed at too low a density or the cavity is not completely filled. Voids are most likely to occur at the top of wall cavities, above windows, around doorways, and in the corners of ceiling cavities. Voids also occur if the installation holes are improperly located between the vertical framing studs or if there are too few fill holes. It also may be difficult to achieve the recommended R-values with loose-fill insulation in the eave area of an attic.

Fluffing

Fluffing occurs when insulation is installed to a minimum thickness but not to the minimum weight requirements. The result is a less dense application of insulation that requires fewer bags. When insulation is fluffed, air passes more easily through it, leading to increased heat loss. Additionally, the fluffed loose-fill insulation eventually may settle and result in a thinner layer with a lower overall R-value.[2] Fiberglass is typically more problematic with fluffing than cellulose or rock wool. The best way to verify if fluffing has occurred, either accidentally or by dishonest contractors, is to count the number of bags used during installation and compare it to the instructions and coverage charts on the bag. The manufacturer should specify the amount of insulation per square foot (or square meter) of space needed to obtain the required R-value.

Safety guidelines

Pipes for kitchen stoves, wood stoves, and furnaces should only be insulated with fiberglass or rock wool because cellulose may smolder if flue temperatures become hot enough. Similarly, electrical devices and recessed lights, except those which are rated for direct contact with insulation, require a minimum of 3" of clearance from insulation.[2]

Health considerations

While the debate continues as to the health effects of loose-fill insulations, it is important to be protected during any type of insulation installation. A National Institute of Occupational Safety and Health (NIOSH)–approved respirator and protective eyewear and clothing such as goggles, gloves, long-sleeved shirts, and pants will minimize contact with the insulation. The home's ductwork should be sealed properly, as well as any other openings where insulation could leak out of the wall or ceiling cavities and into the living space. Insulation fibers also can be drawn into air-distribution systems if the ducts are not sealed properly, allowing the fibers to circulate within the living space.

Cellulose Loose-Fill Insulation

The term *cellulose* refers to the base fiber for all plant life. Wood, paper, and other plant-based products all are cellulosic materials. Cellulose loose-fill insulation is produced from recovered wood pulp materials. These include used newsprint and boxes that have been shredded and pulverized into small fibrous particles and subsequently treated with boron-based chemicals to make the material fire retardant. Dry loose-fill cellulose insulation is installed in attics and walls with pneumatic blowing machines, whereas existing walls may be insulated by blowing insulation in through access holes (Fig. 7.3).

Figure 7.3 Cellulose installation by pneumatic equipment. (*Greenstone*)

Originally manufactured as a sound deadener, cellulose soon caught on as an effective, dense insulation material. Early cellulose insulation remained a small portion of the market as fiberglass became increasingly popular after World War II. When the energy crisis arose in the 1970s, the demand for better insulation grew, and a resurgence of interest in cellulose insulation soon followed. The cellulose industry expanded rapidly, but the increased demand allowed a number of inferior manufacturers to enter the competition. Once the energy crisis subsided, the cellulose industry experienced a shakeout and again settled into a relatively small share of the insulation market. The 1980s saw relatively few changes in the products or the ranks of major cellulose insulation producers. Consequently, the number of active cellulose producers reduced in number from 200 companies in 1983 to 61 companies in 1991.[3]

According to the Cellulose Insulation Manufacturers Association (CIMA), an advocacy organization for the cellulose insulation industry, cellulose commands about 10 percent of the insulation market. Cellulose dominates the manufactured homes market (at least 60 percent) and enjoys a healthy share of the retrofit industry.

Another form of cellulose insulation, spray-applied in wet or damp form, is covered in Chap. 9. As a self-supporting material, it relies on water, adhesive, or a combination of both to build bond strength to a substrate and within itself. Spray-on products also may be used in wall cavities (fully open and dried before covering) or on other suitable exposed wall or overhead surfaces.

Standards

Cellulose insulation has been exposed to a broad range of construction, environmental, and various code requirements that have called for a more elaborate definition of physical properties. These requirements have been identified and met in the following federal regulations, federal procurement specifications, and industry standards[4]:

16 CFR Part 1209 (The CPSC Safety Standard). This is the Consumer Products Safety Commission (CPSC) safety standard that covers four product attributes: settled density, corrosiveness, critical radiant flux (a measure of surface burning), and smoldering combustion. It is illegal to market cellulose insulation that does not conform with this section of the *Code of Federal Regulations.*

16 CFR Part 460 (The FTC R-Value Rule)

ASTM C-739 [Standard Specification for Cellulosic Fiber (Wood-Base) Loose-Fill Thermal insulation]. This is the industry standard for loose-fill cellulose insulation. It covers all the factors of the CPSC regulation and five additional characteristics: R-value, starch content, moisture absorption, odor, and resistance to fungus growth.

ASTM C-1149 (Standard Specification for Self-Supported Spray Applied Cellulosic Thermal/Acoustical Insulation)

HH-I-515E (The General Services Administration Purchasing Specification for Loose-Fill Cellulose Insulation; requires ASTM C-739 conformance)

The states of California and Minnesota have their own insulation regulations that are based on the American Society for Testing and Materials (ASTM) standards and, in the case of cellulose insulation, on the CPSC standard. Of course, the insulation requirements of all pertinent building codes also apply to the installation of cellulose. Building codes are required by the Consumer Products Safety Act to follow the CPSC standard. Thus cellulose insulation conforming with the federal standard is approved for installation in any code jurisdiction.[4]

Loose-fill cellulose insulation, like all loose-fill insulation, should be installed in accordance with ASTM Standard C-1015, "Standard Practice for Installation of Cellulosic and Mineral Fiber Loose-Fill Thermal Insulation."

Product description

Cellulose is a relatively low-cost insulation product, is easy to install, and is not subject to convective heat loss. Studies show that cellulose (as well as rock wool) is more resistant to airflow than fiberglass because it has greater density. Cellulose (as well as rock wool) also may be more effective at reducing air leakage and associated heat loss because its higher density causes it to settle and seal more around rafters and in corners.[2]

Cellulose loose-fill insulation settles more than rock wool or fiberglass loose-fill insulation. The proportions are about 20 percent for cellulose, 2 percent for rock wool, and 4 percent fiberglass. Therefore, install about 20 percent more blown-in cellulose insulation to offset this settling. Cellulose manufacturers are required by federal law to state "settled thickness" on their bags. Because this can be confusing to consumers, many cellulose producers also specify the "installed thickness."[2]

Blow-in methods are also referred to as *dense-packing*. Dense-pack cellulose is installed at densities of at least 3.5 lb/ft^2 and up to approximately 4.0 lb/ft^2. The insulation flows from a high-velocity insulation blower at 100 ft/s. The air that is trapped between the cellulose fibers contributes to the insulating value, approximately R-3.8 per inch. Technique is important in work with a higher-density installation. The hose has a tendency to become clogged if the installer is inexperienced.

New cellulose insulation technologies are increasing the use of lower-density cellulose produced by "fiberizing" newspaper. Fiberizing breaks the raw material down into individual fibers that are fluffier. This modification means that the product is cleaner, creates less dust, and has a slightly higher R-value.

R-value

The typical R-value of cellulose insulation is between 3.6 and 3.8 per inch. For example, an attic with 10 in of dry cellulose could provide an R-value of 38. A typical manufacturer's coverage chart is shown in Fig. 7.4.

Limitations

Moisture absorption, ranging from 5 to 20 percent of its weight, is one disadvantage of cellulose insulation. This also may alter its physical and chemical properties, as well as settle, if the insulation is not applied at the correct density. Other concerns with loose-fill fiber insulation are displacement as a result of wind and infestations of rodents. It is also possible that, over many decades, dust and dirt accumulation could reduce the R-value, either by compressing the insulation or by filling air pockets.

Weight considerations

Loose-fill cellulose could cause the ceiling to sag if installed at R-38 on $^1/_2$" ceiling gypsum wallboard with framing spaced 24" on center. Therefore, when deciding whether to use these materials for new construction, consider switching to $^5/_8$" ceiling gypsum wallboard or, if possible, changing your ceiling framing widths to 16" on center.

Health considerations

Cellulose fiber is characterized as a nuisance dust but is not a health hazard. The fire retardants used in cellulose insulation are

30 lb. bag

PNEUMATIC APPLICATION COVERAGE CHART							
R-Value at 75°F Mean Temperature	Minimum Thickness		Net Coverage No Adjustment for Trusses			Gross Coverage Based on 2 x 6 Trusses on 16 Centers	
			Maximum Net Coverage		Minimum Weight Per Square Foot		
To Obtain an Insulation Resistance (R) of	Installed Insulation Should Not Be Less Than (inches)	Thickness After Settling (inches)	Square Feet Per Bag	Minimum Bags Required Per 1,000 Square Feet	The Weight Per Square Foot of Installed Insulation Should Not Be Less Than (lbs.)	Square Feet Per Bag	Bags Required Per 1,000 Square Feet
R-50	15.0	13.5	16.7	60.1	1.802	17.3	57.8
R-42	12.6	11.4	19.8	50.5	1.514	20.8	48.2
R-40	12.0	10.8	20.8	48.0	1.441	21.9	45.8
R-38	11.4	10.3	21.9	45.6	1.369	23.1	43.4
R-32	9.6	8.6	26.0	38.4	1.153	27.7	36.1
R-30	9.0	8.1	27.8	36.0	1.081	29.6	33.7
R-24	7.2	6.5	34.7	28.8	.865	37.7	26.5
R-22	6.6	5.9	37.8	26.4	.793	41.4	24.1
R-19	5.7	5.1	43.8	22.8	.685	48.3	20.7
R-13	3.9	3.5	64.0	15.6	.468	70.7	14.2
R-11	3.3	3.0	75.7	13.2	.396	83.5	12.0
Sidewalls (pressure filled-density 2.6 PPCF)							
R-13 (2 x 4)	3.5	3.5	39.6	25.3	0.758	43.7	22.9
R-20 (2 x 6)	5.5	5.5	25.2	39.7	1.192	27.8	36.0

Figure 7.4 Typical manufacturer's coverage chart. (*Greenstone*)

also regarded as nonhazardous. For example, the toxicity of boric acid is one-sixth that of table salt. Nevertheless, respiratory protection should be worn while handling and installing the insulation material.

Environmental considerations

Cellulose is an excellent example of recycled material use in insulation. Insulating a typical 1500-ft^2 ranch-style home with cellulose insulation productively recycles as much newsprint as an individual will consume in 40 years.[5] Most cellulose insulation is approximately 80 percent postconsumer recycled newspaper by weight. The remaining 20 percent is comprised of fire-retardant chemicals and/or acrylic binders depending on the product. In 1994 alone, the cellulose industry used approximately 840 lb of recycled newspaper. Experts suggest that if all new homes constructed in the United States were insulated with cellulose, over 3.2 million tons of waste newsprint would be used each year.[5]

According to CIMA, cellulose has a very low comparative embodied energy, calculated to be 20 to 40 times less than mineral fiber insulations. (*Embodied energy* is the total energy, such as the fuels, electric power, transportation, and job-site related power, used to extract, fabricate, package, transport, install, and commission a building product, material or system.)

Fire resistance

Ever since cellulose insulation was first marketed in the late 1940s, sellers of competing products have raised questions about the safety of the material. Cellulose insulation, as an organic material, will burn without special processing. Unlike two competing insulation materials, fiberglass and rock wool, which are naturally fire resistant, cellulose's fire resistance is achieved by adding chemicals.

According to Dan Lea, executive director of CIMA, the common fire retardants in cellulose insulation are borax, boric acid, and ammonium sulfate. Public concerns may be due more to misinformation than fact. For example, boric acid is commonly used as an eyewash. The salts of borax are used in laundry products but have a toxicity level even lower than that of boric acid. Ammonium sulfate is used as a food preservative and a soil fertilizer.

The CPSC does not believe cellulose insulation is a hazardous product. Fire statistics do not support the hazard claim, and knowledgeable fire officials who have studied the matter agree. Extensive evidence indicates that cellulose is a positive factor in residential building fire safety, mainly due to the material characteristics of cellulose. Once the surface of a cellulose insulation layer is charred, it no longer flames, and the charred material actually becomes a barrier against rapid combustion deeper in the insulation. Smoldering combustion may continue, but its progress through the insulation will be very slow due to the dense fiber structure of cellulose and its fire-retardant characteristics.[6]

The most recent findings were released in test results made available in February 2000. Independent laboratory tests, commissioned by CIMA and conducted according to the ASTM E119 protocol by Omega Point Laboratories of Elmendorf, Texas, have shown that cellulose insulation can increase the fire resistance of walls by up to 77 percent compared with uninsulated walls. Cellulose can now be used in a 1-hour fire-wall assembly that meets the new *International Building Code* and *International Residential Code*. Walls for the test were constructed with both $^{1}/_{2}$" and $^{5}/_{8}$" type X gypsum wallboard. The insulation was standard off-the-shelf cellulose installed by a local contractor.[7] This is an increase in fire resistance as compared with earlier tests sponsored by the cellulose industry and the mineral fiber insulation industry. These stated that cellulose produced a 22 to 55 percent increase in fire resistance.[6]

The biggest long-term performance concern with cellulose insulation is the possible loss of fire-retardant chemicals. There are other reports that claim cellulose insulation may be safe initially but that over time the fire retardants bake out, leech out, settle out, break down, sublime, evaporate, or somehow disappear. Because borates are water soluble, they can leach out if the insulation gets wet. Some people claim that the chemicals gradually disappear even if the material does not get wet, although these claims have not been substantiated independently. According to Dan Lea of CIMA, there is a shift within the industry toward ammonium sulfate fire retardants, which actually improve in fire-retardant performance over time. A concern with ammonium sulfate, however, is the corrosion of metals in contact with the insulation, particularly with wet-spray applications.

According to CIMA, the Forest Products Laboratory of the University of California at Berkeley performed an extensive literature search and reviewed all relevant published studies on cellulose insulation chemical permanency. The study concluded that "the only substantive report that indicated an aging effect is that recently reported by the California Bureau of Home Furnishings and Thermal Insulation." CBHF said of its study: "The results are inconclusive and variable, and certainly cannot be used to condemn this material." Numerous other studies, including tests by scientists and technicians at Oak Ridge National Laboratory, Tennessee Technological University, Allied Signal Corp., U.S. Borax Corp., Underwriters Laboratories, and the United States Testing Company, found no sign of "disappearing fire retardants."[6]

The competitive nature of the insulation business has generated a great amount of literature in support of, or in defense of, the material characteristics and performance of each product. Since an independent test is not within the scope of this book, one must weigh all the information in order to arrive at a general consensus as to the actual fire-resistance characteristics of cellulose insulation.

For example, the North American Insulation Manufacturers Association (NAIMA) claimed in one report that "independent tests confirm [the] potential fire hazards of cellulose insulation." In defense of cellulose insulation, CIMA states that "all six cellulose products tested exceeded the requirements of the only material standard that references the test method used in the study." According to CIMA, the NAIMA tests "actually proved the safety of cellulose insulation."[6]

Even when a fire is classified as "insulation related," the insulation is seldom the first material to ignite. Heat-producing devices and electrical short circuits were major factors in insulated-related fires. In the vast majority of cases, a heat-producing device, such as a recessed lighting fixture, is covered by the insulation. Heat builds up and is conducted through wiring or metal brackets to a wood structural member. This indicates that it is usually the wood or electrical insulation that ignites first.

Installation standards and practices

Dry loose-fill cellulose insulation is typically installed in attics and walls with pneumatic blowing machines (although in some attics the insulation can be poured in place). Even though installation methods may vary slightly depending on the material, the machine used, or the actual job-site conditions, the CIMA standard guidelines will provide a general framework in order to better understand installation procedures. The following specifications are for general information only.[8] These guidelines cover the application of cellulosic loose-fill thermal insulation in attics, sidewall cavities, and between floors of single- and multifamily dwellings by means of pneumatic equipment and by pouring in place in attics (see Fig. 7.1).

Preliminary inspection

An inspection of the building should be made prior to installation, with special consideration given to the following areas:

1. Holes in ceilings or sidewalls that would allow the insulation to escape should be sealed.
2. Weak areas of interior walls that may not be able to withstand pressures during the filling operation should be reinforced or filled using less pressure.
3. Walls with alterations, such as built-in bookshelves and cabinets, that may create isolated cavities require special entry holes.

4. Wall cavities that are used as air ducts for heating or air-conditioning systems must not be filled with insulation.
5. Openings in heating or air-conditioning systems in insulated areas must have blocking placed around them but not so as to restrict airflow.
6. Wall cavities that open into basements or crawl spaces must be sealed.
7. The external siding of existing buildings should be inspected for paint peeling or other evidence of moisture problems because insulation or a vapor barrier alone may not solve such problems. Other remedial actions may be necessary.

Preparation

For new construction, several key areas need to be addressed. First of all, if individual vents are used in the soffit, the rafter space immediately in front of and on either side of the vent should be provided with an air chute (Figs. 7.5 and 7.6). Other spaces should be totally blocked. Where a continuous strip vent is used in a soffit, an air chute should be provided every third rafter space, with the other spaces completely blocked. The small cavities around door and window frames should be insulated prior to installation of the interior covering. The material should not be forced into the cavity so tightly that frames or finishes are distorted. Finally, insulating the corners of attics in buildings with hip roofs may require special nozzles or placement tools. Alternately, corners can be insulated with suitable insulation before the gypsum wallboard or plasterboard is installed. Any other areas that will be inaccessible after the interior finish is installed must be handled in like manner.[8]

For existing structures, preparation should be performed in critical areas where the insulation may not be contained. For example, in joist areas, where soffit vents are installed, the opening from the attic into the soffit area may be blocked by use of pieces of batt-type insulation between and at the ends of the joists. Insulation should not totally fill the space between ceiling and roof. There should be a 1-in opening next to the roof for ventilation from the soffit area (or a chute or baffle may be installed).

For new and existing structures, a number of areas typically will be addressed in a similar manner for each project type. These include

1. Blocking should be placed around access to the attic to prevent insulation from falling out.

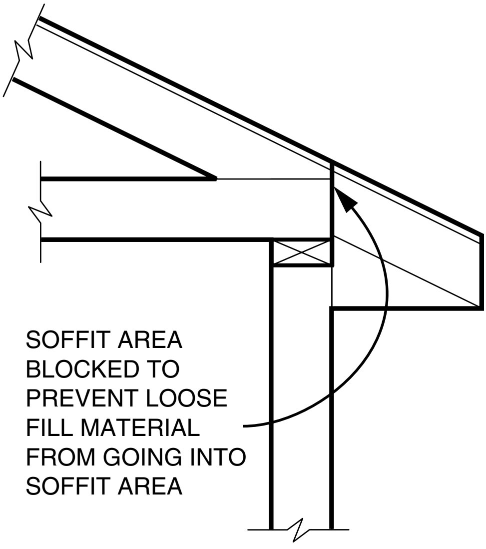

Figure 7.5 Blocked soffit. (*CIMA*)

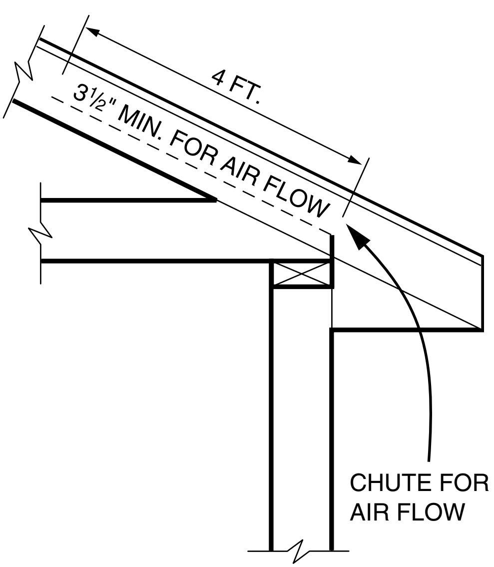

Figure 7.6 Roof venting. (*CIMA*)

2. Blocking should be placed around recessed light or heating fixtures, chimneys, and flues. Clearance between heat-producing elements and combustible construction should follow applicable codes. Blocking should be placed permanently so as to keep insulation a minimum of 3 in away from all sides of recessed lighting fixtures and other heat-producing devices. The open area above recessed lighting fixtures and other heat-producing devices should not be insulated, per the *National Electrical Code*.
3. Cabinet bulkheads, stairway wells, and wall cavities that open into an attic should be covered by backer board to support the insulation.
4. The open side of any wall between a heated and unheated area should be covered by backer board to form a cavity for retaining the loose-fill material.

Coverage requirements

When installing insulation, care should be taken not to exceed the square-foot coverage shown on the label. (ASTM C739 requires that each bag of cellulose loose-fill insulation be labeled with technical information, including the maximum net coverage per bag of the particular insulation for all commonly specified R-values.) The labeled thickness is the minimum thickness required for a given R-value. The initial installed thickness in ceiling applications will exceed the settled thickness shown on the coverage chart. The bag count and weight-per-square-foot requirements of the coverage chart must be followed to provide the specified R-value at settled density.

Application procedures

Ceiling areas. When installing insulation by pneumatic means in accessible ceilings, it is important that the blowing machine be set as recommended by the machine manufacturer. Specifiers do not need to compensate for settling in attics because federal law (the CPSC standard and the FTC R-Value Rule) requires R-value and coverage data to be stated at settled density. Specifiers, installers, and buyers need to understand that the "minimum thickness" column on cellulose coverage charts represents settled thickness if the chart has only one thickness column. The "bag count" and "weight" columns are the "official" coverage statements.[4]

Installations in enclosed ceiling cavities must be made by pneumatic means, and the cavity should be filled completely. This is done by inserting a fill tube into each cavity and withdrawing it as the cavity is filled. The air setting on the machine should be set as recommended by the machine manufacturer for sidewall application. Coverage will be proportional to that shown on the manufacturer's coverage chart under sidewalls, depending on the cavity size.[8]

Sidewalls in existing buildings. Installation into sidewall cavities must be made by pneumatic means. The air setting on the machine should be set as recommended by the machine manufacturer according to the size nozzle being used. After fill holes are drilled, all cavities should be checked for fire blocking or other obstructions with an electrician's fish tape or other similar tool. A mathematical check should be made in the first few stud spaces to ensure that the proper amount of insulation is being installed. Installers also should verify with the manufacturer's coverage chart.[8]

In wall applications, standard practice is to compact loose-fill cellulose to a density that will prevent settling. While this is a matter of some controversy, most authorities recommend a density of at least 3.0 lb/ft^3 for cellulose insulation in walls. Materials with high nominal settled densities (2.0 lb/ft^3 and higher) should be installed at 3.5 lb/ft^3. Research has confirmed that settling is virtually nil with any cellulose insulation at densities of 3.5 lb/ft^3 or higher. Compacting cellulose insulation may produce a very slight reduction in R-value.[4]

If filling the wall cavity through the external siding in an existing building, the following procedure is recommended by CIMA. First, drill holes from $^5/_8$ to 2" in diameter, depending on the siding, in each wall cavity. The vertical distance between the access holes and the top or bottom plate should not exceed 2 ft; the vertical distance between the holes should not exceed 5 ft. Homes with shingle or lapped siding should have the holes drilled as near the shadow line as possible. Homes with brick veneer should have holes $^5/_8$ to $^3/_4$" in diameter drilled in the mortar joints. All holes should be filled with suitable plugs[8] (Fig. 7.7).

Filling the wall cavity with a fill tube in some applications is desirable. When using this method, only one entry hole per cavity is necessary. The fill tube should be inserted far enough to reach within 18" (45.72 cm) of the plate farthest from the point of entry. Fill-tube size will depend on the size of hole that can be drilled (see Figs. 7.8 and 7.9 for alternate points of entry for the fill tube).

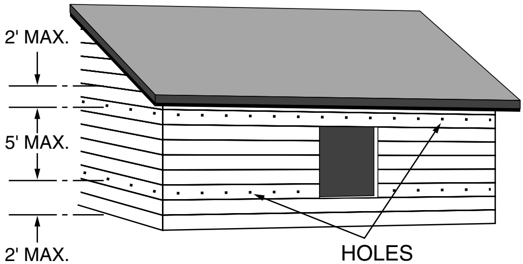

Figure 7.7 Installation holes. (*CIMA)*

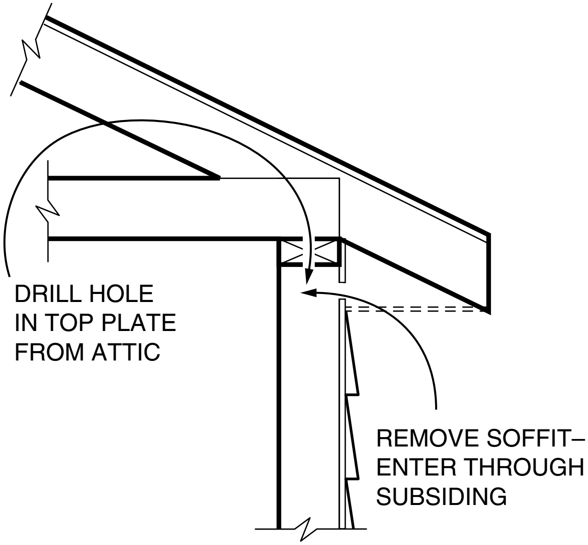

Figure 7.8 Soffit access. (*CIMA*)

Sidewalls in new buildings. Various types of permanent retainer systems are used to install dry cellulose insulation in new walls. All systems are proprietary, and the manufacturers provide detailed instructions and often special training programs for their use. All systems require pneumatic installation and compression of the material to sufficient density to prevent settlement. The Insulation Contractors Association of America (ICAA) recommends a density of 1.5 times nominal settled density for sidewall installations. Some manufacturers recommend an installed density of at least 3.5 lb/ft^3 in sidewalls.

Dry cellulose insulation can be installed in new walls using temporary retainers that are clamped in place to create a closed cavity.

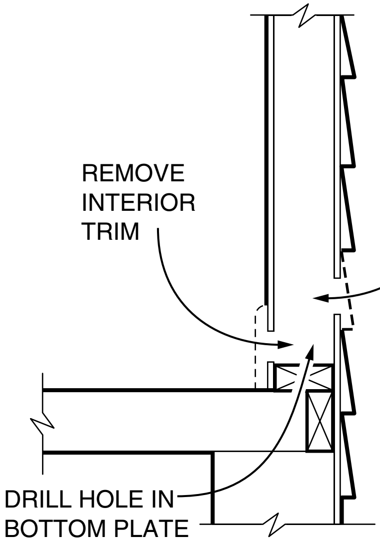

Figure 7.9 Wall access. (*CIMA*)

Insulation is blown into the temporary cavity at sufficient density to keep it in place when the retainer is removed.

One manufacturer of a proprietary product uses a polyester tire chord vapor retarder as the retainer during installation. Convenient access to the cavity is advantageous and allows visual inspection of the process during installation. The ParPac system uses any loose-fill cellulose insulation and is installed at a density of 3 lb/ft^3, resulting in an R-value of 3.61 per inch (Figs. 7.10 and 7.11).

Vapor retarders. As discussed in Chap. 4, the need for vapor retarders and their proper location within a wall assembly are influenced by the interior and exterior environmental conditions as well as the wall's thermal and vapor flow characteristics. It is important to note that each building is fairly unique in terms of wall construction, interior use, and environmental conditions, and should be evaluated individually by the building designer. The homeowner also could consult an insulation manufacturer and building code official for recommendations on where to place a vapor retarder.

When installing loose-fill insulations, a material such as 6-mil (0.006") polyethylene plastic sheeting can be used as a vapor retarder. Some cellulose manufacturers recommend against use of vapor retarders in walls insulated with spray-applied cellulose.

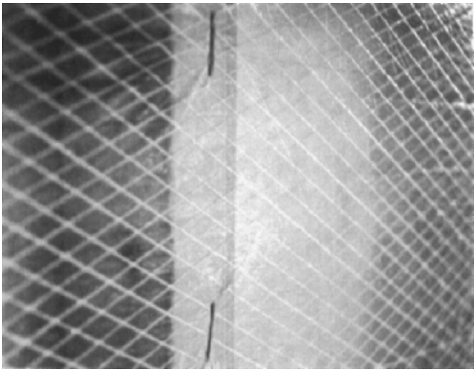

Figure 7.10 Polyester tire chord vapor retarder. (*ParPac, Inc.*)

Figure 7.11 Installation through vapor retarder. (*ParPac, Inc.*)

CIMA is not aware of any endemic problems resulting from this practice.

A vapor retarder is typically not required under attic insulation when the attic is adequately ventilated, but a vapor retarder must be used when the cold side of ceilings cannot be ventilated. A ground-surface vapor retarder such as plastic film is recommended when there is a crawl space beneath a floor.

In existing construction, most cellulose producers regard vapor retarders as unnecessary with dense-pack cellulose under most conditions. If design temperatures are below −15°F (−26°C), the interior surfaces of exterior walls and ceilings where the cold side cannot be ventilated can be painted with a vapor barrier paint. As with new construction, a ground-surface vapor retarder, such as plastic film, is recommended when there is a crawl space beneath a floor.

Ventilation. Ventilation guidelines are specified in the locally adopted building codes. The more stringent requirement should be used if the following CIMA guidelines contradict with the building code. In vented attics without vapor retarders, standard practice is to provide 1 ft^2 of net vent area for each 150 ft^2 of ceiling area. In vented attics with vapor retarders, standard practice is to provide 1 ft^2 of net vent area for each 300 ft^2 of attic floor area. When using a combination of roof and eave vents and no ceiling vapor barrier, there should be 1 ft^2 of net vent area for each 300 ft^2 of ceiling area. Vents should be installed with 50 percent of the total area in the eaves and 50 percent of the total area in the roof near the peak. If the residence is built over an unheated crawl space, there should be 1 ft^2 of net vent area for each 150 ft^2 of floor area.

Installation precautions and limitations

As stated earlier, the following items may be in concert with or in contradiction with the adopted state and federal building codes. The building codes are a minimum level of safety and quality and must be adhered to.

1. Heaters and recessed light fixtures must not be covered by the insulation unless the fixture has a direct contact rating. It is recommended that a minimum of 3" of airspace be maintained between any fixtures and the blocking.
2. Cold air returns and combustion air intakes for hot air furnaces must not be blocked or insulation be installed in a manner that would allow it to be drawn into the system.
3. Insulation must not be in contact with chimneys or flues. A minimum of 3" of airspace must be maintained, with blocking used to retain the insulation.
4. The homeowner should be advised that in tightly constructed homes or when insulating existing homes that have fuel-fired heating systems within the living area or basement, an air duct must be installed between the furnace room and a well-ventilated outside area to provide combustion air. A local heating contractor should be contacted for proper duct size and installation.
5. The homeowner should be advised that the relative humidity within the living area should be kept below 40 percent when outside temperatures fall below 32°F (0°C).

6. Dry cellulose insulation is not recommended for use in sidewalls below grade.
7. Dry cellulose insulation is not recommended for filling the cavities of masonry walls.
8. Dry cellulose insulation is to be used in the temperature range of −50 to 180°F (−45.6 to 82.2°C).
9. The installer must wear appropriate respiratory protective equipment.
10. Installers and specifiers are advised to refer to other relevant documents, including the *National Electrical Code,* ASTM Standard C1015, CIMA Technical Bulletin 1, and CIMA Technical Bulletin 3 for additional information.

Fiberglass

Fiberglass is one of a group of glassy, noncrystalline materials historically referred to as man-made mineral fibers (MMMFs) or man-made vitreous fibers (MMVFs). Glass fibers are made from molten sand, glass, or other inorganic materials under highly controlled conditions. The glass typically is melted in high-temperature gas or electric furnaces. The material is then spun or blown into fibers that are then processed into the final product.

Most major manufacturers use 20 to 30 percent recycled glass content. Rock wool (or slag wool) loose-fill insulation is similar to fiberglass except that it is spun from blast furnace slag (the scum that forms on the surface of molten metal) and other rocklike materials instead of molten glass.

Fiberglass loose-fill insulation is available in two forms: processed either from a by-product of manufacturing batts or rolls or from “prime” fibers produced especially for blowing applications. Both must be applied through pneumatic means using a mechanical blowing machine, whether it be “open blow” applications such as attic spaces or closed-cavity applications such as those found inside walls or covered attic floors.

Product description

Fiberglass loose-fill insulation is inorganic and noncombustible. The fibers will not rot or absorb moisture and do not support the growth of mildew, mold, or fungus. Fiberglass absorbs about 1 percent of its weight, but any insulation can absorb moisture if exposed to extremely high humidity. The moisture vapor absorption of fiberglass loose-fill insulation shall not be more than 5 percent by weight when tested in accordance with ASTM C1104. It is also not subject to drastic settling, usually about 1 or 2 percent in attic spaces up to a maximum of 4 percent.[2]

R-value

The R-value of loose-fill fiberglass, when settled naturally as in an attic at 0.7 lb/ft^3, is 2.2 per inch. When installed at a density of 2.0 lb/ft^3 in a wall, the R-value is 4.0 per inch. One of the most significant criteria for achieving the desired R-value is meeting the designated minimum weight per square foot of material. It is also important that the minimum thickness be achieved, since this, along with the required weight per square foot of material, is essential to obtain the desired R-value. As mentioned earlier, the correct values for coverage with each loose-fill material are stated by the manufacturer in a bag label specifications chart.

Fiberglass blown insulation can be purchased installed for about 7 cents per inch-thick square foot. Except for blown cellulose insulation, which costs about the same, fiberglass in blown (or batt) form is the cheapest insulation on the market for the insulating value achieved.[9]

Limitations

Laboratory attic tests have shown that light-density loose-fill products may suffer a reduction as attic temperatures drop further. For example, the actual R-value of loose-fill fiberglass insulation has been shown to decrease by 20 to 40 percent under extreme winter conditions. Oak Ridge National Laboratory measured R-values as low as R-12 at an attic temperature of 9°F for an R-19 fiberglass installation. Follow-up testing at the same laboratory seems to suggest that convection currents actually resulted in an increase of only $20 in energy cost (gas heating bills) per annum. Electric resistance heat costs were slightly higher.[10]

Health considerations

A contentious point of debate continues to revolve around the health concerns of fiberglass insulation. Health and safety research on fiberglass has been ongoing for nearly 60 years. Member companies with NAIMA, the trade association of North American manufacturers of fiberglass, rock wool, and slag wool insulation products, have committed tens of millions of dollars in research projects with leading independent laboratories and universities in the United States and abroad. Recent studies have presented results that suggest that the carcinogenic concerns about fiberglass may only have an impact under extreme exposure conditions. An Occupational Safety and Health administration (OSHA) report in 1994 stated that fiberglass insulation is carcinogenic, but results indicated that there was virtually no risk to home occupants. The greatest risk was the exposure to installers during installation.[11]

In 1997, the American Conference of Governmental Industrial Hygienists (ACGIH), representing over 1600 academic and government professionals engaged in occupational safety and health programs, concluded that the "available evidence suggests that [fiberglass]…is not likely to cause cancer in humans except under uncommon or unlikely routes or levels of exposures." The ACGIH designated fiberglass as an "A3, animal carcinogen." The A3 designation indicates that the substance may cause cancer in experimental animals at relatively high doses and by routes of exposure that "are not considered relevant" to workers.[12]

The Canadian government classified fiberglass as "unlikely to be carcinogenic to humans" and concluded that glass wool "is not entering the environment in quantities or under conditions that may constitute a danger in Canada to human life or health." The CPSC (1992) also has found that "fibrous glass is carcinogenic in animals only when surgically implanted into the lung or abdomen. In tests where animals were exposed by inhalation, the expected route of human exposure, the animals did not develop tumors. Therefore, the animal implantation studies do not establish a hazard to humans."[13]

Nevertheless, fiberglass as a simple irritant is well documented. Workers in fiberglass manufacturing plants, as well as people working with or using materials that contain fiberglass, may develop a skin irritation. This mechanical irritation is a physical reaction of the skin to the ends of fibers that have rubbed against or become embedded in the skin's outer layer. Any skin irritation caused by fiberglass is temporary. Washing the exposed skin gently with warm water and mild soap can relieve it. The vast majority of workers and consumers, however, can control skin irritation by following recommended work practices when handling the material. Fiberglass is also a catalyst for eye irritation if deposited in the eye by the user's fingers or through fibers in the air. If this should happen, the eyes should not be rubbed but rinsed thoroughly with warm water, and a doctor should be consulted if irritation persists.[12]

Fiberglass released into the air during its manufacture or handling also may create temporary upper respiratory irritation. Like skin irritation, upper respiratory irritation is a mechanical reaction to the fibers. It is not an allergic reaction, and the irritation generally does not persist. Such exposures to high concentrations of airborne fiberglass may result in temporary coughing or wheezing. These effects will subside after the worker is removed from exposure.[12]

As will be discussed later in this chapter, proper clothing and handling and the use of approved respiratory protection can effectively control exposure to airborne fibers and therefore reduce the likelihood of skin or upper respiratory tract irritation.

Environmental considerations

NAIMA tracks the fiberglass industry's recycling efforts through an annual survey of its members. A total of 6,107,397,000 lb of pre- and postconsumer glass waste have been recycled during the production of fiberglass insulation over the past 6 years. Much of present-day fiberglass insulation contains upwards of 40 percent recycled glass depending on the manufacturing facility.[14]

Fire resistance

Loose-fill fiber glass is naturally fire resistant.

Installation standards and practices

Fiberglass loose-fill insulation typically is installed in attics and walls with blowing machines, but most attics can be poured in place if necessary. Although installation methods may vary slightly depending on the material, the machine used, or the actual job-site conditions, the NAIMA standard guidelines will provide a general framework to better understand installation procedures.[15]

In order to estimate the amount of loose-fill fiberglass insulation to be installed, the area to be insulated is measured first. This should be the net area only, since the area occupied by framing members should be deducted from the total wall or attic space. From these calculations, the required number of bags or pounds of insulation is determined from the bag label chart for the desired R-value. (ASTM C764 requires that each bag of fiberglass loose-fill insulation be labeled with technical information, including the maximum net coverage per bag of the particular insulation for all commonly specified R-values.) Any deviation from the quantity specified will affect the desired R-value. This holds true in both open- and closed-blow installations.

According to NAIMA, thickness must not be used as the sole factor in determining the R-value of loose-fill insulation. When blown-in insulation is installed properly (at the recommended weight per square foot or bags per 1000 ft^2), it may have an "installed thickness which is greater than the stated minimum thickness." This is sometimes described as *overblow* in order to compensate for any potential insulation settlement. If the correct number of bags are installed and the thickness exceeds the minimum thickness, the labeled R-value will be achieved or exceeded.[16]

If these products were installed at the minimum thickness, the overblow would produce a coverage per bag that would exceed the maximum net coverage shown on the bag label, but the weight per square foot would be less and the R-value would be lower than the intended R-value. In any event, if the thickness installed using the correct number of bags is less than the stated minimum, then additional material must be added to bring the installed thickness up to the required minimum thickness.[16]

If an existing installed insulation amount needs to be verified, NAIMA provides a few recommendations. These involve taking measurements of the insulation thickness, removing and weighing a known area of insulation, and calculating the weight per square foot of the insulation. The measured weight per square foot and the installed thickness are then compared with the value shown on the manufacturer's label. Meeting or exceeding the labeled values ensures that the proper R-value has been achieved.[16]

Installers are required to provide a data sheet verifying the amount and achieved R-value installed. This is known as the *United States Federal Trade Commission's Labeling and Advertising of Home Insulation Rule,* and it mandates that the consumer is to receive a signed and dated contract or receipt for the insulation thickness installed. The receipt for loose-fill insulation must show the type of insulation, the coverage area, the thickness, the R-value, and the number of bags installed. The installer also must provide a manufacturer's fact sheet. The fact sheet for loose-fill insulation must contain, in addition to the manufacturer's name, address, and type of insulation, a chart containing the R-value and coverage information. Installers must have this information and must show it to customers before they agree to buy the insulation. Similarly, a seller of new homes must put the following information in every sales contract: the type, thickness, and R-value of the insulation that will be installed in each part of the house.[16]

General work practices applicable to all work involving synthetic vitreous fibers (SVF) such as fiberglass (rock wool and slag wool) have been established by OSHA. Excerpts of the guidelines are as follows[17]:

1. Minimize dust generation.
   - Keep the material in its packaging as long as practicable and if possible.
   - Tools that generate the least amount of dust should be used. If power tools are to be used, they should be equipped with appropriate dust-collection systems as necessary.
   - Keep work areas clean and free of scrap SVF material.
   - Do not use compressed air for cleanup unless there is no other effective method. If compressed air must be used, proper procedures and control measures must be implemented. Other workers in the immediate area must be removed or similarly protected.
   - Where repair or maintenance of equipment that is either insulated with SVF or covered with settled SVF dust is necessary, clean the equipment first with a HEPA vacuum or equivalent (where possible) or wipe the surface clean with a wet rag to remove excess dust and loose fibers. If compressed air must be used, proper procedures and control measures must be implemented. Other workers in the immediate area must be removed or similarly protected.
   - Avoid unnecessary handling of scrap materials by placing them in waste disposal containers and by keeping equipment as close to working areas as possible, which prevents release of fibers.

2. Ventilation
   - Unless other proper procedures and control measures have been implemented, dust collection systems should be used in manufacturing and fabrication settings where appropriate and feasible.
   - Exhausted air containing SVFs should be filtered prior to recirculation into interior workspaces.
   - If ventilation systems are used to capture SVFs, they should be checked and maintained regularly.

3. Wear appropriate clothing.
   - Loose-fitting, long-sleeved, and long-legged clothing is recommended to prevent irritation. A head cover is also recommended, especially when working with material overhead. Gloves are also recommended. Skin irritation cannot occur if there is no contact with the skin. Do not tape sleeves or pants at wrists or ankles.
   - Remove SVF dust from the work clothes before leaving work to reduce potential for skin irritation.

4. Wear appropriate personal protective equipment.
   - To minimize upper respiratory tract irritation, measures should be taken to control the exposure. Such measures will be dictated by the work environment and may include appropriate respiratory protective equipment. See OSHA's respiratory protection standard.
   - When appropriate, eye protection should be worn whenever SVF products are being handled.
   - Personal protective equipment should be fitted properly and worn when required.

5. Removal of fibers from the skin and eyes.
   - If fibers accumulate on the skin, do not rub or scratch. Never remove fibers from the skin by blowing with compressed air.
   - If fibers are seen penetrating the skin, they may be removed by applying and then removing adhesive tape so that the fibers adhere to the tape and are pulled out of the skin.
   - SVFs may be deposited in the eye. If this should happen, do not rub the eyes. Flush them with water or eyewash solution (if available). Consult a physician if the irritation persists.

Before starting, verify that the machine is set in accordance with the instructions on the bag. The machine settings were developed by manufacturers using machines in good working order and proper application techniques. Always keep the hose level, and install with a minimum of hand deflection. It is also important to always blow parallel with, and not across, the joists. To verify that proper amounts are being applied, it is wise to section the attic into quadrants and make sure one-quarter of the specified number of bags is used in each section to achieve the desired R-value.

Applying insulation in unfloored attics. NAIMA recommends that the installer keep the hose parallel to the floor, with the insulation falling

10 to 12 ft in front of the hose. It is best to back away from the work while blowing, to prevent packing. The installer can blow three or four joist spaces from one position by moving the hose to the right or to the left. Where working space is tight, the installer should prevent the insulation from packing by allowing it to blow off his or her hand.

Special construction conditions will require extra attention during installation. For example, the insulation is to be installed on both sides of obstructions such as solid cross-bracing, wiring, and masonry chimneys. If a batt or baffle is not used to block off the ends of joists, the insulation is to be applied to the outer edge of the plate. When roof construction does not allow full depth to the ends of the joists, the insulation can be "bounced" off the underside of the roof to increase density in that area, but be sure not to block the eave vents[15] (Fig. 7.12).

Clearance needs to be maintained around heat-producing devices, fossil-fuel appliances, and light fixtures, or as specified in the local building code. For example, the insulation is not to be placed in airspaces surrounding metal chimneys or fireplaces. Unfaced fiberglass insulation can be used between wood framing and masonry chimneys.

The installer should even out any high or low spots to verify that the minimum thickness has been achieved. Some areas will not be covered by design. Access panels, stair wells, and fan covers will need a piece of batt insulation on top of areas where loose-fill insulation has not been applied.

If the attic space is already floored, the installer should attempt to blow no more than 4 to 6 ft under flooring. This will require the

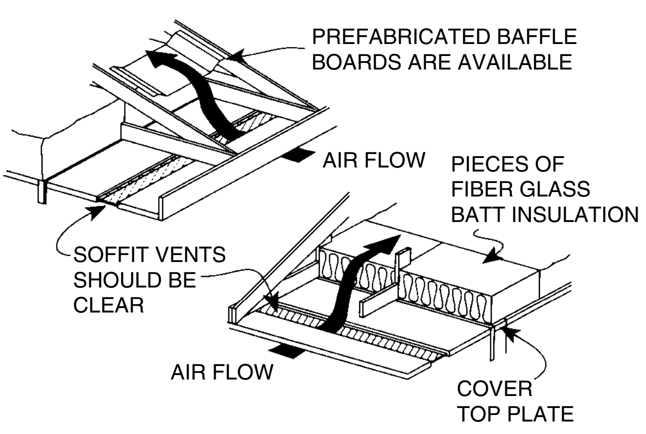

Figure 7.12 Air flow clearance. (*NAIMA*)

removal of floorboards (or plywood sheathing) approximately every 8 to 12 ft to guarantee adequate blowing coverage. When blowing below a floor, the installer should insert the hose approximately 4 to 6 ft under the floor and gradually pull it out as the space fills with insulation. Twist and turn the hose as it is removed to ensure complete coverage of the area under the floor. In finished attic knee walls and slopes, it is possible to use retainers and blow knee walls, but it is easier to use batts (Fig. 7.13).

Applying insulation in sidewalls. Regardless of the outside finish, all existing house sidewalls are insulated in a similar manner. [As opposed to the Blow-In Blanket System (BIBS), which is installed while the home is under construction. See Chap. 9.] The only variable is the method required to remove the exterior finish in order to access the stud cavity. There can be many variations of the procedures for the removal and replacement of different types of sidewall materials. Any method that gives sufficient access to the sidewall area can be used, but an experienced carpenter, framer, or mason should be used to guarantee that the existing exterior finish material will be returned to its original condition.

Generically speaking, the first step is to have isolated portions of the outside finish removed. Openings are then made in the sheath-

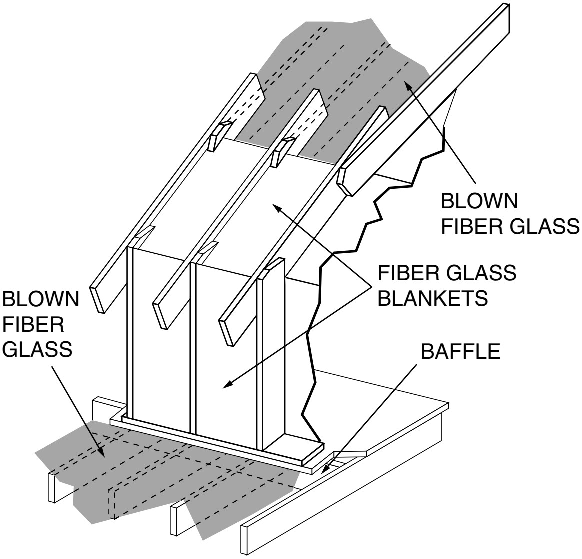

Figure 7.13 Attic knee walls and slopes. (*NAIMA*)

ing so that the loose-fill fiberglass can be blown into the empty stud spaces. The “double blow” method, with two openings (top and bottom), is commonly used for sidewalls. Different applicators have different methods of filling sidewalls, but it is generally recommended that the lower holes be filled first to ensure that the lower parts of stud cavities are filled. Some stud sections may require three or more openings because of construction features, such as firestops, blocking, junction boxes, electrical cables, and bracing (Fig. 7.14).

NAIMA’s guidelines state that openings should be made into the stud area for each 4 to 5 ft in wall height. Since blowing is limited to no more than 4 ft down or 12" up a space, this is the only way to ensure the stud space will be filled properly. Blowing through a single opening in an 8-ft wall could leave some of the stud space with voids or no insulation. One way to check the actual stud cavity depth is to drop a plumb bob into the wall. Areas above and below windows and below firestops and bracing also must be opened to determine the exact location of obstructions and ensure that the cavity is filled completely.[15]

Mineral Wool

The term *mineral wool* historically refers to two materials: rock wool and slag wool. (Fiberglass is also included in some references to mineral wool.) Rock and slag wool fall within a group of

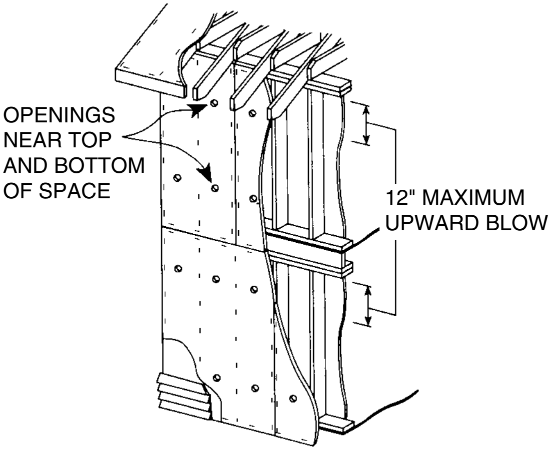

Figure 7.14 Application holes. (*NAIMA*)

materials historically referred to as man-made mineral fibers (MMMFs) or synthetic vitreous fibers (SVFs); however, a more appropriate name is man-made vitreous fibers (MMVFs), reflecting the glassy, noncrystalline nature of these materials.

The mineral wool form of MMVFs was developed initially in the late 1800s by melting slag and spinning it into insulation for use in homes and industry. Over the past century, mineral wool manufacturing has evolved into a large and diversified industry as more and more products have been developed.

Rock wool and slag wool each use different raw materials in their manufacture. Rock wool is made from natural minerals, made primarily from natural rock such as basalt or diabase. Slag wool is made primarily from iron ore blast furnace slag. Slag wool accounts for roughly 80 percent of the mineral wool industry, compared with 20 percent for rock wool, in the United States. These proportions are reversed in European countries.[18]

While mineral wool was at one time the most common type of insulation, its market share was lost largely to fiberglass in the 1960s and 1970s. In the past few years, however, the product appears to have been making a comeback. There are currently several manufacturers of mineral wool in the United States and about eight plants that produce it.[18]

Rock and slag wool insulations are produced by a centrifugal wheel process. Natural rocks or iron ore blast furnace slag are melted, and the hot, viscous material is spun into fiber by pouring a stream of molten material onto one or several rapidly spinning wheels. As droplets of the molten material are thrown from the wheel(s), fibers are generated. As the material fiberizes, its surface generally is coated with a binder and/or dedusting agent (e.g., mineral oil) to suppress dust and maintain shape. The fiber is then collected and formed into batts or blankets or baled for use in other products, such as acoustical ceiling tile and spray-applied fireproofing, insulating, and acoustical materials.[19]

Because of the manufacturing process and the differing performance characteristics of specific products, rock or slag wool insulation materials are comprised of a wide range of fibers with varying thicknesses or diameters. Typically, individual fibers range between 1 and 15 μm in diameter, with an average diameter of 3 to 7 μm. (A micron is 1/1,000,000 of a meter or 1/25,400 of an inch.) By comparison, a human hair is about 70 μm in diameter.[19]

When viewed under a microscope, rock and slag wool fibers resemble single rods. Because they are noncrystalline in nature, these fibers break across their long axis, resulting in shorter fibers of the same diameter. They do not split lengthwise into thinner, smaller-diameter fibers, as do many crystalline fibers such as asbestos, an important factor when considering potential exposures.

Product description

Similar to fiberglass in texture and appearance, mineral wool, an inorganic fiber, will not absorb moisture. Rock and slag wool fibers are dimensionally stable, have high tensile strength, and do not support combustion. There is no significant settling with rock and slag wool as long as it is installed properly. Mineral wool will not support the growth of mildew, mold, or bacteria when tested in accordance with the specifications of the ASTM (ASTM C665).

R-value

The blown material has an R-value of 2.7 per inch depending on the installed density. The poured material has the same characteristics as the blown material, but with a slightly higher R-value of 3 per inch. Small amounts of moisture have little effect on the material's R-value.

Limitations

Mineral wool (and to a lesser extent, fiberglass) tends to "hang up" on protrusions and nails in the wall cavity. It also can settle over time if not blown properly, so the manufacturer's recommendations should be followed.

Weight

Loose-fill rock wool, being a heavier material, can cause ceiling sag if installed at R-38 on $^1/_2$" ceiling gypsum wallboard with framing spaced 24" on center. Consider switching to $^5/_8$" ceiling gypsum wallboard or, if possible, changing the ceiling joist spacing to 16" on center.[2]

Health considerations

Health and safety research on rock and slag wool has been ongoing for more than 50 years. NAIMA member companies have helped fund three areas of research involving rock and slag wool. These include exposure assessments of current production workers and end users, analyses of the rates and causes of death of former production employees, and animal test studies. Airborne levels of respirable rock and slag wool fibers have been demonstrated to be very low, less than 1 fiber per cubic centimeter of air in most instances. Human epidemiologic studies have not demonstrated evidence of a dose-related causal association between lung cancer or nonmalignant respiratory disease and occupational exposure to rock and slag wool. Animal inhalation studies using massive doses of rock and slag wool fibers, hundreds to thousands of times greater than human exposures, have not shown a relationship between inhalation of rock and slag wool fibers and lung cancer either. Since 1987, several major reviews have been undertaken on the health and safety of rock and slag wool. All these reviews concluded that inhalation of rock and slag wool fibers does not induce significant disease in animals.[19]

Various other studies have not established a link between casual exposure to rock and slag wool and lung cancer either; however, limited evidence does demonstrate an association between exposure to rock wool and cancer in manufacturing workers.

The use of injection/implantation studies as the sole determinant of the carcinogenic hazard of a fibrous material is not generally accepted for human health hazard assessment. These studies, however, have not produced significant tumors, except for one injection test at an exceedingly high concentration.[20] However, the fact that rock wool fibers, when intentionally inserted into animals, have produced tumors may not be a practical analysis for casual exposure. Based primarily on these studies using nonphysiologic routes of exposure, the International Agency for Research on Cancer (IARC) considered the animal evidence as limited for rock wool and inadequate for slag wool and, following its own guidelines, has classified both rock and slag wool as a "2B, possibly carcinogenic to humans." For reference purposes, the IARC also has classified coffee, saccharin, gasoline engine exhaust, and more than 150 other common substances as "possibly carcinogenic to humans." In general, IARC rules dictate that this designation be given if there is sufficient evidence of carcinogenicity in animals, even if the route of exposure is artificial (nonphysiologic) and human data are inadequate or limited.[19]

Rock and slag wool fibers are a catalyst for skin irritation. This irritation is a mechanical reaction of the skin to the ends of rock and slag wool fibers that have rubbed against or become embedded in the skin's outer layer. Workers in contact with mineral wool during manufacturing processes or installation are susceptible to this temporary nuisance. It can be relieved by gently rinsing the exposed skin with warm water. Hot water and scrubbing will exacerbate the condition.

Eye irritation occurs when rock or slag wool are deposited in the eye by the user's fingers or through airborne fibers. If this occurs, the eyes should not be rubbed but rinsed thoroughly with warm water. A doctor should be consulted if the irritation persists.

If sufficient amounts of rock and slag wool are released into the air during manufacture or handling, some workers may experience temporary upper respiratory tract irritation. Such exposures to high concentrations of airborne rock and slag wool fibers may result in temporary coughing or wheezing, a mechanical reaction. These effects will subside after the worker is removed from exposure. The use of approved respiratory protection can effectively control upper respiratory tract irritation by limiting exposure to airborne fibers.

With publication of the OSHA hazard communication standard in 1983 and the IARC decision in 1987 to classify rock and slag wool as "possibly carcinogenic to humans," rock and slag wool manufacturers have added cancer warnings to their product labels. While this may appear alarming to an uninformed user of rock and slag wool products, the primary purpose of the labels is simply to identify a potential hazard. The labels do not signify that there is any real risk to humans at actual levels of exposure. The manufacturers of these products remain confident that the risk associated with the use of rock and slag wool products, if there is any risk at all, can be effectively controlled via reduction of workplace exposures and adherence to simple recommended work practices.[19]

Some of the mineral wool insulation manufactured before about 1970 has been found to contain lead particles. According to industry sources, lead slag is no longer used in the manufacture of mineral wool, although lead can be present as a trace impurity. OSHA has expressed concern in situations where new insulation is installed over pre-1970 mineral wool and lead particulates are released into the air. Exposures will vary markedly from job site to job site because of such factors as the size of the space, the method of application, and the amount of lead dust in the mineral wool. Exposures are likely to be highest when insulation is blown into place in a confined space.[21]

Environmental considerations

NAIMA tracks the slag wool industry's recycling efforts through an annual survey of its members. During the past 6 years, NAIMA's data show that 6,289,156,000 lb of blast furnace slag have been recycled during the production of slag wool insulation.[14]

Fire resistance

Rock and slag wool have good fire resistance due to the physical and chemical properties. The fibers are noncombustible and have melting temperatures in excess of 2000°F and supply fire protection, as well as sound control and attenuation.[14] Mineral wool is also a good material for insulating around chimneys because it does not support combustion.

Installation standards and practices

General work practices, applicable to all work involving synthetic vitreous fibers (SVFs) such as rock wool and slag wool, have been established by OSHA. These are listed in the loose-fill fiberglass section of this chapter.

Perlite

Perlite is a granular-type loose-fill insulation quarried mainly in the western United States. It is a naturally occurring silicous rock. Perlite is different from other volcanic glasses because when the crushed ore is heated to a suitable point in its softening range, it expands from 4 to 20 times its original volume. This expansion is attributed to the presence of water, between 2 and 6 percent, in the crude perlite rock. When the rock is quickly heated to above 1800°F, the material pops in a manner similar to popcorn as the trapped water vaporizes to form microscopic cells, or voids, in the heat-softened glass. After expansion, an air blast separates and grades the particles according to size. This expansion process accounts for the lightweight quality of expanded perlite. While the crude rock may range from transparent light gray to glossy black, the color of expanded perlite ranges from snowy white to grayish white.

Product description

Perlite is used widely as a loose-fill insulation in masonry construction. In this application, perlite is poured into the cavities of concrete block, where it completely fills all cores, crevices, mortar areas, and ear holes. A nominal R-value of 2.7 per inch typically is used for calculation purposes; however, a range of 2.5 to 4.0 has been achieved. Expanded perlite can be manufactured to weigh as little as 2 lb/ft^3, making it adaptable for numerous applications. In addition to providing thermal insulation, perlite is fire-resistant, has low water absorption, reduces noise transmission, and is resistant to rot, vermin, and termites. Perlite loose-fill insulation is packaged in bags and must be poured into place. It is not suitable for blow-in installation methods. It is best used for attics and is reasonably well suited for walls.

Vermiculite

Vermiculite is a mineral closely related to mica, primarily mined in Montana and South Carolina. Consisting of silica, magnesium dioxide, aluminum oxides, and other minerals, vermiculite expands when heated to form a lightweight material with insulating properties. There are two types of vermiculite: untreated and treated. The treated material is coated with asphalt to make it water-repellent for use in high-moisture areas. Untreated vermiculite absorbs water and, once wet, dries very slowly.

Product description

Aluminum magnesium silicate is constructed of approximately 1 million separate layers per inch, with a minute amount of water between each layer. Flakes of the mineral are placed in a furnace at 1800°F, which changes the water to steam, causing the vermiculite to expand to 15 times its original size. (The name originates from the vermicular, or wormlike, movement of the layers during expansion.) The expanded material is soft and pliable, silvery or gold in color, and contains less than 1 percent water by weight (Fig. 7.15).

Untreated vermiculite has an R-value of 2.3 per inch, compared with an R-value of 2.5 per inch for the treated material. Vermiculite is usually hand-installed, is nonabrasive, pours easily into irregular spaces, and is suitable for both horizontal and vertical applications. It is noncombustible, odorless, resistant to vermin, and nonirritating.

As discussed in Chap. 16, W. R. Grace Co., the manufacturer of Zonolite vermiculite loose-fill insulation, was hit with three class-action lawsuits after failing to warn the public that the Zonolite attic insulation it sold from 1963 through 1984 contained tremolite

Figure 7.15 Vermiculite. (*Strong Lite Products Corp.*)

asbestos. Grace discontinued its attic insulation in 1984 but still produces a loose-fill vermiculite masonry insulation. The U.S. Environmental Protection Agency (EPA) estimated in 1985 that 940,000 American homes contained or had contained Zonolite attic fill.[22] Although it is not possible that all Zonolite installations were contaminated, more than 70 percent of the vermiculite ore mined in the world came from the Libby Montana mine, which has been closed since 1990. This particular mine was unusual because the area also included a natural deposit of tremolite asbestos.

If you know you have vermiculite insulation in your attic or walls and you are concerned about it, it probably makes sense to test the material to see if it contains asbestos. A trained consultant or licensed contractor should collect the sample and get it analyzed at a laboratory.

Small-Market Products

Wood shavings, granulated cork, and expanded polystyrene beads are loose-fill insulation products that are seldom seen today. For example, wood shavings, although rarely used today, were once a very popular insulation product because of their wide availability and low cost. Shavings often were treated with lime or other chemicals to increase resistance to water absorption, fire, and fungal growth. This insulation product is still a common sight in older homes across North America.

Appendix

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Chapter

8

Blanket Insulation: Batts and Rolls

Blanket insulations are flexible, bound products made from mineral (glass, rock, and slag) or cotton fibers. They are available in widths suited to standard spacings of wall studs and attic or floor joists. They come in rolls or batts in standard widths, usually to fit between framing on 16 or 24" centers. Continuous rolls can be hand-cut and trimmed to fit. Batts are available in a variety of precut lengths. Available with or without vapor retarder facings, the thickness and density of the insulation varies depending on the R-value desired. Batts with a special flame-resistant facing are also available in various widths for applications such as basement walls where the insulation will be left exposed. Newer products on the market include plastic-wrapped batts and fiberglass batts encapsulated in nonwoven fabric.

Fiberglass Batts and Rolls

As discussed in Chap. 7, fiberglass is one of a group of glassy, noncrystalline materials historically referred to as man-made mineral fibers (MMMFs) or man-made vitreous fibers (MMVFs). The current terminology is synthetic vitreous fibers (SVFs). The synthetic fiber is made from molten sand, glass, or other inorganic materials under highly controlled conditions. After the glass is melted in high-temperature gas or electric furnaces, the material is spun or blown into fibers that are then processed into the final product. Batt insulation is glass that is spun into threads, coated with a binding agent, and collected into a thick matte of fibers of varying thicknesses. Perhaps the most common of all residential insulation materials, it is estimated that since the development of fiberglass insulation in the 1910s, it has been used in approximately 90 percent of homes in the United States (that contain insulation).[1]

Product description

Fiberglass blanket insulation is made from sand (SiO_2), limestone ($CaCO_3$), and sodium carbonate (Na_2CO_3) and is usually the least expensive insulation on the market for the insulating value achieved.[2] Because it is inorganic, it will not rot or absorb moisture, is noncombustible, and does not support the growth of mildew, mold, or fungus. The North American Insulation Manufacturers Association (NAIMA) recommends the use of fiberglass insulation that meets the requirements of the current edition of American Society for Testing and Materials (ASTM) C665 Standard, "Specification for Mineral Fiber Blanket Thermal Insulation."

Each type comes either in continuous rolls or in packages of precut lengths called *batts* (Fig. 8.1). Relatively easy to install, both types are roughly equal in price per square foot. The decision to purchase batts or rolls depends on the specific application and/or preference of the installer. This is covered in more detail later in this chapter.

Batts and rolls are manufactured for standard joist and stud spacings. Lengths of batts available include 47, 48, 90, 93, 94, and 96 in. Rolls are available in lengths of 39 ft 2 in, 40 ft, and 70 ft 6 in. Widths of rolls and batts can be found in the following sizes: 11, 15, 15¼, 16, 23, 23¼ and 24 in.

Nominal Dimensions Available

	Batts	Rolls
Lengths	47″ (1194 mm), 48″ (1219 mm) 90″ (2286 mm), 93″ (2362 mm) 94″ (2388 mm), 96″ (2438 mm)	39′2″ (11.94 M) 40′ (12.19 M) 70′6″ (21.49 M)
Widths	11″ (279 mm), 15″ (381 mm) 15¼″ (387 mm), 16″ (406 mm) 23″ (584 mm), 23¼″ (590 mm) 24″ (610 mm)	11″ (279 mm) 15″ (381 mm) 23″ (584 mm)

Figure 8.1 Typical sizes of batts and rolls. (*NAIMA*)

Fiberglass does not take up water within the glass fibers, but water vapor passes freely between the fibers. Therefore, fiberglass insulation must be used in conjunction with a vapor barrier placed on the appropriate side. Batt and roll insulation is available unfaced or with a facing already attached. Unfaced blankets are used in conjunction with a polyethylene vapor barrier where applicable. The most common facings available for blanket products are kraft paper and foil (Figs. 8.2 through 8.5).

All manufacturers of fiberglass insulation products provide performance and installation information such as R-value, number of

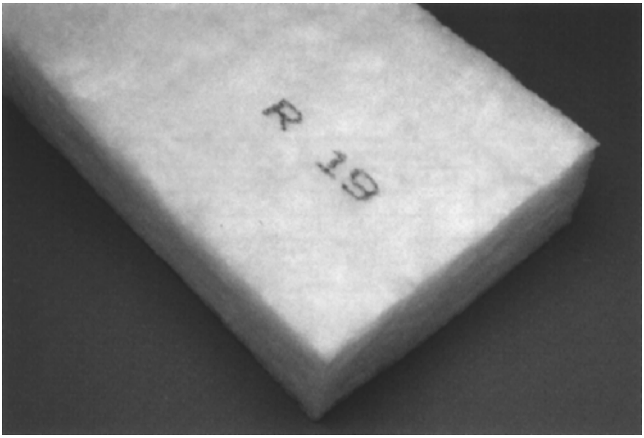


Figure 8.2 Unfaced batt. (*CertainTeed*)

Figure 8.3 Kraft paper–faced batt. (*CertainTeed*)

Figure 8.4 Foil-faced batt. (*CertainTeed*)

Batt Insulation Characteristics		
Thickness (inches)	R-value	Cost (¢/sq.ft.)
3½	11	12-16
3⅝	13	15-20
3½	15 (high density)	34-40
6 to 6¼	19	27-34
5¼	21 (high density)	33-39
8 to 8½	25	37-45
8	30 (high density)	45-49
9½	30 (standard)	39-43
12	38	55-60
This chart is for comparison only. Determine actual thickness, R-value, and cost from manufacturer or local building supply.		

Figure 8.5 Typical cost.

pieces per package, coverage per bag, size, and type either on preprinted bags or on labels attached to generic bags.

R-value

Although the typical R-value is 3.2 per inch, R-values can range from 3.04 to 4.3 for fiberglass blanket insulation. In addition to bag labeling, R-values are also printed on the facings of batts and rolls. Unfaced insulation is coded with stripes or ink-jet-printed to identify the R-value. The most common R-values in standard sizes for fiberglass insulation are R-11, R-13, and R-15 for $3^1/_2$"-thick products; R-19, R-21, and R-22 for $5^1/_2$"-thick products; and R-25, R-30, and R-38. One manufacturer's table of standard sizes and R-values for batt insulation is shown in Fig. 8.6.

If greater R-values are desired, it is possible to install multiple layers of blanket insulation where there is adequate space. Since R-values can be added, thermal calculations are simple. For example, if a ceiling requires R-38 insulation, then two layers of R-19 batts or rolls can be used. Only one layer should have a vapor retarder, facing the correct side of the wall depending on the climate, while additional layers normally should be unfaced. It is

R-Value		Thickness		Width	
R	RSI	in.	(mm)	in.	(mm)
UNFACED					
8	1.4	2½	(64)	16 & 24	(406 & 610)
11	1.9	3½	(89)	11¼, 15, 15¼, 19, 23, 23¼, 44, 48 & 84	(286, 381, 387, 483, 584, 591, 1118, 1219 & 2134)
13	2.3	3½	(89)	15¼, 16, 23¼ & 24	(387, 406, 591 & 610)
15	2.6	3½	(89)	15¼ & 23¼	(387 & 591)
19	3.3	6¼	(159)	11, 11¼, 15, 15¼, 16, 19, 23, 23¼, 24 & 48	(279, 286, 381, 387, 406, 483, 584, 591, 610 & 1219)
21	3.7	5½	(140)	15, 15¼ & 23¼	(381, 387 & 591)
25	4.4	8	(203)	15, 16, 19, 23, 24, 32 & 46½	(381, 406, 483, 584, 610, 813 & 1181)
30	5.3	10	(254)	16, 19 & 24	(406, 483 & 610)
30C*	5.3	8¼	(210)	15¼ & 23¼	(387 & 591)
38	6.7	12	(305)	16 & 24	(406 & 610)
38C*	6.7	10	(254)	15¼ & 23¼	(387 & 591)
KRAFT-FACED					
11	1.9	3½	(89)	11, 15, 16, 23 & 24	(279, 381, 406, 584 & 610)
13	2.3	3½	(89)	11, 15, 16, 19, 23 & 24	(279, 381, 406, 483, 584 & 610)
15	2.6	3½	(89)	15 & 23	(381 & 584)
19	3.3	6¼	(159)	11, 15, 16, 19, 23 & 24	(279, 381, 406, 483, 584 & 610)
21	3.7	5½	(140)	15 & 23	(381 & 584)
22	3.9	8	(203)	15, 19 & 23	(381, 483 & 584)
25	4.4	8	(203)	15 & 23	(381 & 584)
26	4.6	8	(203)	16 & 24	(406 & 610)
30	5.3	10	(254)	11, 15, 16, 19, 19¼, & 24	(279, 381, 406, 483, 489 & 610)
30C*	5.3	8¼	(210)	15 & 23	(381 & 584)
38	6.7	12	(305)	16 & 24	(406 & 610)
38C*	6.7	10	(254)	15 & 23	(381 & 584)

**Cathedral Ceiling Batts*

Figure 8.6 Batt insulation specifications. (*CertainTeed*) important not to compress the blankets to a less than normal thickness during installation because the rated R-value will be reduced.

The popularity of cathedral ceilings over the last 10 years has created the demand for a modified type of blanket insulation. R-30 and R-38 fiberglass insulation batts are 10 and 12", respectively. These sizes are too thick when placed between nominal 2×10 or 2×12 framing members, and still maintain the 1" continuous airspace required by most building codes for roof-ceiling ventilation requirements. Known as high-performance or high-density batts, the modified R-30 and R-38 insulations typically are designated with a "C" suffix. The R-30 superbatts are $8^1/_4$ to $8^1/_2$" thick, as opposed to standard R-30 fiberglass batts of $9^1/_2$ to 10". (Thickness may vary by manufacturer.) R-38 superbatts are 10 to $10^1/_4$" thick, as opposed to standard. Since these batts achieve the same R-value as the thicker types, they do not need to be compressed to fit the angles and spaces typically found in cathedral ceilings. Because they contain more fiberglass, these higher-density batts are more expensive than low-density batts. Similarly, medium-density batt insulation is also becoming increasingly popular. Measuring the same thickness as R-11, a $3^1/_2$"-thick batt can now achieve R-values of 13 or 15.

Sidewalls

Fiberglass blanket insulation products are manufactured to fit in both 2×4 and 2×6 wood frame construction. Standard sidewall widths of both 15 and 23 in are available. If steel stud framing is used, 16- and 24" widths are available for steel stud construction. R-11, R-13, and R-15 are used in nominal 4" walls, whereas R-19 and R-21 are used for nominal 6" walls (Fig. 8.7).

It is important to note that proper installation is necessary in order to guarantee that the actual R-value achieved is the R-value intended. For example, homes built with 2×6 construction typically use a standard R-19 batt that measures 6 to $6^3/_4$" thick to fill a $5^1/_2$" wall cavity. Compressing the insulation causes it to lose some of its thermal effectiveness, reducing its R-value to approximately R-18. Using an R-21 high-density batt that measures $5^1/_2$" thick guarantees that there is no compromise to the R-value during installation.

Attics and ceilings

The most common blanket products for attics and flat ceilings are R-30 and R-38 batts. As mentioned earlier, high-performance batts

Figure 8.7 Installing batt insulation. (*CertainTeed*)

are also available as R-30C or R-38C. Because the high-performance batts achieve the recommended R-values in less space, they allow room for ventilation between the insulation and the roof deck without the need for roof baffles or the installation of larger roof joists (Fig. 8.8).

In order to achieve R-values of 38 and higher, two layers can be used and their R-values combined. For example, an R-19 batt added to an R-30 will yield an R-49. When installing a second layer, always use unfaced insulation, because using a second vapor retarder will trap moisture between the two layers. It is also recommended that the second layer be applied across the joists in open attic spaces (Fig. 8.9).

A combination of blankets and blown-in insulation also can be used. A batt or roll can be installed during the initial construction process, and a layer of blown insulation can be added at a later time.

Floors and crawl spaces

R-11, R-13, R-15, R-19, R-21, R-25, and R-30 roll or batt insulation can be used under floors and in crawl spaces, as determined by the locally adopted building code and/or International Energy Conservation Code (IECC). When insulating floors over unheated basements or crawl spaces, faced products should be used.

Another strategy is to insulate the walls in well-sealed crawled spaces as an effective alternative to underfloor insulation. This

Figure 8.8 High-performance fiber glass batt. (*CertainTeed*)

Figure 8.9 Encapsulated fiber glass insulation. (*CertainTeed*)

method usually requires less insulation, minimizes temperature swing in piping and ductwork, and may even help cool the house in summer because some heat can escape through the uninsulated floor. It is critical that the space not have air leakage to the exterior, because this would allow heat to escape during the winter months.[3]

For insulating foundation walls of heated crawl spaces, use either unfaced insulation where the building code does not require a vapor retarder, or insulation with a special facing recommended for exposed applications. The insulation should be fastened to the sill plate and draped down the wall. The recommended R-value for this application varies by geographic area.

Basements

For finished basements, standard or high-performance batts can be used depending on the R-value required. It is important to verify if there are any moisture penetrations in the basement walls prior to insulation installation. As in sidewall construction, vapor retarders should be installed either as facing on the insulation or as polyethylene sheeting.

For unfinished basements that contain furnaces, water heaters, ducts, etc., manufacturers offer special basement wall insulation that is available in 4- or 6-ft widths in 50-ft rolls. It typically comes with a white or aluminum, flame-resistant polypropylene protective facing and is intended for use in applications where the insulation will be left exposed. It can be applied either full or half wall height (Fig. 8.10).

Limitations

Unlike loose-fill insulation products, fiberglass blanket insulation can be difficult to work with in tight or irregular spaces. Special attention to wall obstructions or areas where compression may occur is necessary so as not to compromise the overall effectiveness of the installation. This is also true if heavier insulations, such as cellulose or slag wool loose-fill insulation, are installed over (and compress) fiberglass blanket insulation.

Health considerations

As discussed in Chap. 7, debates have been intensifying since the mid-1980s as to the safety of using fiberglass insulation. The concern has been that the fibers that comprise fiberglass may replicate the affects of the fibers found in another silicon dioxide material, asbestos. The structure and size of these glass fibers vary. The smaller fibers, which cannot be seen by the naked eye, can enter the lungs, whereas larger, visible fiberglass particles can be irritating to the skin, eyes, nose, and throat. According to a recent

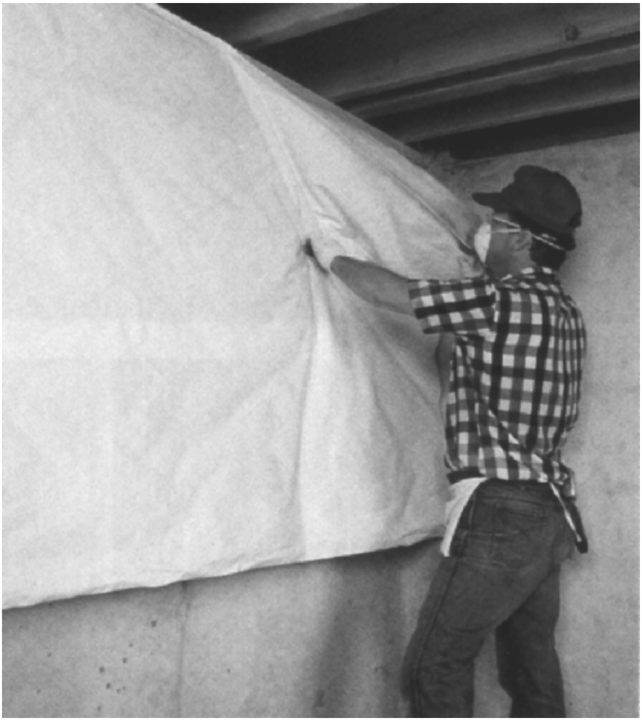


Figure 8.10 Polypropylene-faced fiber glass roll. (*CertainTeed*)

report, the larger size of fiberglass fibers is a critical physical property difference from asbestos. "Since large-diameter fibers fall out of suspension in the air faster than small-diameter fibers, work with SVFs is less likely to generate high concentrations of airborne fibers than work with asbestos."[4]

Fiberglass is listed by the International Agency for Research on Cancer (IARC) as a possible carcinogen and by the National Toxicology Program (NTP) as "reasonably anticipated to be a carcinogen."[1] Although occupational and residential exposures to fiberglass fibers are low when compared with past asbestos exposures, all fiberglass insulation is required to have a cancer warning label as mandated by the Occupational Safety and Health Administration's (OSHA) hazard communication standard.[1] Full hazard disclosure is also found in the product's Manufacturer's Safety Data Sheet (MSDS).

The Consumer Product Safety Commission (CPSC) also has found (1992) that "fibrous glass is carcinogenic in animals only when surgically implanted into the lung or abdomen. In tests where animals were exposed by inhalation, the expected route of human exposure, the animals did not develop tumors. Therefore, the animal implantation studies do not establish a hazard to humans."[5]

A common complaint about fiberglass has been the use of formaldehyde in its manufacturing process, and the danger the chemical may present to humans. Conventional fiberglass insulation is made with 5 to 7 percent phenol formaldehyde resin.[6] Industry officials report that formaldehyde is found in the final product in only trace amounts. After being sprayed on as part of the manufacturing process, it goes through an oven curing process where the majority of the formaldehyde is cured and the excess collected by precipitators to ensure that harmful amounts are not released into the atmosphere.[1]

The greatest concern with fiberglass, however, is not necessarily aimed at the home occupants surrounded by the insulation but at the installers of the insulation. Workers in fiberglass manufacturing plants, as well as people working with or using materials that contain fiberglass, may develop a skin irritation. This mechanical irritation is a physical reaction of the skin to the ends of fibers that have rubbed against or become embedded in the skin's outer layer. Any skin irritation caused by fiberglass is temporary. Washing the exposed skin gently with warm water and mild soap can relieve it. The vast majority of workers and consumers, however, can control skin irritation by following recommended work practices when handling the material. Fiberglass is also the catalyst for eye irritation if deposited in the eye by the user's fingers or through fibers in the air. If this should happen, the eyes should not be rubbed but rinsed thoroughly with warm water, and a doctor consulted if irritation persists.[7]

Fiberglass released into the air during its manufacture or handling also may create temporary upper respiratory tract irritation. Like skin irritation, upper respiratory tract irritation is a mechanical reaction to the fibers. It is not an allergic reaction, and the irritation generally does not persist. Such exposures to high concentrations of airborne fiberglass may result in temporary coughing or wheezing. These effects will subside after the worker is removed from exposure.[7]

In response to these health concerns, several manufacturers have developed new products that attempt to reduce the amount of airborne glass fibers. Generically called *encapsulated batts,* these blanket products seal the fiberglass in a polyethylene covering that minimizes contact and also serves as a vapor barrier. Reportedly easier to install, there is no itching, and the price is only about 5 to 30 percent higher than traditional batts depending on the manufacturer.

One product is produced by fusing together two different types of glass, which gives the fiber a curving or twisted configuration and eliminates the need for binders to hold the fibers together. The fibers are more resilient, stronger, and less prone to breakage, so fewer fiber particles will get into the air or into the installer's skin. Since the fiber is twisted, a binder (typically formaldehyde) is not required to hold batts together.[6]

Another formaldehyde-free fiberglass insulation product uses an acrylic binder to hold the fibers together. Unlike the phenol-formaldehyde resin used in conventional fiberglass, it does not off-gas formaldehyde during either manufacture or use. The acrylic binder is a thermosetting resin. Although heat is used to cure the binder, as with phenol-formaldehyde, this binder releases very few volatiles.[8]

As will be discussed later in this chapter, proper clothing and handling and the use of approved respiratory protection can effectively control exposure to airborne fibers and therefore reduce the likelihood of skin or upper respiratory tract irritation.

Environmental considerations

Fiberglass uses two resources, sand and recycled glass. Sand does not have an impact on nonrenewable natural resources. Recycled plate and bottle glass is considered a secondary raw material, so, when used as raw material, recycled glass is changed into a product that can save energy and reduce pollution.[1]

All fiberglass companies use at least 20 percent recycled glass cullet in their insulation products to comply with the U.S. Environmental Protection Agency (EPA) recycled-content procurement guidelines. Johns Manville's fiberglass is certified by Scientific Certification Systems (SCS) to contain 25 percent recycled glass (18 percent postconsumer bottles and 7 percent postindustrial cullet). Johns Manville's manufacturing equipment readily handles colored glass, making it easier for the company to use postconsumer recycled cullet. CertainTeed and Owens Corning rely primarily on postindustrial cullet from flat glass manufacturers.[9]

Fire resistance

Fiberglass is naturally fire resistant, but faced insulations will contribute to flame spread unless flame-resistant materials are used.

Vapor retarder

Batts and rolls are available with facings of asphalt-coated kraft paper, aluminum foil, or plastic film already attached. The facings extend over the sides of the insulation to provide strengthened flanges that can be stapled to wood framing to hold the insulation in place where recommended by the manufacturer. (Some faced products may be pressure-fit between framing without stapling.)

The kraft paper or standard foil vapor retarder facings on many blanket insulation products are combustible and should not be left exposed. Gypsum board is one such covering material. Special care must be taken to keep open flame and other sources of heat away from the facing. In addition to the home's habitable rooms, garages, storage rooms, utility rooms, and laundries are areas where faced insulation also should be covered. If in doubt, always consult individual manufacturers' installation instructions. It is also important to repair damaged vapor retarders by covering the damaged area with scrap vapor retarder material and taping it in place or, in the case of small rips, by using duct tape or polyvinyl tape.

The National Institute of Standards and Technology (NIST) recently published a study that demonstrated that the permeance of the asphalt-impregnated kraft facing used as a vapor retarder on batt insulation can rise dramatically under very humid conditions. These results suggest that in very moist areas such as shower rooms, kraft paper alone may not be sufficient to keep moisture out of the walls. A better strategy is to install a continuous polyethylene vapor retarder.[10]

Some blanket products are available without these facings. If unfaced fiberglass insulation is used, a separate vapor retarder should be applied after the insulation is installed.

Special low-flame-spread vapor-retarder facings are available that can be left exposed. (Flame-resistant facings are labeled FS25, or flame spread index 25.) Sometimes, the flame-resistant cover can be purchased separately from the insulation. Fiberglass blanket products also are available for basement walls that can be left exposed. These blankets have a flame-resistant facing and are labeled to show that they comply with ASTM C665, type II, class A.

Installation standards and practices

As mentioned in Chap. 7, general work practices applicable to all work involving SVFs such as fiberglass (rock wool and slag wool) have been established by U.S. Occupational Safety and Health Administration (OSHA). Excerpts of the guidelines are as follows[11]:

1. Minimize dust generation.
   - Keep the material in its packaging as long as practicable and if possible.
   - Tools that generate the least amount of dust should be used. If power tools are to be used, they should be equipped with appropriate dust-collection systems as necessary.
   - Keep work areas clean and free of scrap SVF material.
   - Do not use compressed air for cleanup unless there is no other effective method. If compressed air must be used, proper procedures and control measures must be implemented. Other workers in the immediate area must be removed or similarly protected.
   - Where repair or maintenance of equipment that is either insulated with SVF or covered with settled SVF dust is necessary, clean the equipment first with a HEPA vacuum or equivalent (where possible), or wipe the surface clean with a wet rag to remove excess dust and loose fibers. If compressed air must be used, proper procedures and control measures must be implemented. Other workers in the immediate area must be removed or similarly protected.
   - Avoid unnecessary handling of scrap materials by placing them in waste disposal containers and by keeping equipment as close to working areas as possible that prevents release of fibers.

2. Ventilation
   - Unless other proper procedures and control measures have been implemented, dust-collection systems should be used in manufacturing and fabrication settings where appropriate and feasible.
   - Exhausted air containing SVFs should be filtered prior to recirculation into interior workspaces.
   - If ventilation systems are used to capture SVFs, they should be checked and maintained regularly.

3. Wear appropriate clothing.
   - Loose-fitting, long-sleeved and long-legged clothing is recommended to prevent irritation. A head cover is also recommend-

ed, especially when working with material overhead. Gloves are also recommended. Skin irritation cannot occur if there is no contact with the skin. Do not tape sleeves or pants at wrists or ankles.
- Remove SVF dust from the work clothes before leaving work to reduce potential for skin irritation.

4. Wear appropriate personal protective equipment.
   - To minimize upper respiratory tract irritation, measures should be taken to control the exposure. Such measures will be dictated by the work environment and may include appropriate respiratory protective equipment. See OSHA's respiratory protection standard.
   - When appropriate, eye protection should be worn whenever SVF products are being handled.
   - Personal protective equipment should be fitted properly and worn when required.

5. Removal of fibers from the skin and eyes.
   - If fibers accumulate on the skin, do not rub or scratch. Never remove fibers from the skin by blowing with compressed air.
   - If fibers are seen penetrating the skin, they may be removed by applying and then removing adhesive tape so that the fibers adhere to the tape and are pulled out of the skin.
   - SVFs may be deposited in the eye. If this should happen, do not rub the eyes. Flush them with water or eyewash solution (if available). Consult a physician if the irritation persists.

Insulation should be installed just before the interior finish is applied. In addition to the removal of all construction debris from the spaces to be insulated, the following checklist should be completed. (If any part of this work is done following the installation of the insulation, the vapor retarder may be damaged, and gaps may be made in the insulation.)

1. Sidewalls, floors, roofs, and ceilings have been framed.

2. Roofing is finished and doors, windows, subflooring, and sheathing are in place.

3. Plumbing, heating, ventilating, and air-conditioning work has been completely roughed in.

4. Cabling and wiring (including telephone and other low-voltage wiring) have been completely roughed in.

Stapling methods. There are three commonly accepted methods of installing faced insulation in wood framing members. These are referred to as *inset stapling*, *face stapling*, and *pressure fit*. (Faced blanket insulations typically provide a stapling flange for attaching the insulation to the framing members; Fig. 8.11.)

It is important to note that wherever batts or rolls of any type are too short to fill a stud cavity, a piece should be cut to size to fill the gap. When insulation is too long, it should be cut to fit properly, not doubled over or compressed. For standard wall heights, use precut batts rather than continuous rolls. This will tend to expedite the installation process. Rolls should be used where length requirements permit. If cutting is necessary, the best knife has been found to be one with a serrated blade. Utility knifes are more common.

It is easiest to cut kraft-faced batts with the paper face down. Cutting from the paper side can rip the paper and ruin its efficiency as a vapor barrier. To cut insulation properly, lay the blanket on a board with the kraft or foil facing down. Place a straight edge or 2×4-in piece of lumber over the area of insulation to be cut. Press the straight edge down hard, and cut with the knife. Blades should be replaced periodically because they tend to dull during use.

Inset stapling. When using the inset stapling method, place the insulation in the cavity, and check to be sure that it completely fills the cavity, top to bottom. It is recommended that a single batt be used in sidewalls. However, when insulating with 47- or 48-in batts, make sure the two pieces are butted snugly together. Gently press the insulation at the sides into the framing cavity, usually about $^3/_4$

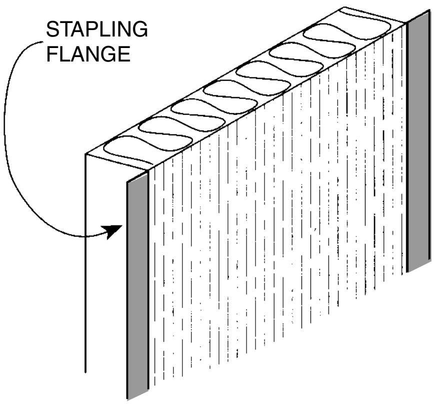


Figure 8.11 Stapling flange. (*NAIMA*)

in, until the outside edge of the flange is flush with the face of the framing. When inset stapling insulation between inclined or vertical framing members, as in cathedral ceilings or walls, start stapling at the top and work down. Use enough staples to hold the insulation firmly in place, and avoid gaps and "fishmouths" between flanges and framing[12] (Fig. 8.12).

Face stapling. Place the insulation between the framing members, and check to be sure that the blanket fits the cavity at both ends. With facing material flush with the face of the framing, the flanges will overlap the framing. Staple the flanges to the face of the framing using enough staples to hold the insulation firmly in place, and avoid gaps and fishmouths. The flange of the faced insulation placed in the next cavity will overlap the previously stapled flange[12] (Fig. 8.13).

Both methods are used widely and can provide acceptable performance. Inset stapling is usually preferred by the wall finish trades because it allows adhesive application of wall board. Another problem occurs when stapling over the face of the framing; the layers of paper can get bunched up. This makes it harder for the gypsum wallboard crew to find places to nail, and often results in more nail pops.

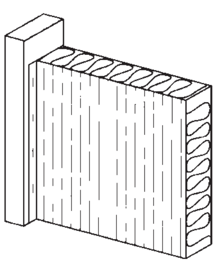


Figure 8.12 Inset stapling. (*NAIMA*)

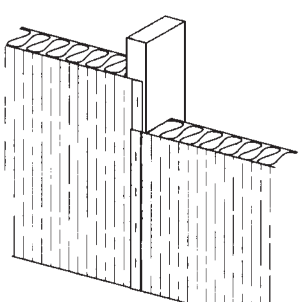


Figure 8.13 Face stapling. (*NAIMA*)

Pressure fit. To install faced products by pressure fit, gently place the insulation into the cavity space between the framing members. The insulation facing must be flush with the face of the stud and fit snugly at the sides and ends.[12]

Unfaced insulation. Many insulation subcontractors prefer unfaced batts for most applications because they are faster to install. Similar to the pressure-fit technique, gently place the insulation into the cavity space between framing members. It is important that insulation be correctly sized for the cavity, and fit snugly at the sides and ends.

Sidewalls. First of all, verify with the local building code all requirements regarding insulation materials, ventilation clearances, and firestops. Make sure that any openings between floors are fire-stopped with fireproof caulk, unfaced fiberglass, or rock wool. Plumbing and wiring chases, flue chases, hearths, and chimneys all need fire stops.

Measure the ceilings and walls to determine the square footage, and divide by the number of square feet in a package. The coverage of each package of insulation varies according to manufacturer, R-value, and width. Some installers prefer the 16"-wide batts rather than the typical 15"-wide batts. These wider batts are made for walls framed with metal studs, but when used with wood framing, the extra inch of width makes a good, snug fit between studs.

In order to avoid incidental compression during packaging, it is wise to fluff up the batts, making sure that each is expanded to its full thickness. Running a thin putty knife between the fiberglass and the stud also fluffs and aligns the batt after it is in place. Full-length batts, which are typically cut to 93" for an 8-ft wall, can be used in empty stud bays where there are no electrical or plumbing obstacles.

An all-too-common practice by installers when encountering obstacles within the stud cavity is to omit the insulation, or incorrectly compress the batt. This may be marginally sufficient when the electrical wiring is located close to the inside wall surface. When the wiring is in the center of the cavity, either a shallow cut in the insulation may be used to allow the wiring to pass through the insulation or it may be split lengthwise and the wiring sandwiched within (Figs. 8.14 and 8.15).

The splitting technique also works for insulating behind vertical runs of plumbing, and not only insulates copper pipes but also

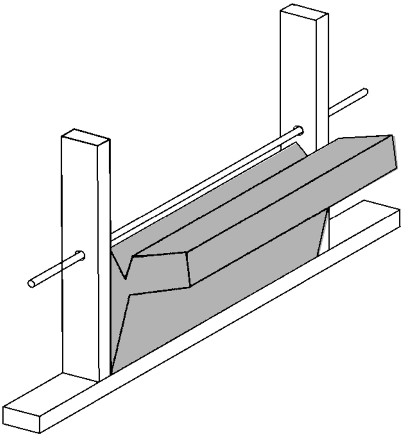


Figure 8.14 Splitting technique. (*NAIMA*)

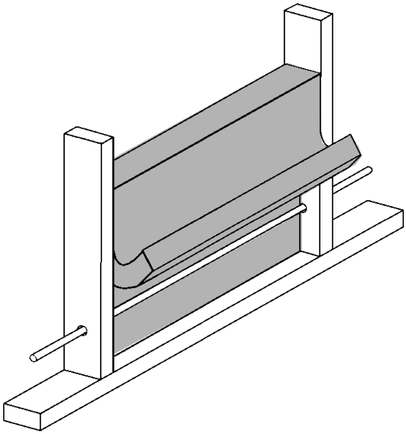


Figure 8.15 Splitting technique. (*NAIMA*)

helps to reduce noise from PVC waste stacks. To guard against pipes freezing, insulation should never be placed between piping and the warm side of the wall.

Junction boxes for wall switches and convenience outlets at outside walls should be insulated between the rear of the box and the sheathing. Place insulation behind the junction box, and if necessary, cut insulation to fit snugly around it. If installing kraft-faced batt insulation, use the outside of the box as a guide to slice the paper carefully, which lessens the chance of ripping it.

Some installers prefer using 4-ft batt lengths because they are easier to maneuver around wiring and plumbing in the bays. If batts are stacked in a bay, make sure that the butt joint between the batts is tight. The batts should fit snugly in the bay and should fill the width of the stud from the sheathing inward.

Special cutting of insulation may be required for less than standard width or length cavities or for insulating around window and door framing, stud corners, and band joists and between chimneys and framing.

Ceiling joists below an attic. When ceiling insulation is installed at the same time as wall insulation, it can be installed from below. Batts or rolls, faced or unfaced, are installed between ceiling joists and butted together. Faced batts should be stapled to joists unless the manufacturer recommends pressure-fit applications.

It is particularly important that clearance for air movement from vent openings be maintained. This should be a minimum of 1 in of unblocked free airspace between the roof sheathing and the insulation. (Verify the amount of airspace required with all applicable building codes.) The insulation should extend far enough to cover the tops of the exterior walls but should not block the flow of air from the eave vents. To make sure that the eave vents (also referred to as *soffit vents*) are not blocked, attic vents or baffles should be installed to provide unrestricted airflow from the soffit to the attic if prohibited by insulation placement. It is important also for the insulation to cover the top plate. Use baffles if necessary to keep the insulation from blocking the passage of air (Fig. 8.16).

Vapor retarders are not a standard recommendation for attics. Exceptions may include very cold climates or isolated cases where there is high humidity in the house during the winter. An attic vapor barrier is not required by building codes, as long as the attic is sufficiently ventilated. If used, proper orientation of the vapor retarder is consistent with other locations in the home. For example, if the vapor retarder faces the inside of the room in sidewall installation, it also will face the inside of the room from the ceiling. Penetration of the vapor retarder by recessed lights, attic openings, and vents can provide paths for conditioned air and moisture to escape into the attic.[12]

Bridging or cross-bracing of ceiling or floor joists is insulated by splitting a batt vertically at the center and packing one half into the lower opening and the other half into the upper opening. Another method is to butt the insulation to the bridging and then fill the bridging space with scrap or loose insulation.[12]

After the ceiling gypsum wallboard has been installed, temporary flooring should be laid across the joists to provide some foot-

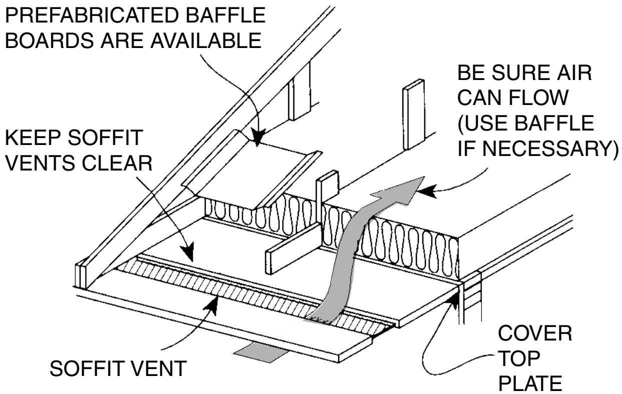


Figure 8.16 Baffle placement. (*NAIMA*)

ing. It is easiest to place the insulation blanket at the outer edge of the attic space and work toward the center. This allows for more headroom in the center of the space, where cutting and fitting can be performed. Stapling is not required if insulation is laid in over finished ceilings.

If the joist cavities are completely filled and the required R-value has not been achieved, insulation in long runs perpendicular to the direction of the joists should then be placed. Leftover pieces can be used for small spaces.

Insulation should be kept 3 in away from recessed lighting fixtures unless the fixture has an IC rating. (The IC label, for *insulation contact,* can be found on the inside of the fixture.) A type IC insulated ceiling fixture is designed for direct contact with insulation. If insulation is placed over an unrated fixture, it may cause the fixture to overheat and perhaps start a fire. Insulation always should be installed at least 3 in away from the recessed fixture's wiring compartment or ballast or any metal chimneys, gas water heater flues, or other heat-producing devices.

Attic rooms. Attics that are used as living spaces are to be insulated as other habitable rooms are. Attic framing can be a little difficult to work with, so rafters and collar beams should be insulated with separate pieces of fiberglass insulation. Trying to fit a continuous length of insulation where collar beams and rafters meet may result in gaps or compression of the insulation.

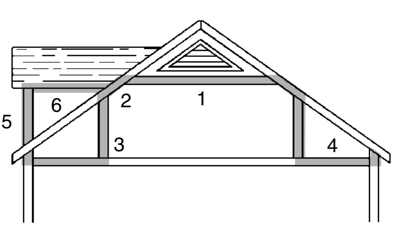
When selecting and installing insulation for the rafter portion, 1 in of ventilation space should be provided between the insulation and the roof sheathing. Eave vents and baffles that run along the entire ceiling cavity will ensure proper airflow.

The framing member size of the rafter will determine the batt selection. For example, 2" × 10" joists will require R-30C high-density insulation that measures $8^1/_4$", and will automatically provide the required ventilation space when installed properly.

Verify that the exterior thermal envelope is insulated. This will require insulation in knee walls, end walls, dormers, and any other surface that encompasses the conditioned space. As soon as the insulation has been installed, finish the walls and ceiling with an approved interior finish, such as gypsum wallboard.[12] See Fig. 8.17 for proper attic insulation locations.

Cathedral ceilings. The "rules" for cathedral ceilings are similar to those applied to attic rooms. A ventilation baffle should be installed at the eave of every joist to make sure that the ventilation space is not blocked by insulation. Baffles used in cathedral ceilings to maintain an air passage to the ridge should not extend farther than the wall plate and should not block soffit vents, because any obstructions in the soffit will disrupt airflow. As mentioned earlier, fixture ratings, vapor retarder orientation, and proper placement must be respected.

Floors. 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. Like walls, floor cavities should be completely filled with insulation without gaps or voids.



(1) Between collar beams. (2) Between rafters.
(3) Knee walls. (4) Ceilings with cold spaces above.
(5) Dormer walls. (6) Dormer ceilings.

Figure 8.17 Attic rooms. (*NAIMA*)

The most efficient use of floor insulation requires contact with the subfloor and both joists.

Given the deeper joist members commonly used in the longer spans of engineered wood systems, the amount of floor insulation required by some codes can be less than the space available. For example, an R-19 batt is $6^1/_4$" thick. A floor framed with 2 × 8s is about $7^1/_2$" deep, whereas a 2 × 10 floor is $9^1/_2$". To avoid a gap in this situation, the batt must be pushed up into the cavity. This is easily achieved with the proper intermittent supports.

The easiest and most effective method of holding insulation in place is to use straight, rigid wire insulation hangers (preferably galvanized) with pointed ends. The hangers are made for joist spacings of 12, 16, 18, 20, and 24", and may be used against wood, metal, or concrete. The hangers, which are slightly longer than the joist spacing, are placed by hand between the joists and bowed upward into the insulation, causing the insulation to press gently against the subflooring. Spacing of hangers is as required to prevent sagging of the insulation, preferably 12" apart and not more than 6" from ends of batts and rolls (Fig. 8.18).

When insulating floors where the insulation is less than the thickness of the joists and the method of installation does not hold the insulation up against the subflooring, it will be necessary to insulate the headers or band joists at outside walls. This is so because there will be an airspace between the top of the insulation and the subfloor that will allow heat to be lost at outside walls. Therefore, it is recommended that the insulation be pushed up to the subfloor.

Although floor framing is typically 16 or 24" on-center bays, historical home designs may vary. Therefore, a number of insulation hanger systems are available:

1. Metal rods, or spring rods, or “tiger claws” are available through insulation distributors. They are easy to use, but compress the insulation in the middle.
2. Wood lath provides a sturdy support for insulation.

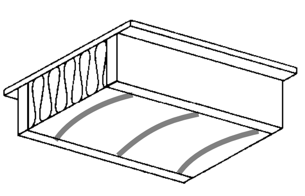


Figure 8.18 Insulation hangers. (*NAIMA*)

3. Plastic mesh should be attached to the bottom of the framing. Draping the mesh over the joists leads to compression that reduces insulating value.
4. Polypropylene twine resists rot, mildew, rodents, and other dangers. The twine needs to be stapled every 12 to 18".
5. Plastic straps are typically a thin strap made of recycled plastic. The ends are wider for easy stapling. The strap can attach to the joist bottom or lift a batt up into the cavity without compressing it.
6. Galvanized wire, nylon mesh, or galvanized screen (chicken wire is also suitable) will hold the insulation in place. After the insulation has been pushed into place, the mesh or screen is stapled or nailed to the joist faces.
7. Galvanized, malleable wire may be laced around nails protruding from the faces of the joists, or the wire may be stapled to the joists. Wire and nail spacings are as required to prevent sagging of the insulation.

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 also could lead to a higher-quality job, because there is less chance for compression or gaps.

If insulating over an unheated area, the vapor retarder should be in substantial contact with the subfloor. Where the header is parallel with the floor joists, it may be necessary to adhere insulation to the header or fill the joist area with insulation. If you insulate above an unheated crawl space or basement, you also will need to insulate any ducts or pipes running through this space. Otherwise, pipes could freeze and burst during cold weather in northern climates.

Cantilevered overhang areas must not be overlooked. If the underside of the cantilever has been closed, insulation must be installed by sliding batts into place from the room below (Fig. 8.19).

For homes where the underside of the floor is exposed and readily accessible, such as homes on pilings or certain garage areas, the insulation should be covered with a suitable exterior material to protect it from high winds and physical abuse.

Heated crawl space. More common in northern climates, heated crawl spaces help protect water pipes from freezing while also elim-

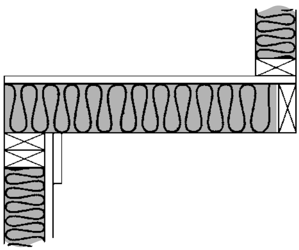


Figure 8.19 Cantilevered overhang. (*NAIMA*)

inating the need for under-floor insulation. The first step is to measure and cut small pieces of insulation and fit them snugly into the band joist between the floor joists. (Before installing the insulation, check for any air leakage at the foundation sill joint, and caulk or seal this joint as needed.) Use R-13 blanket insulation as a minimum on structures with 2 × 4" sill plates, and R-19 with 6"-wide sill plates. If the fiberglass has a facing or vapor retarder, be sure that the insulation is installed with the vapor retarder toward the heated space (only in cold climates). The insulation can be stapled by the paper or foil facing or fastened with wire fasteners. (Verify with local practice and building codes for proper vapor retarder placement.)

On the two sides where the floor joists are perpendicular to the band joist, cut the insulation material to a snug fit, and gently push it into place between the floor joists. Be sure that it fits snugly against the band joist without being compressed. On the sides where the floor joists are parallel to the band joist, cut longer pieces of insulation (sections of 4 ft or less are easiest to work with). The insulation can be held in place with staples (if faced), tiger claws, thin wire, or fishing line criss-crossed around tacks or nails at 1-ft intervals.

Insulation for the crawl space walls should be cut long enough to cascade down the walls and extend 2 ft along the ground on the crawl space floor. Furring strips should then be installed to hold the insulation in place by nailing it to the sill. By not driving the nails completely through the furring strips the insulation is compressed as little as possible. After the insulation has been installed, a 6-mil polyethylene vapor retarder should be spread across the entire floor. The vapor retarder should be placed under the crawl-space wall insulation (Fig. 8.20). Rocks or bricks can be set on top of the crawl-space wall insulation that extends out on the floor in order to hold it in place.

Basement walls. If fiberglass blanket insulation is to be used for masonry or concrete basement walls, there are two methods that

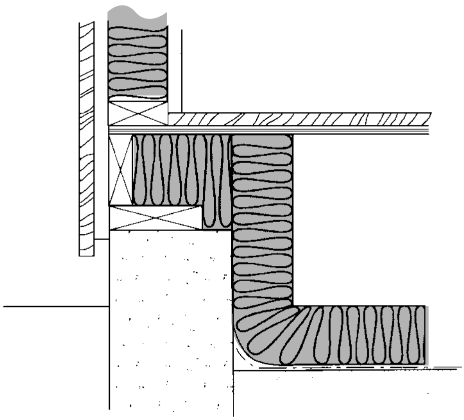


Figure 8.20 Heated crawl space walls. (*NAIMA*)

can be adopted. Installing furring strips directly to the masonry wall will allow the use of R-3 or R-6 batt insulation applied directly to the wall (Fig. 8.21). A separate frame wall also could be built, usually of 2 × 4" or 2 × 6" wood framing. The top plate is nailed to the underside of the joists or to blocking between joists. Batt insulation is then installed as in typical sidewall applications.

The framed wall can be very advantageous for installing thicker insulation or if additional electrical wiring is to be run, as is common in most basement renovation projects. It is important to note that the band joists need to be insulated separately. Insulation is then installed as described earlier under "Sidewalls."

It is important to note that the sealing of a basement may pose a threat of radon gas. If the home is in an area that is known to have soils containing radon, testing measures must be implemented. Venting measures and proper concrete slab construction will be mandatory if a significant concentration (greater than 4.0 pCi/liter) is discovered.

Slag Wool and Rock Wool

As discussed in Chap. 7, *mineral wool* refers to three types of insulation made from raw materials that are spun into loose-fill or batt products:

1. Glass wool, or fiberglass, made from recycled glass or silicates
2. Rock wool, made from virgin basalt, an igneous rock
3. Slag wool, made from steel-mill slag

Rock and slag wool fall within a group of materials referred to as *man-made vitreous fibers* (MMVFs), reflecting the glassy, noncrys-

Figure 8.21 R-3 masonry wall insulation between furring strips. (*CertainTeed*)

talline nature of these materials. The mineral wool form of MMVFs was developed initially in the late 1800s by melting slag and spinning it into insulation for use in homes and industry. Over the past century, mineral wool manufacturing has evolved into a large and diversified industry as more and more products have been developed.

Rock wool and slag wool each use different raw materials in their manufacture. Rock wool is made from natural minerals, primarily natural rock such as basalt or diabase. Slag wool is made primarily from iron ore blast furnace slag. Slag wool accounts for roughly 80 percent of the mineral wool industry, compared with 20 percent for rock wool.[9] Rock wool is predominantly used in blanket insulation products.

Rock and slag wool insulations are produced by a centrifugal wheel process. Natural rocks or iron ore blast furnace slag are melted, and the hot, viscous material is spun into fiber by pouring a stream of molten material onto one or several rapidly spinning wheels. As droplets of the molten material are thrown from the wheel(s), fibers are generated. As the material fiberizes, its surface generally is coated with a binder and/or dedusting agent (e.g., mineral oil) to suppress dust and maintain shape. The fiber is then collected and formed into batts or blankets or baled for use in other products, such as acoustical ceiling tile and spray-applied fireproofing, insulating, and acoustical materials.[13]

Product description

The mechanics of rock wool blanket insulation are similar to those of fiberglass blanket insulation. The batt insulation has an R-value of 3.6 per inch and is manufactured for standard joist and stud spacings. Unfaced batts are a good material for insulating around chimneys because the material does not support combustion. Small amounts of moisture have little effect on R-value.

Health considerations

An extensive discussion of the health effects of mineral wool insulation was presented in Chap. 7. In review, injection/implantation studies have determined the carcinogenic hazard of this fibrous material. Although not generally accepted for human health hazard assessment, the International Agency for Research on Cancer (IARC) has classified both rock and slag wool as a "2B, possibly carcinogenic to humans."

Mineral wool is a form of insulation that in the past has been shown to contain lead particles. The lead health hazard during installation came from lead particulate released into the air. Exposure levels were found to be higher than acceptable standards, especially with blown-in applications.[14]

Rock and slag wool fibers are a catalyst for skin irritation. This irritation is a mechanical reaction of the skin to the ends of rock and slag wool fibers that have rubbed against or become embedded in the skin's outer layer. Workers in contact with mineral wool during manufacturing processes or installation are susceptible to this temporary nuisance. It can be relieved by gently rinsing the exposed skin with warm water and then washing with mild soap.

Eye irritation occurs when rock wool fibers or slag wool are deposited in the eye by the user's fingers or through airborne mineral wool fibers. If this occurs, the eyes should not be rubbed but rinsed thoroughly with warm water. A doctor should be consulted if the irritation persists.

If sufficient amounts of rock and slag wool are released into the air during manufacture or handling, some workers may experience temporary upper respiratory tract irritation. Such exposures to high concentrations of airborne rock and slag wool fibers may result in temporary coughing or wheezing, a mechanical reaction. These effects will subside after the worker is removed from exposure. The use of approved respiratory protection can effectively control upper respiratory tract irritation by limiting exposure to airborne fibers.

Environmental considerations

Given the relative use of these two materials, mineral wool has, on average, 75 percent postindustrial recycled content. (*Postindustrial recycling* refers to the use of industrial by-products, as distinguished from material that has been in consumer use.)[16] According to the North American Insulation Manufacturers Association (NAIMA), over 938 million lb (425 million kg) of blast furnace slag was used in 1992 to produce slag wool.[9]

Fire resistance

Rock and slag wools have good fire resistance because of their physical and chemical properties. The fibers are noncombustible and have melting temperatures in excess of 2000°F, supplying fire protection as well as sound control and attenuation.[9] Mineral wool is also a good material for insulating around chimneys because it does not support combustion.

Availability

Mineral wool insulation products also appear to be extremely popular outside the United States. For example, a softer mineral wool batt product is now available from a Canadian manufacturer. In contrast to the stiff and brittle rock wool batts, this new product is highly compressible, which allows easier insertion between framing members and a friction-fit installation. At the present time, the soft mineral wool batt insulation is more fragile than fiberglass insulation and is about 15 percent higher in cost.[16]

Installation standards and practices

General work practices, applicable to all work involving synthetic vitreous fibers (SVFs) such as rock and slag wool, have been established by OSHA. These are listed in the fiberglass section of this chapter.

In all cases, however, manufacturers' specific recommendations as outlined in their Material Safety Data Sheets (MSDSs) should be consulted. The installation methods for rock wool batt insulation are similar to those for fiberglass batt insulation. Please refer to the preceding section for general installation guidelines and procedures.

Plastic Fiber Insulation

The recycled content and clean manufacturing process of plastic fiber insulation are expected to make this product quite popular when it enters the marketplace in the near future. Plastic fiber batts are made from recycled polyethylene terephthalate (PET), commonly used to make milk containers. Although the batts are difficult to cut with standard tools, the insulation does not cause skin irritation. The batt insulation is extremely soft yet looks like high-density fiberglass.

R-values vary depending on the density of the product. R-values range from 3.8 to 4.3 per inch. The material does not burn when exposed to an open flame, but it melts at a low temperature. Major U.S. insulation manufacturers are expected to produce plastic fiber insulation products within the next few years.[15]

Cotton

Cotton insulation, also known as *agricultural fiber,* is available in blanket form and is installed in the same manner as fiberglass batts. This material has been produced for years, but developmental and marketing strategy changes have not allowed this product to gain a significant foothold in the residential market. Cotton insulation was developed originally as Insulcot by a small West Texas company using virgin cotton. Promoted initially as a nonirritating alternative to fiberglass, early market research revealed a consumer interest in the use of recycled fiber, and the company switched to mill scraps from denim and T-shirt mills. The developer eventually licensed production of the insulation to Greenwood Mills, a large textile manufacturer.[9] This was discontinued in late 1997 due to the excessive cost of production.[17] InnoTherm Products, LLC, has now purchased the equipment and technology for manufacturing batt insulation out of recycled cotton fabric from Greenwood Cotton Insulation Products. InnoTherm expects to begin commercial production of the insulation in 2000. The company is planning to pursue both automotive and building insulation markets, focusing initially on commercial building applications.[18]

Product description

Cotton insulation is a batt insulation with kraft paper facing made from polyester fibers and ground-up denim scrap from blue jean and T-shirt factories. Cotton thermal insulation is 75 percent cotton and 25 percent polyester and is treated with a flame retardant and insect/rodent repellents. The polyester improves tear strength and recoil characteristics. It meets the same class I standards for fire resistance as fiberglass insulation. The batts come in widths of 15, 16, 23, and 24". R-values include R-11, R-13, R-19, and R-30.[19]

Cotton insulation does not irritate the skin during installation and is composed of approximately 95 percent postindustrial recycled fiber. According to one installer, the fibers are a lot tougher than glass fibers, making cutting with a knife a little difficult.[19]

Fire resistance

Although treated with borates as a fire retardant, a Habitat for Humanity environmental home insulated with Insulcot in Austin, Texas, burned in March 1994 when a plumber's torch ignited some exposed insulation. Fire retardants for cellulose insulation were reportedly used in Insulcot, but different chemicals were used in a later composition.[9]

Availability

New production of cotton insulation is scheduled to start in 2000.

Appendix

The Energy Efficiency and Renewable Energy Clearinghouse (EREC)
P.O. Box 3048
Merrifield, VA 22116
800-DOE-EREC
Fax: 703-893-0400

Cellulose Insulation Manufacturers Association (CIMA)
136 South Keowee Street
Dayton, OH 45402
937-222-2462
http://www.cellulose.org/

CertainTeed Corporation
750 E. Swedesford Road
Valley Forge, PA 19482
800-233-8990
800-782-8777
http://www.certainteed.com/pro/insulation/
http://www.cphome.com/

Johns Manville
P.O. Box 5108
Denver, CO 80217
800-654-3103
303-978-2000
http://www.jm.com/

Knauf Fiber Glass
Glenn Brower
One Knauf Dr.
Shelbyville, IN 46176
800-825-4434
317-398-4434
Fax: 317-398-3675
Email: *gab2@knauffiberglass.com*

North American Insulation Manufacturers Association (NAIMA)
Catherine L. Imus
44 Canal Center Plaza, Suite 310
Alexandria, VA 22314
703-684-0084
Fax: 703-684-0427
E-mail: *insulation@naima.org*
Website: *http://www.naima.org*

Owens Corning
Bill Edmunds
Fiberglas Tower
Toledo, OH 43659
800-438-7465
614-321-7731
Fax: 614-321-5606
http://www.owenscorning.com

Southface Energy Institute
241 Pine Street
Atlanta, Georgia 30308
404-872-3549
Fax: 404-872-5009
http://www.southface.org

Thermafiber Mineral Wool
James Shriver
3711 W. Mill Street
Wabash, IN 46992
219-563-2111
Fax: 219-563-8979
E-mail: *jshriver@thermafiber.com*

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Chapter

9

Sprayed-in-Place Insulation

Whether referred to as *self-supported, wet-spray, damp-spray stabilized, spray-on,* or *dimensionally stable,* sprayed-in-place insulations are basically modified loose-fill products that are blown into wall cavities or attics. Cellulose, fiberglass, and rock wool are the most common materials used today. This method is similar to the exposed sprayed fireproofing systems commonly found on structural members in many commercial buildings. In contrast to the materials discussed in Chap. 7, a special blowing machine that combines an adhesive, water, and the insulating materials sprays the mixture into or over open wall and ceiling cavities. Sprayed-in-place insulation systems are especially advantageous when insulating irregular or out-of-square framed structures as well as walls with unusual interior geometry (such as cross-bracing, blocking).

Sprayed-in-place insulation adheres tightly to walls, framing members, and any other construction materials it may come into contact with. When installed properly, sprayed-in-place insulation uniformly covers the applied area, completely surrounding any obstructions within the cavity. The adhesive binds the insulation material to itself and to the application area. The adhesive is either a liquid that mixes with the insulation at the nozzle of the blowing machine or a powder premixed in the insulation material.

When applied correctly, this insulation resists settling and shifting and allows the cavity to be filled completely. By forming a continuously uniform blanket throughout the wall cavity, sprayed-in-place insulation allows no air gaps and provides very good resistance to air leakage while not creating any inherent resistance to moisture transmission.

Sprayed-in-place insulation is most practical for new construction or unfinished spaces such as basements with exposed studs. Installing sprayed-in-place insulation is often messy, since some of the insulation can become airborne or adhere to the stud faces and floor. After spraying, the stud faces are scraped clean to provide a flush blanket in the wall cavity. The excess insulation is recycled into the blowing machine for reuse as long as it is free of debris.

Sprayed-in-place insulation in unfinished spaces needs time to dry before being enclosed or sheathed. Sealing up the wall too soon after application sometimes leads to moisture problems, such as mold and mildew growth. The drying time for the insulation varies depending on the type of insulation material and its moisture content, the moisture content of the framing members, and the climate. Most products in use today require no more than 24 hours for drying.

There are a few general limitations. For example, the chemical fire retardants in some products may corrode the metal fasteners, piping, conduit, or structural members they contact. The long-term stability of some plastics in contact with such chemicals is also of concern.

R-value is important, but it is only one of the many factors that affect the actual performance of insulation as installed. Other important factors to consider include air permeability, ability of the insulation to "tighten" the building against air infiltration, susceptibility to convective heat loss under cold conditions, the potential for moisture permeation and accumulation and its deteriorating effects, and proper installation.

Sprayed-in-place insulation of any form should not be relied on to prevent moisture movement within an insulated cavity. Whether blown-in fiberglass, rock wool, slag wool, or cellulose is used, vapor retarders are required unless proper ventilation is provided. As with fiberglass batt insulation, materials used for vapor retarders for blown-in insulations must have a permanence rating of less than 1 perm. In a ceiling where the space above is adequately ventilated, a vapor retarder may not be required. The exception would be in cases where the cold side cannot be ventilated.[1]

Generally speaking, sprayed-in-place insulation systems (including installation costs) are usually more expensive than blanket insulation products. When comparing "apples with apples," sprayed-in-place fiberglass or cellulose insulation costs are comparable. Wet-spray rock wool and slag wool are often less expensive where available. Prices vary, however, depending on local supply and on labor rates.[2]

A similar system, proprietarily known as the Blow-In-Blanket System (BIBS), uses a form of wet- or dry-applied wall insulation. Fiberglass material is blown into the netted wall cavity either dry or with an adhesive binder.

Wet-Spray Cellulose

Cellulose insulation, as discussed in Chap. 7, is produced from recovered wood pulp materials. These include used newsprint and boxes that have been shredded and pulverized into small fibrous particles. Wet-spray cellulose, sometimes called *damp-spray cellulose* or *water-stabilized cellulose,* uses the same base material as loose-fill insulation, except that it is applied using special applicators that mix the material with an adhesive, allowing it to adhere to the surface it is applied to (Fig. 9.1). The adhesive(s) may be added to the insulation at the time of manufacture and, if necessary, activated by the addition of water when installed, or the adhesive may be added to the insulation at the time of installation.[3] Application of the insulation with the glue binder and liquid purportedly results in lower-density cellulose insulations that do not settle like dry-applied loose-fill cellulose insulations. This procedure requires trained or certified contractors for this specific

Figure 9.1 Applying wet-spray cellulose. (*Greenstone*)

installation. Wet-spray cellulose is excellent for sound control. It can be used in walls between rooms and other areas that require sound control. Many application systems are proprietary and are designed for use with specific products and equipment.

Product description

Wet-spray cellulose is designed for use in attics or wall cavities that are fully open (prior to the installation of the interior finish material). The sprayed material conforms to any substrate, around pipes, obstructions, and over cracks, reducing air infiltration and forming a highly efficient and effective thermal barrier.

After application, the insulation is planed even with the stud faces by the use of a “stud scrubber” (Fig. 9.2). The scrubber shaves the insulation mass so that it is flush with the face of the studs, thereby creating an insulation “blanket” custom-fit to the wall cavity (Fig. 9.3). The wall can be closed shortly after installation of the insulation; however, vapor retarders, as well as some types of paint and vinyl wallcoverings, should not be applied to the inner surface of the wall until the insulation has dried. Moisture-to-fiber ratios influence the drying time required after application. Although these times may vary with each manufacturer, 24 hours is a consistent average among most products. Moisture control is critical with wet-blown insulation because overly moist insulation requires a longer drying period before a wall can be closed up. It is also recommended by some that vapor retarders of any type should not be used with spray-applied cellulose. This recommendation may conflict with some building codes.

Standards

Cellulose insulation has been exposed to a broad range of construction, environmental, and various code requirements that have called for a more elaborate definition of physical properties. These requirements have been identified and met in the following federal regulations, federal procurement specifications, and industry standards.[4]

> Cellulose insulation intended for spray-on application in new walls is classified as a type II material under American Society for Testing and Materials (ASTM) Standard C1149. These materials normally contain adhesive to produce the cohesion necessary to make the insulation self-supporting. The adhesive may be

Figure 9.2 Stud scrubber. (*Greenstone*)

liquid added during the spraying process, or it may be dry adhesive contained in the insulation during the manufacturing process and activated by moisture during application.

16 CFR Part 1209, “Consumer Products Safety Commission Interim Safety Standard for Cellulose Insulation,” also referred to as the *CPSC Safety Standard.* This is the Consumer Products Safety Commission (CPSC) safety standard that covers four product attributes: settled density, corrosiveness, critical radiant

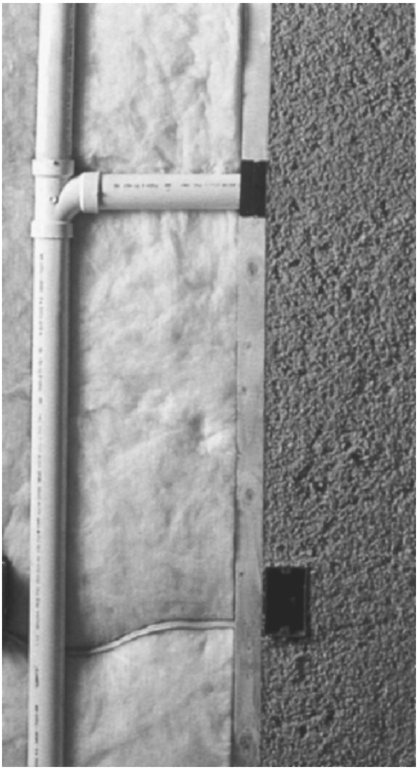

Figure 9.3 Fiberglass (*far left*) and cellulose (*near left*) (*Greenstone*)

flux (a measure of surface burning), and smoldering combustion. It is illegal to market cellulose insulation that does not conform with this section of the *Code of Federal Regulations*.

16 CFR Part 460, "FTC Trade Regulation Rule, Labeling and Advertising of Home Insulation," also known as the *FTC R-Value Rule*.

ASTM C167, "Test Methods for Thickness and Density of Blanket or Batt Thermal Insulations."

ASTM C168, "Terminology of Terms Relating to Thermal Insulating Materials."

ASTM C739, "Specification for Cellulosic Fiber (Wood Based) Loose Fill Thermal Insulation." This is the industry standard for loose-fill cellulose insulation. It covers all the factors of the CPSC regulation and five additional characteristics: R-value, starch content, moisture absorption, odor, and resistance to fungus growth.

ASTM C755, "Recommended Practice for Selection of Vapor Barriers for Thermal Insulation."

ASTM C1015, "Practice for Installation of Cellulosic and Mineral Fiber Loose Fill Thermal Insulation."

ASTM C1149, "Standard Specification for Self-Supported Spray Applied Cellulosic Thermal/Acoustical Insulation."

ASTM C1338, "Test Method for Determining Fungi Resistance of Insulation Materials and Facings."[11]

ASTM E 970-89, "Test Method for Critical Radiant Flux of Exposed Attic Floor Insulation Using Radiant Heat Energy Source."

Cellulose insulation is formulated and labeled as self-supporting, spray-applied material. Spray-applied cellulose installed in closed walls and in attics is approved for use in every code jurisdiction on the basis of conformance with the CPSC safety standard for loose-fill cellulose.

Although many of the tests described in ASTM C1149 differ from those in C739 and the similar CPSC 16 CFR Part 1209 procedures, manufacturers are justified in claiming CPSC compliance on the basis of the C1149 methodology because the tests described in C1149 are "reasonable test procedures."[4]

ASTM C1149 covers 10 material attributes: density, thermal resistance, surface burning characteristics, adhesive/cohesive strength, smoldering combustion, fungi resistance, corrosion, moisture vapor absorption, odor, and flame resistance permanency. Material installed using liquid adhesive (type I) also has substrate deflection and air erosion characteristic requirements. Obviously, under C1149, spray-applied material is tested in the sprayed state. The requirements for type III material defined by ASTM C1149 cover some attributes of stabilized cellulose. Specifiers may wish to require conformance with this standard.[4]

R-value

The typical R-value of spray cellulose insulation ranges from 3.5 to 3.8 per inch depending on the manufacturer. See Fig. 9.4 for one manufacturer's coverage specification sheet.

Limitations

Wet-spray cellulose for residential application is limited to enclosed or covered applications.

COCOON STABILIZED INSULATION — ATOMIZED PNEUMATIC APPLICATION COVERAGE CHART				
		Net Coverage No Adjustment for Trusses		
R-Value at 75 F Mean Temperature	Minimum Thickness	Maxiumum Net Coverage		Minimum Weight Per Square Foot
To Obtain an Insulation Resistance (R) of	Installed Insulation Should Not Be Less Than: (inches)	Square Feet Per Bag	Minimum Bags Required Per 1,000 Square Feet	Wt./ Sq. Ft. of Installed Insulation Shouldn't Be Less Than: (lbs)
R-50	13.5	20.5	48.8	1.464
R-42	11.4	24.4	41.0	1.230
R-40	10.8	25.6	39.0	1.172
R-38	10.3	27.0	37.1	1.113
R-32	8.6	32.0	34.1	.937
R-30	8.1	34.2	29.3	.878
R-24	6.5	42.7	23.4	.703
R-22	5.9	46.6	21.5	.644
R-19	5.1	53.9	18.5	.556
R-13	3.5	78.8	12.7	.381
R-11	3.0	93.1	10.7	.322
Sidewalls (Wall Spray)				
R-13 (2 x 4)	3.5	51.4	19.4	.583
R-20 (2 x 6)	5.5	32.7	30.6	.917

NOTE: The above coverage figures compensate for settling and are for estimating purposes only. To achieve stated R-Value do not exceed minimum square feet coverage per bag. Actual coverage will be influenced by job conditions and application techniques. This product is intended for spray applied application. This coverage chart does not apply to dry loose fill application.

Figure 9.4 Coverage chart. (*Greenstone*)

Health considerations

Cellulose fiber is characterized as a nuisance dust but is not a health hazard. The fire retardants used in cellulose insulation are also regarded as nonhazardous. For example, the toxicity of boric acid is one-sixth that of table salt. Nevertheless, respiratory protection should be worn while handling and installing the insulation material. Cellulose will not cause skin irritation. Special clothing is not required during installation.

Environmental considerations

Most cellulose insulation is approximately 80 percent postconsumer recycled newspaper by weight. The remaining 20 percent is comprised of fire-retardant chemicals and/or acrylic binders depending on the product. In 1994 alone, the cellulose industry used approximately 840 million lb of recycled newspaper. Experts suggest that if all new home construction in the United States were insulated with cellulose, over 3.2 million tons of waste newsprint would be used each year.[4]

According to the Cellulose Insulation Manufacturers Association (CIMA), cellulose has a very low comparative embodied energy, calculated to be 20 to 40 times less than mineral fiber insulations. (*Embodied energy* is the total energy, such as the fuels, electric power, transportation, and job-site power, used to extract, fabricate, package, transport, install, and commission a building product, material, or system.)

Fire resistance

Boron-based chemicals are added to the cellulose as a fire retardant. These chemicals also work as fungicides in protecting against mold, mildew, and other microbes. Manufacturers will list the specific product as having a class 1 rating for flame spread and smoke development when tested in accordance with ASTM E84.[5]

Cellulose insulation made from postconsumer paper is not a fire hazard. All cellulose insulation, including that made from postconsumer materials, must meet the flammability standards set by the CPSC. Because of its density, cellulose insulation keeps oxygen (the fuel of fire) away from structural building components, making them fire resistant.

In fire testing done at the National Research Council of Canada (NRCC), wet-spray cellulose, although not combustible, may have contributed to poor fire resistance as compared with dry-blown cellulose or rock wool batts. Since wet-spray insulation adheres to the wall sheathing, when the sheathing is exposed to the fire and collapses, it pulls the insulation out of the cavity, exposing the entire cavity to the fire. A cavity without any fireblocking or fireproof insulation functions like a chimney, but this may only be a problem with party (fire) walls that separate habitable dwellings.[2]

Installation standards and practices

Although this book is not intended to serve as a training manual for wet-spray cellulose installers, the following guidelines will provide a general framework for a better understanding of the application procedures. The guidelines listed below are to be used for general information purposes only and are not intended to supplant or override instructions provided by a specific manufacturer or applicable installation standards. When installing wet-spray cellulose materials, it is essential that the guidelines of the manufacturer are followed, unless superseded by local, state, or federal codes.[6]

Preliminary inspection and equipment. An inspection of the building should be made prior to installation, with special consideration given to the following areas:

1. All voids around windows and doors should be sealed to stop air infiltration. Various materials such as foam backer rod or urethane spray foam are available for this purpose.
2. All pipes, ducts, conduits, wiring, and outlets should be installed in the wall before the insulation is applied.
3. Any small areas from which the insulation is to be excluded, such as electrical boxes, should be masked.
4. Seal all vertical plumbing and electrical penetrations through both top and bottom plates of all walls.
5. Cover finished areas including windows, doors, fireplaces, etc. It is faster to protect finished surfaces than to clean them later. For this purpose, 2 or 4 mil polyethylene sheeting works well.
6. Cover electrical boxes until the spraying is completed. Duct tape works well.
7. If recycling the wet-spray cellulose, a totally clean floor is absolutely essential before starting to spray. Objects such as nails, wood, wire, etc. could damage the machine. Sweep these from the floor before starting to spray the wet-spray cellulose.
8. Shovels, brooms, and trash cans are usually needed for recycling and cleanup.

Application. Wet-spray cellulose insulation should be applied with the manufacturer-approved spray application machines and spray nozzles. The nozzles are a tube with a liquid atomizing unit attached to intermix fibers and liquid. Nozzles may have from two to six spray tips and must provide a consistent fiber-to-water ratio. A $2^1/_2$" semispiral hose, which allows the material to tumble and stay in the air stream, should be used. A diaphragm pump capable of 200 to 300 lb/in^2 at a flow rate of 2 to 5 gal/min is used to supply the pressure.

The blower machine may be mounted in a truck or trailer to be positioned at the job site as close to a door as practicable to make recycling easier and increase production. An alternative is to take the machine into the building in a central location. This works very well when spraying in cold weather.

The hose, a minimum of 100 ft in length, should be pulled to the farthest point to be insulated and have as few bends as possible. The water line, run alongside the hose, should be taped to the last 10 or 12 ft of insulation hose for ease of use. After all hoses and nozzles have been connected and properly tested, the installer is ready to begin. It is important to note that specific recommendations from the thermal insulation manufacturer must be followed. Liquid flow tests also should be made periodically to ensure a proper liquid-to-fiber ratio.

When spraying, the installer should aim with a downward spray angle of approximately 5 to 10 degrees and about 4 ft away from the wall. When spraying layers on layers, the cavity becomes one solid mass, with no inner voids, giving it structural integrity. As the nozzle moves from one side to the other, angle the nozzle sideways and maintain 5 to 10 degrees down, spraying into the existing insulation. Nearing the top of the wall, keep the nozzle angled down. To fill the very top, under the plate, turn the nozzle angle up and step in a little closer to pack the insulation against and into the top of the cavity. After the top portion is almost full, step back and level out the nozzle to finish the cavity. Be careful not to overfill the top portion of the wall cavity. The cavities under windows, soffits, etc. must be treated the same as the top plate.

A smooth and steady movement of the nozzle also will help to decrease the amount of overspray (the portion of material from a spray pattern not filling or adhering to intended substrates). Many new applicators have problems with falloff.

The thicker the wall, the more weight is pulling on the sprayed insulation. Therefore, it is very important to know the fiber-to-water ratio and keep it consistent. The thicker the walls, the more important this becomes.

The wider the distance between the studs, the less surface area the sprayed material has to attach itself to. Thus, 16" on-center stud spacing is much more forgiving than 24" on-center stud spacing. In framing with 2 × 8s, 24" on-center studs can be sprayed successfully with the right equipment and material.

The angle of the nozzle and the velocity of the material are the two most important factors to reduce falloff. The sprayed insulation must hit the substrate and stay. This can be achieved only with the proper angle. If the angle is not correct, the material will tend to deflect or slide off the studs and substrate. This can be mastered with practice and training.

A “stud scrubber,” a rotating brush that grooms the insulation level with the face of the studs, is the best tool for cleaning down walls. Scrubbing typically can be performed immediately after the spray-on application. The product does not have to be dry in order to plane the wall cavity. Recycling of excess material is also performed as the installation process progresses. Normal drying will occur within 24 to 48 hours depending on climatic conditions, depth of fill, and initial moisture content. The manufacturer’s recommended drying times should be followed.

Recycling the excess material translates to very little waste, although it can be more time-consuming. The material must be mixed properly when recycling, or problems are likely to occur. If the material is mixed improperly, the wall cavity insulation may be too wet, causing inconsistent flow and leading to instability, and the insulation may fall out of the wall cavity. The moisture or fiber volume must be adjusted carefully when the recycling method begins. The recycled material adds moisture mixed with the dry product. Adjusting the water pressure or changing the spray tips will help maintain the same moisture percentage throughout the job.

Installation of the interior finish should not be done until the insulation has dried. This should be monitored using a moisture meter. (CIMA recommends the Wagner Electronics Model L6101.) The wet-spray cellulose may be enclosed when it is sufficiently dry, having a measured moisture content of 25 percent or less.

Wet-spray cellulose can be applied successfully in freezing conditions, but the manufacturer should be consulted for recommendations on spraying in severe climates and conditions. Since the entire spray system can freeze up, heating the building while spraying is necessary if the temperatures are below freezing. After the spraying is completed, the heat can be turned off. The windows should be opened in order to facilitate air movement and moisture removal. If heat is used during the drying process, it is imperative to have ventilation to the outside. Dry heat, such as electric, works the best. It will speed up the drying process. Propane or gas heat can add high percentages of moisture and should be avoided.

The wet-spray cellulose will take longer to dry in colder climates. If ambient temperatures are expected to drop below 40°F before drying is completed, it may be necessary to use supplemental heat until the moisture content measures 25 percent or less.

Vapor retarders

As discussed in Chap. 4, the need for vapor retarders and their proper location within a wall assembly are influenced by the interior and exterior environmental conditions, as well as the wall's thermal and vapor flow characteristics. When installing loose-fill insulations, a material such as 6-mil (0.006-in) polyethylene plastic sheeting can be used as a vapor retarder. Some cellulose manufacturers recommend against the use of vapor retarders in walls insulated with spray-applied cellulose. CIMA is not aware of any endemic problems resulting from this practice.[7] Research reviewed for this book does not suggest that there is sufficient evidence to eliminate vapor retarders from conventional construction. It is important to note that each building is fairly unique in terms of wall construction, interior use, and environmental conditions, and should be evaluated individually by the building designer. If unsure, the homeowner could consult the local or state building codes about the use of vapor retarders. The insulation manufacturer also may provide recommendations on where to place a vapor retarder.

Installation precautions and limitations

As stated earlier, the following items may be in concert with or in contradiction with the adopted state and federal building codes. The building codes are a minimum level of safety and quality and must be adhered to.

1. Heaters and recessed light fixtures must not be covered by the insulation unless the fixture has a direct-contact rating. It is recommended that a minimum of 3 in of airspace be maintained between any fixtures and the blocking.
2. Cold air returns and combustion air intakes for hot-air furnaces must not be blocked, or the insulation installed in such a manner as to allow it to be drawn into the system.
3. Insulation must not be in contact with chimneys or flues. A minimum of 3" of airspace must be maintained, with blocking used to retain the insulation.

4. This insulation is not recommended for filling the cavities of masonry walls.
5. Consult the manufacturer about using wet-spray cellulose below grade or ground level because of moisture considerations.
6. This insulation is to be used in the temperatures range of −50 to 180°F.
7. The installer must wear appropriate respiratory protective equipment.

Spray-on Fiberglass

As discussed in Chap. 7, fiberglass is one of a group of glassy, noncrystalline materials historically referred to as *man-made mineral fibers* (MMMFs) or *man-made vitreous fibers* (MMVFs). The fiber is made from molten sand, glass, or other inorganic materials under highly controlled conditions. After the glass is melted in a high-temperature gas or electric furnace, the material is spun or blown into fibers that are then processed into the final product. The base material for spray-on fiberglass is fiberglass loose-fill insulation. Inorganic and noncombustible, the fibers will not rot or absorb significant amounts of moisture. Fiberglass does not support the growth of mildew, mold, or fungus.

The terminology used in the spray-on fiberglass industry can be overlapping in discipline and at times confusing. Applying wet-spray fiberglass is similar to applying sprayed-on fireproofing. The material typically is left exposed and is suited for commercial projects or, on rare occasions, high-end residential projects. There are two predominant methods of spraying fiberglass loose-fill in residential construction. The most common method is proprietarily known as the *Blow-In-Blanket System (BIBS)*. A second method, known as *dimensionally stable fiberglass,* uses loose-fill insulation applied in a manner similar to stabilized cellulose insulation and is discussed later in this chapter.

The Blow-In-Blanket System (BIBS)

A technological variation from the simple blown-in loose-fill fiberglass insulation discussed in Chap. 7 is the Blow-In-Blanket System (BIBS). Developed by Ark-Seal, Inc., in 1985, BIBS is a patented and trademarked system that is installed exclusively by certified contractors using proprietary equipment and approved ingredients. The system is used in residential and commercial construction for thermal and acoustical insulation. The system also can be used to insulate floors, attics, and cathedral ceilings. BIBS insulation technically could qualify as a loose-fill insulation product because the netting used in this system is actually creating the wall cavity. The presence of a binder is the reason it is included in this chapter (Figs. 9.5 and 9.6).

In 1998, Ark-Seal unveiled a dry product, proprietarily known as the *Blow-In-Blanket Dry System*. R-values for a 2 × 4 wall and a 2

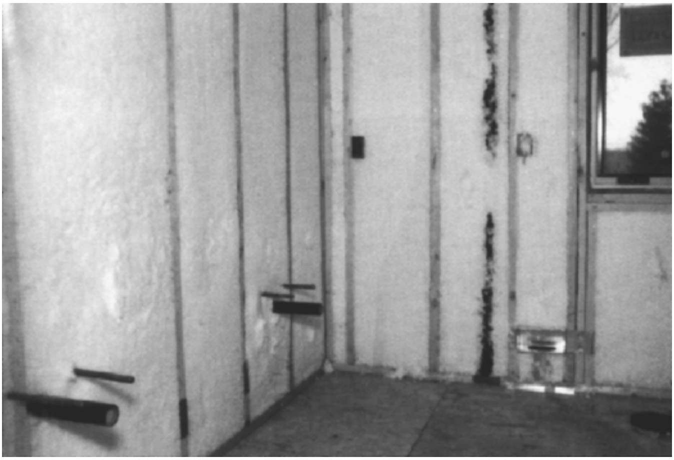

Figure 9.5 BIBs in sidewalls. (*Ark-Seal*)

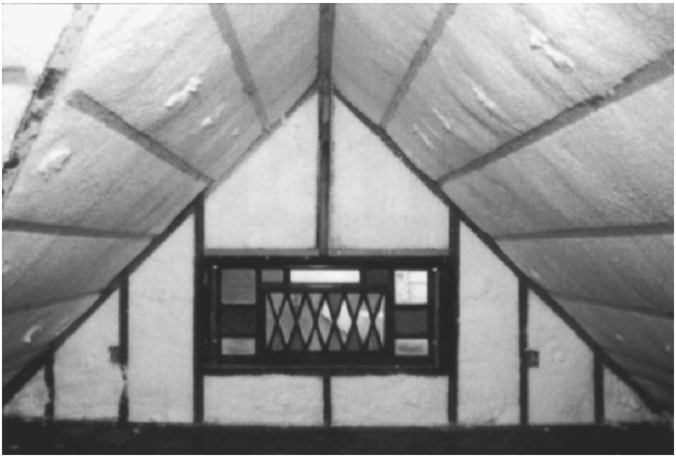

Figure 9.6 BIBs in cathedral ceiling. (*Ark-Seal*)

$\times$ 6 wall are R-15 and R-23, respectively. As with the original system, fiberglass is blown in behind a special netting. Since the insulation is dry, gypsum wallboard can be applied immediately. The original Blow-In-Blanket System will be discussed in this chapter.

Product description

The original BIBS insulation consists of adhesive-coated white fiberglass loose-fill fibers that are blown into wall cavities and retained by a lightweight polypropylene netting that is typically stapled to wood framing studs. Double-sided tape or special hooks are used for attaching the netting to metal stud framing. The netting is slit with a utility knife where necessary so that the installation hose will fit through to the area to be filled. Wall cavities are then filled with insulation through a hose connected to the "heart" of the system, a patented high-pressure machine called "the big blower." A thin mist of latex binder blends with the fiberglass at the blower to prevent the fiberglass from sagging. Insulation is added to the wall cavity until the netting bulges out about 1 to $1^1/_2$". The fibers will compress beneath the gypsum wallboard to achieve the proper density and R-value (Fig. 9.7).

The Blow-In-Blanket System completely fills the wall cavity, including all wiring and fixtures, while eliminating voids and air gaps. Tests conducted by the National Association of Home Builders' (NAHB) National Research Center show that the Blow-In-Blanket System reduces air infiltration by up to 68 percent over conventional batt-type insulation. (This may not be as dramatic as it appears, since tests show that wall insulation is insignificant in controlling air leakage; gypsum wallboard is a much bigger factor.)[8]

The BIBS insulation has a resistance to settling and drifting. When installed correctly, BIBS insulation provides a uniform density even in hard-to-insulate sidewall areas. Typically installed using a two-person crew, BIBS insulation can be used in renovation and new construction for either wood or steel stud framing systems.

R-value

Insulating values of up to R-15 for 2 $\times$ 4 walls and up to R-23 for 2 $\times$ 6 walls can be achieved. The ASTM C518 test for the Blow-In-Blanket System states that the R-value is 4.2 per inch, although some manufacturers have the R-value listed as 4.0 per inch (Fig. 9.8).

Figure 9.7 Installing the blow-in-blanket system. (*CertainTeed*)

Limitations

The only limitation is that BIBS insulation must be installed by a certified BIBS contractor. There are currently about 300 licensed installers in the United States and another 400 in other parts of the world.[9] The loose-fill insulation also must be fully compatible with The Blow-In-Blanket System. As with any loose-fill insulation product (see Chap. 7), dishonest installers can even "fluff" BIBS insulation by installing it at lower density than disclosed to the homeowner.

Fire resistance

BIBS insulation meets HH-I-1030B testing criteria for smoldering combustion and ASTM E136 criteria for noncombustion. The flame spread rating is 0, and the smoke development rating is 5.

Installation standards and practices

The Blow-In-Blanket System must be operated by a certified BIBS contractor. This requirement should help maintain a consistent quality of installation of the product. Natural ventilation must be

Sidewall Applications

When installed with BIBS equipment in sidewalls, the following thermal performance based on a nominal 27 lb. bag is achieved at the thicknesses, weights and coverages specified:

Thickness				Density		Minimum Weight		Maximum Coverage per Bag	
in.	mm.	R-Value	RSI	Lbs./Cu. Ft.	Kg/Cu. Meter	Lbs./Sq. Ft.	Kg/Sq. Meter	Sq. Ft.	Sq. Meters
3½ (2X4)	89	14	2.5	1.8	28.8	0.525	2.563	51	4.7
3½ (2X4)	89	15	2.6	2.3	36.8	0.671	3.276	40	3.7
5½ (2X6)	140	22	3.9	1.8	28.8	0.825	4.028	33	3.1
5½ (2X6)	140	23	4.1	2.3	36.8	1.054	5.146	26	2.4
7¼ (2X8)	184	29	5.1	1.8	28.8	1.087	5.307	25	2.3
7¼ (2X8)	184	31	5.5	2.3	36.8	1.389	6.782	19	1.8
9¼ (2X10)	235	37	6.5	1.8	28.8	1.387	5.772	20	1.9
9¼ (2X10)	235	39	6.9	2.3	36.8	1.772	8.652	15	1.4

Figure 9.8 BIBs sidewall specification chart. (*CertainTeed*)

provided to properly dry the insulation material during and after its application.

Dimensionally Stable Fiberglass

Dimensionally stable (DS) fiberglass is a patented process by Guardian Fiberglass, Inc., called *UltraFit DS*. Relatively new to the market, DS fiberglass spray-on insulation is applied by a process that is similar to that used for stabilized cellulose insulation. A fine mist of water is combined with the loose-fill fiberglass and a dry adhesive binder. As in wet-spray cellulose applications, the excess fiberglass material is scrubbed off the face of the studs and is immediately recyclable.

Product description

DS fiberglass can be used in nonexposed applications of residential or light commercial projects, whether it be new construction or renovation. The UltraFit DS System does not contain any chemicals or additives that are conducive to corrosion of pipes, wires, or metal stud framing systems. The inorganic qualities of this system do not cause fungus growth or promote an attraction for insects or pests.

The binder is a powdered inorganic adhesive that gets mixed in with the loose-fill fiberglass at the manufacturing plant. Once the job site has been prepared and cleaned, a certified installer blows the DS fiberglass through a hose into the wall. Nozzles mix water with the fiberglass as it is sprayed into the wall, activating the premixed adhesive. This chemical reaction automatically bonds the fibers together, creating a monolithic blanket of insulation in sidewall applications that significantly reduces voids and air gaps. After spraying, the installer goes back over the face of the wall framing with a power scrubber to plane off excess insulation, which is vacuumed up and fed back into the hopper. The drying time is also similar to wet-spray cellulose. A curing period of 24 hours is the typical waiting period after application before gypsum wallboard can be installed.

According to the manufacturer, there is very little airborne glass fiber during application. Water is used to activate the glue, which keeps the material wet during application.

Limitations

Only qualified contractors approved by Guardian Fiberglass, Inc., may install and market the UltraFit DS System. Any installation must be done in accordance with all product label instructions, as set forth by Guardian Fiberglass, Inc., as determined by its testing. Guardian fiberglass also must be used during installation.

Airtightness test results have not been released as of this writing. It also has not been determined if airborne fiberglass particles released during installation are problematic.

Fire resistance

DS fiberglass is noncombustible, as determined by tests based on ASTM E136.

Installation standards and practices

General work practices applicable to all work involving synthetic vitreous fibers (SVFs) such as fiberglass (rock wool and slag wool) have been established by the U.S. Occupational Safety and Health Administration (OSHA). Excerpts of the guidelines are as follows[10]:

1. Minimize dust generation.
   - Keep the material in its packaging as long as practicable and if possible.
   - Tools that generate the least amount of dust should be used. If power tools are to be used, they should be equipped with appropriate dust collection systems as necessary.
   - Keep work areas clean and free of scrap SVF material.
   - Do not use compressed air for cleanup unless there is no other effective method. If compressed air must be used, proper procedures and control measures must be implemented. Other workers in the immediate area must be removed or similarly protected.
   - Where repair or maintenance of equipment that is either insulated with SVF or covered with settled SVF dust is necessary, clean the equipment first with a HEPA vacuum or equivalent (where possible), or wipe the surface clean with a wet rag to remove excess dust and loose fibers. If compressed air must be used, proper procedures and control measures must be implemented. Other workers in the immediate area must be removed or similarly protected.
   - Avoid unnecessary handling of scrap materials by placing them in waste disposal containers and by keeping equipment as close to working areas as possible, which prevents release of fibers.

2. Ventilation
   - Unless other proper procedures and control measures have been implemented, dust-collection systems should be used in manufacturing and fabrication settings where appropriate and feasible.
   - Exhausted air containing SVFs should be filtered prior to recirculation into interior workspaces.
   - If ventilation systems are used to capture SVFs, they should be checked and maintained regularly.

3. Wear appropriate clothing.
   - Loose-fitting, long-sleeved, and long-legged clothing is recommended to prevent irritation. A head cover is also recommended, especially when working with material overhead. Gloves are also recommended. Skin irritation cannot occur if there is no contact with the skin. Do not tape sleeves or pants at wrists or ankles.
   - Remove SVF dust from the work clothes before leaving work, to reduce potential for skin irritation.

4. Wear appropriate personal protective equipment.
   - To minimize upper respiratory tract irritation, measures should be taken to control the exposure. Such measures will be dictated by the work environment and may include appropriate respiratory protective equipment. See OSHA's respiratory protection standard.
   - When appropriate, eye protection should be worn whenever SVF products are being handled.
   - Personal protective equipment should be fitted properly and worn when required.

5. Removal of fibers from the skin and eyes.
   - If fibers accumulate on the skin, do not rub or scratch. Never remove fibers from the skin by blowing with compressed air.
   - If fibers are seen penetrating the skin, they may be removed by applying and then removing adhesive tape so that the fibers adhere to the tape and are pulled out of the skin.
   - SVFs may be deposited in the eye. If this should happen, do not rub the eyes. Flush them with water or eyewash solution (if available). Consult a physician if the irritation persists.

The following work also typically should be performed in order to properly prepare the job site prior to installation:

1. Examine all surfaces and conditions to which the insulation is to be applied. Ensure that they are adequate to provide a satisfactory application of the specified materials.
2. Provide adequate protection to adjacent surfaces by means of drop cloths or polyethylene sheets.
3. Close off and seal any duct work in areas where sprayed insulation is being applied.
4. Clean off any dust, loose dirt, foreign material, etc. on surfaces to which the insulation is to be applied, which could otherwise create a false bond.

Health considerations

As discussed in Chap. 7, the debate has been intensifying since the mid-1980s as to the safety of using fiberglass insulation. The concern has been that the fibers that comprise fiberglass may replicate the affects of the fibers found in another silicon dioxide material, asbestos. The structure and size of these glass fibers vary. The smaller fibers, which cannot be seen by the naked eye, are suspected of entering the lungs, whereas larger, visible fiberglass particles can be irritating to the skin, eyes, nose, and throat.

Fiberglass is listed by the International Agency for Research on Cancer (IARC) as a potential carcinogen and by the National Toxicology Program (NTP) as "reasonably anticipated to be a carcinogen." Although occupational and residential exposures to fiberglass fibers are low when compared with past asbestos exposures, all fiberglass insulation is required to have a cancer warning label as mandated by the OSHA Hazard communication standard.[11]

The Consumer Product Safety Commission also has found that "fibrous glass is carcinogenic in animals only when surgically implanted into the lung or abdomen. In tests where animals were exposed by inhalation, the expected route of human exposure, the animals did not develop tumors. Therefore, the animal implantation studies do not establish a hazard to humans."[12]

Nevertheless, fiberglass as a simple irritant is well documented. Fiberglass released into the air during its manufacture or handling also may create temporary upper respiratory tract irritation. Like skin irritation, upper respiratory tract irritation is a mechanical reaction to the fibers. It is not an allergic reaction, and the irritation generally does not persist. Such exposures to high concentrations of airborne fiberglass may result in temporary coughing or wheezing. These effects will subside after the worker is removed from exposure.[13]

Workers in fiberglass manufacturing plants, as well as people working with or using materials that contain fiberglass, may develop a skin irritation. This mechanical irritation is a physical reaction of the skin to the ends of fibers that have rubbed against or become embedded in the skin's outer layer. Any skin irritation caused by fiberglass is temporary. Washing the exposed skin gently with warm water and mild soap can relieve it. The vast majority of workers and consumers, however, can control skin irritation by following recommended work practices when handling the material. Fiberglass is also the catalyst for eye irritation if deposited in the eye by the user's fingers or through fibers in the air. If this should happen, the eyes should not be rubbed but rinsed thoroughly with warm water, and a doctor should be consulted if irritation persists.[13]

Environmental considerations

Fiberglass uses two resources, sand and recycled glass. Sand does not impose an impact on nonrenewable natural resources. Recycled plate and bottle glass is considered a secondary raw material, so, when used as raw material, recycled glass is changed into a product that can save energy and reduce pollution.

Wet-Spray Rock Wool and Slag Wool

Rock wool and slag wool fall within a group of materials historically referred to as *man-made mineral fibers* (MMMFs) or *synthetic vitreous fibers* (SVFs); however, a more appropriate name is *man-made vitreous fibers* (MMVFs). First patented as a commercial product in the United States in 1875, MMVFs were not used as a wet-spray insulation for residential open-wall cavities until approximately 10 years ago in Texas.

Rock wool and slag wool each use different raw materials in their manufacture. Rock wool is made primarily from natural rock such as basalt or diabase. Slag wool is made primarily from iron ore blast furnace slag. The base material of wet-spray rock wool is the same material used in rock wool loose-fill insulation (see Chap. 7), except that it is smaller in particle size and mixed with an adhesive.

Product description

Wet-spray rock wool insulation is applied in the same manner as wet-spray cellulose insulation. The mineral wool material, which contains a dry adhesive, is mixed with a small amount of water and blown into open wall cavities at a density of approximately 4 lb/ft^3. The water activates the binder, which strengthens the bonding of the material to the sheathing and studs. After spraying onto the substrate, contractors screed the wall framing members using a motorized roller that runs down the face of the studs (Fig. 9.9). The mixture ratio is usually 1 gal of water per 55 lb of rock wool, but may vary among manufacturers. The vapor retarder, if applicable to the specific locality or building code, can be installed immediately after the wet-spray insulation cures.

Like other wet-spray insulation types, rock wool is very effective for insulating behind and around electrical boxes, wires, and pipes. It can fill the most difficult wall cavities, leaving virtually no voids. It will not support the growth of mildew, mold, or bacteria when tested in accordance with the specifications of the ASTM (C1338).

Although prices will vary depending on local supply and labor rates, wet-spray rock wool and slag wool are often less expensive than wet-spray fiberglass and wet-spray cellulose insulation.[2]

Figure 9.9 Rock wool wall scrubber. (*American Rockwool*)

R-value

Rated R-value in wall applications is 4.1 per inch, or about R-14.5 in a $3^1/_2$" wall cavity. Small amounts of moisture have no effect on the R-value, provided the material is not mechanically disturbed and is allowed to dry.

Limitations

Wet-spray rock wool insulation must be installed by a certified contractor if possible. Manufacturer's recommendations must be followed because the quality of the installation is directly rated to the proper mixing of water with the insulation.

Health considerations

As discussed in Chap. 7, human epidemiologic studies have not demonstrated evidence of a dose-related causal association between lung cancer or nonmalignant respiratory disease and occupational exposure to rock and slag wools. Animal inhalation studies using massive doses of rock and slag wool fibers, hundreds to thousands of times greater than human exposures, have not shown a relationship between inhalation of rock and slag wool fibers and lung cancer either. Since 1987, several major reviews have been undertaken on the health and safety of rock and slag wools. All these reviews concluded that inhalation of rock and slag wool fibers does not induce significant disease in animals.[14]

With publication of the OSHA hazard communication standard in 1983 and the IARC decision in 1987 to classify rock and slag wool as "possibly carcinogenic to humans," rock and slag wool manufacturers have added cancer warnings to their product labels. While this may be alarming to an uninformed user of rock and slag wool products, the primary purpose of the labels is simply to identify a potential hazard. The labels do not signify that there is any real risk to humans at actual levels of exposure.

The use of injection/implantation studies as the sole determinant of the carcinogenic hazard of a fibrous material is not generally accepted for human health hazard assessment. These studies, however, have not produced significant tumors except for one injection test at an exceedingly high concentration.[15] However, the fact that rock wool fibers, when intentionally inserted into animals, have produced tumors may not be a practical analysis for casual exposure. Based primarily on these studies using nonphysiologic routes of exposure, IARC considered the animal evidence as limited for rock wool and inadequate for slag wool and, following its own guidelines, classified both rock and slag wool as a "2B, possibly carcinogenic to humans."[14]

Some of the mineral wool insulation manufactured before about 1970 has been found to contain lead particles. According to industry sources, lead slag is no longer used in the manufacture of mineral wool, although lead can be present as a trace impurity.[16]

Rock and slag wool fibers are a source of skin irritation. This irritation is a mechanical reaction of the skin to the ends of rock and slag wool fibers that have rubbed against or become embedded in the skin's outer layer. Workers in contact with mineral wool during manufacturing processes or installation are susceptible to this temporary nuisance. It can be relieved by washing the exposed skin gently with warm water and mild soap.

Eye irritation occurs when rock wool or slag wool are deposited in the eye by the user's fingers or through airborne mineral wool fibers. If this occurs, the eyes should not be rubbed but rinsed thoroughly with warm water. A doctor should be consulted if the irritation persists.

If sufficient amounts of rock wool and slag wool are released into the air during manufacture or handling, some workers may experience temporary upper respiratory tract irritation. Such exposures to high concentrations of airborne rock and slag wool fibers may result in temporary coughing or wheezing, a mechanical reaction. These effects will subside after the worker is removed from exposure. The use of approved National Institute of Occupational Safety and Health (NIOSH) respiratory protection can effectively control upper respiratory tract irritation by limiting exposure to airborne fibers.

Fire resistance

Rock and slag wool fibers are noncombustible.

Installation standards and practices

Certified contractors, if available, should install a proprietary wet-spray rock wool insulation product. It is still prudent, whether installing or observing an installation, to follow a number of general work practices during spraying. These general work practices, applicable to all work involving synthetic vitreous fibers (SVFs) such as rock wool and slag wool, have been established by OSHA.

These are listed in the sprayed-in-place fiberglass section of this chapter.

Appendix

The Blow-in Blanket Contractors Association (BIBCA)
1051 Kennel Drive
Rapid City, SD 57701
800-451-8862

The Energy Efficiency and Renewable Energy Clearinghouse (EREC)
P.O. Box 3048
Merrifield, VA 22116
800-DOE-EREC (363-3732)
Fax: 703-893-0400

Cellulose Insulation Manufacturers Association (CIMA)
136 South Keowee Street
Dayton, OH 45402
937-222-2462

Insulation Contractors Association of America (ICAA)
1321 Duke Street, Suite 303
Alexandria, VA 22314
703-739-0356

North American Insulation Manufacturers Association (NAIMA)
44 Canal Center Plaza, Suite 310
Alexandria, VA 22314
703-684-0084
Fax: 703-684-0427
E-mail: *insulation@naima.org*
Website: *http://www.naima.org*

Ark-Seal, Inc., International
2190 So. Klammath Street
Denver, CO 80223
800-525-8992
303-934-7772
Fax 303-934-5240
E-mail: *arkseal@hotmail.com*

Cocoon/Greenstone
6500 Rock Spring Dr.
Suite 400 Bethesda, MD 20817
888-592-7684
Fax: 402-379-2780
http://www.greenstone.com/

Guardian Fiberglass, Inc.
Gary Romes
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517-629-6361
Fax: 800-748-0437
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Thermafiber Mineral Wool
James Shriver
3711 W. Mill Street
Wabash, IN 46992
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Fax: 219-563-8979
E-mail: *jshriver@thermafiber.com*

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Chapter

10

Foamed-in-Place Insulation

Foamed-in-place insulation materials have become fairly popular in the commercial and residential building industry since the early 1970s. The technical data, however, can be as dizzying as high school chemistry because the benefits of the different materials are determined by more than just R-value alone. Cost, thoroughness of installation, and air and vapor retarder properties all are to be considered when selecting a foamed-in-place insulation product.

A plastic foam material consists of a gas phase dispersed in a solid plastic phase and derives its installed properties from both. The solid plastic component forms the matrix, whereas the gas phase is contained in voids or cells. It is often referred to as the *blowing* or *foaming agent.* Although specific processes vary, foamed-in-place insulations start as a liquid that is sprayed through a nozzle into wall, ceiling, and floor cavities. The chemical reaction created by the mixing at the nozzle causes the material to expand while it is sprayed onto or into a wall cavity. The insulation is a cellular material with millions of tiny air-filled cells. The term *cellular plastic,* a synonym for *plastic foam,* is derived from the structure of the material.[1]

Foams are classified as open-cell or closed-cell. In *open-cell foams,* the individual cells are interconnected. These insulation materials are of low density and flexible, with a rigidity similar to that of a sponge or sponge rubber. Polyicynene, for example, uses water as a blowing agent and heat to create the open-cell structure that provides the thermal performance, and can be installed in any thickness.

In *closed-cell foams,* each cell (more or less spherical in shape) is completely enclosed by a thin wall or membrane of plastic. These foams comprise the high-density, rigid foams like polyurethane foam. The typical installation is only 2.5 to 3", not filling the cavity completely. Closed-cell foams also take longer to completely dry (cure), although spray polyurethane foam (SPF) typically rises and sets in between 5 and 15 seconds and is dry to the touch in less than a minute.

Foamed-in-place materials require special equipment to meter, mix, and spray into place. Installation of foamed-in-place insulation is always done by certified insulation installers. Spray-foam materials cost more than conventional blanket insulation but provide a more complete coverage and may perform as an air retarder. An approved 15-minute barrier, such as gypsum wallboard, must cover all foam materials on the inside of a building except where approved by building codes or local building code officials based on diversified fire tests specific to the application.

Foam systems provide good air leakage control, moisture control, and sound control, in addition to providing thermal insulation. In other words, many of these products in certain climates can serve as a one-step insulation, moisture/vapor barrier, and wind barrier system. The foam system can take the place of building wrap, fiberglass, polyethylene vapor barrier, tape, foam, and caulking and eliminates the labor-intensive work associated with airtightness detailing when insulating with conventional insulation products.[2] Elimination of the air barrier may offset some of the additional costs.

Polyurethane foam insulation has come under scrutiny in the past two decades in the wake of growing environmental awareness. The public health concerns resulting from the use of formaldehyde in urea formaldehyde foam insulation (UFFI) may have been the catalyst for more public and scientific protests surrounding the environmental consequences of chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) that are used in the blowing agents that create the foam's insulating cells. (For a complete discussion of UFFI, see Chap. 16.)

A chlorofluorocarbon (CFC) is a compound consisting of chlorine, fluorine, and carbon. CFCs are very stable in the troposphere. They were developed in 1930 by DuPont and General Motors for use as safe refrigerant alternatives to sulfur dioxide and ammonia, which were corrosive and toxic. DuPont began selling CFCs under the trade name Freon for use in refrigerators (CFC-11) and air conditioners (CFC-12). Besides being used as refrigerants, CFCs were used as nontoxic and nonflammable blowing agents for making foam (CFC-11, CFC-12). During the early 1970s, scientists discovered that CFC molecules did not easily decompose in the lower atmosphere because of their chemical stability. Instead, they were drifting into the stratosphere and attacking the ozone layer, which shields the earth from harmful ultraviolet radiation.[3] They are broken down by strong ultraviolet light in the stratosphere and release chlorine atoms that then deplete the ozone layer.[4]

A hydrochlorofluorocarbon (HCFC) is a compound consisting of hydrogen, chlorine, fluorine, and carbon. The HCFCs are one class of chemicals being used to replace the CFCs. They contain chlorine and thus deplete stratospheric ozone, but to a much lesser extent than CFCs.[4]

The initial hypothesis linking CFCs and depletion of the stratospheric ozone layer was first published in 1974. Between 1974 and 1987, scientists continued to research and understand atmospheric processes that were affecting stratospheric ozone.[5]

The ozone layer is the region of the stratosphere containing the bulk of atmospheric ozone that lies approximately 10 to 25 miles above the Earth's surface. Depletion of this layer by ozone-depleting substances (ODS) will lead to higher ultraviolet radiation (UVB) levels, which in turn will cause increased skin cancers and cataracts and potential damage to some marine organisms, plants, and plastics.[4]

In 1987, an international team of scientists collected and analyzed evidence reportedly linking the Antarctic ozone hole to ozone-depleting chemicals. In response to this growing threat, the international community negotiated the Montreal Protocol, which led to the U.S. Congress passing the Clean Air Act Amendments of 1990. These amendments set into place restrictions on the production and consumption of ODS, a ban on nonessential products, requirements for approving the use of safe substitutes only, and a requirement for warning labels.[5]

A July 1992 ruling required producers of class I substances (CFCs, halons, carbon tetrachloride, and methyl chloroform) to gradually reduce their production of these chemicals and to phase them out completely as of January 1, 2000. As of 2003, there will not be any production and/or importing of HCFC-141b, the most common blowing agent of polyurethane products. An identical ban on HCFC-142b and HCFC-22 will be enforced in 2010. As of 2015, there will not be any production and/or importation of any HCFCs, except for use as refrigerants in certain equipment.

The scheduled phase-out of CFCs and HCFCs has played a role in the research and development of various spray-foam materials. (The switch by conventional polyurethane manufacturers from CFC-11 to HCFC-141b has greatly reduced the ozone-depletion impacts, but even HCFC depletes ozone to some extent.[6]) Polyurethane, once an industry leader, now has competition from Icynene, Air-Krete, Tripolymer Foam, and other products that have been developed without using CFCs or HCFCs for foaming agents.

Icynene

Icynene Insulation System is the registered trademark for polyicynene insulation that is manufactured by Icynene, Inc. This foamed-in-place product arrived on the Canadian market in 1986. The low-density, open-cell modified polyurethane typically is foamed into open cavities and is installed with conventional spray equipment.

Product description

Polyicynene is an organic material developed from products of the petrochemical industry that has the texture and appearance of angel food cake. The foam is made up of millions of tiny cells filled with air that provide permanent control of air and moisture movement. The product is applied on the building site by a trained and licensed installer and provides a custom insulation that fits into virtually any size of cavity (Figs. 10.1 and 10.2).

The Icynene Insulation System is a two-part system consisting of isocyanate MDI and polyicynene resin. The two liquid components are mixed under heat and pressure in a 1:1 ratio within a spray-gun mixing chamber. Water serves as the foaming agent, reacting with the other components to generate CO_2, which expands the foam. This eliminates polyurethane's HCFC-related environmental problems but also means a lower R-value because the cells are filled with air, not a blowing agent. Triggering the gun allows the material to be released to the substrate, similar to spray painting, where it reacts from the mixture and expands to 100 times its liquid size. Within seconds, the foam expands to its full thickness, filling (and sometimes overfilling) the cavity. The labor involved in applying 10" of foam is not a great deal more than in a 2" application, so thicker applications are more cost-effective than thinner ones.

Figure 10.1 Spray application of Icynene. (*Icynene*)

Figure 10.2 Icynene after being scarfed. (*Icynene*)

According to the manufacturer, the Icynene Insulation System provides an environmentally safe, complete insulation and air retarder system that windproofs and seals wall, floor, and ceiling cavities against air movement, including spaces around electrical outlets and light fixtures, at baseboards, and behind window and door frames. In fact, the company promotes the Icynene Insulation System for its air-sealing properties as well as for its insulating properties. The foam does not shrink or sag and adheres to most surfaces. Because the foam remains flexible, it expands and contracts with seasonal movement of a building to remain airtight.

The Icynene insulation is noncorrosive. It is neutral, neither acidic nor alkaline, and it cannot support bacterial or fungal growth. Since it is a "breathing" foam, any moisture in the building's concrete or lumber can escape through the insulation as the building dries out, reportedly eliminating any risk of rot or mildew.

The Icynene insulation is sprayed in place by a professionally trained and licensed contractor after electrical and plumbing services are in place. Gypsum wallboard typically is installed directly over the Icynene insulation 10 minutes after application. According to the manufacturer, building wrap, polyethylene, taping, foaming, and caulking are eliminated because the foam works as an air retarder. (A separate vapor retarder is indicated for regions with cold winters.) Designers and builders should still verify this design requirement with local experts based on climate behavior and use of polyicynene.

Icynene, Inc., has developed a second formulation that can be foamed, by pouring, into closed cavities. The product expands from bottom to top to fill the cavity. A minimum of two pours, or lifts, are typically recommended. The cavity-fill product has a slightly greater density with an R-value of 4 per inch.

R-value

The R-value of the Icynene insulation is rated at 3.6 per inch. In a nominal 2 × 4 wall, this equates to an R-value of about R-13. In a 2 × 6 wall, this is about R-20. Unlike foams filled with CFCs or HCFCs, the R-value of air-filled foam does not decline as it ages.

Limitations

In the event that cavities are overfilled, excess insulation needs to be trimmed off due to its great expansion rate. A hand saw or Sawz-All blade can be used for scarfing the excess material. Polyicynene is not biodegradable, but the insulation waste can be used in the attic as loose-fill insulation. Working with Icynene, although not difficult, is a little laborious when it is necessary to run additional plumbing or electrical cabling through cavities after application of the foam.

Health considerations

Icynene insulation is water-based and does not produce formaldehyde, CFCs, or HCFCs. It has been tested extensively in both Canada and the United States and found to have no harmful emissions. The product also has been recommended for use in homes where specific environmentally sensitive conditions need to be maintained. The Icynene Insulation System is endorsed by the Envirodesic Building Program. Envirodesic certification identifies a growing family of cleaner products, healthier buildings, and expert services that promote "maximum indoor air quality".[7]

Fire resistance

Icynene insulation will be consumed by flame, but since it contributes no fuel in the event of fire, it will not sustain flame on removal of the flame source. It must be covered by gypsum board or another acceptable 15-minute thermal barrier if required by applicable building codes.

Standards

Icynene has been evaluated by the Council of American Building Officials National Evaluation Service and complies to the BOCA, SBCCI, and ICBO *Uniform Building Codes* and the *Canadian National Building Code*. It has been the subject of research projects by the NAHB Research Center, Upper Marlboro, Maryland; Oak Ridge National Laboratories, Oak Ridge, Tennessee; and the Florida Solar Energy Center, Cape Canaveral, Florida.

Air Krete

Air Krete, a proprietary cementitious foam insulation, has been around since the mid-1980s. It is an inorganic foam made from magnesium oxychloride cement (which is derived from sea water) and a particular variety of ceramic talc mined in Governor, New York. These minerals are mixed with a proprietary foaming agent ("glorified soap suds," according to Air Krete inventor R. Keene Christopher) and sprayed with pressurized air through a foaming gun.[8]

Air Krete was developed and patented by Air Krete, Inc., of Weedsport, New York. The company licenses manufacturers and installers and provides the proprietary ingredients. According to the manufacturer, the marketing strategy is to license the Air Krete technology to various manufacturers in the United States and worldwide so that these manufacturers can be in close proximity to their market areas, typically within a 200-mile radius.

Product description

Foamed under pressure with a microscopic cell generator and compressed air, the insulation is fireproof, insect-proof, and nontoxic. It can be foamed in place in closed-wall cavities or masonry-block cavities. Gypsum wallboard, paneling, planks, and lath and plaster are interior finishes that have performed well with Air Krete.

For open-cavity installations, a fine screen is stapled across the opening to hold the foamed-in-place material when it is being installed. Air Krete will need a short drying period before a wall can be closed up. The resulting product is nontoxic, odorless, lightweight, and rigid, but the material is friable (easily crumbled) when dry.[9] Air Krete eliminates air infiltration per American Society for Testing and Materials (ASTM) C518.76 at 750°F and does not shrink per ASTM 951. It also does not expand or settle and is 100 percent cavity filling. The product is fully cured in 28 days.

Air Krete is also a soundproofing material that is used very effectively in interior sound partitions. Water noises are effectively reduced when Air Krete is used to encase plumbing pipes. The insulation used to be pink but now has a blue-green tint, achieved with an inert mineral pigment.[8] No CFCs or HCFCs are used as foaming agents. It is fireproof, rot-proof, and bug-proof and does not off-gas at all.

R-value

Air Krete maintains an R-value of 3.9 per inch.

Limitations

The cured material is friable and will turn into powder when rubbed lightly by hand. Friability does not seem to be a problem in closed cavities, but one may want to test the material before using it in locations subject to extreme vibration.

Air Krete is not flexible after it cures. Since it does not bond to surfaces, shrinkage or movement in a frame wall may open up small gaps. Gaps created by wood framing that has dried out also may be a likely cause of this problem. Air Krete is relatively high in cost. Labor is also an important factor, owing to the work involved in stapling the screen over the cavities.[8]

Health considerations

This product is considered nonhazardous as a waste using U.S. Environmental Protection Agency (EPA) methods. The MSDS reports that eye, skin, or respiratory protection is not required.

Environmental considerations

Air Krete is nontoxic, does not create any ozone-depleting CFCs, has very low VOC emissions, and does not contain any formaldehyde or carcinogenic fibers.

Fire resistance

Air Krete is most impressive as a noncombustible insulation. The material does not burn, does not release any smoke, and is often used as fire-stop material. It is also reported that a standard, 2 × 4 framed wall filled with Air Krete insulation has even passed a 2-hour firestopping test.[8]

Spray Polyurethane Foam (SPF)

Foamed-in-place polyurethane foam, typically referred to as *spray polyurethane foam* (SPF), is a closed-cell, higher-R-value foamed plastic insulation that is fabricated by an installer at the home site from two liquid components. Closed-cell foams insulate differently from conventional mass insulations. For example, a 1" sample of polyurethane foam consists of millions of tiny closed plastic cells filled with an inert gas. The inert gas resists heat transfer better than regular air.

Application equipment allows for the materials to be metered, mixed, and then either sprayed in place or poured into cavities. A cousin to SPF insulation is the single-component foam. Typically used for sealing around windows, doors, etc., it is available in spray cans at just about any hardware or home improvement store.

Product description

SPF compounds are comprised of isocyanates and polyols that have been in use for over 30 years. It is applied in liquid, two-part states. As the two materials mix, they expand, typically at an average ratio of 30:1 (or more). During the process of the two parts mixing, a chemical reaction generates an internal heat. If installed improperly, the foam can generate an internal heat high enough to start a fire inside the core of the foam. Spray formulations are fast-reacting to allow vertical and overhead applications. Additional layers can be applied almost immediately in consecutive passes.

Usually pale yellow in color, polyurethane foam resists water, mildew, and fungus; does not shrink or settle; contains no urea formaldehyde; is 80 percent cured in a few minutes; and is 95 percent cured in 24 hours. Polyurethane foam adheres to most surfaces, insulates hard-to-reach areas, is odorless, and resists mildew and fungus. Polyurethane foam also has no nutritional value that would attract insects or other pests

As discussed in previous chapters, intrusion of air into the stud wall cavity causes convection (movement of warm air to the top of the cavity and cold to the bottom). Like other foamed-in-place insulation products, polyurethane foam contains no seams or joints, thereby eliminating air leakage. After the insulation is installed properly, there should not be any air circulation from one side of the stud space to the other. Polyurethane foams reduce the temperature variance and the effect of convective looping. Any structural cracks or breaks in the system will reduce the effectiveness of the insulation, however.

Polyurethane foam (closed-cell, $1\frac{1}{2}$ to 2 lb/ft^3 density) has a structural quality that actually increases the twist and rack resistance of framed walls. The National Association of Home Builders Research Center (NAHB) conducted tests on 45 different wall designs, with and without foam. These tests proved that foam walls are three times as strong as walls without foam. (Additional testing of SPF by the NAHB Research Center between metal studs produced similar results.) Polyurethane foam is tack-free within seconds of the application, and 80 percent of the physical properties are present after 12 hours.[10]

R-value

Depending on the specific manufacturer, SPF products can have some of the highest R-values of any residential insulation. A range between 6 and 7 per inch can be expected.[10]

Limitations

All polyurethane foam insulations must be installed by certified installers. Safety gear and ventilation equipment are required during installation. The installation of polyurethane foam can be a messy process. Since the material adheres to any surface, extensive masking may be required on specific job conditions.

CFCs were formerly used as blowing agents but were banned from use by the Montreal Protocol, an international plan to limit the production and ultimately the release of CFCs. Currently, polyurethane foam insulation is blown with HCFCs such as HCFC-141b, which are less threatening to the earth's upper atmosphere but still have ozone-depleting potential. Production of this chemical for use as a blowing agent is to cease by January 1, 2003. Ferrous metals should be painted with a primer prior to application of rigid polyurethane foams.

Polyurethane foams are not UV stable and can be biodegraded by both direct and indirect sunlight. If exposed for any long period of time, the finished product needs to be coated with an elastomeric coating designed to protect the SPF from sunlight. Without some type of UV protection, the foam will degrade, compromising the thermal performance. SPF typically turns from a light yellow to a dark orange or brown color after UV exposure. Eventually, the surface degrades into a light powder that can be eroded by wind and rain to expose the foam below, thus starting the process again. The eroded surface of the SPF appears similar to that of an eroded dry creek bed within a few years.

Fire resistance

Building codes require foam plastics to be fire tested, usually with ASTM E84 as a minimum criterion. Some polyurethane foam manufacturers produce two formulations. One type is a class 2 foam with a flame spread of 30 and smoke development of 220 (class 2 foam is less than 75 flame spread and less than 450 smoke development) at 1", and the other is a class 1 foam with a flame spread of 25 or less and smoke development of 210. All cellular plastics such as spray-foam products are required by building codes to be covered by a 15-minute thermal barrier when installed in a habitable area. A 15-minute thermal barrier can be $^1/_2$" sheet rock, spray cementitious products, or other tested materials. Exposed foam is a potential fire risk and should be protected from open flames during the construction phase and prior to installation of the thermal barrier.

Cost

One manufacturer admitted that full-cavity applications of polyurethane foam are two to three times as expensive as conventional insulation systems. One should note, however, that a 2000-ft^2 home with 2 × 4 walls, 1" of polyurethane foam, and an R-11 batt cost slightly more than the same wall with an R-15 batt.[10]

Water-Blown Polyurethane

Product description

In an effort to curtail the use of HCFCs in polyurethane products, several manufacturers have developed insulations that use non-ozone-depleting hydrofluorocarbon (HFC). Foam-Tech, Inc., uses HFC-134a as the foaming agent in its SuperGreen polyurethane foam.

The hydrofluorocarbons (HFCs), compounds consisting of hydrogen, fluorine, and carbon, are a class of replacements for HCFCs. Because they do not contain chlorine or bromine, they do not deplete the ozone layer. All HFCs have an ozone-depletion potential of 0.[4] The higher cost of this foaming agent results in an upcharge of about 10 percent over conventional polyurethane. Preferred Foam Products of North Branford, Connecticut, produces the HFC-based foam components for Foam-Tech, the sole customer. While HFCs are ozone-safe, they may still have significant greenhouse gas impact.[11]

Open-celled semirigid water-blown polyurethane does not contain any ozone-depleting chemicals, CFCs, HCFCs, fibers, formaldehyde, or asbestos. Open-cell SPF is applied with specialized equipment designed for the application of a two-component urethane system from the interior to open-wall cavities. (The foam expands up to 120 times its liquid volume within seconds and is applied by approved contractors with qualified installers.) The R-value is 3.81 per inch. Open-cell SPF, like all other SPF products, is used as an air barrier system that reportedly can withstand 160-mph wind gusts (Fig. 10.3).

Another manufacturer, Resin Technology Company, has developed a closed-cell water-blown polyurethane (RT-2050) with an installed density of about 2 lb/ft^3 (32 kg/m^3) and an open-cell water-blown polyurethane with an installed density of 0.5 to 0.8 lb/ft^3 (8 to 12.8 kg/m^3). The latter is described as a flexible open-cell polyurethane foam, similar to Icynene.[6]

Figure 10.3 Water-blown polyurethane. (*Sealection 500*)

Phenolic Foam

Product description

Phenol-formaldehyde, or phenolic foam, is still available as an insulation product but is not as common because of its corrosive catalysts. It uses air as a blowing agent and has very good fire-resistance properties. It does exhibit some shrinkage over time, which degrades its thermal performance. Phenolic foams still have a high strength-to-weight ratio and are less flammable than most other plastic foams. Typically used in board product form, the major disadvantage of phenolic foam is its shrinkage. Tripolymer foam is a non-CFC, non-HCFC cavity-fill insulation that is essentially a phenolic foam. It is discussed in the next section of this chapter.[6]

Tripolymer Foam

Tripolymer products are phenol-based synthetic polymers made exclusively by C. P. Chemical Company, Inc., of White Plains, New York. Known proprietarily as Tripolymer Foam, it is essentially a modified phenolic foam that has been installed in over 1.8 million homes nationwide over the past 30 years. Tripolymer Foam is a non-CFC, non-HCFC cavity-fill insulation used primarily in masonry block walls. It has been used extensively in schools, hospitals, universities, and residential housing as insulation and soundproofing.

Product description

Tripolymer Foam is installed by C. P. Chemical's network of certified insulation applicators. Specially engineered equipment (patent nos. 4,103,876 and 4,246,230) have been designed by C. P. Chemical Company for application of Tripolymer Foam insulation and are required in the installation of the foam.

Tripolymer Foam products are phenolic-based, methylene-linked synthetic polymers. The Tripolymer Form system consists of two components: an aqueous resin solution and foaming agent/catalyst. These materials are mixed together with compressed air and blown into walls and spaces by trained applicators, usually from the exterior of the home to minimize extraneous residue adhering to interior materials.

Tripolymer Foam does not wet or distort gypsum wallboard systems and can be used to insulate brick, block, stucco, wood frame, or steel frame structures. It first looks like shaving cream but sets in approximately 10 to 30 seconds. Final curing is within 48 to 72 hours, depending on thickness. There is no further expansion once the foam leaves the delivery hose. It has very good fire-resistance properties, is fungi-resistant, and nontoxic, and does not contain any petrochemicals or fire-retardant chemicals (Fig. 10.4).

The cellular structure of Tripolymer Foam provides an effective acoustical barrier against airborne sound transmission. This system lends itself to new construction and interior partition walls, as well as existing construction where noise problems become evident. A minimum thickness of 2" is recommended. Tripolymer Foam reduces the resonance vibration of interior finishes that normally amplify sound levels. The actual amount of noise reduction is affected by the composite wall and ceiling construction.

R-value

Tripolymer Foam insulation has an R-value of 4.6 per inch at 75°F, 5.0 per inch at 0°F, and 4.8 per inch at 32°F. The manufacturer reports that there is no thermal degradation or reduction in R-value over time.

Limitations

Few, if any, limitations exist for residential use of this foam. The manufacturer does warn that it should not be used against surfaces with temperatures in excess of 212°F for prolonged periods of time.

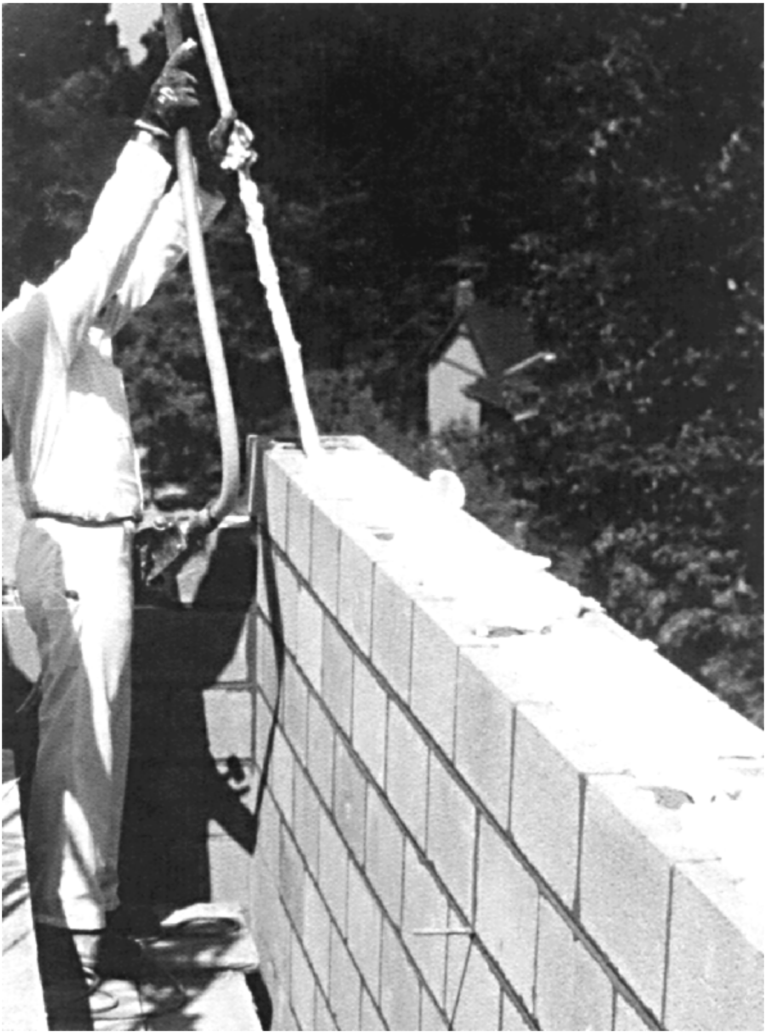

Figure 10.4 Tripolymer foam insulation. (*C.P. Chemical Co., Inc.*)

The foam will not support compressive loads, nor should it be used for flotation (such as floating docks) or applied underground without adequate protection.

Some users have reported a certain amount of shrinkage over time, which degrades its thermal performance. Independent testing conducted by MacMillan Research, Ltd., examined a sample of foam and found that it showed no shrinkage in the accelerated aging test. After 6 days under such conditions, a loss in weight of 4.7 percent was experienced, and no discoloration was apparent. (The 6 days in incubation is the approximate equivalent of 2 years in actual use.)[12] These results seem to contradict earlier observations of shrinkage, sometimes of up to $^1/_4$" away from the studs.[13] C. P. Chemical Company reported that the only objectionable shrinkage usually is associated with improper equipment use. Typically, shrinkage of $^1/_8$" in a wall cavity is the maximum shrinkage to be expected.

Environmental considerations

Tripolymer Foam is reportedly environmentally safe because it does not produce or emit CFCs or HCFCs.

Fire resistance

Increased fire resistance over other plastic foams is one of this product's strengths. Fire characteristics when tested according to ASTM E84 reveal that the product has a flame spread of 5, smoke development rating of 0, and fuel contribution of 0. It also dramatically improves the fire safety ratings of any applied material because it will not burn or produce smoke.

Tripolymer Foam increases the fire ratings of many wall systems. ASTM E119 test results show that when Tripolymer Foam is installed in $3^1/_2$" steel stud walls, fire ratings increase from 1 hour to 1 hour and 45 minutes. In a $3^1/_2$" wood stud wall system, fire ratings increased from $^1/_2$ hour to $1^1/_2$ hours plus. In renovation applications, Tripolymer Foam can be used to raise existing fire ratings of noncompliant or substandard fire-rated walls without the demolition of existing walls or the addition of extra layers of gypsum wallboard.

Installation precautions and limitations

Materials should be installed according to the manufacturer's instructions through equipment manufactured by C. P. Chemical and by a factory-trained/certified insulation contractor with a current certification card. The spraying equipment generates 3.5 to 10 ft^3/min of material from guns attached to delivery lines that can run up to 300 ft in length. Tripolymer Foam products can be installed easily and efficiently in new or existing masonry construction, either during construction or after completion by a pressure-fill method.

In masonry cavity walls, the foam insulation is installed between masonry wythes, occupying the full thickness of the cavity. Filling is to be performed as the masonry walls are constructed, since fills are not to exceed 10 ft in height. Tripolymer Foam can be foamed in place between brick veneer and cement blocks during construction. The application hose is dropped to the bottom of the cavity and withdrawn as the foam fills the cavity. The foam insulation also can be installed in a similar manner in masonry cores for the full thickness of the cell as the wall is constructed. Fills are not to exceed 15 ft in height.

If construction practice prohibits working with the masons as the walls are erected, the foam can be installed in masonry walls by drilling holes either in the face of the concrete masonry unit or in a mortar joint. The hose is inserted around the entire wall area at 5 ft above floor level. Filling is repeated at a height no greater than 15 ft in vertical height until completion of wall area fill cores.

Existing residential wood frame construction is easily insulated with Tripolymer Foam by removing exterior siding and drilling through the exterior sheathing. The foam is then injected into the cavity space through 1 to 2" openings. The foam also can be sprayed into new wood stud construction.

Appendix

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Chapter

11

Rigid Board Insulation

Rigid insulation is made from fibrous materials or cellular plastic foams and is pressed, extruded, or molded into boardlike forms. Board products can provide both thermal and acoustical insulation, possess modest strength properties with low weight, and provide adequate coverage with few heat-loss paths when installed properly. Rigid insulation boards also may be manufactured with various facers to enhance or protect certain physical properties.

Even though rigid board products are typically more expensive than other types of insulating materials, they are used commonly in buildings where there are space limitations, where rigidity is critical to the application, or where higher R-values are necessary. Rigid board insulation R-values can range from 4 to 8 per inch of thickness depending on the composition and the method of aging.

Board insulation products can be applied in a variety of locations. Exterior sheathings applied over wall framing members (especially with steel stud framing systems), within wall cavities, in masonry veneer wall cavities, or behind an interior finish material are but a few examples.

A number of board insulation products are also used with low-slope roofing systems. Although predominantly found in commercial construction, the most common types include cellular glass, glass fiber, mineral fiber, perlite, polyisocyanurate, polystyrene (expanded and extruded), wood fiberboard, and composites. (Polyisocyanurate is the most common roof insulation according to 1999 statistics.)

Rigid insulation is also being used in innovative ways in new construction to create more energy-efficient homes. Stressed-skin walls can replace traditional stick framing with engineered panels consisting of a foam core with structural sheathing adhered to both sides. Known as *structural insulated panels* (SIPs), they usually incorporate expanded polystyrene (EPS) or polyisocyanurate foam as the core material. Insulating concrete formwork is another foam-based product that is used in lieu of traditional construction (see Chap. 15 for SIPs and ICF).

Many variables affect the installed thermal performance of rigid board insulation. These include the density of the foam, the blowing agent used to create the foam, the method of aging, the cellular structure, the durability of the material, the presence of dents and chips, the thickness and type of facer (if any) that is used, the thickness of the board, and the conditions in which the foam is installed. Owing to the quantity and variety of products, interested readers will require more information than what can be presented within the scope of this book. The long-term thermal performance of any insulation product always should be evaluated prior to its selection or application. Manufacturer's literature is a place to start, but any information should be complemented with independently sponsored research.

Rigid insulation can be used as an air infiltration retarder when installed properly. With respect to moisture movement, special attention must be paid to the use of rigid board products on the exterior of a wall when a vapor retarder is already in place on the interior of the wall. Permeance ratings must be verified to ensure that moisture vapor will not become trapped within the wall assembly.

Chlorofluorocarbons (CFCs) are no longer used as a blowing agent for plastic foams. Hydrochlorofluorocarbons (HCFCs), originally a U.S. Environmental Protection Agency (EPA)–approved blowing substitute for (the discontinued) CFCs, are currently found in extruded polystyrene foam boards and polyisocyanurate foam boards. As discussed in detail in Chap. 10, the scheduled phase-out of HCFCs also has played a role in the research, development, and modification of various rigid board insulation products.

Burrowing insects can reduce the thermal performance and structural integrity of the insulation. Although rigid board insulation offers no food value to insects, it provides the potential for insects to easily tunnel from the ground to more desirable materials. The foam is also an attractive nesting environment. For these reasons, some manufacturers treat their foam products with an insecticide, usually a borate compound. Additional precautions such as treating the earth around the building with insecticides, using bait station treatment methods, keeping an inspection area bare of insulation board, removing all wood debris, maintaining specific above-grade clearances, or installing the foam board over the interior of the basement walls rather than the exterior also will help minimize the risk of insect infestation.

All organic cellular plastics, whether or not they contain fire retardants, should be considered combustible and handled accordingly. Terms such as *fire-retardant* and *flame-resistant* are sometimes used to describe the combustibility characteristics of foams. While they are valid measures of the performance of these materials under small fire exposure, they are not intended to reflect hazards under exposure to large-scale fire conditions.[1] The combustion characteristics of foam insulation products vary with the combustion temperatures, chemical formulation (which will determine thermoplastic or thermoset behavior), and available air. Plastic foam insulation may appear relatively difficult to burn, but when ignited, it burns readily and emits a dense black smoke containing toxic gases (as do all organic combustibles commonly used in construction). Foam insulation used in construction requires a fire-protective covering such as $^1/_2$"-thick gypsum wallboard or similar 15-minute code-approved thermal barrier. Building codes contain many exceptions regarding the use of thermal barriers, so always verify requirements with the local building code or fire officials and insurers.

Geofoam is another popular buzzword of late. Even though the term has been used since 1992, there is still some confusion as to its definition. Quite simply, *geofoam* is the generic name for any foam material, usually expanded polystyrene, used in a geotechnical (above-grade or in-ground) application. Ground stabilization, embankment, or other ground-fill applications where a lightweight fill material is required can use geofoam to reduce stresses on underlying soils. Geofoam is now recognized worldwide as a geosynthetic product category in the same sense as geotextiles, geomembranes, geogrids, etc.[2] (Fig. 11.1).

Expanded Polystyrene (EPS)

Polystyrene, a thermoplastic polymer, is manufactured for building insulation by extrusion or molding. Extruded polystyrene (XPS) was formerly called *extruded expanded polystyrene* (XEPS) foam

Figure 11.1 Geofoam. (*R-Control Building Systems*)

board. It is created by the process of extrusion, which results in fine, closed cells that contain a mixture of air and refrigerant gas. Extruded polystyrene is discussed in the next section.

The other manufacturing process is molding, which produces coarse, closed cells containing air. Molded expanded polystyrene (MEPS) foam board, now called *expanded polystyrene* (EPS), can be molded into many everyday items such as coffee cups, coolers, protective cushioning for shipping materials, or insulation boards for construction applications. This closed-cell material, often referred to as *beadboard* in construction jargon, is less expensive than extruded polystyrene and generally is white in color.

EPS is used for a variety of building applications. These include cavity wall insulation, exterior insulation and finish systems (EIFS), exterior sheathing, perimeter insulation, and underslab insulation. Low-slope roof applications include flat or tapered roof insulation for built-up roof systems and ballasted, mechanically attached, or fully adhered single-ply membrane roof systems. Specialty products also include cores for structural insulated panels and concrete masonry unit core inserts (Fig. 11.2).

Product description

EPS is a molded, closed-cell plastic made from petrochemicals derived from crude oil and natural gas. EPS starts out as unexpanded polystyrene beads containing the blowing agent pentane and flame-retardant additives. In a vessel, the beads are exposed

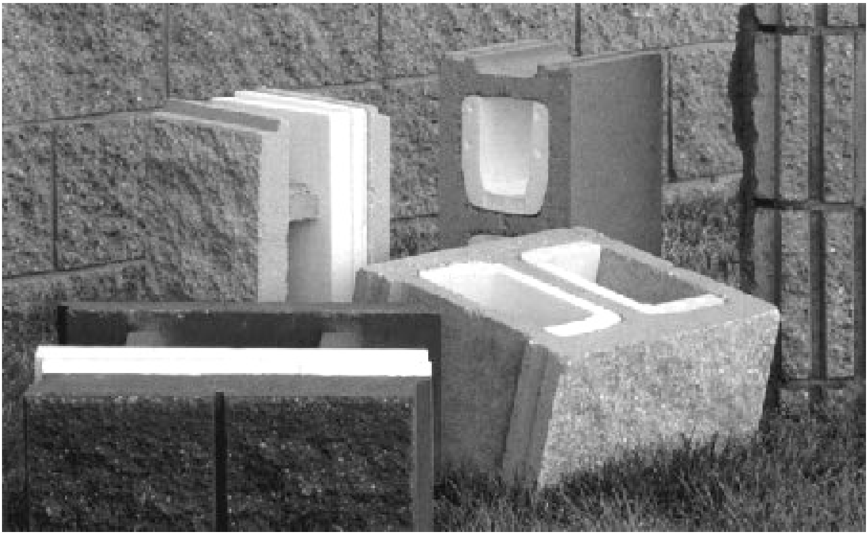

Figure 11.2 CMU core inserts. (*Korfil*)

to heat (steam) and are expanded from 30 to 50 times their original size. Following a stabilization period, the beads are injected into a mold and, under more heat and pressure, are further expanded and fused into blocks. After curing, the blocks are cut into the required sizes with hot-wire cutting equipment. The wires are electrically heated to over 400°F. The wires are drawn down through the block to achieve the desired length and width. The blocks are then pushed through additional hot wires via a conveyer to achieve the desired thickness.

EPS is a lightweight, strong, resilient, noncorrosive, dimensionally stable material that does not cause skin irritation. Typically, expanded polystyrene has a lower R-value than extruded polystyrene because of its lower density and because it does not contain refrigerant gas. The main advantage of this board over extruded polystyrene is that it typically costs 40 percent less.[3]

EPS is manufactured in varying densities, from less than 1.0 lb/ft^3 to over 2.0 lb/ft^3 depending on the application. The high-density board is more moisture-resistant and can be used on the exterior of a foundation, provided the surrounding soil is dry and sandy. EPS foam used for roofing materials must be of sufficient density to resist damage from foot traffic (Fig. 11.3).

EPS is water-resistant, although the spaces between the foam beads can absorb water. When used as a sheathing, it is not

Figure 11.3 EPS below grade. (*R-Control Building Systems*)

considered a vapor barrier. Typical water vapor permeance for 1" of material ranges from 5.0 for the low-density foams to 2.0 for the high-density materials. Although EPS provides a high level of moisture resistance and breathability, recommended design practices for walls and foundations should be followed in the selection of vapor and moisture barriers for severe exposures. A vapor diffusion retarder is necessary if water transmission through the insulation might present a problem for the user.

Although EPS is affected by and possibly can deteriorate from contact with organic solvents, their vapors, and solvent-based adhesives, it can be used for specific low-slope roofing systems. Compatibility always should be confirmed. For example, only low temperature bitumens can be applied to the boards. Cover boards are necessary in asphalt or adhered systems to protect the insulation.[4]

R-value

EPS thermal insulation meeting American Society for Testing and Materials (ASTM) C578 type I (0.9 lb/ft^3 minimum density) has a typical R-value of 3.8 per inch, whereas the higher-density type IX (1.80 lb/ft^3) boards are approximately 4.35 per inch. Board thickness ranges from $\frac{1}{2}$ to 36", and lengths up to 24 ft are available depending on the supplier and end use (Fig. 11.4).

Stable or *stabilized R-value* refers to the quantitative ability of a foam insulation material to retain its as-manufactured R-value. Over time, some foam insulations lose their blowing agent and with it up to 25 percent of their R-value. This process is called *thermal drift*. As long as the EPS foam is kept dry, the R-value is permanent because its cellular structure contains only stabilized air.[5] Even if allowed to absorb some moisture, it appears that EPS retains its R-value.

R-Value* at 40° and 75° F

Insulation Only

Thickness	Standard Board Size	**AFM Type I EPS (Nom. 1.00 pcf)		AFM Type VIII EPS (Nom. 1.25 pcf)		AFM Type II EPS (Nom. 1.50 pcf)		AFM Type IX EPS (Nom. 2.00 pcf)	
		40°	75°	40°	75°	40°	75°	40°	75°
1/2"	4' x 8' or 4' x 9'	2.08	1.93	2.13	1.96	2.28	2.09	2.38	2.18
3/4"	4' x 8' or 4' x 9'	3.13	2.89	3.19	2.94	3.41	3.13	3.57	3.26
1"	4' x 8' or 4' x 9'	4.17	3.85	4.25	3.92	4.55	4.17	4.76	4.35
1 1/2"	4' x 8' or 4' x 9'	6.26	5.78	6.38	5.88	6.83	6.23	7.14	6.53
2"	4' x 8' or 4' x 9'	8.34	7.70	8.50	7.84	9.10	8.34	9.52	8.70
2 1/2"	4' x 8' or 4' x 9'	10.43	9.63	10.63	9.80	11.38	10.43		
3"	4' x 8' or 4' x 9'	12.51	11.55	12.75	11.76				
3 1/2"	4' x 8' or 4' x 9'	14.60	13.48						
4"	4' x 8' or 4' x 9'	16.68	15.40						

Design Consideration: System R-Values can be increased approximately 2.5 with the use of a bright foil laminate. A minimum 1/2" air space on the reflective foil surface of the sheathing is required to achieve this additional R-Value. (Reference: ASHRAE Handbook Fundamentals)

* R-Value means resistance to heat flow. The higher the R-Value, the greater the insulating power.
** Types designated by ASTM C 578 Specifcation Standard.

AFM EPS size and number of pieces per package vary. Check label on package. Manufacturer has fact data sheet on file and is available on request.

Board sizes supplied normally range from 4' x 8' to 4' x 9', up to 4" thick. Other sizes can be provided for special conditions as required.

Figure 11.4 EPS R-values. (*R-Control Building Systems*)

Published data on EPS indicate that even at 7.0 percent moisture by volume, EPS retained 90 percent of its R-value. (Most listings for absorption by volume list about 3 percent as the normal limit.[6])

Limitations

EPS can degrade when exposed to sunlight or temperatures over 180°F. It also must be protected from solvents, and only compatible adhesives and sealants should be used. If the insulation is to be used in the interior of a house, it needs to be covered with a fire-resistant material such as gypsum wallboard. EPS, although containing a flame-retardant additive, should be considered combustible and should not be exposed to an open flame or any source of ignition. Thin beadboard also can warp or chip easily, so it should not be used in high-use applications, such as movable window insulation.

Environmental considerations

Most EPS products are actually 90 percent or more air, because it is the only rigid foam of insulation that has never been made with CFCs, HCFCs, or hydrofluorocarbons (HFCs) (verify with the specific manufacturer). During manufacture, polystyrene beads are expanded with pentane, a hydrocarbon that contributes to smog but is not implicated in ozone depletion or global warming. The pentane quickly diffuses out of the insulation and is replaced by air during the manufacturing process. To meet federal and state clean air requirements, several EPS manufacturers have redesigned their plants to collect and control up to 95 percent of the pentane used in production. BASF Corporation also has developed a low-pentane EPS bead formulation.[7]

EPS products also can be made from recycled EPS. This is accomplished by crumbling the old EPS foam into small particles, mixing it with virgin prepuff, and remolding the material into usable products. Most clean EPS waste can be recycled into cushion packaging, but because of building code requirements, waste EPS construction products can only be recycled into noninsulation building applications.

EPS is inert and nontoxic. The styrene used in polystyrene insulation is identified by the EPA as a possible carcinogen, mutagen, chronic toxin, and environmental toxin. Furthermore, styrene is produced from benzene, another chemical with both environmental and health concerns.[7]

Extruded Polystyrene (XPS)

Another board insulation is made of extruded polystyrene (XPS) and often referred to as foamboard. XPS is a homogeneous product consisting of fine, closed cells containing a mixture of air and an insulating gas also used in other industries as a refrigerant. Available brands of extruded polystyrene are easily recognized by their colors: blue, pink, green, or yellow.

XPS is often referred to by one of its proprietary names, *Styrofoam*. Styrofoam extruded polystyrene insulation was developed originally by the Dow Chemical Company in the early 1940s as a flotation material in liferafts and lifeboats.

XPS is manufactured by pushing freshly expanded foam through an extrusion die. A number of edge configurations are available, some straight and some with a profile designed to interlock to ensure a continuous thermal break and help to seal the joints between the panels.

XPS is used for insulating foundations and concrete slabs, for residing underlayments, and for exterior wall sheathing, for protected membrane roof applications, and as the insulation for structural insulating panels (SIPs) and insulating concrete forms (ICFs) (see Chap. 15). It is also installed either on the interior or exterior where space is limited such as cathedral ceilings, flat roofs, etc. (Fig. 11.5).

Product description

The creation of XPS foam begins when solid polystyrene crystals, along with special additives and a blowing agent that forms gas bubbles, are fed into an extruder. Within the extruder, the mixture is combined and melted under controlled conditions of high temperature and pressure into a viscous plastic fluid. The hot, thick molten mass is then forced in a continuous process through a shaping die. As it emerges from the die, it expands to a foam and is shaped, cooled, and cut as required.

XPS products can range in thickness from $^1/_2$ to 3" (or thicker for SIPs applications) and in board sizes of 2' × 8', 4' × 8', and 4' × 9' for a variety of sidewall, below-grade, and roofing applications. Total R-values per board can range from 2.8 to 20 depending on board thickness. The R-value of XPS is R-5, regardless of density. A number of edge treatments such as square edge, ship lap, and tongue and groove are available. Polyethylene facers are also available for additional board durability.

Figure 11.5 Extruded polystyrene. (*Tenneco*)

Thin $^1/_4$ to $^3/_8$" XPS insulation products are also produced in a fanfold bundle design. Typically, 4' × 50', the fanfolded bundle unfolds to cover large areas quickly, resulting in reduced overall installation time. These also can be sandwiched between two perforated plastic capsheets or with a laminated inner layer for use as exterior sheathing in residing applications (Figs. 11.6 and 11.7).

Not only is XPS naturally hydrophobic (no chemical affinity for water), but its fine, closed-cell structure and smooth, continuous skin also help the foam resist moisture. This property also results in resis-

Figure 11.6 Fanfolded bundle. (*Pactive*)

tance to cell damage that would be induced by freezing/thawing temperature fluctuations if water were present in the cells.

Although XPS is more expensive than EPS, it has a higher R-value, lower water absorption levels, and a higher compressive strength than EPS. The high-density board product can handle relatively high pressures such as applications under concrete slabs.

Figure 11.7 Residing underlayment. (*Pactive*)

The foamboard does not cause skin irritation, and when board joints are properly sealed, XPS can act as an air barrier.

XPS is also used for low-slope roofing systems. XPS will deteriorate from contact with organic solvents and adhesives, and only low-temperature bitumens can be applied to the boards. Cover boards are necessary in asphalt or adhered systems to protect the insulation.[4]

R-value

Unlike EPS, the R-value of XPS does not depend on the density of the material. The R-value is consistently 5.0 per inch.

Limitations

XPS can be attacked by many petroleum-based solvents in adhesives, paints, stains, water-repellent or preservative coatings, and bituminous waterproofing. Solvents should be allowed to evaporate before touching the foam.

XPS must be protected from sunlight because, over time, ultraviolet (UV) light degrades it. When installed on the job and left exposed to the sun, the surface of XPS becomes yellow and dusty. (The dust can be brushed off before installation.)

Environmental considerations

The styrene used in polystyrene insulation is the same material used in many household products such as disposable foam dinner plates. Identified by the EPA as a possible carcinogen, mutagen, chronic toxin, and environmental toxin, the relatively small quantities associated with building occupant exposure should not be a cause for concern. It is produced from benzene, another chemical with both environmental and health concerns.[7]

Fire resistance

XPS softens at 165°F and melts at around 200°F. It is flammable and gives off noxious fumes when burned. XPS must be covered with a fire-rated sheathing when used in interior applications.

Installation and applications

The issue of thermal bridging in steel-framed walls has been attributed to the reduction of whole-wall R-values in these applications. In a study performed by National Association of Home Builders (NAHB) Research Center, R-values measured for steel-framed wall assemblies (including gypsum wallboard and plywood sheathing) were lower than values typical for similar wood-framed walls. For example, a 6" steel stud wall with R-19 batt insulation measured only R-10.1, demonstrating a 47 percent loss in insulation value at the center of the cavity. The wood-framed walls only lost 10 percent of the nominal insulating value.[8]

Tests show that foam sheathing helps block the rapid heat loss that would otherwise cut in half the value of cavity insulation. In fact, the application of foam sheathing increased the insulating value of the steel stud wall by more than its rated R-value. For example, the test wall has an R-value of 10.1. Adding 1" of XPS with an R-value of R-5.0 increased the wall's R-value to R-16.2. The efficiency of the 1" XPS board was 122 percent. By blocking the thermal bridge, foam sheathing restores some of the insulating value of cavity insulation that had been bypassed by the steel studs.[8]

In comparison, foil-faced polyisocyanurate insulation had a notably lower thermal efficiency. Another test wall increased from R-10.1 to R-17.1, whereas the nominal value of the polyisocyanurate board itself was listed at R-6.8. The foil facer may be the reason the board's efficiency rating was a slightly lower 102 percent efficiency rating.[8] (Fig. 11.8).

Placing foam tape on the face of the studs also was studied. The tape increased the insulating value by only R-0.5. It started out at $^5/_{16}$" and was compressed directly under the screw to only $^1/_8$". There appears to be little to gain by increasing the thickness of the wall cavity. The best-performing wall measured in this study was $3^5/_8$" thick with an R-11 batt and 2" of XPS insulation. It surpassed a wood-framed R-19 wall by a value of R-0.5.[8]

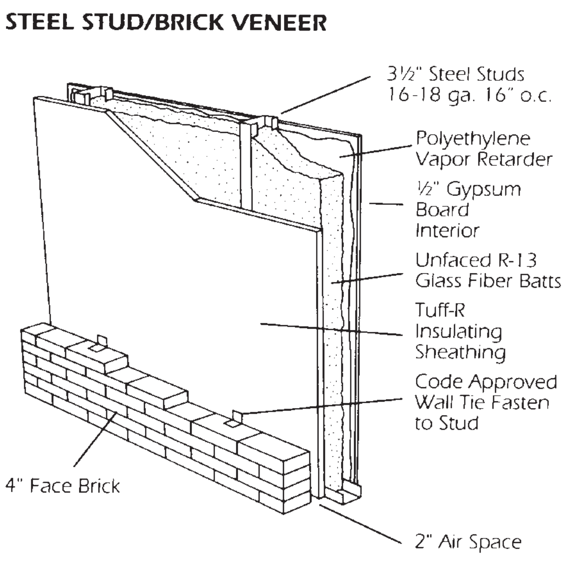

Figure 11.8 Wall assembly. (*Celotex*)

Cold spots and streaking

Tests show that foam sheathing reduces the potential for dust streaking on the inside surface of walls in northern climates. On the test wall with only plywood sheathing, the gypsum wallboard temperature remained constant over the insulated cavity. However, it began dropping rapidly about 2" from the edge of the stud. Directly over the stud the gypsum wallboard temperature was 10°F lower than the temperature over the cavity. The wall with 2" of XPS sheathing showed only a 2.5°F temperature drop from cavity to stud. These cold spots sometimes promote condensation on the inside wall surface. Dust attracted to the water causes streaks, sometimes called *ghosting*.[8]

The temperature of the interior wall surface plays a major role in this process. The report cited previous research indicating that slight ghosting can be expected when the wall temperature over the stud is 3.3°F lower than the temperature over the cavity, and that severe streaking occurs when the temperature is 8°F lower. In this test, walls with plywood sheathing showed 8 to 10°F lower temperatures over the studs, making them likely to develop streaks. The report states that no ghosting problems would be expected in any of the walls with insulated sheathing. However, walls with 1" of XPS showed a temperature drop of about 4 to 5°F. If a 3.3°F temperature difference is the magic number, then these walls may face some risk for streaking.[8]

Polyurethane

Product description

Polyurethane (PUR) plastics were developed originally in the 1930s and were used primarily in military and aerospace applications until the 1950s. Their application in consumer and industrial products became popular in the late 1950s, when they were used mostly for cushioning (flexible foam), coatings (polyurethane modified oil-based), and thermal insulation applications (rigid foam). In the 1970s, there was a growth in the use of rigid PUR foam thermal insulation in refrigerators, as panel products, and in spray-applied insulating foam. Development of new chemical recipes and catalysts in Europe and the United States resulted in a next-generation product called *polyisocyanurate foam* (PIR). Also called *polyiso foam,* it first appeared on the U.S. market in the mid-1970s.

PUR and PIR insulations are manufactured by chemical reactions between polyalcohols and isocyanates. Both are a closed-cell board product in which the cells contain refrigerant gases instead of air. The boards are usually double-faced with foil or sometimes come bonded with an interior or exterior finishing material. The boards must be protected from prolonged exposure to water and sunlight, and if used in an interior application, they must be covered with a fire-resistant thermal barrier material such as gypsum wallboard.

Thermal drift is an issue with each of these foams. Over the first few years after installation, the R-value of the foam drops as the gas slowly escapes from the cells and is replaced by ambient air. Experimental data on polyurethane foams indicate that most thermal drift occurs within the first 2 years after manufacture. Foil and polymer sheet facers on foam boards can inhibit the escape of gas from the cell structure. Laboratory and field testing data suggest that the stabilized R-value of rigid foam with metal foil facers remains unchanged after 10 years, usually 7.1 to 8.7 per inch.[9]

Rigid PUR and PIR foams will, when ignited, burn rapidly and produce intense heat and dense smoke and gases that are irritating, flammable, and/or toxic. As with other organic materials, the most significant gas is usually carbon monoxide. Thermal decomposition products from PUR foam consist mainly of carbon monoxide, benzene, toluene, oxides of nitrogen, hydrogen cyanide, acetaldehyde, acetone, propene, carbon dioxide, alkenes, and water vapor.[1]

Polyisocyanurate

Polyisocyanurate (PIR) rigid insulation is actually a mixture of rigid PUR and PIR. By incorporating the chemical benefits of both products, PIR is sometimes referred to as PUR/PIR foam. Other monikers include *iso board* and *polyiso*. Most commonly sold with a shiny foil facer on one or both sides, PIR foam board rigid insulation has the highest R-value of any common insulation material. Although somewhat water resistant, PIR is not recommended for below-grade applications. PIR products must meet the requirements of ASTM C1289, "Standard Specification for Faced Rigid Cellular Polyisocyanurate Thermal Insulation Board."

Product description

PIR is a thermoset, closed-cell, rigid foam plastic insulation that is manufactured through a controlled chemical reaction. Liquid raw materials expand and are molded into boards, and facers are applied to the top and bottom surfaces. Facers provide strength, improve rigidity, enhance thermal performance, and help limit thermal drift. These facers are usually asphalt-saturated organic and inorganic felts, inorganic glass fiber mats, or aluminum foil and are selected to enhance the end use of the foam (Figs. 11.9 and 11.10).

For example, foil-faced PIR is used most commonly as wall sheathing in residential construction or in masonry cavity wall construction. The facers protect the foam core from UV degradation. Roof applications rely on glass fiber facers or glass fiber–reinforced organic felt facers. Most commonly supplied as 4' × 8' or 4' × 9' sheets in a range of thickness from $^{1}/_{2}$ to 4", PIR board insulation is

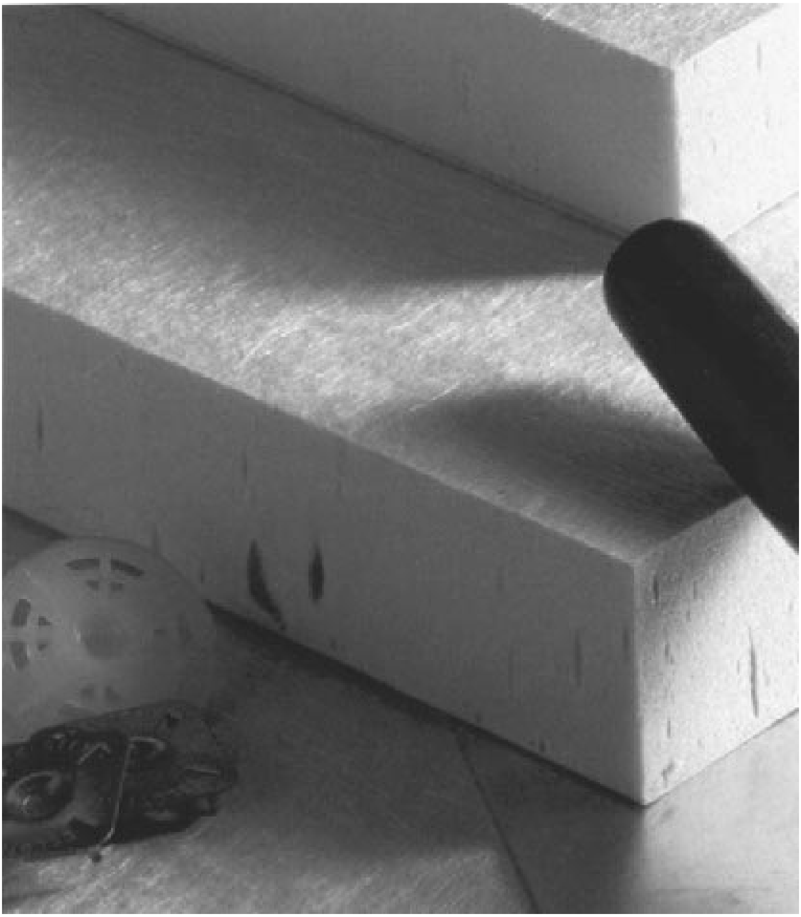

Figure 11.9 Polyisocyanurate core with fiberglass mat. (*Celotex*)

Figure 11.10 Foil-faced polyisocyanurate sheathing. (*Celotex*)

moisture-resistant, is classified as a water-repellent panel sheathing, and is resistant to the solvents often found in construction adhesives.

It is also a cost-effective roof insulation product because it is approved for installation directly to the steel roof deck without the need for a thermal barrier. Although not as critical to residential applications, PIR is stable over a large temperature range (−100 to +250°F). It can be used as a component in roof systems that use hot bitumen, but the insulation material will blister if the hot asphalt product is applied directly to it. As mentioned earlier, PIR with glass fiber or organic felt facers will lose thermal resistance over time, which must be taken into account when designing the roofing system.[4]

R-value

PIR is a closed-cell foam that contains a low-conductivity gas (HCFC) in the cells. Over time, the R-value of the foam drops as some of the gas escapes and air replaces it. As mentioned earlier, *stabilized R-value* is a term used by some manufacturers to accurately represent the long-term R-value of the installed board product. The thicker the product, the longer it takes to stabilize. Impermeable facers such as aluminum foils or patented coated-paper facers used on PIR products are essential in maintaining a relatively high, aged R-value. For example, foil-faced PIR boards have R-values that range from 7.2 to 8.0 per inch. Glass-fiber-faced PIR sheathing, such as that used as an EIFS or roofing substrate, has an R-value of 5.6 per inch.[5]

Limitations

More expensive than most other types of insulation, PIR boards must be protected from prolonged exposure to sunlight or water (unless facers are used), and when they are used in an interior application, a fire-resistant covering generally is required.

Environmental considerations

Recycled material is used in many PIR products. The Polyisocyanurate Insulation Manufacturers Association (PIMA) says that almost all products today meet the EPA procurement guidelines for federally funded buildings, which call for a minimum 9 percent recycled content. Rather than using recycled foam, however, manufacturers buy polyol chemical components with recycled content. The foil facers used on PIR products are typically 70 to 80 percent recycled aluminum. The industry reportedly used 20 to 30 million pounds of recycled postconsumer chemicals in 1993.[7]

Limitations

In 1992, most PIR insulation manufacturers changed their products' blowing-agent components from a chlorofluorocarbon (CFC-11) to a hydrochlorofluorocarbon (HCFC-141b). PIR insulation manufacturers will again need to find a suitable blowing-agent replacement because the EPA will restrict the production of HCFCs, including HCFC-141b, as of January 1, 2003. It is unclear as to what specific blowing agent(s) PIR insulation manufacturers will use, or when products using new blowing agent(s) will enter the marketplace. Some manufacturers are test marketing products manufactured with hydrocarbon blowing agents. The physical properties and field performance of PIR insulation using the next generation of blowing agents(s) are also largely unknown at this time, although preliminary data show comparable performance with current products.

Fire resistance

PIR insulation, a thermoset material, stays intact during fire exposure by forming a protective char layer and remaining in place during the tunnel test (the tunnel test is the ASTM E84, "Standard Test Method for Surface Burning Characteristics of Building Materials," which assesses the spread of flame on the surface of a material). Nevertheless, most PIR sheathing products cannot be left exposed and must be covered with an interior finish of a minimum $^1/_2$" gypsum board or equivalent thermal barrier. Some manufacturers produce PIR panels with a 1.25-mil (up to 16.5 mil) embossed acrylic-coated aluminum sheet laminated to 1.0-mil aluminum sheets on each side of the PIR core that are rated for interior exposure. These panel types are used primarily in industrial and agricultural buildings but are also commonly installed on the interior of basement walls and may be left exposed.

Perlite Board

Product description

As discussed in Chap. 7, perlite is a granular-type insulation made from a naturally occurring silicous rock quarried mainly in the western United States. Perlite is different from other volcanic glasses because when the crushed ore is heated to a suitable point in its softening range, it expands from 4 to 20 times its original volume.

Used for low-slope roofing systems, perlite insulation is manufactured as a rigid board that is composed of these expanded volcanic minerals combined with organic fibers and binders. An asphalt emulsion is used to treat the top surface to inhibit the absorption of bitumens. Perlite is compatible with bitumens and other adhesives, fire-resistant, dimensionally stable, and compatible with other roofing materials. The board will withstand impact, but care must be taken when handling the boards because they can break easily. The thermal resistance of the insulation is stable, but it has a relatively low R-value. Typically, perlite is not used with ballasted, loose-laid membranes because the board will readily absorb moisture.[4]

Wood Fiber

Product description

Fiberboard, historically called *structural insulating board,* is made primarily from wood, cane, or other organic fibers combined with a variety of binders.[10] Fiberboard was popular during the two decades after World War II. During manufacture, the raw material is reduced to a pulp, and then the fibers are chemically treated with waterproofing materials. Some boards are impregnated with asphalt either during or after the manufacturing process for moisture resistance. Sheet size is typically $^1/_2$, $^{25}/_{32}$, or 1", with standard lengths of 8 ft. Historically, this board type was used for interior finishes, sheathing, roof insulation, and roof deck planks.[10]

When used for low-slope roofing systems, the surfaces of the boards can be left plain, coated with asphalt, or impregnated with asphalt. Wood fiberboard is compatible with bitumens and adhesives, is impact-resistant, and is dimensionally stable. The material is flammable and must be protected from an ignition source. This insulation will hold water and must be protected from moisture. The thermal resistance of wood fiberboard is stable, but the R-value is relatively low.[4]

Mineral Fiber

Product description

Although the term *mineral fiber* historically refers to rock wool and slag wool, fiberglass products are also included in this category. These are also called *man-made vitreous fibers* (MMVFs), referring to the glassy, noncrystalline nature of these materials. A binding agent helps form the fibers into a rigid insulation board to be used for low-slope roofing systems. A glass-mat facer is applied to the top surface of the board. Mineral fiber insulation is compatible with bitumens and other adhesives, fire-resistant, dimensionally stable, and compatible with other roofing materials. Mineral fiber insulation is not as sensitive to moisture as fiberglass insulation because the separate mineral fibers absorb (but retain) only minimal moisture.

Fiberglass insulation board is a slightly modified product. After bonding fiberglass into a board shape, asphalt is used to bond a kraft paper facer to the top surface of the board. The paper facer will deteriorate if wetted, and the fiberglass board will retain water, reducing the thermal value.

The thermal resistance of mineral fiber is stable and has a relatively high R-value compared with other insulation materials. Mineral fiber board has a low compressive strength and is not recommended for loose-laid, ballasted roofing systems or mechanically fastened roofing membranes.[4]

Phenolic Foam

Product description

Based on research conducted for this book, the phenolic foam insulation board industry in both Canada and the United States declined rapidly and essentially disappeared in 1993–1994. Incidents of deck corrosion have been reported in cases where the insulation is in direct contact with steel roof decks and moisture is present.[11]

Phenolic foam board products were manufactured from phenol formaldehyde resin as an open- or closed-cell product. For several years, a high-R-value phenolic rigid insulation board was on the market. This closed-cell insulation had a typical R-value of 8.3 per inch. Because the foam boards often shrank, warped, or decomposed, manufacturers stopped making them.[12]

Cellular Glass

Product description

Cellular glass insulation is a rigid roof insulation board composed of heat-fused, closed glass cells blown with hydrogen sulfide. Available for low-slope roofing systems, the boards typically have kraft paper facers applied to the surfaces after the material is formed. Cellular glass is compatible with bitumen and other adhesives and is fire-resistant. The board itself is moisture-resistant, but the paper facers, to which other materials are adhered, will deteriorate if wetted. The boards are rigid and require care in handling so that they do not crack or spall. The thermal resistance of cellular glass is stable but not as high as it is for other insulation materials.[4]

Composite

Product description

Composite board insulation is usually is made of two different insulation materials that are laminated together. Mainly used for low-slope roofing, a typical example of a composite board is PIR or EPS combined with perlite or wood fiberboard. Composites also can incorporate insulation with other roofing materials, such as PIR laminated to a nailable substrate such as oriented strandboard.

The advantage of using a composite board is that it combines the benefits of two different materials in one board. Composites generally are compatible with bitumens and are impact-resistant. The fire, moisture, and thermal resistance can vary depending on the materials used.[4]

Contoured Foam Underlayment

Product description

Contoured foam underlayment (CFU) is a drop-in rigid foam insulation product that is custom made to fit snugly behind different styles of vinyl siding. This new product is intended to improve the rigidity of vinyl siding as well as its resistance to denting and warping. CFU typically is made from XPS foam that provides an R-value of 2.8 to 3.3 per inch and has a permeance rating of 5 (it is not a vapor barrier). Installation is relatively simple because the CFU is placed behind the siding and cut to size as necessary. The siding is snapped into its final position and nailed to the structure in accordance with the siding manufacturer's recommendations.

CFU is also available from some manufacturers as an integrated, fused vinyl siding and foam product. The installation is similar to conventional siding except that two courses go up at once and special accessories are used for corner and trim details.

Compressed-Straw Panels

Product description

Compressed-straw panels are not new. The process for producing compressed agricultural fiber (CAF) panels was invented in Sweden in 1935 by Theodor Dieden and later developed into a commercial product in Britain under the name *Stramit* by Torsten Mossesson in the late 1940s. Although the original patents have expired on the technology for producing compressed straw panels, numerous companies using the Stramit process are popular in Europe and Australia.

As revealed during the short-lived U.S. manufacture of Stramit panels, straw is compressed under a high temperature of approximately 390°F. The straw fibers become limp and form around each other, essentially "bonding" together without any adhesives. The panels ranged in thickness from 2 to 4" and were faced with heavy-weight kraft paper. Most of the products were prerouted for electrical wiring, and clips were sold to join panels securely together.

Several companies that have produced compressed straw panels and straw core stressed-skin panels have had difficulty continuing operations due to exaggerated R-values, inflated shipping costs, and poor marketing strategies. Nevertheless, cabinet carcasses, carpet underlayment, and interior sheathing products have started to achieve a small market share in the United States. It remains to be seen if a viable straw-based insulation board product will become a mainstay in residential construction.

Exterior Insulation and Finish Systems

Exterior insulation and finish systems (EIFS) are multilayered exterior wall systems that are used in both commercial and residential construction. Sometimes referred to as *synthetic stucco,* the basic five primary components include a rigid insulation board, an adhesive to attach the insulation board to a suitable substrate, a reinforcing mesh that is embedded in a base coat over the insulation board, and a textured finish. EIFS (pronounced "eefs" or "eefus") were developed in Europe in the early 1950s and were introduced to the United States around 1969. They were first used on commercial buildings and later on homes. EIFS currently account for about 17 percent of the U.S. commercial exterior wall market and about 3.5 percent of the residential wall market (Fig. 11.11).

Product description

Direct applied systems do not incorporate the use of rigid board insulation and are not within the scope of this book. Also polymer-based, the synthetic stucco is applied to a variety of water-durable substrates such as concrete masonry units and concrete.

There are two fundamental wall construction concepts of EIFS that will be discussed here. These are known as the *barrier-type method* and the *drainable type*. Although variations exist between proprietary barrier-type and drainable-type systems, an EIFS typically consists of the following three components:

1. A rigid insulation board, which is secured to the exterior wall surface with a specially formulated adhesive and/or mechanical attachment
2. A durable, water-resistant base coat, which is troweled on top of the insulation and reinforced with fiberglass mesh (or scrim) that is embedded in the wet base coat for added strength
3. A durable finish coat material, an acrylic polymer that usually contains an integral pigment and sand or marble aggregate and

Figure 11.11 EIFS. (*Dryvit*)

is troweled over the base coat, providing the finished exterior surface, which can be applied in a wide variety of colors and textures

For a barrier-type EIFS, the base coat, finish coat, and any related building sealants (e.g., sealants around windows) are intended to create a surface that serves as a barrier against all water penetration. Any water that penetrates this barrier and infiltrates the wall assembly effectively has leaked into a building's interior. This design is the original EIFS concept that was brought to the United States and is the most common method used on existing EIFS-clad buildings. As discussed later in this chapter, recent construction flaws have exposed a number of weaknesses in the barrier-type system. Even the United States Gypsum Company recently released a report that stated "'barrier' EIFS construction is not practical or reliable for residential or commercial construction."[13]

The drainable-type EIFS installation, also known as a *water-managed* or *rain-screen system,* is similar in concept to masonry cavity wall drainage construction. This method is growing quickly in popularity and is even required by some building codes. Some proprietary systems use an insulation board manufactured with drainage channels that is installed against an exterior wall substrate or weather-resistive barrier. Other EIFS may use some other type of material over the weather-resistive barrier and behind the insulation board to provide a drainage plain. These materials could include a drainage fabric, a metal or plastic lath, or a series of vertical spacers, similar to small furring strips, to remove any water that penetrates the exterior skin (Figs. 11.12 and 11.13).

Drainable-type EIFS are designed so that any incidental water that penetrates the exterior barrier surface drains down the drainage channels, fabric, or membrane and escapes from the base of the wall (or any horizontal obstruction) before it can leak into a building's interior. A drainable-type EIFS is flashed and weeped and features special construction details such as drainage tracks, drip edges, etc. to prevent moisture from entering in or around window openings (Figs. 11.14 and 11.15).

The insulation board used in EIFS can be EPS, XPS, or PIR. Attachment of the insulation board, whether by mechanical fastening or by adhesives, will be per manufacturer's installation instructions. Proprietary systems will outline acceptable substrates to be used. These include cement board, exterior-grade gypsum sheathing, glass-mat-faced gypsum sheathing, exterior-grade plywood, or exterior-grade oriented strandboard (OSB).

Most EIFS are formulated with an integral pigmented (colored) acrylic-based finish coat that provides resistance to fading, chalking, and yellowing. Although surfaces can be painted, the integral colors are designed to maintain their original appearance over time. An EIFS is very flexible in order to avoid the unsightly cracking problems that are common with stucco, concrete, and brick exteriors. An EIFS is usually about $4 to $6 per square foot.

Legal history

The barrier-type EIFS was plagued by large-scale moisture intrusion problems in the 1990s in various locations around the country. Few locales received more attention than those in Hanover County and Wilmington, North Carolina, the sites of the initial discovery of moisture damage problems in 1995. Although damage was reported across the United States, experts believe the accelerated number of housing starts in the Wilmington area may have overwhelmed homebuilders' ability to maintain quality control, thereby leading to the use of substandard building components and unqualified applicators using non-code-approved EIFS.

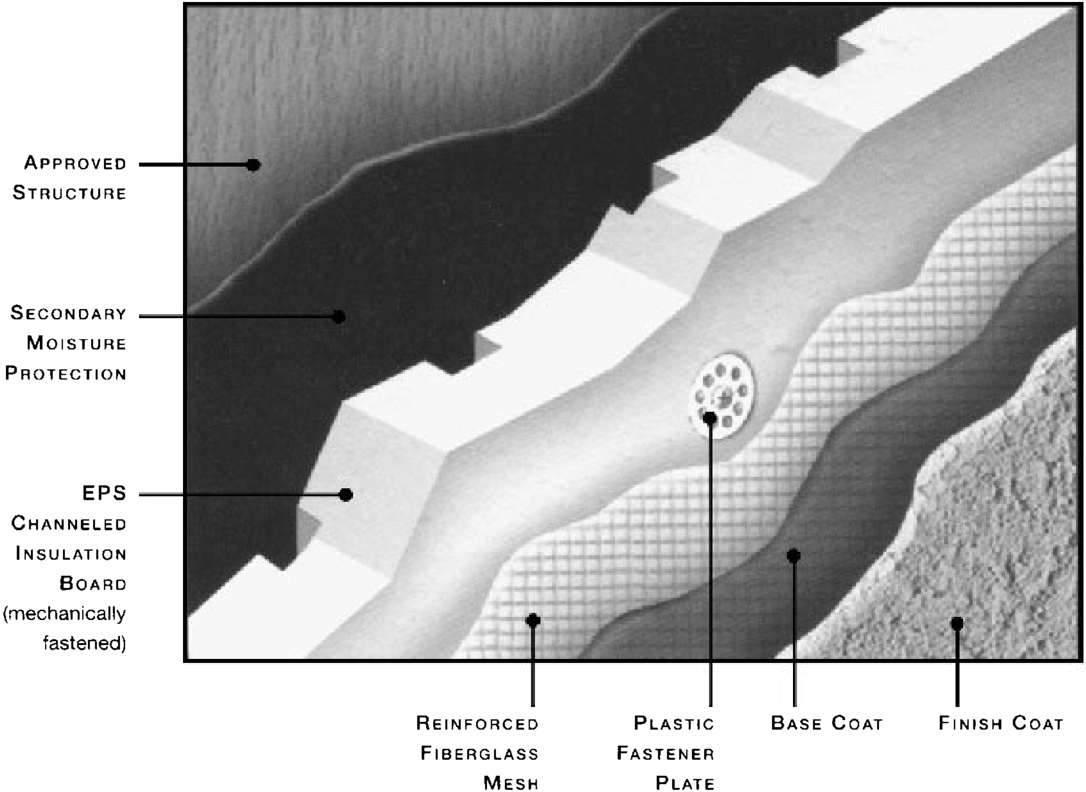

Figure 11.12 Drainable type—grooved EPS. (*TEC Specialty Products*)

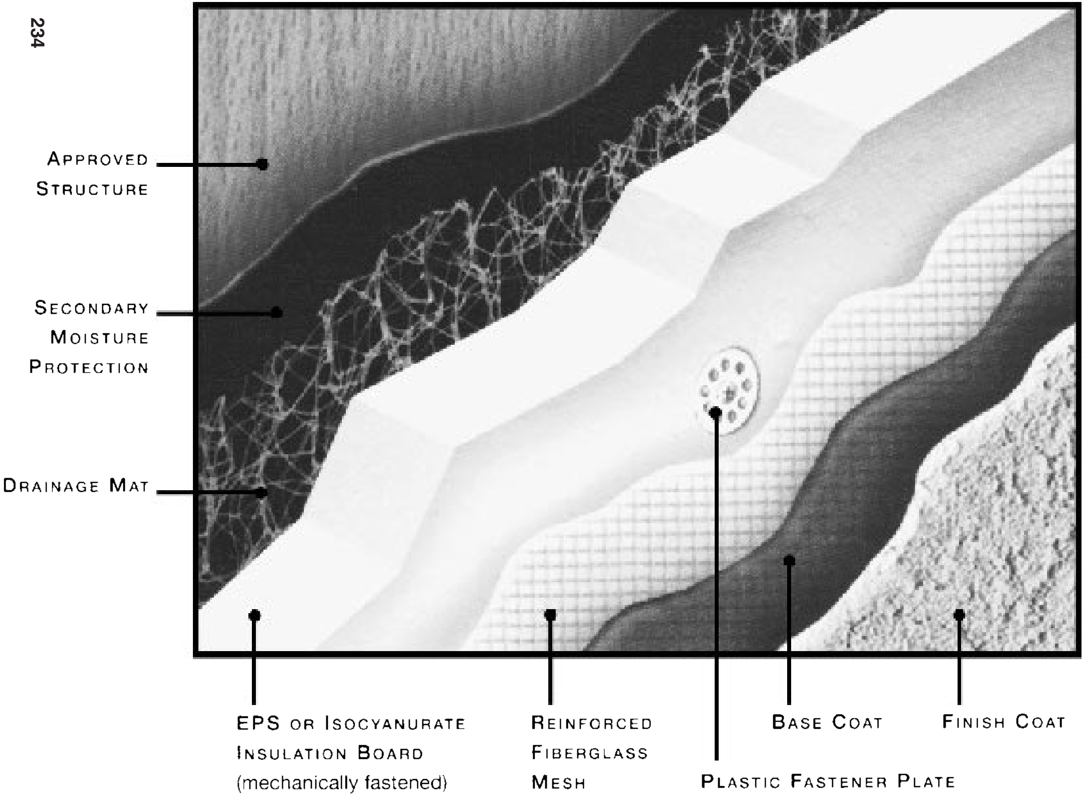

Figure 11.13 Drainable type—drainage fabric. (*TEC Specialty Products*)

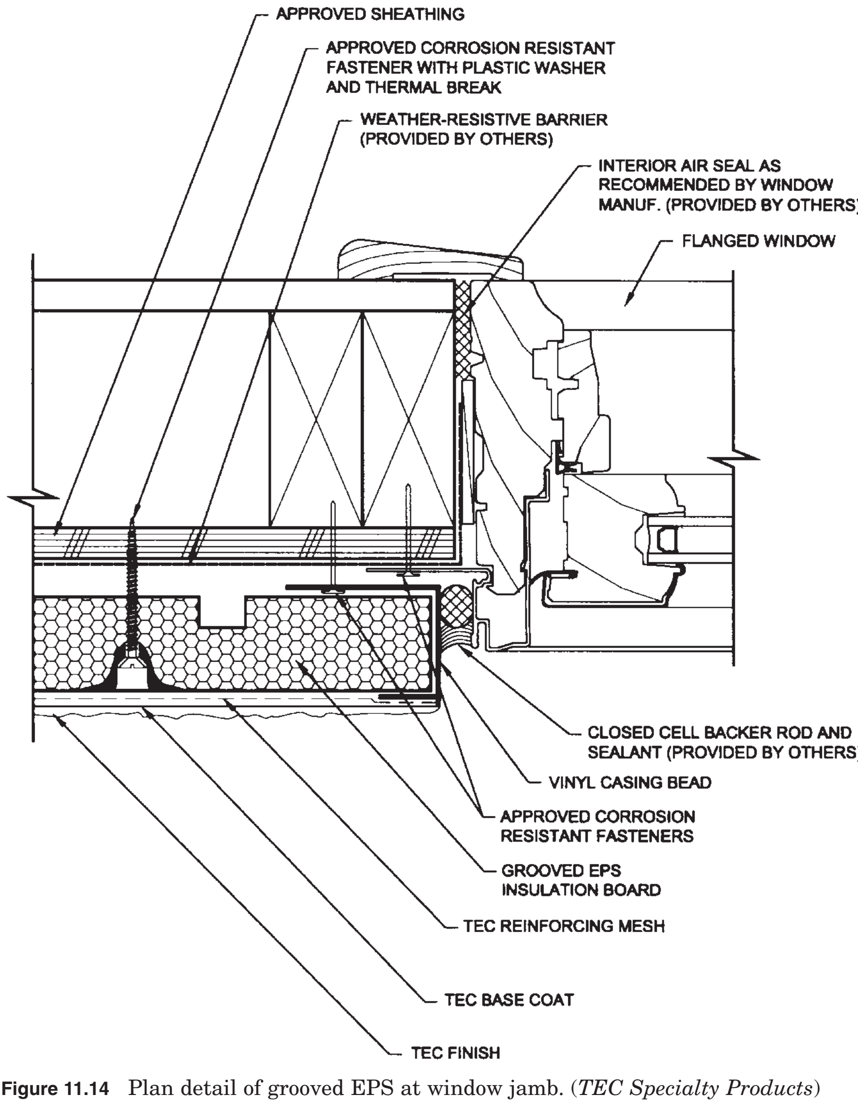

Figure 11.14 Plan detail of grooved EPS at window jamb. (*TEC Specialty Products*)

The specific cause of the EIFS problem has been studied extensively by the National Research Council of Canada (NRCC). According to NRCC reports, wind-driven rain most commonly enters the waterproof barrier EIFS surface in and around windows and other penetrations and at wall-roof intersections. Because a barrier-type EIFS provides no means for allowing water to escape the wall cavity, escape occurs only through evaporation into the structure or through the breathable EIFS. If it is not allowed to

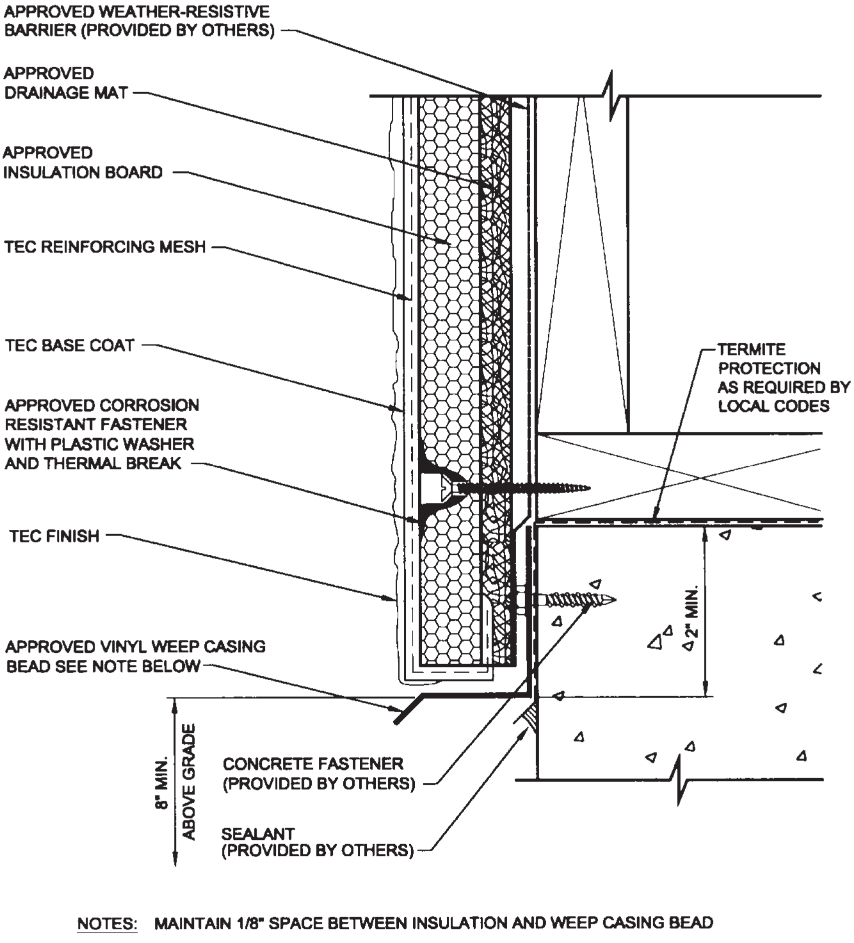

Figure 11.15 Section detail of drainage fabric at foundation. (*TEC Specialty Products*)

evaporate, as was the case in Wilmington because of the unusual climatic conditions coupled with the state building codes, it can remain in the wall for extended periods of time and eventually damage and even rot wood framing, sheathing, and other moisture-sensitive building components.

The class-action lawsuits stemming from these problems typically involved the barrier-type EIFS that used insulation board over plywood, oriented strandboard, exterior-grade gypsum, or other nonmasonry substrate on an exterior wall assembly. Drainable systems that included a secondary weather barrier did not suffer the same problems incurred by the barrier-type EIFS.

Limitations

Problems associated with an EIFS include cracking, surface degradation, impact damage, inadequate closure (e.g., sealants at windows), and system delamination. Each of these problems can result in water leaking into a building's interior. The culprit does not appear to be the synthetic stucco finish, but the barrier-type EIFS. It is inevitable in building construction that water will always find a way into a wall assembly. It is when the water or moisture *cannot get out* that problems seem to occur.

There are a number of areas that are more prone to water intrusion in residential applications of EIFS. These include

1. Interfaces between an EIFS and dissimilar materials.
2. Window joints around the perimeter of a window.
3. Seams and joints in the construction of the window unit, such as jambs and the sill interface.
4. Ganged window units that are not factory mulled.
5. Roof terminations against the lower edge of a wall.
6. Chimneys, decks, and any other penetration of the EIFS. This includes the installation of cap flashing, cricket flashing at trapped valleys, and effective kick-out flashing for roof-to-rake wall intersections.
7. Missing, damaged, or deteriorated sealant between the EIFS cladding and windows and doors, and around electrical fixtures, electric meter bases, hose bibs, refrigerant lines, etc. (Annual inspections of all seals by the homeowner is a good idea.)
8. Using sealants that are not polyurethane- or silicone-based (ASTM C920, "Standard Specification for Elastomeric Joint Sealants.")
9. Using a high-pressure power washer. (Low-pressure washing, such as with a garden hose, may be used.)
10. Kick-out flashing (cants) at roof-to-wall intersections.
11. Diverter flashing or crickets around trapped valleys.
12. Inadequate flashing (flashing should "terminate to daylight").
13. Inability or lack of access for visual inspection and treatment of the foundation for pest control. (The termination of EIFS should always be above finished grade.)

Periodic maintenance should include a thorough check of the flashing and sealing to ensure that the building envelope remains watertight. Damaged or missing flashing should be repaired or replaced immediately; likewise, cracked or deteriorated sealants should be repaired immediately or removed and replaced. Periodic use of a moisture meter will test for moisture content.

Installation standards and practices

To ensure long-term performance of an EIFS, the EIFS Industry Members Association (EIMA) recommends that the following steps be taken prior to and during construction:

1. Selection of an EIMA member manufacturer who can provide technical support, documented product and system test results, and building code compliance information.
2. Verification that all components are supplied and/or approved by one manufacturer.
3. Selection of a knowledgeable, experienced applicator who has current approval of the manufacturer or other manufacturer-certified education requirements.
4. A thorough review by the EIFS manufacturer of any unusual project details or conditions before the work commences.
5. Verification that the proper materials (with identification and labels intact) were shipped and stored in accordance with the manufacturer's requirements.
6. Checking to make sure the applicator is using all components from the same company.

Appendix

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770-968-7945
Fax: 770-968-5818
http://www.eifsfacts.com

Energy Efficiency and Renewable Energy Clearinghouse (EREC)
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800-DOE-EREC (363-3732)
Email: *doe.erec@nciinc.com*

EPS Molders Association
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http://www.epsmolders.org/

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http://www.pima.org/contactus.html

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Pactive Building Products
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678-589-7337
http://www.tennecobuildingprod.com/index.html

USG Corporation
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Chicago, IL 60606
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E-mail: *usg4you@usg.com*
http://www.usg.com/

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Chapter

12

Radiant Barriers and Reflective Insulation

Images from B movies have propagated an unwarranted depiction of "radiation" and its effects on human health. In reality, radiation is the "stuff" of life. The sun emits electromagnetic waves, a form of radiation, that directly transport energy in a straight path at the speed of light across the vacuum of space. As postulated by Albert Einstein in 1905, electromagnetic radiation travels at 186,281.7 mi/s and is only slightly slowed when passing through the earth's atmosphere.

Radiation, or more specifically, electromagnetic radiation, is energy that can be detected only when it interacts with matter. This is best exemplified by the warmth that is felt on a person's face when stepping out into the sun after standing under a shade tree. Wood stoves work by this same principle by transferring heat primarily via long-wave radiation to solid objects such as furniture, walls, floors, and people that are in "their" line of sight.

The *electromagnetic spectrum* refers to the complete range of possible electromagnetic radiation energies. The six types of electromagnetic radiation (wavelengths or frequencies) in order of increasing energy level are

1. *Radio waves.* Radio waves (including television and radar communications) are the region of the electromagnetic spectrum with very long wavelengths.
2. *Infrared radiation.* Infrared radiation, or heat energy, is the region of the electromagnetic spectrum with wavelengths long

enough to cause molecules to vibrate, increasing the temperature of the molecules.

3. *Visible light.* Visible light is the region of the electromagnetic spectrum where photons have enough energy to interact with certain pigment molecules in the retina of the eye to allow sight. This corresponds to the region of greatest solar output. All the colors of the rainbow fall into this small region, ranging from violet through indigo, blue, green, yellow, orange, and red.
4. *Ultraviolet radiation.* Ultraviolet radiation is the region of the electromagnetic spectrum where photons are sufficiently energetic to change energy states within atoms and molecules, sometimes even breaking them apart. Ozone absorbs certain types of ultraviolet (UV) radiation from the sun, which protects biologic organisms from the effects of UV rays.
5. *X-rays.* Most commonly known are its medical applications, since x-rays can be used to investigate the structure of molecules. X-rays are energetic photons that are produced in nuclear reactions and solar storms.
6. *Gamma rays.* Gamma rays are the most energetic of photons in the electromagnetic spectrum and the most biologically damaging. Gamma rays are produced in nuclear fusion reactions and can strip electrons away from molecules and atoms.

Although *light* is the name given to the type of electromagnetic radiation that can be seen, the bulk of the earth's radiant emittance occurs in the infrared portion of the electromagnetic spectrum. A barrier to limit the transfer of infrared radiation is commonly referred to as a *radiant barrier.* In residential design applications, a radiant barrier is a single sheet of reflective material positioned so that it faces an open space, such as an attic or wall cavity. Generally more effective in hot climates than in cool climates, radiant barriers often are used in buildings to reduce summer heat gain and winter heat loss. The radiant barrier itself provides no significant thermal resistance and must be installed in conjunction with an airspace to be effective.

Reflective insulation is the use of radiant barriers in combination with other materials such as a system of reflective sheets and airspaces designed together to fill a cavity and act as insulation. Reflective insulation systems typically are fabricated from aluminum foils with a variety of backings such as kraft paper, plastic film, polyethylene bubbles, or cardboard.

The use of a reflective surface to intercept the flow of radiant energy is actually historical in origin. Metal foil, which is solid metal reduced to a leaflike thinness by beating or rolling, has been around for centuries. The first mass-produced and widely used foil was made from tin. Aluminum was discovered in 1825 and replaced tin as the base material of foil in 1910, when the first aluminum foil rolling plant was opened in Switzerland.

This process evolved into the production of Reynolds Wrap, an American kitchen staple since 1947 that has protected leftovers, candy bars, and even NASA's "space blankets." (Reappropriated for consumers, the "survival blanket" is a thin plastic sheet that has a thin layer of metallized aluminum powder that is electrostatically fused over the plastic sheet on either one or both sides and is available in most camping stores.)

Thermal Principles

As discussed in Chap. 3, there are three modes of heat transfer: convection, conduction, and radiation. *Convection* is the transfer of heat in a fluid or air that is caused by the physical movement of the molecules of the heated air or fluid. When warm air in a room rises and forces the cooler air down, convection is taking place. Convection also can be caused mechanically (forced convection), by a fan or by wind.

Conduction is the process by which heat transfer takes place in solid matter, resulting from physical contact. The transfer of heat by conduction is caused by molecular motion in which molecules transfer their energy to adjoining molecules and increase their temperature. A typical example of conduction is seen when heat is transferred from a stove burner to a tea kettle, causing its contents to boil.

The third method of heat transfer, *radiation,* can be "observed" by the way the sun warms the surface of the earth. Radiation is the only method by which solar energy can cross millions of miles of empty space and reach the earth. While conduction and convection can be transferred only through a medium, radiation can be transferred across a perfect vacuum by electromagnetic waves.

The sun's transmission of electromagnetic waves to material surfaces, where they are absorbed and experienced in the form of heat, is analogous to a television signal. For example, a television transmitter emits an electromagnetic wave that travels through space. The wave is captured by the antenna and converted to a video image by the television. The radiant heat transfer between objects operates independently of air currents and is controlled by the character of the material's surface and the temperature difference between objects. Warm objects and cool objects will emit radiation, just at different rates. For example, radiant heat transfer takes place when a person feels cold while standing in front of a cold window, even if the inside air is warm. The human body radiates its stored heat toward the cold window surface. (The window is also emitting heat toward the warm body, just at a much slower rate.)

All matter emits radiation, provided that its temperature is above absolute zero. (Absolute zero is 459°F below zero.) Electromagnetic radiation does not contain any heat but only energy. The energy travels in a straight line at the speed of light until it is absorbed or reflected by another substance. Heat is generated when the energy in the different parts of the electromagnetic spectrum is transferred to the molecules in the substances that absorb the heat rays. The transfer of radiant energy from one object to another occurs without adding temperature to the airspace between them. For heat to move by radiation, there must be only a space between the objects. If the objects are touching, then the heat moves by conduction, not by radiation.

Incident energy striking an object can be absorbed by the object, reflected by the object, or transmitted through the object if it is not opaque. Since the building materials available for radiant barrier application are opaque, transmittance is not applicable to this discussion.

Absorptance is the quantitative measure of a material's ability to absorb radiant energy. Although an ideal blackbody is hypothetical, objects are often identified by comparison of their radiative properties with those of a blackbody at the same temperature. A blackbody radiator is referred to as *black* because an ideal blackbody is a hypothetical object that absorbs all radiation incident on its surface. Since it does not reflect any radiation (including visible light), it appears black. An approximate blackbody is lampblack, which reflects less than 2 percent of incoming radiation. Pot belly stoves, for example, are flat black so that they will freely emit radiant heat. In theory, a mirrored surface may reflect 98 percent of the energy, while absorbing 2 percent of the energy (although aluminum foil does not have to be shiny to reflect 95 to 97 percent). A good blackbody surface will reverse the ratio, absorbing 98 percent of the energy and reflecting only 2 percent.

Emittance refers to the ability of a material's surface to emit radiant energy. In layperson's terms, this means to "give off heat." Materials that radiate a large amount of heat and absorb a large percentage of the radiation that strikes them have high emittance values. The lower the emittance of a material, the lower the amount of heat that is radiated from its surface. Aluminum foil has a very low emittance value of 0.03 to 0.05 (Fig. 12.1).

Emittance value is often expressed as a material's emissivity. *Emissivity* is the ratio of the radiant energy emitted by a source to that emitted by a blackbody at the same temperature, expressed in a value ranging from 0 to 1. Most common building materials, including glass and paints of all colors, have high emissivities near 0.9. These materials are ineffective barriers to radiant energy transfer because they are capable of transferring 90 percent of their radiant energy potential.

Kirchoff's law states that for any object, absorptivity equals emissivity. This means that an object that is a strong absorber at a particular wavelength is also a strong emitter at that wavelength and an object that is a weak absorber at a particular wavelength is also a weak emitter at that wavelength. Emissivity of a blackbody is 1. Conversely, a perfect reflector has an emissivity of 0.

Material Surface	Emittance
Asphalt	0.90-0.98
*Aluminum foil	0.03-0.05
Brick	0.93
Concrete	0.85-0.95
Glass	0.95
Fiberglass / Cellulose	0.8-1.0
Iron (polished)	0.06
Iron (rusty)	0.85
Limestone	0.36-0.90
Marble	0.93
Paint: white lacquer	0.80
Paint: white enamel	0.91
Paint: black lacquer	0.80
Paint: black enamel	0.91
Paper	0.92
Plaster	0.91
Silver	0.02
Steel (mild)	0.12
Wood	0.90

Figure 12.1 Emittance values. (*RIMA*)

Reflectance (or *reflectivity*) refers to the measure of how much radiant heat is reflected by a material. Reflectivity and emissivity are inversely related. When the emissivity and reflectivity are added together, the sum is 1. Therefore, a material with a high reflectivity has a low emissivity, and a low emittance is indicative of a highly reflective surface. For example, since aluminum has an emissivity of 0.03, it has a reflectance of 0.97. Since it eliminates 97 percent of the radiant transfer potential, aluminum foil is very effective as an excellent radiant barrier and reflective insulation product.

Radiant Barriers

Product description

Mass-type insulations limit heat flow by possessing low thermal conductivity, allowing less heat to be transferred, or by trapping still air within the insulation, thereby limiting convection. A radiant barrier is a reflective surface on or near a building component that intercepts the flow of radiant energy to and from the building component. Typically a layer of reinforced foil, a radiant barrier reduces the amount of heat radiated across an airspace that is adjacent to the radiant barrier. The effectiveness of a radiant barrier is based on its ability to reflect the radiation that strikes it and at the same time not radiate energy. As discussed earlier, the lower the emissivity, the higher is the reflectance and the better is the radiant barrier.

Radiant barrier materials must have high reflectivity (usually 0.9, or 90 percent, or more) and low emissivity (usually 0.1 or less) and must face an open airspace to perform properly. A radiant barrier by itself provides no thermal resistance; it must be installed in conjunction with an airspace. For example, aluminum foil is a good thermal conductor but has an extremely low R-value. If it is placed between materials that are attempting to transfer thermal energy by radiation, it must be separated from these materials by an air layer. The foil effectively eliminates the normal radiant energy exchange across the airspace. If the airspace is not maintained, conduction is introduced. For example, where a radiant barrier surface comes in contact with another surface, such as mass insulation, direct conduction of heat will occur at all the points of contact.

The Department of Energy (DOE) reported that radiant barriers tend to offer a much lower potential for energy savings in colder climates. Radiant barriers are more effective in blocking summer heat gain and saving air-conditioning costs.[1] At present, there is no standardized method for testing the effectiveness of radiant barriers in reducing heating and cooling bills. Numerous field tests have been performed, however, that show that radiant barriers are effective in reducing cooling bills by limiting total heat gain. For example, solar energy is absorbed by the roof on a sunny day, which in turn heats the roof sheathing. This causes the underside of the sheathing and the roof framing to radiate heat downward toward the attic floor. If a radiant barrier is placed below the roof sheathing or on the attic floor, much of the heat radiated from the hot roof is reflected back toward the roof and not emitted to the attic airspace. This makes the top surface of the insulation cooler than it would have been without a radiant barrier and thus reduces the amount of heat that moves through the insulation into the rooms below the ceiling. The best results from this installation are achieved when there is ventilation between the radiant barriers and the roof. This prevents that space from overheating and reducing the effectiveness of the radiant barriers. Test results indicate that cooling bill savings are more dramatic in homes having lower amounts of conventional insulation. The DOE has established typical savings amounts based on attic insulation values[2] (Figs. 12.2 and 12.3).

The North American Insulation Manufacturers Association (NAIMA) performed a number of tests in 1988 that studied the effects of adding radiant barriers to existing homes. These tests showed that radiant barriers located on the top of the rafters and draped between the cavities resulted in a 20 to 26 percent reduction in summer ceiling heat flow for a home with R-19 ceiling insulation. Studies were not performed with R-30 insulation and radiant barriers.[3]

Installation standards and practices

Radiant barriers can be manufactured in a variety of ways. Commercial products include radiant barrier material that is preapplied to rigid insulation, applied to structural sheathing, and as reinforced sheet radiant barrier material. Sheet materials include single-sided and double-sided foils. Radiant barriers that are manufactured as multilayered foil systems with airspaces are discussed in the reflective insulation section of this chapter. The application of sheet material is discussed in this section.

The installation of multiple layers of radiant barrier materials is generally discouraged. One layer of a typical radiant barrier material will block 95 percent of radiant heat gain. A second layer for the purpose of blocking additional radiant gain will block less than 5 percent. The material and labor costs incurred when installing

Present Value Savings for Radiant Barrier Attached to Bottoms of Rafters
(Note: R-11, R-19, R-30, and R-38 refer to the existing level of conventional insulation.)

City	Present Value Savings, Dollars per Square Foot of Attic Floor			
	R-11	R-19	R-30	R-38
Albany, NY	0.17-0.19	0.08-0.09	0.04-0.05	0.03-0.04
Albuquerque, NM	0.24-0.27	0.12-0.15	0.08-0.10	0.06-0.08
Atlanta, GA	0.21-0.25	0.10-0.13	0.06-0.08	0.05-0.07
Bismarck, ND	0.18-0.20	0.09-0.10	0.05-0.06	0.04-0.05
Chicago, IL	0.17-0.19	0.08-0.10	0.05-0.06	0.04-0.05
Denver, CO	0.19-0.22	0.10-0.12	0.06-0.08	0.05-0.07
El Toro, CA	0.19-0.22	0.10-0.12	0.06-0.08	0.05-0.07
Houston, TX	0.23-0.28	0.12-0.15	0.07-0.10	0.05-0.08
Knoxville, TN	0.22-0.25	0.11-0.13	0.07-0.09	0.05-0.07
Las Vegas, NV	0.30-0.36	0.15-0.19	0.09-0.12	0.07-0.10
Los Angeles, CA	0.11-0.12	0.06-0.07	0.04-0.05	0.03-0.04
Memphis, TN	0.23-0.27	0.11-0.14	0.07-0.09	0.06-0.08
Miami, FL	0.28-0.36	0.15-0.20	0.09-0.13	0.07-0.10
Minneapolis, MN	0.18-0.19	0.08-0.10	0.05-0.06	0.03-0.04
Orlando, FL	0.26-0.32	0.13-0.17	0.08-0.12	0.07-0.10
Phoenix, AZ	0.36-0.43	0.17-0.23	0.10-0.14	0.08-0.12
Portland, ME	0.14-0.15	0.06-0.06	0.03-0.04	0.03-0.03
Portland, OR	0.14-0.16	0.07-0.08	0.04-0.05	0.03-0.04
Raleigh, NC	0.20-0.24	0.10-0.12	0.06-0.08	0.05-0.07
Riverside, CA	0.27-0.37	0.13-0.17	0.07-0.10	0.06-0.08
Sacramento, CA	0.23-0.26	0.12-0.14	0.07-0.10	0.06-0.08
Salt Lake City, UT	0.21-0.24	0.10-0.12	0.06-0.08	0.05-0.07
St. Louis, MO	0.21-0.24	0.10-0.13	0.06-0.08	0.05-0.07
Seattle, WA	0.11-0.12	0.05-0.05	0.03-0.03	0.02-0.02
Topeka, KS	0.22-0.26	0.11-0.13	0.07-0.09	0.05-0.07
Waco, TX	0.26-0.31	0.13-0.17	0.08-0.11	0.06-0.09
Washington, D.C.	0.20-0.23	0.09-0.12	0.06-0.07	0.05-0.06

Note: First value applies to houses with no air-conditioning ducts in attics. Second value applies to houses with air-conditioning ducts in attics.

Figures in table are based on a radiant barrier with an emissivity of 0.05 or less, with the radiant barrier covering the insides of the gables. Savings are for a 25 year period.

Figure 12.2 Energy savings. (*Department of Energy*)

multiple layers will not be recouped by the additional energy use savings.

Likewise, a radiant barrier material with two foil sides is only modestly better than one with a single foil side. In an attic airspace, one foil side blocks up to 95 percent of the radiant heat transfer. A second foil surface can block only a portion of the remaining 5 percent. Therefore, a second foil surface usually is not cost-effective.

Attic locations

Radiant barriers are easiest to install during construction. Nevertheless, installing a radiant barrier system in an existing

Present Value Savings for Radiant Barrier Draped over Tops of Rafters or Attached to Roof Deck
(Note: R-11, R-19, R-30, and R-38 refer to the existing level of conventional insulation.)

City	Present Value Savings, Dollars per Square Foot of Attic Floor			
	R-11	R-19	R-30	R-38
Albany, NY	0.16-0.17	0.07-0.08	0.04-0.05	0.03-0.04
Albuquerque, NM	0.21-0.24	0.11-0.14	0.07-0.09	0.06-0.07
Atlanta, GA	0.19-0.22	0.09-0.12	0.06-0.07	0.04-0.06
Bismarck, ND	0.17-0.18	0.08-0.09	0.05-0.06	0.03-0.04
Chicago, IL	0.15-0.17	0.07-0.09	0.04-0.05	0.03-0.04
Denver, CO	0.17-0.19	0.09-0.10	0.05-0.07	0.05-0.06
El Toro, CA	0.17-0.20	0.09-0.10	0.05-0.07	0.05-0.06
Houston, TX	0.20-0.25	0.10-0.14	0.06-0.09	0.05-0.07
Knoxville, TN	0.19-0.22	0.10-0.12	0.06-0.08	0.05-0.07
Las Vegas, NV	0.27-0.32	0.14-0.17	0.08-0.11	0.06-0.09
Los Angeles, CA	0.10-0.11	0.06-0.06	0.03-0.04	0.03-0.04
Memphis, TN	0.20-0.24	0.10-0.13	0.06-0.08	0.05-0.07
Miami, FL	0.25-0.31	0.13-0.18	0.08-0.11	0.06-0.09
Minneapolis, MN	0.16-0.18	0.07-0.09	0.04-0.05	0.03-0.04
Orlando, FL	0.23-0.28	0.11-0.15	0.07-0.10	0.06-0.09
Phoenix, AZ	0.31-0.38	0.15-0.20	0.09-0.13	0.07-0.11
Portland, ME	0.13-0.13	0.06-0.06	0.03-0.03	0.02-0.03
Portland, OR	0.13-0.14	0.06-0.07	0.04-0.04	0.03-0.04
Raleigh, NC	0.18-0.21	0.09-0.11	0.06-0.07	0.04-0.06
Riverside, CA	0.24-0.33	0.11-0.15	0.07-0.09	0.05-0.07
Sacramento, CA	0.20-0.23	0.10-0.13	0.06-0.08	0.06-0.07
Salt Lake City, UT	0.19-0.21	0.09-0.11	0.05-0.07	0.04-0.06
St. Louis, MO	0.18-0.21	0.09-0.11	0.05-0.07	0.04-0.06
Seattle, WA	0.10-0.11	0.04-0.05	0.02-0.03	0.02-0.02
Topeka, KS	0.20-0.23	0.10-0.12	0.06-0.08	0.05-0.06
Waco, TX	0.23-0.28	0.11-0.15	0.07-0.09	0.05-0.08
Washington, D.C.	0.18-0.21	0.08-0.10	0.05-0.06	0.04-0.05

Note: First value applies to houses with no air-conditioning ducts in attics. Second value applies to houses with air-conditioning ducts in attics.

Figures in table are based on a radiant barrier with an emissivity of 0.05 or less, with the radiant barrier covering the insides of the gables. Savings are for a 25 year period.

Figure 12.3 Energy savings. (*Department of Energy*)

home can be relatively easy provided there is sufficient working room in the attic.

According to the DOE, there are five possible locations for the installation of an attic radiant barrier system to be effective[2] (Fig. 12.4):

1. Before the roof sheathing is applied, the radiant barrier is draped over the rafters or trusses. The radiant barrier should droop $1\frac{1}{2}$ to 3" between each rafter. An airspace is necessary between the radiant barrier and the roof sheathing. This is suitable for new construction only.

2. The radiant barrier is attached to the faces of the rafters or top chords of the roof trusses. If the barrier is single-sided, the reflective face should face downward, toward the attic, to minimize any dust accumulation. An airspace ($^3/_4$" minimum) is necessary between the radiant barrier and the roof sheathing.
3. The radiant barrier is attached to the bottom of the rafters or top chords of the roof trusses. An airspace ($^3/_4$" minimum) is necessary between the radiant barrier and the roof sheathing.
4. The radiant barrier can be laid out on the attic floor over the top of existing attic insulation, provided the insulation does not fill the cavity. As with all radiant barrier installations, an airspace must be maintained to avoid any conductive heat transfer. If the barrier is single-sided, the reflective face should face downward, toward the attic insulation (and above the airspace), to minimize any dust accumulation. This application always should be done with a perforated radiant barrier and one that has foil on both sides for maximum performance.
5. The radiant barrier material is preattached directly to the underside of the roof deck. Plywood and oriented strandboard products laminated with foil on one side are available.

There are some basic safety considerations that an installer, either a professional or a homeowner, should consider during radiant barrier installation:

1. Although American Society for Testing and Materials (ASTM) installation standards do not require special protection when handling radiant barrier materials, handling conventional insulation may cause skin, eye, and respiratory system irritation. If in doubt about the effects of the insulation, protective clothing, gloves, eye protection, and breathing protection should be worn.
2. Be especially careful with electrical wiring, particularly around junction boxes and old wiring. Never staple through, near, or over electrical wiring. Repair any obviously frayed or defective wiring in advance of radiant barrier installation.
3. Work in the attic only when temperatures are reasonable.
4. Working with a partner not only will expedite the process, but assistance will be immediately available should a problem occur.
5. Unfinished attics can be especially dangerous. Step and stand only on the attic joists or trusses, or use dimensional lumber for a working platform.

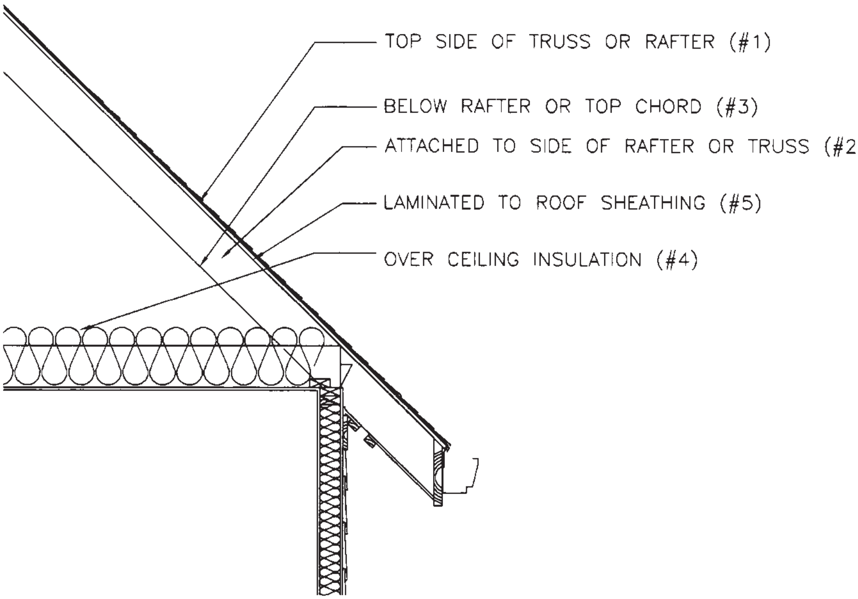

Figure 12.4 Radiant barrier locations. (*Bynum*)

6. In most attics, roofing nails penetrate through the underside of the roof.
7. Make sure that the attic space is well ventilated and lighted.
8. Do not cover any recessed lights or kitchen and bathroom vents with radiant barrier material during an attic floor application.

Radiant barriers can be used above unheated basements and crawl spaces and in wall and floor applications. These assemblies require specific design conditions, airspace clearances, and vapor retarder placement to be effective. (Unless perforated, radiant barrier materials will qualify as a vapor retarder. Perforated foils typically are used only when laying on top of existing attic insulation.) Foil-faced fiberglass batts with a fire-retardant binder, stapled to the sides of the wall studs, require an airspace between the foil facing and interior sheathing to be effective. A larger wall cavity, and subsequently deeper wall stud framing members, will be required. Another less common technique is to use foil-faced gypsum wallboard over furring strips on the interior stud faces. The furring strips create an airspace between the foil facing and cavity insulation.

"Vent skin" construction is commonly used in Florida. In this assembly, a radiant barrier is applied to the exterior of the wall, followed by furring strips and sheathing. The airspace created by the furring strips typically is vented top and bottom so that outdoor air can circulate into and through the space (Fig. 12.5).

Since radiant energy travels in a straight line through the air and is not affected by air currents, airtight seals are not necessary for a radiant barrier to perform effectively. Since radiant barriers are both barriers to heat transfer and vapor retarders, proper radiant barrier selection must be coordinated with vapor retarder placement to avoid trapping condensation in certain climates. Perforated radiant barriers are also used if moisture vapor condensation could present a problem, as in placement of the radiant barrier on top of mass insulation on an attic floor.

Limitations

Since radiant barriers redirect radiant heat back through the roof, tests have demonstrated that radiant barriers can cause a small increase in roofing material temperatures. Roof-mounted radiant

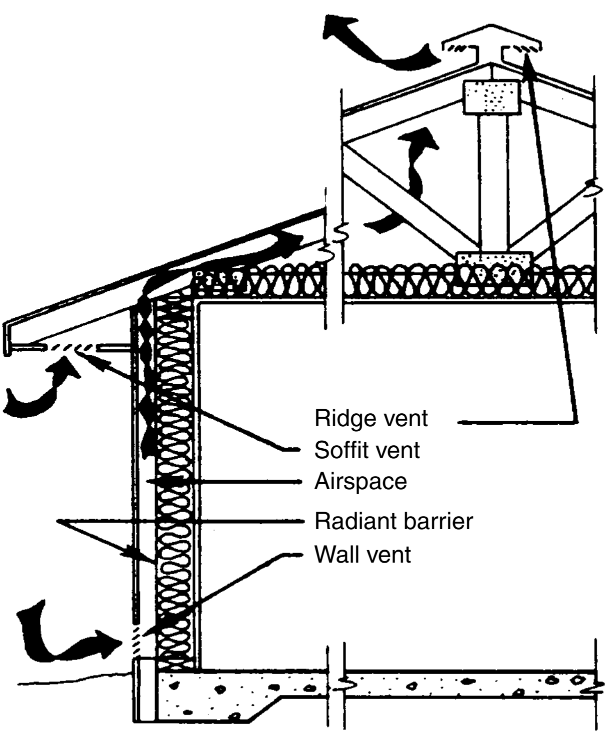

Figure 12.5 Vented radiant barrier wall section. (*Bynum*)

barriers may increase shingle temperatures by 2 to 10°F, whereas radiant barriers on the attic floor may cause smaller increases of 2°F or less. The effects of these sustained higher temperatures on the roof shingles or substrate have not been shown to degrade the life of shingles.

If the radiant barrier is installed directly on top of attic floor insulation, condensation of moisture vapor can become a problem. For example, moisture vapor from the interior of a house may move into the attic during the winter months. A radiant barrier on top of the insulation could cause the vapor to condense on the radiant barrier's underside. As is the case when a vapor retarder is placed on the wrong side of insulation, radiant barrier materials function as an additional vapor retarder on the opposite side of the wall cavity. For this reason, this application would call for a perforated radiant barrier. This can be especially critical in cold climates.

Installing a radiant barrier directly on top of attic floor insulation also can compromise its effectiveness due to dust accumulation. This location is also not appropriate when a large part of the attic is used for storage, since the radiant barrier surface must be exposed to the attic space. It also can be punctured or torn during any service work that may need to be done in the attic.

Durability during installation is an important consideration when comparing products. Thicker foil layers and the use of a reinforcing material are superior to the lower-cost foils that have minimal tear resistance.

Fire ratings

A radiant barrier must receive a Class A/Class 1 fire rating. A flame spread index of 25 or less and a smoke development index of 450 or less must be achieved according to ASTM E84. These ratings should be printed on the product or listed on the manufacturer's material safety data sheets (MSDS) or other technical data literature.

Cost

Installing an attic radiant barrier is obviously easier and less expensive during new construction. If a retrofit project is undertaken, the amount of room the contractor has to maneuver in in the attic will affect cost. Radiant barrier material costs vary, ranging from $0.10 to $0.45 per square foot. Although most materials can be installed by a homeowner, a contractor may charge an additional amount for installation costs.

The energy savings payback period will vary extensively, contingent on the cost of the radiant barrier installation, heating and cooling periods, amount of existing insulation, etc. Data are not available for specific calculations, but regional research in Florida suggests that a payback period of 10 years can be expected in hot southern climates.[4]

Reflective Insulation

Product description

Unlike single-sheet radiant barrier materials, reflective insulation is a multilayer radiant barrier product with an intrinsic R-value. Comprised of layers of aluminum foil, paper, and/or polyethylene, the insulation creates reflective airspaces within the cavity, thereby reducing radiant heat transfer and heat flow by convection. The use of aluminum foil as a reflective insulation ensures a minimum 95 to 97 percent reflectance of long-wave radiant heat.

Reflective insulation installation applications are similar to those of radiant barriers. Since most foil-faced reflective insulation products also retard vapor transmission, special attention must be paid to vapor retarder placement in the wall, floor, or ceiling assembly. Trapping moisture between two vapor retarders can lead to condensation-related decay and damage. This can be problematic in attic floor insulation applications. If, for example, a vapor retarder is located on the interior ceiling side of the insulation, reflective insulation cannot be laid on top of the existing insulation.

Foil-faced polyethylene insulation

The most common reflective insulation products are foil-faced polyethylene sheets, which consist of layers of aluminum foil separated by polyethylene bubbles (Fig. 12.6). The polyethylene air cushioning can be from one to five layers depending on the manufacturer. Many products incorporate stapling flanges at the edge for easy installation. These products are noncarcinogenic, water-resistant, and fungus-resistant. With few exceptions, foil-faced polyethylene insulation is not restricted by code from being left exposed, provided the product is classified with a Class 1, Class A fire rating.

Foil-faced polyethylene insulation is lightweight, easy to install with a staple gun, and can be cut using a utility knife. Tears or excess cuts usually can be repaired with 2 or 3"-wide pressure-sen-

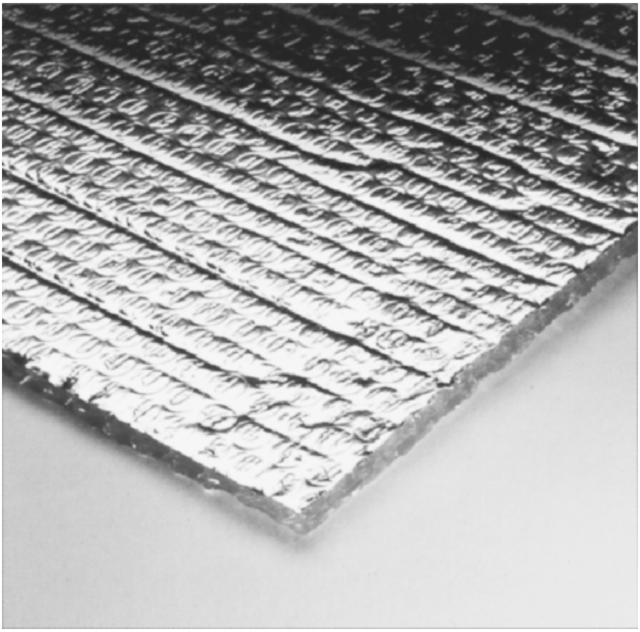

Figure 12.6 Astro-foil reflective insulation. (*Astro-Foil*)

sitive aluminum tape. (Do not use duct tape.) A $^3/_4$" minimum airspace must be maintained on each side of the insulation. The sizes available vary based on specific products. Rolls are usually available in widths of up to 6 ft and lengths of up to 125 ft. Typical thickness are $^1/_4$, $^3/_{16}$, or $^5/_{16}$".

Locations where reflective insulation can be installed include

1. Over roof trusses/rafters
2. Interior sides of wall studs/furring, exposed or encapsulated
3. Undersides of floor joists/trusses, exposed or encapsulated
4. Undersides of first floor joist/trusses at crawl spaces, exposed or encapsulated
5. Below interior ceiling joists/trusses/rafters, exposed or encapsulated
6. As a wrap for HVAC supply ducts
7. As a wrap for water heaters
8. As a wrap for water supply piping
9. As primary insulation for in-floor hydronic staple-up heating systems

R-values

R-values of reflective insulations depend on the direction of the heat flow. This can be confusing when one is accustomed to comparing singular R-values for conventional mass insulations. For example, one manufacturer of $^5/_{16}$" foil-faced polyethylene insulation reports R-values to be 15.0 down, 5.4 up, and 7.31 horizontal.

Sideways (horizontal) heat flow through a wall will result in nominal convection loss. Upward heat flow, as through the ceiling in the winter, is in the same primary direction as convection, so the R-value is significantly reduced. In downward heat flow applications, such as through the floor to a crawl space in the winter or through the roof in the summer, convection is not a factor, resulting in maximum R-values. Reflective insulations must be installed with an airspace in order for the radiant heat to be reflected. Therefore, the R-values are reported as an installed system that includes the R-value of the surrounding airspaces.[5] If the airspace dimension is changed, then the R-value of the system is changed.

Board and paper products

Foil-faced kraft paper is produced as a folded or rolled product and is available with two to five layers in a wide range of effective resistances. The airspaces are formed only when the product is stretched to its full width. Care must be taken in installation to ensure that the paper is sufficiently stretched and that foil layers are not touching, or the material will not be fully effective. Prices vary accordingly, from around 14 to 70 cents per square foot.[6]

There are a number of laminated structural sheathing materials, such as foil-faced paperboard, that have reflective surfaces but are not installed as radiant barriers. Production homebuilders ("national builders") commonly use these materials as the substrate for houses with vinyl siding. Installed in this manner, these products lack only an airspace in order to be used as a radiant barrier. Costs for these products range from 13 to 25 cents per square foot.[6]

A new name on the market is *TechShield,* and is produced by Louisiana Pacific. TechShield is highly polished, kraft paper–backed, perforated aluminum. Formerly labeled *Kool-Ply,* TechShield is a patented radiant barrier overlay that is laminated directly to either oriented strandboard (OSB) or plywood structural panels, and mainly used as roof decking. TechShield radiant barrier decking is installed in the same manner as standard APA-rated sheathing. A $^1/_2$

to $^3/_4$" airspace must be maintained between the foil and the insulation blanket between the roof rafters or ceiling joists (Fig. 12.7).

Standards

The following are the ASTM standards associated with reflective insulation materials and radiant barrier products.

C236-89, "Standard Test Method for Steady-State Thermal Performance of Building Assemblies by Means of a Guarded Hot Box"

C727-90, "Standard Practice for Use and Installation of Reflective Insulation in Building Constructions"

C976-90, "Standard Test Method for Thermal Performance of Building Assemblies by Means of a Calibrated Hot Box"

C1158-90, "Standard Practice for Use and Installation of Radiant Barrier Systems (RBS) in Building Construction"

Figure 12.7 Radiant barrier laminate. (*Louisiana-Pacific Corp., Tech-Shield*)

C1224-93, "Standard Specification for Reflective Insulation for Building Applications"

C1313-95, "Standard Specification for Sheet Radiant Barriers for Building Construction Applications"

C1340-96, "Standard Practice for Estimation of Heat Gain or Loss Through Ceilings Under Attics Containing Radiant Barriers by Use of a Computer Program"

C1371-96, "Standard Test Method for Determination of Emittance of Materials Near Room Temperature Using Portable Emissometers"

E84-95b, "Standard Test Method for Surface Burning Characteristics of Building Materials"

E96-95, "Standard Test Method for Water Vapor Transmission of Materials"

Paints

Coatings can be applied to the interior of a home that will work as radiant barriers. Interior radiation control coating (IRCC) is a non-thickness-dependent silver-colored low-emittance coating. When applied to nonporous building materials such as plywood, OSB, metal siding, or plasterboard, it lowers the normal surface emittance of these materials to 0.24 or lower. It is somewhat less efficient because of its higher emissivity when compared with a foil or film product.[7]

One manufacturer reports that about 40 percent of the radiant energy generated within a room in the winter is reflected back into the room after this paint is applied. Similar results are claimed in the summer: A room coated with a low-E (low-E is an abbreviation for low emissivity) wall paint on the interior of a building's walls will not allow about 40 percent of the radiant energy to be emitted into the room.[8]

A water-based IRCC can be rolled or spray applied (either air atomization or airless is the most effective method of installation) in existing structures where the cost of installing foil or film products may be prohibitive. Brush painting is usually impractical because these coatings have a very low viscosity and are not formulated for brush application. It is imperative that after installation the surface painted with the IRCC face a minimum of a 2" airspace.

Technical data and field testing research are limited with these new products. *Low-E coatings,* as these products are commonly called, have a lower emissivity than the higher-build ceramic coatings. See Chap. 14 for a discussion of ceramic pigmented solar radiation control coatings for exterior application.

Low-E glass

In order to minimize the transfer of radiant heat through glass, a revolutionary product was invented in the early 1980s called *low-E glass.* Low-E glass allows natural light to enter, while reflecting indoor heat energy back into the home in winter. Likewise, it reflects outdoor heat energy back to the outside in summer.[9] There are two types of low-E coatings, softcoat and hardcoat. Softcoat low-E coatings are vacuum deposited on the glass after it comes off the float glass manufacturing line. These coatings are created as the room-temperature glass passes through a series of vacuum chambers where metallic particles are deposited onto the glass surface.

Hardcoat low-E coatings are applied in a pyrolytic process on the float glass manufacturing line before the glass has cooled. This means the coating is sprayed on the molten glass and is fused to the glass as it cools, creating a permanent bond. Although this product is not as thermally effective as softcoat glass, the process produces a coating that is as durable as the glass itself.[10]

While ordinary clear glass allows more solar energy into your home than low-E glass does, clear glass has such a low R-value that it allows not only the solar energy gain but any furnace-generated heat (during the winter) to escape. Low-E windows can achieve R-values as high as R-5, a marked improvement over R-1 single-pane or even R-2 double-pane windows. Low-E windows cost a little more than standard windows and allow slightly less light to enter but are often cost-effective in extremely hot or cold climates.[11]

Miscellaneous

As an interesting sidenote, reflective insulation is also available for windows. Proprietarily known as *Sailshades,* this product is a seven-layered roll product. When raised during winter days, Sailshades allow the benefits of the sun's passive heating to reach the interior of the home. When lowered during winter evenings, the product serves as a wall of insulation for the structure. Similar to foil-faced polyethylene insulation, two outer layers of aluminum foil are bonded to a layer of polyethylene for strength. Two inner layers of bubblepack resist heat flow, whereas a center layer of polyethylene gives the insulation additional strength. The product features an

R-value as high as 8.83. The shades are custom made for each window but are not cheap. A typical 24 × 48" window covering will cost about $176.[12]

Appendix

Radiant Barrier Fact Sheet
DOE/CE-0335P
June 1991
Department of Energy
Assistant Secretary for Energy Efficiency and Renewable Energy

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Chapter

13

Earth

Long before the age of manufactured insulation materials, human beings learned to survive against a climate's thermal discomforts by using the most plentiful of all materials at their disposal: earth. Now, at the dawn of the twenty-first century, this same material is experiencing a renaissance in residential construction. Natural building systems such as adobe, cast earth, cob, wattle and daub, earth shelters, PISÉ, Earthships, and rammed earth are a few of the earth-based construction systems receiving attention. (Straw bale construction is discussed in Chap. 15.)

It may not seem within the scope of this book to review materials that at a first glance are not conventional insulation products. On closer inspection, however, earth shelters, rammed earth, and other natural building systems are significant and viable alternatives because of the intrinsic thermal mass possible when implemented in appropriate designs and climates.

Earth architecture may be the oldest form of construction in human history. Various forms of indigenous earthen structures and materials have been developed throughout the world. Today it is estimated that 40 to 50 percent of the world's population still live in earthen dwellings.[1]

Cob is an old technique that offers the potential to create very sculptural wall shapes. Straw is mixed with small gravel into a sandy soil. The mixture is formed into cobs (lumps), which are thrown onto the wall and worked into the previous applied layer. The rough surface is later trimmed and made smooth. The result is often a softly undulating surface that is commonly tapered inward toward the top. Cob has been used mostly in experimental buildings in the United States, while code testing procedures are still being investigated.

Wattle and daub starts with a latticework of light branches or timber. An earth-plaster mix is forced ("daubed") into the gaps in the latticework and finished to give a serviceable surface.

Adobe, or mud brick, is an ancient building technique dating back at least to the days of Jericho (now Israel) in 8300 B.C. Adobe structures built some 900 years ago in the United States are still in use today. The system of fabrication remains virtually unchanged. First, mud bricks are cast in open molds on the ground using a blend of earth and water with the consistency of cake mix. The molds are then removed immediately or allowed to remain until the next day. The bricks are eventually lifted onto their sides, trimmed, and stacked to air dry and cure.[1]

Rammed earth, also called *stabilized rammed earth,* is a process by which walls are formed in place by pounding damp soil into movable, reusable frames. Rammed-earth tire construction, also referred to as *Earthships,* use discarded automobile tires, recycled aluminum cans, and cardboard that are laid flat and rammed with soil.

Passive solar principles are essential to the effectiveness of earth design. Historians are quick to note that these strategies were hardly a result of the 1970s energy crisis. The Anasazi cliff dwellings, for instance, were built into south-facing cliff walls that received the sun's rays during winter months and were shaded from the sun in the summertime. The Anasazi understood that in winter the sun travels low across the southern sky, and in summer it crosses high overhead. As with their cliff dwellings, passive solar homes with south-facing windows welcome the winter sun and are protected from the summer sun. (Fig. 13.1). Once the winter sun's rays are in a home, the next requirement for passive solar heating is a place to store those rays. This is intrinsic to the success of the earth shelter, which uses its thermal mass to temporarily store and release heat.[2]

The ability of solid earth to function as a thermal mass results in interior temperatures that change very little from day to night. Mass walls absorb solar energy during winter days and then reradiate that energy to offset nighttime heat losses within the building. In the summer months, the mass of the walls absorbs excess heat generated during the day, keeping the interior spaces cool. In a properly designed and oriented house, this typically means savings in heating and cooling bills as well as a more comfortable and even

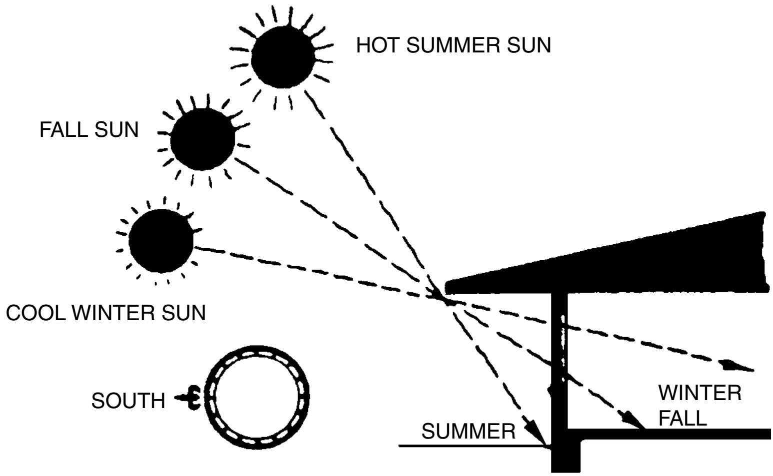


Figure 13.1 Seasonal sun angles. (*McGraw-Hill, Inc.*)

temperature throughout the home. The energy that determines the temperature inside the house radiates directly from the mass of the walls as opposed to a space regulated through mechanically altered air. Each of the systems discussed herein can be constructed with or without additional insulation. Climate, user preferences, and design standards determine the actual assembly configuration.

Ventilation requirements are of prime concern in an earth-integrated home because of the reduced amount of air infiltration. Approximately two air changes per day typically are desirable. Ventilation can be achieved by either a forced-air system or an operable window system with good cross-ventilation that takes advantage of natural air flows. Natural ventilation also can be maximized with a custom ventilation system designed for the particular floor plan, geographic area, and climate. Additional ventilation is also necessary if open-flame or gas appliances are used in the home.

The inclusion of these systems is intended to inform the reader of alternative construction assemblies that may or may not "be for everyone." The very fact that many of these systems have been used for hundreds of years indicates that they are a viable alternative to conventional home construction methods.

Earth Homes

For contemporary residential applications, earthen dwellings are commonly referred to as *earth-sheltered housing*. There are two types of earth home designs. Earth-sheltered housing, or underground housing, is typified by a structure with two or, in most cases, three sides and the roof covered with earth. There are even successful designs that place the entire structure below grade or completely underground (Fig. 13.2). An earth-bermed house uses a conventional roof, with only the sides of the home partially protected with earth (Fig. 13.3). Each type takes advantage of the natural temperature of the earth. At 5 to 7 ft below grade, most climates will only reduce the earth's temperature to around 53°F. This natural temperature regulator means the actual "work" of the mechanical thermal control systems to raise or lower temperatures to the desired human comfort level is greatly reduced.

There are a variety of reasons that homeowners provide when explaining their attraction to living in a home that uses soil as the primary building material. These include

1. Energy efficiency
2. Ecologically sound
3. Unique
4. Low life-cycle cost
5. Reduced maintenance
6. Solar heating
7. Water lines never freeze

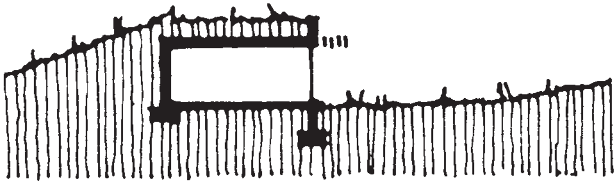


Figure 13.2 Underground earth shelter. (*McGraw-Hill, Inc.*)

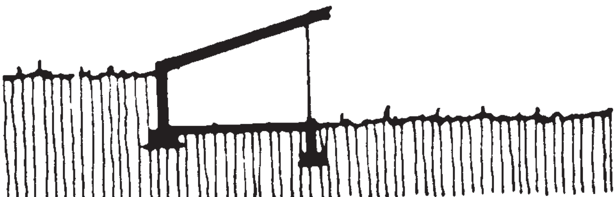


Figure 13.3 Bermed earth shelter. (*McGraw-Hill, Inc.*)

8. Storm resistant
9. Termite resistant
10. Rodent resistant
11. Earthquake resistant
12. Decay resistant
13. Fire resistant
14. Limited visual impact
15. Efficient land use
16. Wood conservation
17. Environmental benefits

The improvement in earth design systems over the past 20 years appears to have corrected many of the mistakes that plagued earth homes in the 1970s. There are a number of variations on a theme when it comes to specifying or constructing this building type. Proper research, inspection of existing structures, and sound construction practice by qualified contractors will provide a comfortable, thermally efficient earth-sheltered home that will last many years.

Product description

There are three generic design types that are commonly found in earth-sheltered homes. These are referred to in this book as the *atrium* (or *courtyard*) *plan,* the *elevational plan,* and the *penetrational plan*. The atrium design is an underground structure in which an atrium serves as the focus of the house and the entry into the dwelling. Unlike the other two design types, the courtyard design offers an open feeling because it has four walls that give exposure to daylight. The subgrade open area, a central outdoor courtyard, is the entrance into the home and is surrounded by the major living spaces. The windows and glass doors that are on the exposed walls facing the courtyard provide light, solar heat, outside views, and access via a stairway from the ground level. Atrium homes are usually covered with less than 3 ft of earth and provide ample access to natural ventilation, primarily because there is no benefit in energy efficiency from greater depths (Fig. 13.4).

The elevational plan is a bermed and roof-covered structure that typically has a glazed, south-facing entry. The other sides and roof

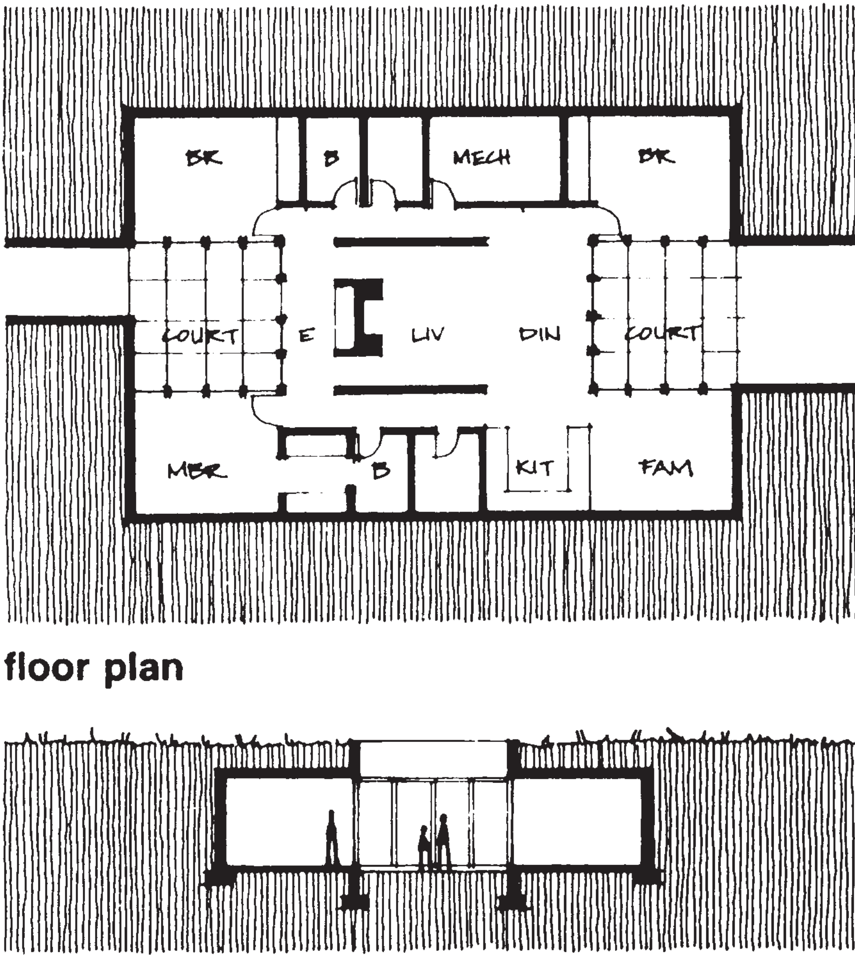
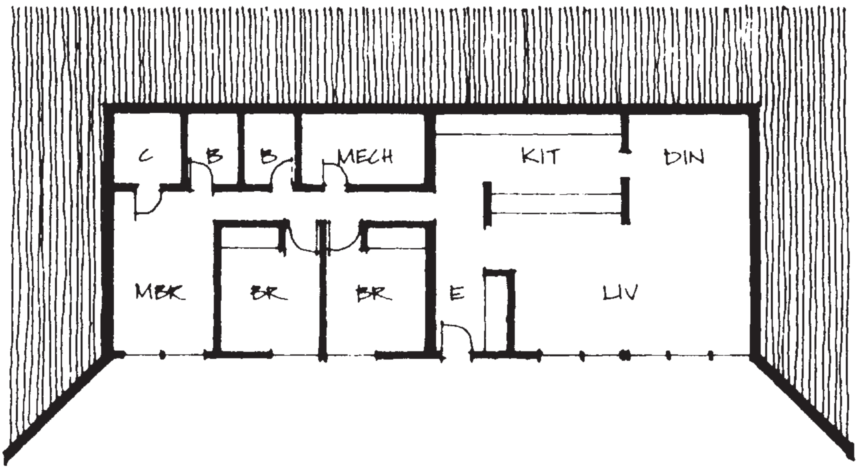


Figure 13.4 Atrium plan and section. (*McGraw-Hill, Inc.*)

are typically covered with earth. The exposed front of the house, usually facing south, allows the sun to light and heat the interior. The floor plan is arranged so that common areas and bedrooms share light and heat from the southern exposure. One drawback is that the northern portions of the house may have reduced daylight and limited internal air circulation unless a custom-designed fresh air ventilation system is installed. Skylights and an open floor plan can help alleviate these problems. Historically, a structure designed in this way has been the most popular and the most economical to build of all earth-sheltered structures. Contemporary



floor plan

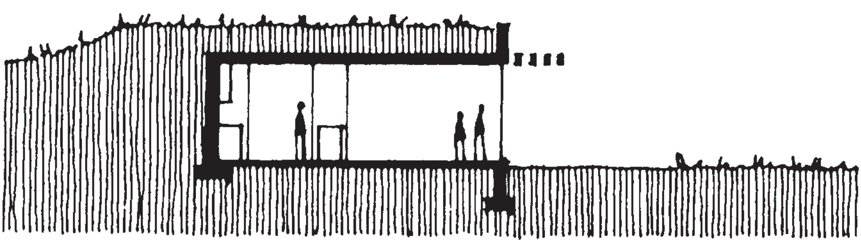


Figure 13.5 Elevational plan and section. (*McGraw-Hill, Inc.*)

designs are now more adventurous; two-story plans, cathedral ceilings, and vaults are slowly becoming the norm (Fig. 13.5).

In the penetrational plan, the house is built at ground level or partially above grade and is bermed to shelter the exterior walls that are not facing south. Earth covers the entire house except around the windows and doors. This design allows cross-ventilation opportunities and access to natural light from more than one side of the house (Fig. 13.6).

The most efficient designs reveal that an airtight wood stove or a small efficient forced-air furnace may be all that is necessary to provide supplemental heat. The only electrical demands come from a small blower that circulates the heat from the wood stove throughout the house. Some homes also have incorporated radiant floor heat, small geoexchange systems, or area heaters in the prime

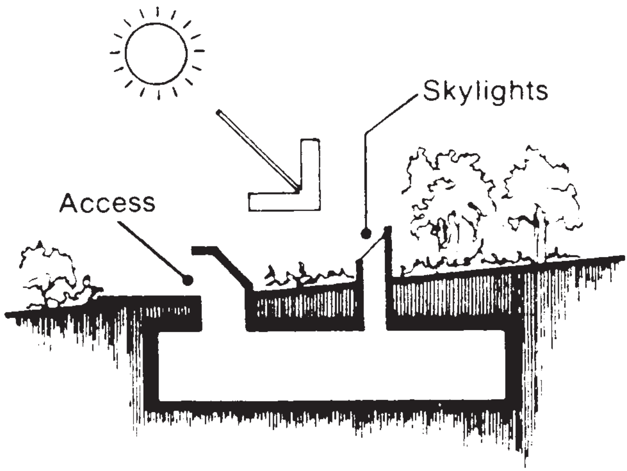


Figure 13.6 Penetrational earth-sheltered home. (*McGraw-Hill, Inc.*)

living areas. Supplemental heat sources also may be preferred in the bathroom areas.

Adequate air exchange must be planned carefully when building an earth-sheltered dwelling. Generally, well-planned natural or mechanical ventilation (by exhaust fans) can dissipate ordinary odors. Any combustion appliances that are installed should be sealed combustion units that have a direct source of outside air for combustion. It is mandatory that the combustion gases are vented directly to the outside. Ventilation and exhaust systems for radon presence also must be addressed in earth-sheltered house design and site selection.

Energy-efficiency claims have far too many variables to rely on one set of statistics in reference to this overview. Typical results based on data gathered for this book show that homeowners may save up to 80 percent in heating and cooling costs as compared with conventional homes, depending on the number, orientation, and treatment of openings. The thermal mass of the earth ensures that the home will never drop to less than +50°F without heat, even in mid-winter.[3]

Additional insulation in an earth-sheltered home will depend on the climate, house design, and construction materials used. For example, cold spots can be eliminated in the structure by specifying 3" of polystyrene insulation placed over the exterior concrete walls prior to backfilling and 6" of insulation over the roof covered by 3 ft of dirt.[3]

Although specifications will be designer-specific, one builder typically constructs homes with a standard 8-ft-high wall of 8"-thick poured-in-place concrete, designed for a minimum of 650 lb/ft^2 lateral load.[4] The standard ceiling is 10 to 12" of concrete designed for a vertical load of 790 lb/ft^2. This system also allows for a minimum of 3 ft of earth cover.[4]

Limitations

Studies show that earth-sheltered houses may be more cost-effective in climates that have significant temperature extremes and low humidity, such as the Rocky Mountains and northern Great Plains. The earth temperatures vary much less than air temperatures in these areas, accentuating the design advantages of the earth berm as a thermal mass, thereby eliminating the need for a more complex heating, ventilation, and air-conditioning (HVAC) system.

Topography plays an important role in site selection. For example, a modest slope requires more excavation than a steep one, whereas a flat site needs the most extensive excavation. Research suggests that the most ideal site is one that has a south-facing slope in a region with moderate to long winters. Construction in other regions or facing in other directions uses skylights and a more complex HVAC system (Figs. 13.7 and 13.8).

Figure 13.7 Earth shelter on a flat site with berm. (*Davis Caves Construction, Inc.*)

Figure 13.8 Earth shelter on a steep slope. (*Davis Caves Construction, Inc.*)

Soil tests must be performed prior to site or design selection because some types of soil are more suitable than others for earth-sheltered construction. For example, the best soils are granular, such as sand and gravel. These soils compact well for bearing the weight of the construction materials and are very permeable, allowing water to drain quickly. The poorest soils are cohesive, like clay, which may expand when wet and has poor permeability. If clay is encountered on site, it is recommended that a porous backfill such as sand or gravel or a drainage mat be used.

Groundwater is also an important factor. Besides building above the water table, choosing a site where the water will naturally drain away from the building is the best way to avoid water pressure against underground walls. Swales and drainage systems must be designed to run water away from the structure to reduce the frequency and length of time the water remains in contact with the building's exterior.

There are a number of waterproofing systems in use today. Although many systems are effective, the best option will possess the following characteristics:

1. Long life-expectancy underground
2. Resealing capacity at underground temperatures

3. Good crack-bridging capability
4. Durability or protection during backfilling

Such systems include but are not limited to

1. Rubberized asphalt (Bituthene)
2. Plastic sheets such as high-density polyethylene and high-density polyethylene
3. Liquid polyurethanes
4. EPDM membranes
5. Bentonite

Installation standards and practices

The characteristics of the site, climate, soils, design, and budget will aid in determining the construction materials to be used. Earth-sheltered houses will require stronger, more durable construction materials than above-grade conventional homes because they must be able to withstand the stress imposed by the surrounding earth. When soil is wet or frozen, it exerts greater pressure on the walls, ceiling, and floors of such a building than the pressure that already exists. Pressure also increases with depth, so a material such as concrete may be the best choice, although reinforced masonry, wood, and steel are also suitable if properly engineered.

Cast-in-place concrete has the most advantages as a construction material. Minimal joints, durability, fire resistance, material strength, and thermal mass qualities are ideal for earth-sheltered design. It also provides a good surface for applying waterproofing. If additional insulation is used, it must be protected to withstand the pressure and moisture of the surrounding ground. Masonry products such as brick or concrete masonry units are also used, but the necessary sealing of mortar joints can be problematic. Although wood can cost less than other materials, it does not offer the strength that a material such as steel does, so it may not be the best choice for structural material in some houses. Steel can be used for beams, bar joists, columns, and concrete reinforcement. Protection against corrosion is required if it is exposed to the elements or to groundwater.

Fire resistance

Depending on the material selection, earth-sheltered houses can be made virtually fire-resistant. Concrete or masonry shells, concrete slab floors, and steel-framed interior walls sheathed with type X or fiber-reinforced gypsum board will eliminate most ignition sources. Special selection of furnishings is necessary to guarantee a comprehensive fire-resistance design.

Rammed Earth

Rammed earth is a building technique that dates back to at least 7000 B.C. in Pakistan. Portions of the Great Wall of China, as well as a five-story hotel built in Germany in 1837, also were constructed of rammed earth. Even in the United States, thousands of rammed-earth houses were built during the Great Depression.[1]

It is important to explain that a rammed-earth wall assembly is not an insulator in the true sense of the definition. The actual insulating value (the resistance to the transmission of heat applied to one side of the wall to the other side) is poor. As mentioned earlier, earth walls are actually good capacitors, serving as good, but temporary, heat-storage masses. Commonly referred to as the *flywheel effect* (the ability to absorb energy and reradiate it over time), the earth can store the energy for constant slow reradiation, resulting in a very smooth temperature swing curve for the building. This principle also applies to the proper placement of thermal mass elements such as floors and interior walls that even out temperature variations in a building due to the temperature storage capabilities of the building's mass.

In a real building application, the interior temperature will be an average of the high and low temperatures outside from several days earlier. This is called the *thermal-lag effect.* While the outdoor temperature may vary 30 to 40°F in a 24-hour period, the inside changes will vary only a few degrees. Thus, when the temperature is 90°F in the day and 60°F at night for several days, the inside of the building will approximate 75°F. The thermal lag is proportional to the wall thickness but influenced by the solar gain. In Arizona, for example, the thermal lag on a 24"-thick rammed-earth wall can be up to 3 days. Designers state that this is most effective when the extreme temperature swings between day and night are over 40°F.[3] Additional insulation also may be necessary, depending on the extent the passive solar principles are applied to the overall design of the home.

Rammed-earth walls are formed in place by pounding damp soil into movable, reusable frames (formwork) with manual or machine-powered pneumatic tampers. The earth material is typically mixed with about 8 percent water and 3 percent cement, although this may vary depending on the soil used. The earth is compacted (tamped) in 4- to 6-in lifts in enclosed formwork similar to that of cast-in-place concrete. Also referred to as *stabilized earth,* these walls achieve compressive strengths estimated to be about half that of concrete. The walls act as a thermal mass, usually requiring no additional insulation. Rammed-earth walls can be 12 to 36" thick but are typically 18 or 24" thick. The final density is usually around 125 lb/ft^3, giving the wall excellent thermal properties. The virtually maintenance-free walls do not require additional finishes unless aesthetically desired. They are also fire-resistant and extremely durable.[1]

One difficulty with the rammed-earth method is that strict limits have to be placed on shrinkage to eliminate cracking. Often cement or hydrated lime is added to improve durability, but successful structures are built using suitable soils without such additives. A sandy, crumbly soil (with a clay content around 15 to 30 percent) may be the best choice because of its good workability and minimal shrinkage.

Product description

Rammed-earth walls can be constructed in one of three typical systems:

1. Individual panels of earth are enclosed within a framework of cast-in-place concrete.
2. The earth walls are fully reinforced with an integral grid of steel reinforcing rods.
3. A continuous solid-earth wall is topped with a bond beam of reinforced concrete.

The finished solid-mass earthen wall, as it comes out of the form, may be finished with exterior stucco and interior plaster. Newer design trends seem to indicate that the natural finish of the rammed-earth wall is growing in popularity. In climates where rainfall can be extreme, walls should be protected against saturation with roof overhangs and elevated foundations. If waterproofing is omitted, moisture may penetrate all the way to the inside surface of the walls during prolonged wind-driven rainstorms.

Additional costs incurred will vary depending on the site, the height and complexity of the wall system, the available soil, and the seismic safety factors. The cost increase over conventional wood-frame construction will be a minimum of 10 percent.

Limitations

It is important to recognize that rammed-earth construction is a "made by hand" product and will exhibit the inconsistencies that characterize any handmade item. For example, the color and texture of the finished wall will vary. Some areas may be rough or inconsistent in density. Construction tolerances will need to be more forgiving than those used in typical construction practice. Shrinkage cracks, honeycombing, and voids are also likely to occur.

PISÉ (Pneumatically Impacted Stabilized Earth)

Another form of monolithic earth wall construction is PISÉ (Pneumatically Impacted Stabilized Earth). A single form is constructed to shape the interior wall surface. Wire reinforcement is then attached, and a mix of earth and cement is sprayed onto the outside. A patented process developed by David Easton, PISÉ uses a gunite hose (similar to the hose used to spray concrete to wall forms or pools) to directly apply rammed earth into the frames. Using one-sided formwork and high-pressure air delivery, trained crews can complete up to 1200 ft^2 of 18"-thick wall per day. A training program is required before a subcontractor is qualified to shoot PISÉ walls.

Earthships

Earthships is the popular term for what are actually rammed-earth tire homes. This construction system, using passive solar design and recycled materials, was developed by Michael Reynolds of Solar Survival Architecture. The environmentally conscious system uses recycled automobile tires filled with compacted earth for thermal mass and structure. The homes can be dug into south-facing hillsides or located on flat sites and bermed to obtain additional thermal mass.

The construction system is actually very simple. The first course of tires of any tire wall must be leveled and dug into undisturbed soil. Tires are laid flat and rammed full of approximately three wheelbarrow-loads of soil. Each tire weighs about 350 lb, and the tires are set in a running-bond fashion. All tire walls that are an integral part of the roofed building should have a continuous wood or concrete bond beam serving as a top plate.

Between 500 and 2500 tires are used in a rammed-earth tire home (for homes of 1000 to 4000 ft^2). Earth is bermed against the outsides of the tire walls, while 2 to 4" of plaster or stucco cover the inside of the tire wall. (Foam insulation also can be applied to exposed exterior or interior walls and covered with stucco.) The building is framed in wood on the south side and roofed with metal to collect rainwater. Aluminum or tin cans are also used for filling in concrete walls that are not load-bearing. Other systems include integrated wastewater treatment, photovoltaic electrical systems, solar hot water, and passive solar heating.

Indoor air quality and other potential environmental problems are still being studied. Published research at present seems to suggest that rubber degradation, carbon black vapor, or other chemical off-gassing may not pose a serious health hazard in this type of construction.[5]

Appendix

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Chapter

14

Coatings

Ceramic Coatings

Insulating coatings (more accurately named *reflective paint coatings*) have been used in industrial applications for years. Until recently, the white roofs seen on many a yellow school bus were perhaps the closest this innovative technology made it into the residential environment. These ceramic coatings basically reflect solar radiant energy and are now being found in a number of residential applications. The ceramic technology in this fluid-applied insulation is a “cousin” to the ceramic particles in the heat shield tiles used on the space shuttles to block heat during reentry into the Earth’s atmosphere. These coatings contain hollow ceramic bubbles that have a tremendous ability to reflect and dissipate heat. Extremely durable and easy to apply, the paint’s thermal properties of reflection, refraction, and dissipation make it a good insulator for walls, roofs, and even interiors. Ceramic-filled paint provides benefits year-round, but it is particularly effective at blocking the radiant heat from the summer sun. It is not intended to replace thermal mass insulations, however, especially in northern climates where retaining indoor heat is of primary concern.

Most products consist of a 100 percent acrylic elastomeric emulsion containing ceramic microspheres that range in size from 10 to 100 μm. Since ceramic particles block radiant heat, it is difficult to give this paint a typical R-value rating, yet tests demonstrate a significant drop between inside and outside temperatures of wall and roof installations. These coatings are typically nontoxic, although there are epoxy-based and urethane-based coatings for industrial applications. The elastomeric coatings for residential use possess excellent resistance to changes in weather.

Product description

Ceramic-filled paints for residential application are available as acrylic, acrylic-elastomeric, and urethane- or epoxy-based. The water-based products are the most popular for residential use at present because of their ease of use and cleanup.

Certain characteristics among all types make the idea of an "insulating paint" actually possible. Ceramic paint has tiny micro-sized hollow ceramic particles or flat platelets in a water-based acrylic vehicle. In the paint can the spheres are suspended, making the paint look and feel like ordinary paint. When the paint is applied, the spheres or platelets move toward the surface to create a heat-reflecting and heat-dissipating surface. As the paint dries on a surface, the microspheres pack together underneath to create an insulating barrier.

Residential consumers have reported that the dried paint looks just like typical exterior house paint. Many of these coatings are designed for high build and can stretch and contract substantially without breaking or wrinkling. Most products can be rolled or brushed on, but spraying will depend on the specific manufacturer's instructions.

Ceramic-filled coatings can seal a substrate and provide a waterproof surface. They are also suitable on metal surfaces where expansion and extreme weathering characteristics, including resistance to ponding, are important. Most products provide a 10- or 15-year limited warranty against chipping, flaking, and peeling. The manufacturer's full written warranty should be reviewed for more specific information.

R-value

R-value ratings are not available for liquid coatings, although manufacturers report a simplistic variety of equivalences in their product-specific literature. These range from equivalent R-values of R-10 to R-24. Color choice influences the effectiveness, with white coatings providing the higher R-values.

Limitations

Ceramic paints are designed to protect against radiant heat and have a reduced effect on conductive heat. The use of these coatings is much more effective in keeping heat out in the summer, but they will, to a lesser degree, keep heat in during the winter.

Color selections are limited. One manufacturer provides only an antique white that is tinted with up to 8 oz of colorant per gallon. Bright white is the most efficient, but tests show that reflective properties are dramatically decreased after minimal color is added.

Fire resistance

American Society for Testing and Materials (ASTM) Standard E84-87 tests of products reviewed for this book report that ceramic paints have both flame spread and smoke development ratings of 5.

Installation standards and practices

Ceramic-filled paint typically is applied at a thickness of up to 15 mil, much thicker than ordinary house paint. This heavy coat often covers small cracks and imperfections and to a small degree even reduces noise indoors. Additional paint can be applied but may not be cost-effective after two or three coats.

Temperature recommendations for application vary among products, typically to a maximum air temperature of 110°F. As with all products, manufacturers' instructions need to be followed for proper application procedures.

Paint Additives

As presented in the Preface of this book, the specific mention of a commercial name does not imply endorsement, nor does failure to mention a manufacturer imply criticism. Research for this book, however, revealed only one manufacturer of paint additives for insulating coatings.

Product description

INSULADD is a ceramic microsphere paint additive that is mixed with ordinary paint to block heat transfer through surfaces. Formulated for use with interior and exterior latex house paints, this additive is also suited for industrial coatings, roof coatings, epoxy, urethane, and high-temperature paints.

As in premixed ceramic coatings, INSULADD works by refracting, reflecting, and dissipating radiant heat. The adhesion, useful service life, coverage, or color of the base paint is reportedly not affected by the additive. INSULADD is suitable with all interior and exterior paints, regardless of the brand.

The mixing process is very simple: Stir one bottle of the additive in with 1 gal of paint. If a sprayer is to be used for paint application, a slightly larger spray tip than normal is needed, and all screen filters should be removed. Two coats of paint with INSULADD in each coat are recommended for the best results. A coverage rate of 200 ft^2/gal for most house paints on smooth surfaces should be achieved.

R-value

The manufacturer claims that an equivalent R-value of R-20 can be obtained relevant to radiant heat gain when INSULADD is mixed with a light-colored house paint.

Appendix

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Nationwide Chemical Coating Mfrs., Inc.
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Email: *natchem@compuserve.com*
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Thermal Control Coatings
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Chapter

15

Integrated Insulation Systems

This chapter explores several products and methods that could not be categorized by conventional means. *Integrated insulation systems* refer to an insulation application that is of and by itself all-inclusive as a wall or roof system assembly. The insulation is not applied in the traditional construction sense but is integral to the construction assembly. Without the insulation, there is not a wall or roof. *Structural insulated panels* and *insulating concrete formwork* are basically hybrid systems, using familiar insulation products and construction materials to form a complete shell assembly. The third system discussed, *straw bale construction,* has been in use for over 100 years and is a unique commodity in that the material used to achieve the insulation value is also the material used to achieve structural integrity. As mentioned earlier, the use herein of a commercial name does not imply endorsement, nor does failure to mention a name imply criticism. The proprietary nomenclature is included to provide clarity only.

Structural Insulated Panels

Structural insulated panels, also known as *stressed skins, stress-skin panels, sandwich panels,* and *structural foam panels,* generically are referred to as *SIPs.* The basic building unit of this system is a sandwich-type panel typically made of two "skins" of wood structural sheathing with a foam core that combines the structural, wall, and roof sheathing with the insulation in a single construction step. (Other materials can be used as "skins," as discussed later in this chapter.) The system provides efficient solutions to such concerns as energy efficiency and dwindling natural resources while saving construction time and labor that results in cost savings not only to the contractor but also to the consumer. SIPs, emerging as a unique alternative building technology for residential building envelope construction, are also being used in panelized housing and commercial and multifamily projects.

SIP technology was first used in residential construction as early as 1952, when Alden B. Dow, architect and son of the founder of the Dow Chemical Company, began designing homes to be constructed of SIPs. The first of these was built in Midland, Michigan, that year, using foam-core SIPs for exterior walls, interior partitions, and roofs.

The energy crunch of the 1970s provided the opportunity for SIP manufacturers to gain additional market share, but it was not until the 1990s that the panelized system gained acceptance. A study prepared for the Structural Insulated Panel Association (SIPA) revealed that SIP production in the United States in 1991 was 15 million ft^2, equivalent to all the walls and roofs in about 4000 homes. This rate is expected to grow to levels ranging from 50 to 112 million ft^2 by the year-end 2000, depending on the aggressiveness with which the industry markets its products. The increase in manufacturing space for SIP lamination and fabrication reinforces this trend, growing from 555,108 ft^2 in January 1996 to 1,148,108 ft^2 as of October 1999.[1]

SIPs are also one of the featured technologies of the Partnership for Advancing Technology in Housing (PATH) initiative. PATH is a public-private partnership that includes government (Department of Energy, Housing and Urban Development, Environmental Protection Agency, Labor, Commerce, Federal Emergency Management Agency, and Department of Defense) and industry working together to develop, demonstrate, and deploy housing technologies and practices so that homes can be built more cheaply, more environmentally sustainably, with more disaster-resistance, and to provide a safer working environment.

Product description

Although product types vary in the industry, the common characteristics of all SIPs are two exterior skins adhered to a rigid plastic foam core (Fig. 15.1). The skin provides the tensile and compressive

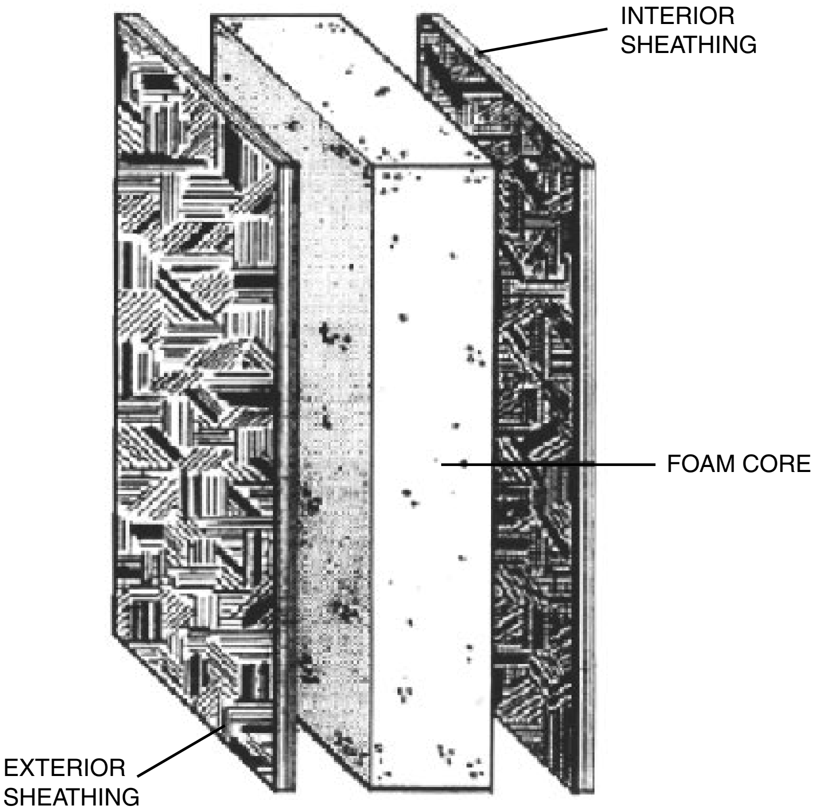

Figure 15.1 Structural insulated panel. (*SIPA*)

strength, whereas the foam core provides the rigidity. This is analogous to the I-beam, with the skins performing not unlike the flanges and the foam core corresponding to with the web.

Panels are available in a variety of sizes and thicknesses depending on application requirements, from 2 to 12" thick, and in sizes from the standard 4 × 8 ft to 8 × 24 ft. This is ideal for their primary application: the exterior structural walls and roofs of low-rise residential and commercial buildings (Figs. 15.2 and 15.3).

The skins of a panel can be of the same or differing materials. The most commonly used are oriented strandboard (OSB) for exterior and interior faces. Waferboard, plywood, sheet metal, cementitious fiberboard, and gypsum board are also available from various manufacturers. The rigid foam cores that provide the insulation value are composed of a variety of foam products depending on the proprietary product's manufacturer (Fig. 15.4).

Figure 15.2 SIP wall panel. (*R-Control Building Systems*)

These include the following:

- Expanded polystyrene (EPS), also known as *beadboard*
- Extruded polystyrene (XPS), commonly referred to as *green board* by Amoco or Styrofoam or *blue board* by Dow
- Polyurethane
- Polyisocyanurates, a polyurethane derivative characterized by its yellowish color in foil-faced applications

(Agriboard uses compressed agricultural fiberboard as a structural insulated panel core bonded to oriented strandboard skins. Manufactured from the straw of cereal grains and native grasses, the product was discontinued in 1999, but similar straw-based products eventually may return to the market.[2])

Figure 15.3 SIP wall panel (*R-Control Building Systems*)

EPS is used most commonly because of its low cost and simple manufacturing process, but EPS cores, with a lower R-value, must be made thicker to be equivalent to the higher insulation properties of other foam products. Nevertheless, foam products have better insulation per inch of thickness than fiberglass and better insulation at lower temperatures and higher humidity than fiberglass for decreased energy use for heating. As a result, the U.S Department of Energy (DOE) and Environmental Protection Agency (EPA) are both proponents of the use of SIP in construction (see EPA/DOE Energy Star Program). Polyurethane and polyisocyanurates are more heavily scrutinized as to actual R-value because blowing agents are used in the production of these two materials that actually evaporate over time, thereby reducing the advertised R-value.

With the high insulation value and low infiltration, a SIP home can be cooled or heated with much smaller heating, ventilating, and air-conditioning (HVAC) equipment and much less electrical

Figure 15.4 SIP. (*R-Control Building Systems*)

energy. Consequently, the homeowner's electricity bill each month will be much less. The SIP home costs about 5 to 10 percent more initially, but this extra cost is quickly offset by additional savings in energy bills. Studies have shown that building with SIPs can result in homes that are up to 60 percent more efficient than site-built homes of comparable size. Wall panels can deliver R-values of R-14 to R-24 and roof R-values of up to R-41 or more, depending on the thickness of the foam core and the manufacturer's system of fabrication.

Panel shipping is economical within a 300- to 500-mile radius, although due to limited manufacturing production availability, most manufacturers indicate that 30 percent or more of their business is shipped 1000 or more miles away. Structural panels typically bear a stamp indicating compliance with building standards and requirements.

SIPs are also recognized for their added security benefits by providing a solid barrier to intruders and vandals. The design of this panel, with its two skins over a foam core, is far more resistant to punching or cutting than the all-too-popular thin foam wall.

Prices vary depending on the panel composition and thickness. A typical engineer-stamped R-17, $3^5/_8$"-thick, 4' × 8' SIP will cost around $80 to $100 per panel.

Panel manufacturing process

SIPs are factory fabricated under controlled conditions, usually subject to a continuous program for quality control and supervision. Although manufacturing techniques vary among companies, two assembly processes are most prevalent: adhesive-bonding and foam-in-place.

The manufacturing process may vary slightly between manufacturers but typically begins with a large OSB panel on a trolley. Foam sheets are then placed on the OSB skin. After a structural-grade adhesive is applied, the rigid foam core is placed on top of a clean sheet of facing material, and the second panel (or skin) is positioned on the opposite side of the insulation core, completing the sandwich. Pressure is applied to the newly formed panel for some period of time. This is done with either an ingenous press (a vacuum on the bottom side and atmospheric pressure on the top) or a hydraulic press. Panels are then set aside until the adhesive has cured completely, about 24 hours.

With the foam-in-place method, the facing boards are held apart by panel-framing or specially made spacers. The chemical components of the foam core, together with a blowing agent, are combined and forced between the braced skins. The expanded insulation material forms a bond with the facing material without the use of any adhesives.

Material properties

SIPs are capable of sustaining all types of loads that are typically imposed on walls, floors, roofs, and other load-bearing elements. They are essentially stressed-skin panels; the cores of rigid plastic foam provide shear strength, and the exterior skins of structural materials provide tensile and compressive strength. A panel's structural composition can be compared with that of an I-beam.

The panel skins are analogous to the flanges of an I-beam, whereas the foam core is comparable with its web. The complete assembly, with exterior and interior faces properly laminated to the foam core, allows for a system that is structurally superior to conventional stud frame structures.

Panels used for exterior walls are load-bearing and can be used to form the entire wall. They also can be applied to framing as non-structural exterior insulated cladding or as a curtain wall. A load-bearing wall panel has superior axial load-bearing capacity, i.e., the strength to support vertical loads from the roof or floor above. A conventional framed wall is designed to support these vertical loads only through its studs. The exterior sheathing, if plywood, provides no contribution because it must have gaps between sheets and is not continuous. Other forms of sheathing are also discounted for the same reason. On the other hand the sheathing on SIPs can use all its capacity to support vertical loads because buckling is prevented by the continuous reinforcement action of the foam core.

The uniform, consistent composition of a SIP, with supportive sheathing on both sides of the core, is superior to a frame wall in racking resistance. The SIP sheathing is adhered to the foam core over the entirety of the panel, and edges are fixed to splines, resulting in the development of excellent racking resistance. This characteristic is an important attribute for resisting earthquake and hurricane forces.

SIPs exhibit other superior structural/strength characteristics. They are highly resistant to local loading. This is evident when one "thumps" a wall panel. The SIP will exhibit a uniform solid sound as opposed to a hollow sound between studs. This means that fasteners with proper anchors for railings, cabinets, fixtures, wall-mounted brackets, etc. can occur anywhere in a SIP wall, but only at studs or other reinforced locations in frame walls.

A SIP wall has great resistance against buckling and bending when compared with equivalent conventional stud construction. This means that a taller wall can be built without increasing wall thickness, or that a wall can resist greater perpendicular loads from such forces as hurricanes.

SIPs are virtually impervious to warping and shrinking and possess excellent dimensional stability. The DOE issues a warning, however, as to the problems with insect infestations. EPS, polyurethane, and polyisocyanurate provide an ideal environment for an insect nest. Insecticides need to be administered to the ground and, if available, the actual panel.[3]

The structural properties of SIPs are as beneficial in their roof applications as when they are used for walls. Flat or sloping roof panels can be stand-alone structures like wall panels or can span between framing members like rafters. When they form a sloping roof, they naturally create a cathedral ceiling on the interior. In bending, the thickness of the foam core dictates and limits the spanning distance by virtue of its shear strength and bond to the sheathing. Similarly, the depth of rafters limits conventional roof spans.

The horizontal loads imposed on buildings during earthquakes or extreme winds can be effectively resisted by the roof's diaphragm action. This two-dimensional structural continuity provides rigidity and stability to the building as well as creating an uninterrupted layer over supporting beams or bearing members. Because SIPs provide the bending strength necessary to withstand live (snow) and dead (roofing and equipment) loads, they usually can span freely from the ridge beam to exterior walls or between widely spaced beams or purlins. If greater rigidity is required, SIPs may be manufactured with increased bending strengths and reduced deflection. In addition to wall and roof panels, SIPs can be used for floors and foundation walls when designed for these specialized applications.

Fire resistance

The flammability of SIPs depends on the composition of the panel and the type of insulation used in the panel core. For example, EPS has a fire-retardant bead that is used in the manufacturing process and makes it self-extinguishing once the flame source has been removed. Building codes require installation of a thermal barrier, typically $^1/_2$" gypsum wallboard, over the panels on the interior side for fire resistance for a 15-minute rating. A 1-hour fire resistive assembly can be achieved by adding two layers of $^5/_8$" type-X gypsum board.[4]

Exposed EPS insulation is affected by intense fire-related heat. According to the DOE, EPS can deform at 167°F and subsequently melt at 200°F. Tests by Underwriter's Laboratory (UL) indicate modest melting of 2" of the foam core in the vicinity of an intentionally set fire; however, the panel skins did not sustain notable damage elsewhere. Actual building fires have revealed that the EPS SIPs fared well.[3] Another advantage of panel buildings over stick-frame buildings is that there are no air cavities in the walls to create a "chimney effect."

SIPs also have demonstrated resistance to seismic activity. One SIP manufacturer has documentation of six homes that withstood the 7.2 magnitude earthquake in Kobe, Japan, in January 1995.

R-value

The foam plastic core of a SIP provides its insulation properties. Depending on the type of foam used (e.g., EPS, XPS, polyurethane, or isocyanurate), R-values are in the range of approximately 4 to 7 per inch of foam thickness. This results in superior energy performance characteristics in walls and roofs. For example, a $4^1/_2$"-thick SIP wall is often used as a substitute for a 2 × 4 stud wall. (A SIP wall with $^1/_2$" of gypsum wallboard is 5" thick, as opposed to the $4^1/_2$" overall thickness of a wood stud wall.) Although both have $3^1/_2$" of insulation, the SIP wall has insulation R-values in the range of R-14 to R-25, whereas the stud wall with fiberglass or mineral wool only has an R-value of R-11 to R-15.

The overall R-value of the stud wall must be downgraded to take into account the part of its area that is occupied by wood framing. This is anywhere between 15 and 18 percent of the wall in which there is no insulation. The core of a SIP, which usually has no stiffeners between splines, is filled entirely with rigid foam. This means there is no thermal bridging. Moreover, when compared with stick-built structures, SIPs have fewer gaps, less settling or compression, less moisture absorption or dust saturation, and fewer cavities that permit convection or air circulation. All these characteristics would reduce insulation performance if present in a wall system. Oak Ridge National Laboratory tests suggest that a SIP performs at 97 percent of the stated R-value, losing only 3 percent to nail holes, seams, splines, and wiring cavities.[5]

The results are evident in both quantified and empirical data. For example, the overall R-value of a conventional wall with 2 × 4 studs and $3^1/_2$" of R-13 fiberglass, as indicated in the *Thermal Envelope Compliance Guide to the Model Energy Code,* is R-13.1. An equivalent SIP wall with $3^1/_2$" of extruded polystyrene foam (R-value = 17.5) is R-20.

As mentioned earlier, EPS is the most common panel core. A $4^1/_2$"-thick panel provides an R-value of R-14 to R-17, a $6^1/_2$"-thick panel provides R-22 to R-25, an $8^1/_4$"-thick panel provides R-29 to R-36, a $10^1/_4$"-thick panel provides R-37 to R-45, and a $12^1/_4$"-thick panel provides an R-value of 44. (The range of R-values is contingent on the specific manufacturer.) Needless to say, these panels also offer superior acoustical properties because noise transmission is diminished owing to the wall's thickness.

Other nonspecific factors seem to influence the superior performance by SIPs when compared with stick-built wall assemblies with the same R-value. This may be due to the differences between foams and fibers in the degradation items that are not included in R-value calculations, such as gaps, moisture, dust, settling, and others.

This was clearly illustrated in a recent field test conducted by the Florida Solar Energy Center (FSEC) under sponsorship of the DOE. Two identical houses were built side by side in Louisville, Kentucky, simultaneously, by the same builder. One had conventional framing, and the other was built with SIPs. However, wall and roof thicknesses were adjusted so that both had the same calculated R-values. Both houses were monitored for heat loss performance, and the SIP house dramatically outperformed the frame house. More important, efforts to forecast seasonal heating energy savings showed a 14 to 20 percent savings for the SIP house in Kentucky's climate. In the published report, the researchers stated that "…there seem to be other factors, which remain unaccounted for, which cause the panel house to use less heat energy." Homeowners throughout the United States are experiencing benefits though lower heating costs, reduced draft, and greater comfort.

Numerous SIPA members, for example, have cited testimonials from owners of SIP homes whose fuel bills have been as much as 40 to 60 percent below those of conventional construction homeowners.

It is widely recognized by energy-performance specialists that urethane foam and XPS are subject to thermal drift, or outgassing of blowing agents from foam cells over time. As a result, the R-value of these cores falls gradually until the thermal drift ceases to have an impact and there is no further degradation. EPS cores are not subject to thermal drift, which results in a constant R-value. EPS foam-core panels have a nominal R-value of 4 per inch. Polyurethane and isocyanurate foam-core panels have a nominal R-value of 6 to 7 per inch. Both contain a blowing agent that escapes over time, subsequently lowering the R-value of each of these foam products.[3] XPS cores have R-values of 5 per inch, indicating that this is the long-term constant after all thermal drift adjustments. Producers of other foams also quote R-values at the fully aged rate, but exact values need to be confirmed by designers.

Unlike fiberglass batts, SIPs are resistant to moisture absorption. Although every attempt should be made to ensure that the panels are kept dry, SIPs will retain their R-value even if some moisture absorption does occur.

Wood frame walls are required to have vapor barriers installed "on the warm side" of fiberglass or mineral wool to prevent water vapor penetration, which may condense and degrade insulation performance. SIPs do not need vapor barriers at all because moisture does not materially affect performance.

In reality, except in such extreme climates as those in Florida and Alaska, it is difficult to identify "the warm side" of fibrous insulation. In Virginia, for example, the warm side is on the inside of the wall in the winter and on the outside in the summer. In Colorado, it can be on the inside at night and the outside during the day. Whenever the vapor barrier is on the incorrect side, water vapor can penetrate and degrade the insulation. Because of nail holes, minute cracks, holes in framing for wiring, and cutouts for receptacles and other penetrations, it may be virtually impossible to prevent water vapor penetration of fibrous insulation, a concern nonexistent with SIP.

This is also a critical issue with typical stick-built roofs. An airspace is required by code to protect the roof system. Because of the presence of water vapor, moisture can condense in the roof system. An airspace is not necessary in SIP roof construction because air vapor cannot enter the system. Another concern would be heat buildup in the roofing mass when asphalt shingles are used. This is a critical issue during the summer months, since heat can prematurely age some roofing products. Several major roof-shingle manufacturers have approved the use of SIPs and are upholding their shingle warranties.

The foam core in a SIP extends uninterrupted in all directions throughout the entire panel, which can be as large as 8×24 ft in area. Breaks in the foam insulation occur less frequently, usually only at panel connections, which are few, or at openings. A frame wall has connections wherever the sheathing or gypsum wallboard joints occur—every 4 ft or so. And because of the nature of panel assembly, the foam is tightly packed against both sheathing faces and perimeter joints.

SIPs form structural envelopes that are extremely tight against infiltration of air, a major source of energy loss. This is primarily due to the large uninterrupted areas of insulation in the panels. In frame walls not only are there frequent joints between sheathing at studs (a weak link in envelope continuity), but there are also nail or screw penetrations at every stud and on both sides of the wall.

Moreover, common points of leakage such as electrical outlet vents and other envelope penetrations often are more difficult to seal in frame structures. Even if these penetrations are poorly sealed in a SIP structure, the insulation performance is not compromised by air circulation into the insulation cavity. This results in exceptionally tight SIP houses, as compared with framed structures, that exhibit very low levels of air infiltration with resulting increases in building energy efficiency and interior comfort.

In the FSEC test in Kentucky, the SIP house proved to have a natural infiltration rate of 0.21 air changes per hour. This compares remarkably well with the average for new houses, in the range of 0.5 to 0.7. More important, however, it is even lower than the recommended minimum of 0.35 (according to ASHRAE Standard 62-1989). Further, it may require a fresh air ventilation system to provide makeup air, according to FSEC researchers. Large differences in air infiltration rates can have dramatic impacts on energy consumption. For example, a difference in air infiltration rates of 0.4 air changes per hour (0.21 versus 0.61) between a SIP house and a conventional house can represent fuel consumption savings in the range of $95 per year (in Texas) to $181 per year (in Minnesota) for a 1540-ft^2 house.

Some people may question why one would build a very tight house and then install a fan to ventilate it. It is important to understand that relying on random leaks in the building and unknown pressure forces due to wind and temperature does not ensure adequate ventilation. Thus it often leads to overventilation and high energy bills or underventilation with possible moisture and health concerns. Further, with leaky duct systems, there can be pressure imbalances that can cause heating systems to malfunction, resulting in health and safety problems.

Environmental considerations

SIP construction can be considered an engineered system. Innovation in the plastics and wood products industry is largely responsible for the rapid growth of new products now used in SIPs: first, plywood and, since 1980, oriented strandboard. The development of these products has a common goal: the need to conserve scarce resources and provide for the optimization of the forest. SIP technology allows society to use forest products that are fast growing and thus renewable. Panel manufacturers are able to remove the strength-reducing characteristics of wood (i.e., knots, splits) and produce superior engineered products. This turns moderate-cost, low-quality hardwoods and plantation thinnings into superior structural building components. As a result, a greater amount of the tree is used, and fewer wood fibers are used to produce a more consistent product than that used in conventional framing.

It is also important to note that the skins of SIPs are made of oriented strandboard (OSB). This OSB is made with new-growth “junk” wood (aspen, jack pine, etc.) that can be regenerated in 5 to 10 years rather than old-growth lumber such as redwood, ponderosa pine, or yellow pine, which are necessary in stick-frame construction. The panels use one-fourth as much wood as stick-framing methods. The EPS is manufactured without the use or production of chlorofluorocarbons (CFCs) or hydrochlorofluorocarbons (HCFCs). Since the insulation is bonded to the sheathing, there is no shrinkage of materials, saving time and money.

Quality-monitored manufacturing systems allow SIP producers to enhance the environment through the efficient use of valuable resources. Systematic design and production techniques significantly reduce process and construction site waste, requiring less landfill disposal, contributing to our country’s resource and solid waste management goals. Designers can optimize the building design using SIPs, resulting in more efficient use of construction materials.

SIP openings for windows and doors are often precut at the factory, reducing the expense of debris disposal from a job site. During panel manufacture, the foam-core materials are optimized for the particular application. Waste materials are limited through creative design and resource management. Sometimes leftover panel pieces and scraps are used for do-it-yourself retrofit applications or even dog houses. Often, unused foam that may be generated in the manufacturing process can be returned to the foam manufacturer, who can reprocess it into appropriate applications or send it to a recycler for further reprocessing. Recycling is one method for handling waste. However, if recycling is not a satisfactory option given a site’s geographic location, foam plastic can be safely land-filled. SIP foams are stable and will not biodegrade or create leachate or methane gas, the two major problems with all landfills. Construction materials are often used in “stable landfills” where the ground is later reclaimed for parks, stadiums, and other similar applications.

In addition, SIP foams can be incinerated safely at regulated waste-to-energy facilities. Its energy value (greater than some soft coals) can provide a secondary fuel source for greater savings to the local utility company. EPS burns cleanly and produces almost no toxic ash. It does not require hazardous landfill disposal.

Noise pollution, the introduction into buildings of unwanted sound, is another form of environmental pollution that concerns many people. SIPs are excellent barriers to airborne sound penetration. This is due to the combination of their closed construction (no air movement in the panel wall) and extremely tight joint connections.

The formaldehyde that is emitted by the OSB skins is less than 0.1 part per million (ppm), well below levels established as acceptable by the U.S. Department of Housing and Urban Development. The rigid foam cores and the structural water-based adhesives used in the manufacturing process have no formaldehyde content.[6]

The issue of air quality is a concern to the public, regulating agencies, SIP producers, and foam manufacturers. EPS foam cores are produced using materials that have never had any adverse effect on the protective stratospheric ozone layer. All U.S. extruders of polystyrene foam had switched to HCFC-142b by 1991, two years ahead of EPA deadlines for CFC phase-out. HCFC-142b is 90 percent less harmful to the ozone layer than its predecessor, CFC-12. Plastic industry members are working to exceed current and future air quality standards through improvements in materials, processing, and control equipment.

Installation standards and practices

Panels are used in construction either as “generic panels” or as parts of a “package unit.” Generic panels are produced in varying thicknesses and different material combinations but in standard sizes such as 4' × 8'. Each panel has explicit physical properties and strength characteristics, and typically panels are sold to builders and others without knowledge of the end application. This is similar to the sale of plywood panels to builders, who are informed of their strength and properties by the manufacturer’s load tables and other standards. It is the builder’s responsibility to cut the plywood panels and install them properly in buildings. (One manufacturer actually verifies the panel’s engineering and application prior to delivery.)

A packaged unit is quite different. The plans of the entire building are analyzed, and panels are designed specifically for each wall, roof, or other application. The manufacturer, often with CAD-generated shop drawings, can precut each panel to precise dimensions, with cutouts for window or door openings. Edges, angles, and all other complex configurations can be cut at the factory. Then all the panels required for an entire building are packaged and shipped to the construction site. This could easily be a great distance, although it is likely that sources of panel production or distribution are locally available to most builders.

Panels are light in weight, generally under 4 lb/ft^2 of panel ($4^1/_2$" thick), and most walls are installed by hand. Connections are made with adhesives and screw fasteners (Figs. 15.5 and 15.6). Panels also may be lifted into position by crane, hoist, or other equipment (Fig. 15.7). Cranes are particularly useful in setting roof panels or lifting bundles of panels to upper floors. SIP walls and roofs are erected quickly and made weathertight very early in the construction sequence.

Figure 15.5 SIP adhesive/sealant. (*R-Control Building Systems*)

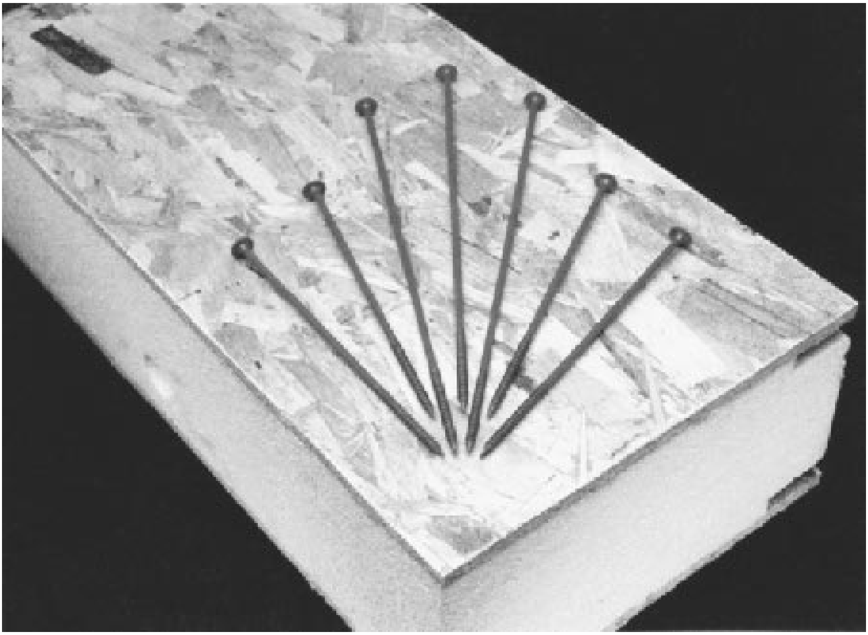

Figure 15.6 SIP screw fasteners. (*R-Control Building Systems*)

Figure 15.7 SIP installation. (*R-Control Building Systems*)

Construction time savings are evidenced when interior gypsum board or other finish is installed. The continuous nailing surface of the OSB skin allows the framer, gypsum wallboard crew, etc. to be unconcerned with locating studs for screwing or nailing.

The exterior finishes of walls, applied to OSB or other sheathing, can include the entire array of available materials (e.g., siding, brick, stucco). Sloping roof panels can be finished with shingles, tile, metal, or other materials (Figs. 15.8 and 15.9).

SIPs made by many if not all manufacturers typically are listed by independent testing agencies and are recognized by ICBO, SBCCI, and BOCA. National building codes readily accept SIPs for their strength and energy performance properties, provided manufacturers can produce documentation to verify that panels meet structural and quality-control requirements for their intended application. Builders and designers should check with the manufacturer for specific compliance with applicable building codes.

Connections and joints

One of the strength characteristics of SIPs is the ability to provide superior building performance, partly because of tight connections

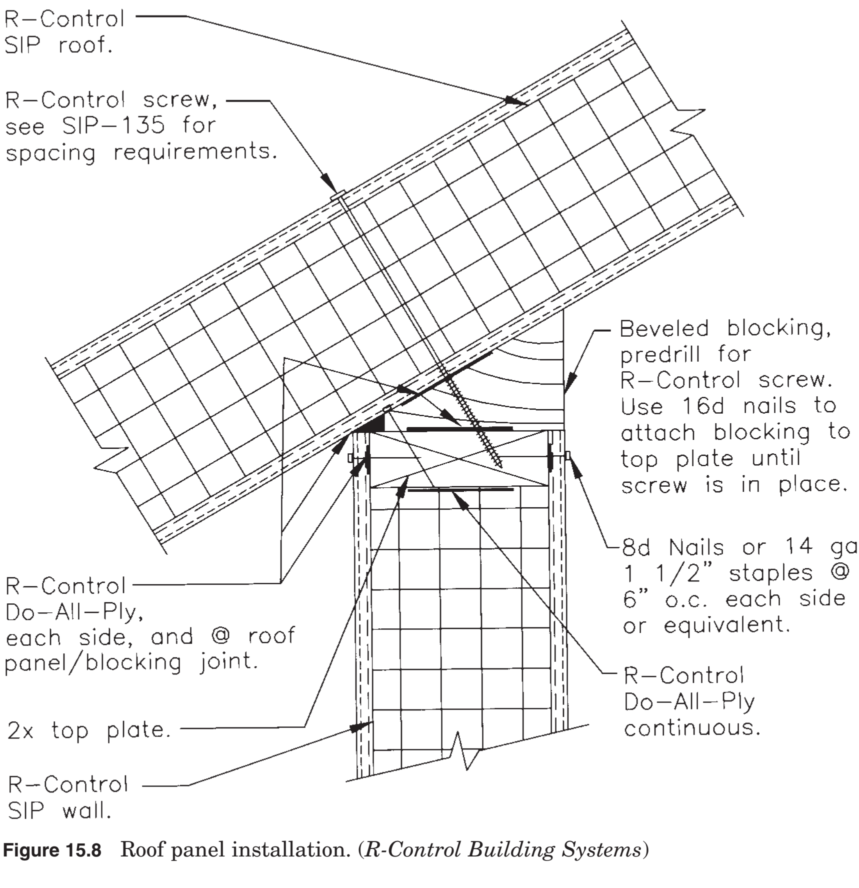

Figure 15.8 Roof panel installation. (*R-Control Building Systems*)

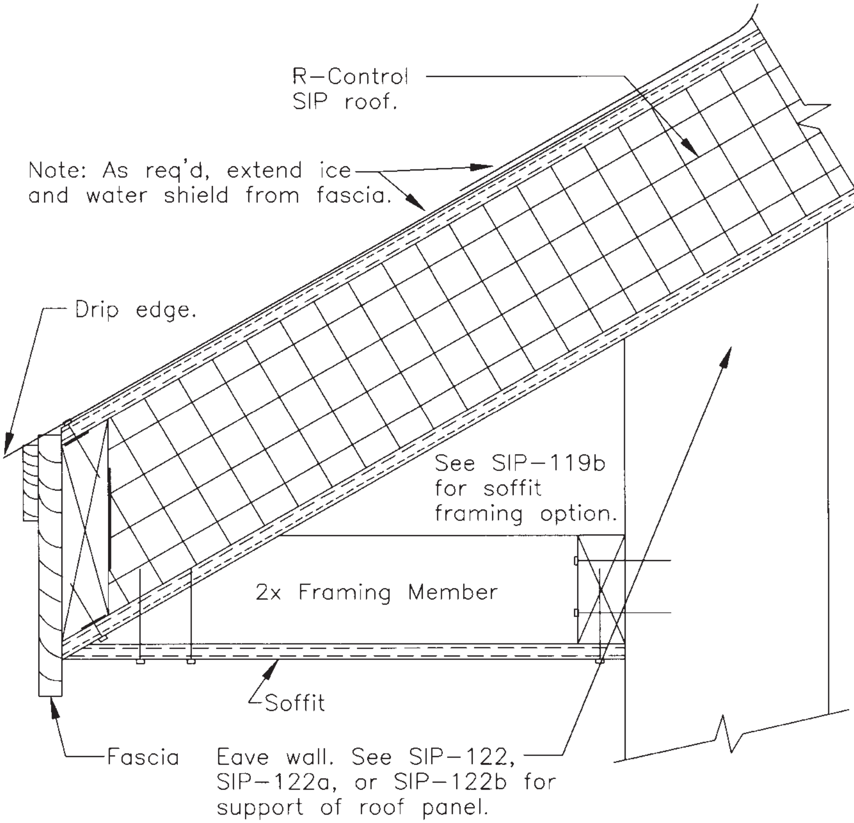

Figure 15.9 Eave detail. (*R-Control Building Systems*)

at the joints between panels. Another strength is the connection between panels and such other adjacent structural elements as beams, purlins, and columns.

Several common wall panel connection methods are used by SIP manufacturers today. A conventional approach involves fitting a 2 × 4, 2 × 6, or larger spline, having the same depth as the foam core, between panels and securing it to the facing material (Fig. 15.10). Each panel edge is prerouted to fit half the width of each spline. The 2× splines use readily available lumber and provide stability. With the double 2× connection approach, the splines themselves bear the building loads. This makes the system, with appropriate headers installed, a cohesive post-and-beam structure.

Panels are fastened together with wood or OSB splines and zinc galvanized screws or ring-shank spikes. Dimensional lumber (2×)

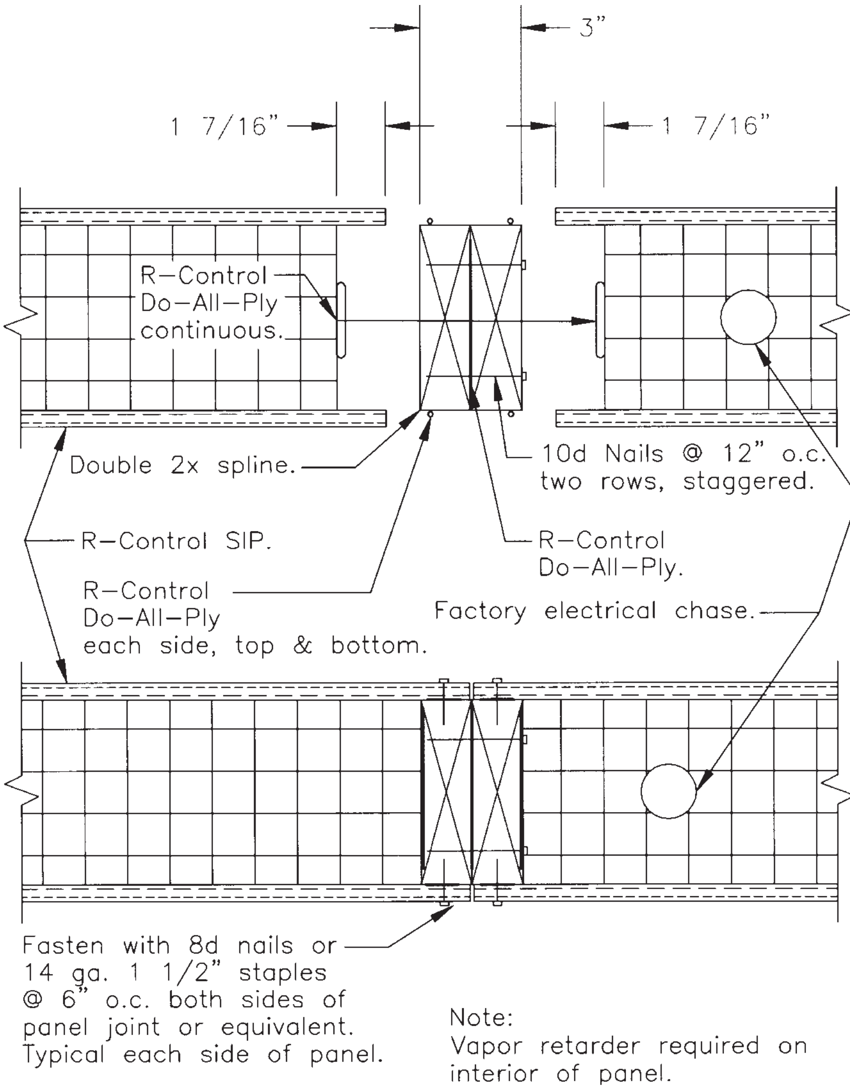

Figure 15.10 Double 2× spline connection. (*R-Control Building Systems*)

is used for top and bottom plates and for headers and sills. Panels typically are rated as header material up to 4 ft. Once a foundation is completed, a panelized shell structure can be completed in a matter of days. One erection contractor quotes 3 days of erection time per 1000 ft^2 building. A typical 1600-ft^2 home takes 3 to 5 days to assemble, including floor, walls, and roof.

The thin-spline approach involves fitting two thin splines (approximately $^1/_2$ to $^3/_4$" thick by 3 to 4" wide) laterally into prerouted grooves in each panel edge. Each spline is usually double glued, stapled or nailed, and caulked at the seam between panels.

No single connection method has proven itself superior over others. Other approaches include

1. A premanufactured, laminated, thermally broken spline
2. A premanufactured locking arm built into each panel
3. A roll-formed steel joint

Individual panel manufacturers recommend the method that is most suitable for their system. For purposes of this discussion, 2× splines will be used.

SIPs are not damaged by rain, but long-term exposure to water could cause the panel edges to swell. After erection of the panels, the edges should be sanded down with a belt or disk sander.

Openings

Rough openings for doors and windows can be precut at the factory, easily cut on site, or accomplished by inserting a filler panel as required. Headers must be installed for window or door openings of more than 4 to 6 ft and usually can be eliminated for smaller openings. Since solid plating is installed around doors and windows, the normal technique consists of routing out approximately $1^1/_2$" in of foam around the perimeter of all rough openings for a 2× framing installation. The framing works effectively as a nailing surface. When nailed to panels above rough openings, the framing let into the panel adds to the box beam effect (Fig. 15.11).

Electrical and plumbing

Wiring a SIPs home is not difficult but may require some nonstandard techniques. Since interior partitions typically are stick built, it is best to make use of the interior walls whenever possible. Most SIP panels come equipped with prerouted electrical wiring chases. These chases create a network of cored-out space through which wiring can be run from the building exterior or basement up through walls and floors to the attic. Wiring chases are predrilled vertically at panel edges, or horizontally at predetermined locations above the finished floor. Some manufacturers typically core at

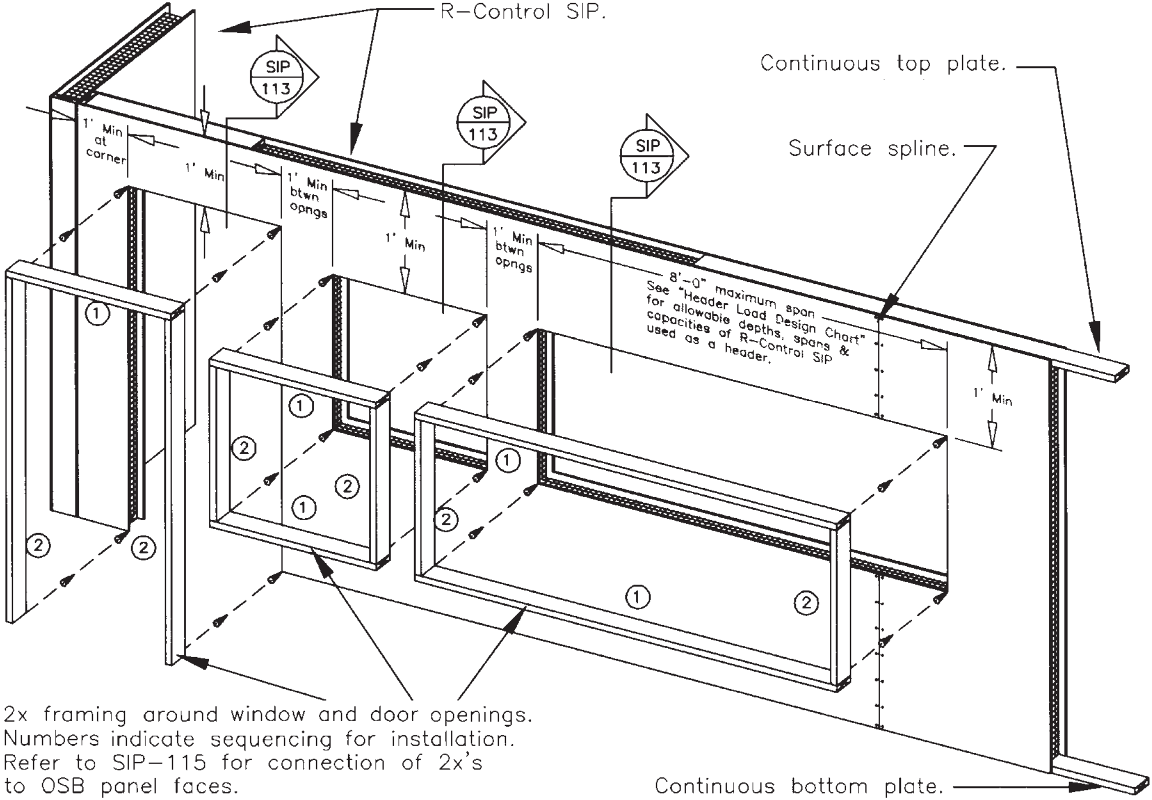

Figure 15.11 Rough openings. (*R-Control Building Systems*)

12 and 44" above finished floor (aff) (Figs. 15.12 and 15.13). UL-approved romex cabling is typically used for residential and light commercial installations.

Many contractors prefer (or if recommended by a specific panel manufacturer) to take horizontal wiring runs through the basement or ceiling joist cavity when horizontal coring is not possible or provided. A raceway behind the wood baseboard, or other type of surface-mounted wire mold, is also a common design feature. This arrangement also allows for flexibility in the field as well as after construction is complete (Fig. 15.14).

Receptacle outlets and switch boxes usually are attached to panel splines or hung on brackets attached to the interior facing material. Wiring for these fixtures as well as thermostats also can be easily installed vertically in the panel edge before the rough door openings are closed in with 2 × 4s. The chases drilled though the roof panels are ideal for running sprinkler piping throughout the roof of the house. If plumbing fixtures are to be located along

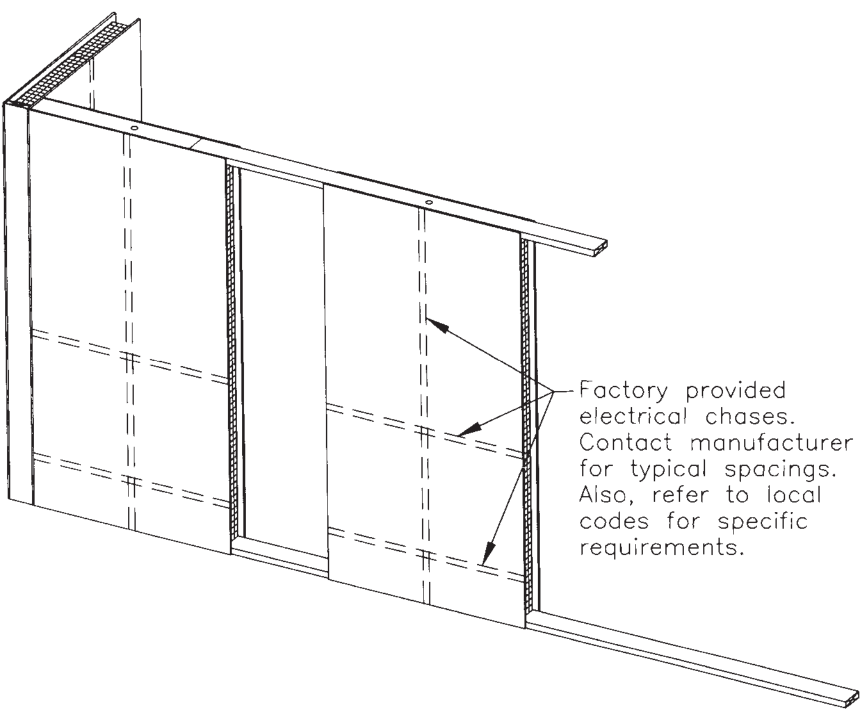

Figure 15.12 Electrical chase locations. (*R-Control Building Systems*)

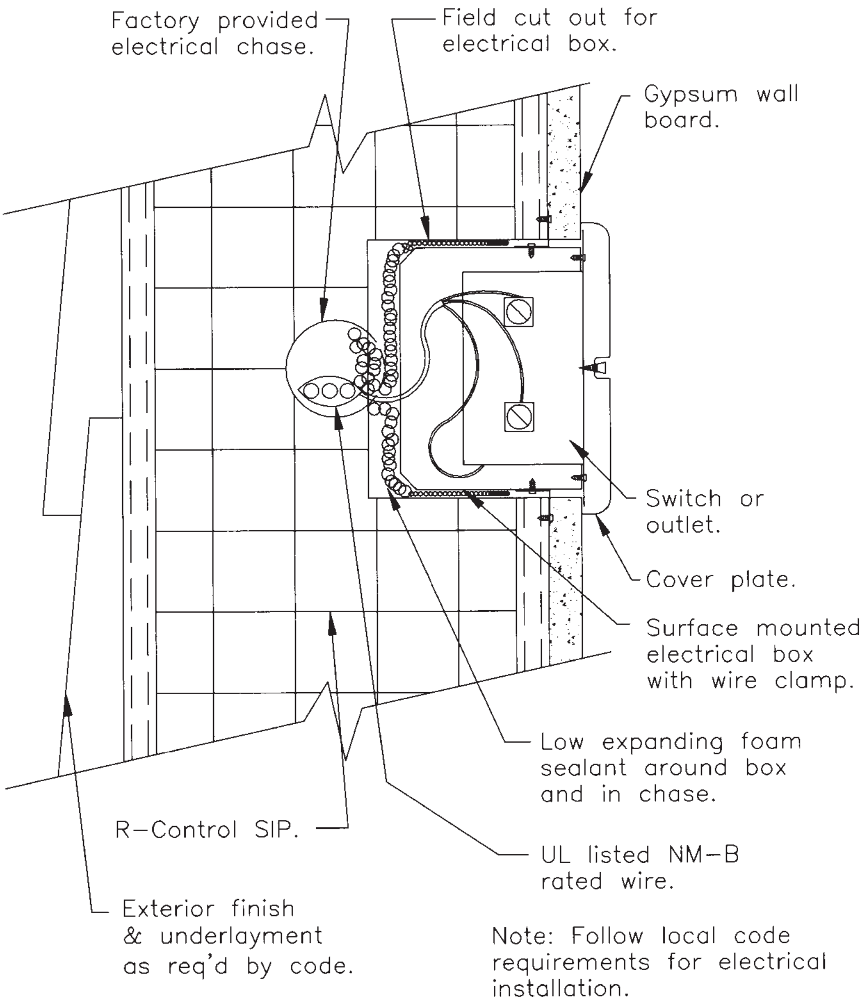

Figure 15.13 Field cut-out for electrical box. (*R-Control Building Systems*)

an outside wall, a furred wall is recommended. It is necessary to predrill 2× splines to allow the horizontal chases to continue unobstructed.

Insulating Concrete Formwork

Insulating concrete formwork (ICF) is a cost-effective, flexible, modular, permanent concrete form system. The basic units of this system are EPS forms that are filled with concrete and steel reinforcing (Fig. 15.15). The departure from typical poured-in-place

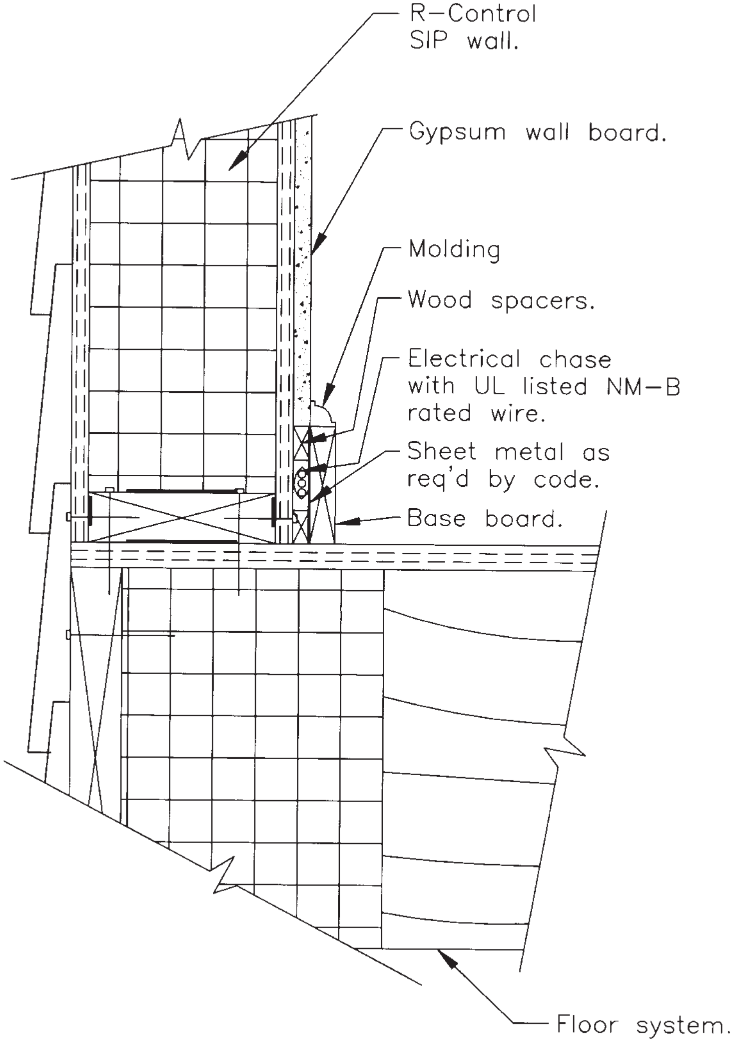

Figure 15.14 Electrical chase in baseboard. (*R-Control Building Systems*)

concrete construction is that the EPS formwork is left in place after the concrete cures for permanent insulating value.

Product description

There are two types of forms: planks and blocks. Planks are individual boards that are assembled onsite with the specific manufacturer's inserts or spacers. Blocks are prefabricated ICF units that are set in place in a stacking system (Figs. 15.16 and 15.17).

Figure 15.15 Installing ICF. (*R-Control Building Systems*)

As mentioned earlier, EPS is foamed polystyrene, a common plastic. (Close visual inspection reveals thousands of tiny white beads.) Its closed-cell, air-filled structure possesses a high resistance to heat flow as well as high mechanical strength relative to its weight. EPS gives the added advantage of being lightweight. In combination with concrete, the system has high insulation values for both thermal and acoustical applications. The flexibility as a wall system makes it unique in that almost any type of wall or foundation system can be built cost-effectively, whether or not thermal and acoustical qualities are required. The EPS is flame-retardant and is designed to withstand the rigors of wet-poured concrete. Finally, no CFCs or HCFCs are used or produced during the creation of EPS.

Although the specific cross-sectional and modular relationships may vary from product to product, the basic concept does not. The foundation or basement wall is assembled by placing interlocking EPS forms one on top of the other (as well as side by side) in a running or stack bond fashion (depending on the system). The forms are held together (or apart, actually) by integral plastic web ties, teeth, or other interlocking design mechanisms. Steel reinforcing is then placed within the forms, and the concrete is poured. It is important to note that although discussed primarily as a foundation system in this chapter, most ICF systems also can be used for full-height walls, including door and window openings. One manufacturer's portfolio includes bridge abutments, swimming pools, and even grade beams.

The basic ICF concept of a stay-in-place, easy-to-assemble form-

Figure 15.16 Plank system. (*R-Control Building Systems*)

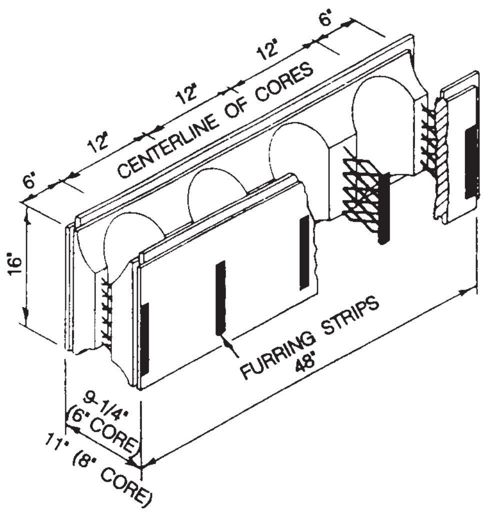

Figure 15.17 Block system. (*American Polysteel, Inc.*)

work is the same among manufacturers; however, proprietary dimensions and physical properties vary slightly. This book does not pass judgment on the superiority of one product versus another. The contractor or homeowner can review the advantages and disadvantages of each. For example, R-Control Insulated Concrete Form by AFM Corporation, Polysteel, SmartBlock, and AAB Blue Maxx were reviewed for this book (see Appendix for manufacturer data). Polysteel has been manufacturing ICF since 1978; AFM has been making EPS products for over 30 years.

As mentioned earlier, the ICF system(s) are either assembled onsite or are prefabricated. Two examples of the site-assembled ICF systems are the R-Control Insulated Concrete Form and the

SmartBlock by ConForm. R-Control Insulated Concrete Form uses 1 × 8 ft EPS panels connected by a Diamond snap-tie every 12" horizontally and vertically. These panels are factory notched for tie placement, field assembled, and can be custom configured for the appropriate condition. The wall thickness, determined by the wall tie, is available in 4, 6, 8, and 10". R-Control Insulated Concrete Form's EPS panel has an insect-resistant additive. ConForm's SmartBlock is 10" wide, 10" high, and 40" long, which creates a $6^1/_2$"-thick, 87 percent solid concrete wall. Each block weighs approximately 2 lb. (The variable form is 12" high and creates nominal wall widths of 4, 6, and 8".) CFCs, HCFCs, or other toxic substances are not used in its manufacture.

In contrast to the site-assembled plank-type systems, Polysteel is a prefabricated block unit, commonly referred to as an "oversized Lego block." The basic unit measures 48" long, and $9^1/_4$" high, or 11" wide. Each block weighs approximately 5 lb, has interlocking tongues and grooves, and has integral furring strips. AAB Blue Maxx's standard unit measures 48" long, $11^1/_2$" wide, and $16^3/_4$" high and weighs approximately 6.2 lb.

The EPS formwork is nonstructural because the structural integrity of the assembly comes from the concrete poured within. The strength of the assembly permits it to be used in almost any civil or structural application to replace concrete block, poured-in-place, or low-rise tilt-up concrete construction. Concrete, when placed inside a formed wall, cures under almost ideal conditions. This temperature control during curing provides a 50 percent increase in compressive strength over conventional formed concrete, according to the Portland Cement Association.

Cost advantages of using ICF can be realized in a variety of ways. According to the ConForm literature, comparative costs range from 30 to 50 percent lower than conventional walls. Stay-in-place formwork eliminates the need for and cost of buying, stripping, cleaning, transporting, and storing reusable forms. The improved fire rating frequently reduces insurance costs and results in higher appraisal values than stick-built homes. Polysteel Forms reports lower life-cycle costs, such as cost savings from utility bills. For example, a home that costs \$820 per year to heat and cool with stick-built construction is reduced to \$240 per year when built entirely of poured-in-place concrete. Construction time and personnel are also reduced. The AAB Blue Maxx system states that a three-person team can erect the formwork, place the steel, and pour the concrete for a 2000-ft^2 house in 1 day (Figs. 15.18 and 15.19).

Figure 15.18 Residence during construction. (*American Polysteel, Inc.*)

Figure 15.19 Finished construction. (*American Polysteel, Inc.*)

R-value

The moisture-resistant, closed-cell configuration of EPS gives superb insulating qualities that will not deteriorate with age. The typical R-values are as follows: R-Control Insulated Concrete Form is R-20, Polysteel is R-22, SmartBlock is R-22, and AAB Blue Maxx is R-26. The principle of permanent insulated formwork containing a high-heat-capacity material such as concrete creates the optimal thermal construction assembly because the structure (concrete) is the thermal mass and the formwork is the insulation. Thus the costly application of additional insulating material is eliminated. The result is an ideal combination of materials that significantly reduces energy consumption in moderate and extreme climates. Polysteel Forms create a superinsulated concrete wall that reduces heating and cooling costs by 50 to 80 percent.

American Polysteel, manufacturer of Polysteel forms, performed an ASHRAE computer simulation on their 6" Polysteel form R wall filled with concrete as compared with a low-mass, high-R-value wall. A Polysteel wall of R-17 was used for the test. Although the test simulation was run for all climates and regions, the illustration results were quite astounding. An exterior wood frame wall of a home in Miami, Phoenix, or Seattle would need to be insulated to more than R-50, whereas a home in New York City, St. Louis, or Washington, D.C., would have to equal R-37 in order to equal the thermal properties of the test wall.

An air barrier is not necessary because of the inherent solid mass properties value of the concrete. One common culprit is also eliminated, in that outlets do not allow air infiltration. A vapor barrier may not be needed in most climates due to the high insulation of the wall assembly. (This requirement should be verified with local building codes and applicable construction practices.) Damp-proofing and waterproofing are required in wall assemblies when used below grade. As stated earlier, verify construction assemblies with the manufacturer's details and instructions.

Sound transmission class (STC) is a single-number rating of the sound insulating value of a material or assembly. The higher the number, the better is the insulator. The STC ratings of concrete and gypsum wallboard, along with the ideal separation that EPS creates between the two materials, provide sound insulation qualities, both airborne and impact, that meet the separation standards of the major building codes and FHA without the application of other acoustic material. For example, Polysteel walls provide an STC of 48 as compared with 32 for a 2 × 6 wood frame wall. AAB Blue Maxx provides an STC of 53, whereas ConForm (including two layers of $^1/_2$-in GWB) provides an STC of 52.

Because each modular unit is so lightweight, pallets can be easily lifted manually from delivery trucks, moved around, and placed anywhere on the building site. The need for forklifts or other heavy equipment is usually eliminated, resulting in more cost savings for the contractor and the consumer. For example, one 6-lb Polysteel form creates the same amount of wall area as would 140 lb of concrete block. Similarly, a 40-lb ConForm pallet produces the equivalent of 500 lb of concrete block for the same area (Fig. 15.20).

EPS forms are designed to meet or exceed the minimum material requirements of all major building codes in the United States, Uniform Building Codes (UBCs), Southern Building Code Congress International (SBCCI), International Conference of Building Officials (ICBO), and Building Officials Code Administration (BOCA). It is important to note, however, that not all the "newer" manufacturers have been approved by the proper code authorities. Specifiers and homeowners need to verify that the product to be used has been approved.

Polysteel walls, with an insulation value of R-22 (filled with reinforced concrete), are bullet-resistant. Proper detailing, caulking, and waterproofing will minimize outside air infiltration, leaks, and drafts. Although some manufacturers claim that the formwork will not be eaten by wood-eating termites or ants, it is still prudent and recommended to sufficiently treat the soil and ICF for these vermin.

Installation standards and practices

These products are described as "builder friendly" and do not require a special skilled labor force. Most manufacturers indicate

Figure 15.20 ICF Installation. (*American Polysteel, Inc.*)

that the learning curve is minimal. Since each system reviewed in this book varies to some degree, specific installation instructions must be followed relative to the specific manufacturer. No two systems are alike, so the following are generalized application directions that were not covered elsewhere in this book.

Footings are required and should include rebar dowels for tying the walls to the footing. If stepped footings are required, it is preferred to step in vertical increments consistent with the modular form unit height.

For plank systems, a 2×4 should be nailed to the footing to guide placement of the first course. Corners are braced and angles cut on both sides. Vertical bracing is applied with "kickers" and ladder bracing per manufacturer's recommendations (Figs. 15.21 and 15.22).

In the case of a prefabricated modular block, such as Polysteel, the first block is set at the corner. Each ICF block is set on another in a running bond after each course is completed. In the case of R-Control Insulated Concrete Forms, preformed corner pieces are set against the outside toe plate (used as a guide). The first pair of 8-ft planks are assembled upside down with half ties and then flipped. The remaining prebuilt sections are set continuously around the perimeter, and the second and subsequent courses are set in a stack bond (Figs. 15.23 and 15.24).

Concrete should have a slump no greater than 6" with a recommended aggregate size of $^3/_8$". Always check slump yourself before pouring. On hot days, or if concrete stays in the truck too long,

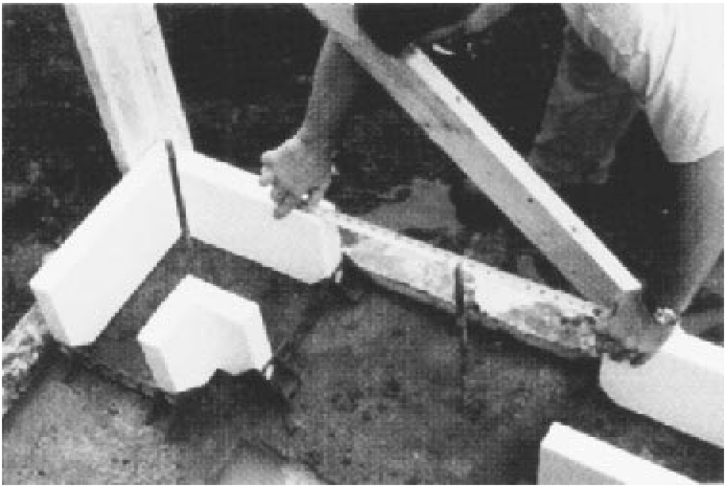

Figure 15.21 Installation of corner units. (*R-Control Building Systems*)

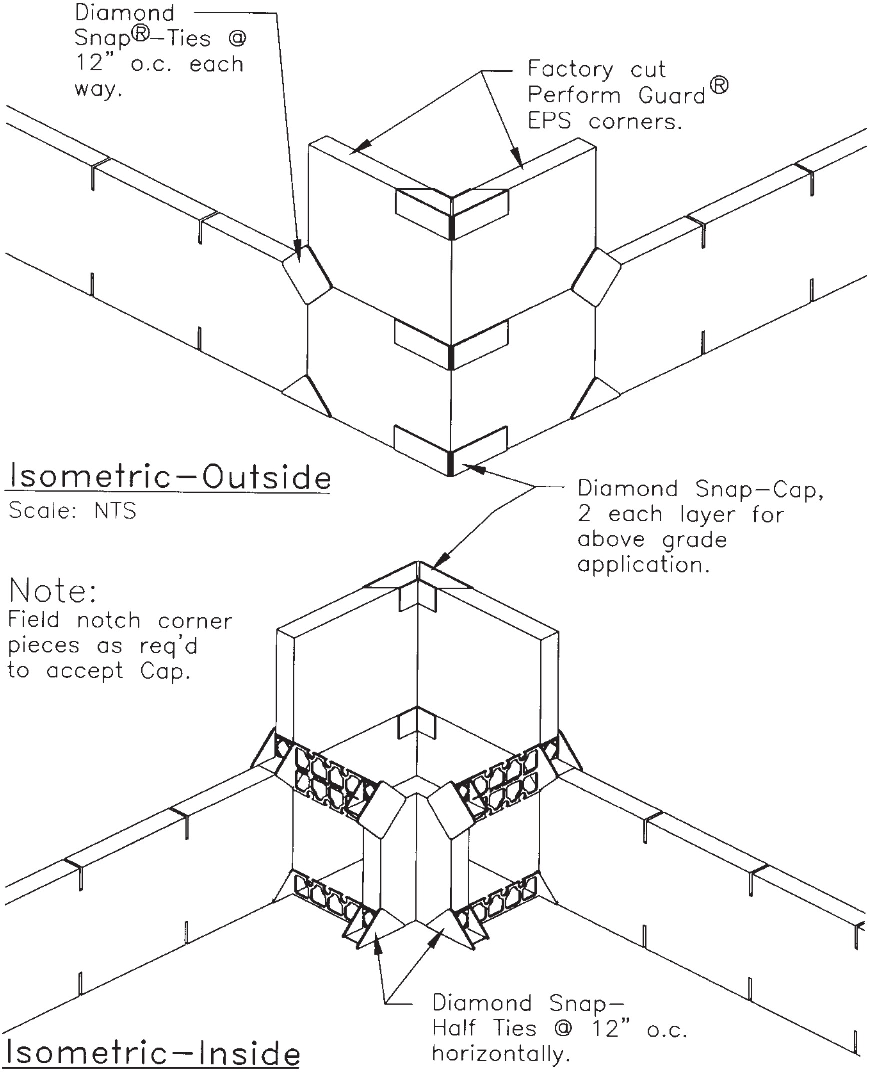

Figure 15.22 Installation of corner units. (*R-Control Building Systems*)

recheck slump. Stiff concrete is a problem. If high-strength concrete is used, or if significant rebar is placed, extra care must be taken to ensure proper filling and elimination of air pockets. Using a rebar to spread the concrete will help, and vibrating by pounding with a mallet (use a section of plywood to protect the foam) will help consolidation. Concrete admixtures can be used for special applications (Fig. 15.25).

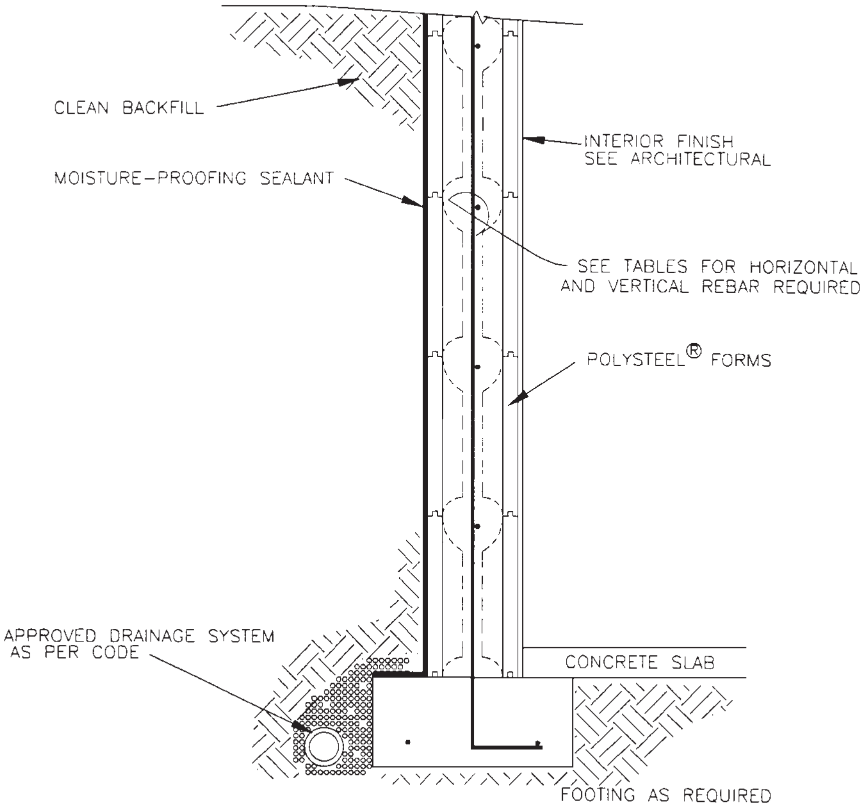

Figure 15.23 Wall-section. (*American Polysteel, Inc.*)

At the top of the wall, the concrete is screeded and troweled smooth, and anchor bolts are set. In general, hot and cold water pipes and electrical conduit and wiring can be placed in chases routed with a hot knife or cut into the wall after the concrete has cured sufficiently (Fig. 15.26).

Interior finishes of wood paneling or GWB and exterior finishes of board and batten siding, wood, vinyl or aluminum siding, brick, stone, or even stucco can be applied to any of the products. The method of attachment varies with each product. For example, screws are set only at each tie with the R-Control Insulated Concrete Form system, whereas Polysteel has integral furring strips, and GWB is typically adhered to ConForm's SmartBlock.

Straw Bale

Straw is the dried dead stems of cereal grains after the seed heads have been harvested. These grains include wheat, oats, barley, rye,

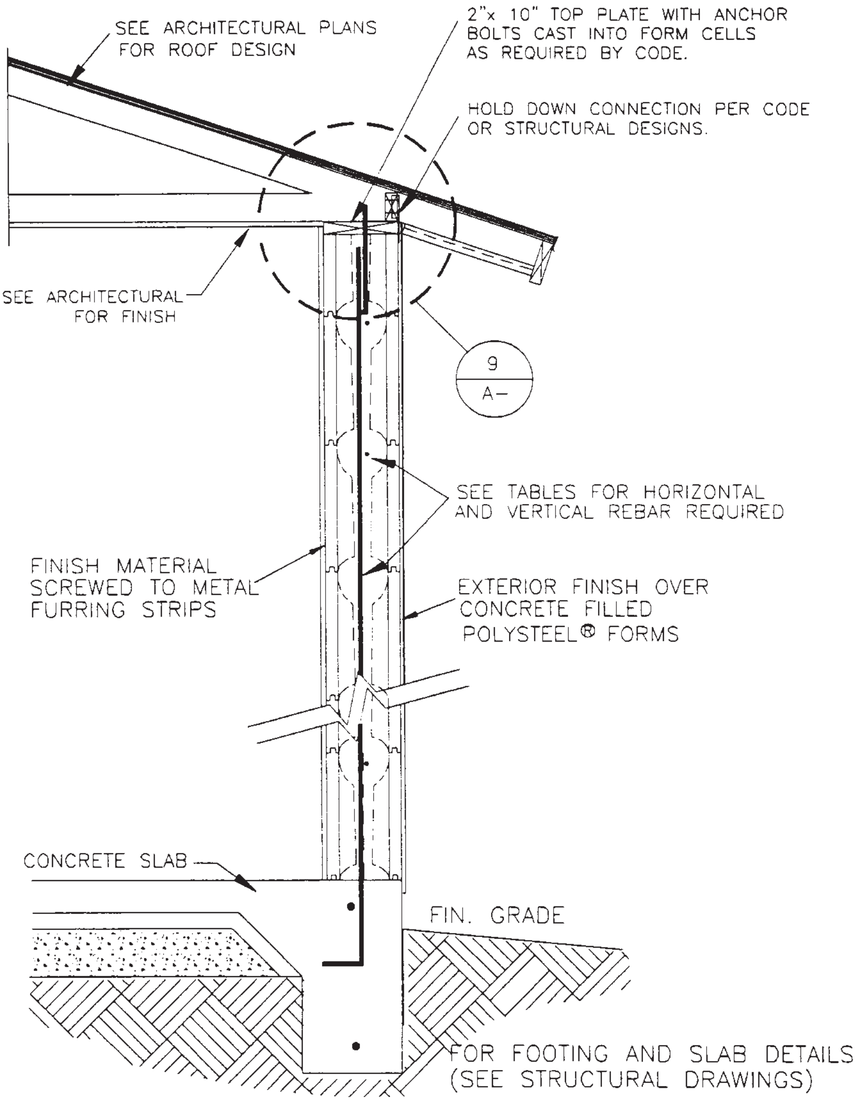

Figure 15.24 Wall-section. (*American Polysteel, Inc.*)

flax, and rice. Straw is different from hay, which is grown for livestock feed and is baled green with the leaves and seedheads included. As the grains are harvested, the straw is tightly packed into bales that are tied with wire, plastic, or sisal string. Unlike hay grasses that are harvested green as livestock feed, straw has a high silica content that reduces its flammability, is nonnutritious, less attractive to pests, and is naturally resistant to rotting. There are no reported or known cases of termites damaging straw bale walls,

Figure 15.25 Concrete preparation. (*R-Control Building Systems*)

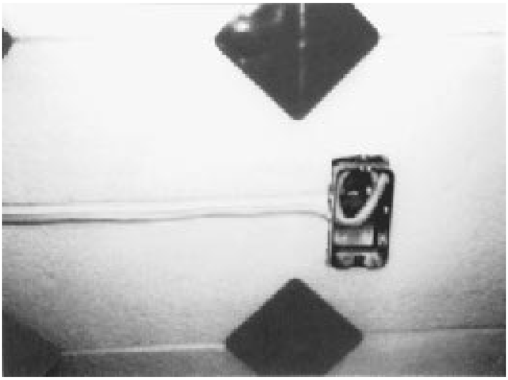

Figure 15.26 Electrical installation. (*R-Control Building Systems*)

although in one case they traveled through the bales to get to wood window frames.[7]

The first stationary, horse-powered baler was built in 1872, followed by steam-powered balers in 1884. These two inventions, especially the horse-powered baler, contributed to the growth of straw bale construction. In the late 1800s, the northwestern Nebraska sandhills were a vast grassland area with limited trees. A shortage of lumber, and little or no access to rail transportation, meant that settlers had to turn to indigenous materials for protection from the elements. The Kincaid Act of 1904 provided new homesteading rules that further helped populate this semiarid region of grass-stabilized sand dunes.

Although claims have been made for the construction of a hay bale home near Lincoln, Nebraska, in 1889, the oldest structure for which there is satisfactory documentation is a one-room schoolhouse built near Minitare (then Tabor), Nebraska, in 1896 or 1897.[8]

Plastered straw bale houses, farm buildings, churches, schools, offices, and grocery stores were developed throughout the region. The straw bales, about 3 to 4 ft long and $1^1/_2$ to 2 ft square, were stacked like bricks, one bale deep, with the joints staggered. Some houses used mortar between the bales, whereas others simply rested one bale directly on the other. Four to five wooden or iron rods were driven down through the bales to hold the wall firmly together. The roof plate, typically supporting a simple hipped roof, was fastened to the top bales of the wall with rods or stakes. Window and door frames were set as the walls rose around them. Numerous examples of these historic structures still exist, many over 100 years old. These artifacts serve as excellent examples of the durability, simplicity of construction, and environmental sensibility that have contributed to the growing popularity of straw bale construction in the twenty-first century (Figs. 15.27 through 15.29).

Product description

Bales are available with two or three wires holding them together. Two-wire bales weigh about 50 lb and are usually 14" high, 18"

Figure 15.27 Berkeley cottage interior. (*Daniel Smith & Associates Architects*)

Figure 15.28 Two-story Escalon house under construction. (*Daniel Smith & Associates Architects*)

Figure 15.29 St. Helena house. (*Daniel Smith & Associates Architects*)

wide, and 32 to 40" long. Three-wire bales weigh 75 to 100 lb and measure are 16 to 17" high, 23 to 24" wide, and 42 to 47" long. The length of bales can be easily changed, but because of the shoot of the baler, the height and width are fixed.

Good building bales should be dry and well compacted with no discoloration from rot or mold. The weight of dry bales (moisture content below 20 percent) is 7 to 9 lb/ft^3. A building-quality bale should be dense enough that it will not deform when two people stand on it. The strings should be tight enough so that when the bale is lifted by the strings, you can fit no more than one finger under the string. Half bales and whole bales are needed so that the bales can be staggered when stacked.

Climatically, the range of building sites includes semiarid locations such as southern Sonora, Mexico, rainy and humid sites in Alabama, and wintry regions such as northern Alberta, Canada, or the coast of Maine. Straw bale buildings also have been built in other parts of the world such as Australia, Canada, Chile, England, Finland, France, Ireland, Mongolia, New Zealand, Norway, Russia, Scotland, and Wales. The building sizes and types are quite varied. Examples include a 10' $\times$ 12' storage shed (built by a fifth grade class with rice straw bales), an art gallery, a 40' $\times$ 80' grocery store, elegant homes, and a 26,000-ft^2 hog barn with a straw-insulated roof.[9]

Straw bale construction guidelines have been created for use as a prescriptive code for load-bearing straw bale structures, but adoption has been limited. The international building codes currently being adopted as this book goes to print do not include specific regulations for straw bale construction. The reference to alternative materials and methods in Chap. 1 requires local building officials to provide approval and permitting for this type of construction. Straw bale codes have already been adopted in parts of Arizona, California, New Mexico, and Oregon, as well as in Austin, Texas, and Boulder, Colorado.

As mentioned earlier, there are few termites that like straw. The only reported cases of termite damage occurred when the termites traveled through the straw to the wood window and door frames. The straw was left untouched. Termite prevention measures, such as termite shields, borate, or other barrier methods, should still be implemented as in conventional housing.[10]

Long-term or repeated exposure to moisture is perhaps the greatest danger that straw bale walls face. Given enough liquid moisture and 2 to 3 weeks, the fungi that are always present in bales produce enzymes that break down straw cellulose. Fortunately, straw moisture content must be above 20 percent (by weight) to support fungal growth. Some codes require a maximum moisture content of 14 percent. Moisture testing in plastered straw bale walls suggests that maintaining the breathability of straw bale walls may be the best insurance against rot. Historical data for unwrapped bale walls demonstrate the importance of maximum breathability; a mansion in Huntsville, Alabama, has successfully endured southern humidity since 1938; a 1978 building near Rockport, Washington, receives up to 75 in of rain a year; and an unplastered building near Tonasket, Washington, with no foundation and unplastered walls shows no apparent deterioration of the bales since 1984. Straw bale wall moisture monitoring is underway in climates as diverse as Portland, Oregon, Alberta, Canada, and Nova Scotia, Canada. Tests to date show rot problems only in areas with leaks or direct bale-concrete foundation or bale-soil contact.

R-value

Much of the published information on the energy performance of straw bale buildings is based on measurements done in 1993 by Joseph McCabe at the University of Arizona as part of his master's thesis. McCabe's findings show that straw bale construction assemblies have an insulating value of R-54.8 for a 23.5"-wide, three-string bale laid flat. The same bale laid on edge has an R-value of R-49.5. For two-string bales laid flat, the R-value is R-42.8. When laid on edge, the R-value is R-32.1.[10] McCabe concluded that the insulating value is 2.68 per inch (0.054 W/m·°C) when heat flow is perpendicular to the orientation of the straw (bales stacked on edge) and 2.38 per inch (0.061 W/m·°C) when the heat flow is parallel to the straw orientation (with the grain). Subsequent studies have been performed with varying results depending on the testing method. In the most recent test, on May 15, 1998, researchers at ORNL completed a second test in their guarded-hot-box chamber. Bales were 19" (480 mm) wide and stacked flat. After being plastered on both sides, the wall was allowed to dry for almost 2 months (to 13 percent moisture content). The test chamber was operated with one side at 70°F (21°C) and the other at 0°F (−18°C), and 2 weeks were provided for the wall to reach steady-state heat flow conditions. Measurements then showed the wall to insulate to R-27.5 (RSI-4.8). On a per-thickness basis, this is 1.45 per inch (0.099 W/m·°C), just over half the value most commonly reported.[11]

In a paper presented in 1998, researchers Tav Commins and Nehemiah Stone suggest that this is the most accurate measure of the R-value of straw bale walls to date. Achieving a wall R-value of R-28 (RSI-4.9) for a straw bale building is significant, but is drastically lower than the R-50 to R-60 (RSI-8.8 to RSI-10.6) figures that have been suggested in the past. The wide variation in tested R-values that may result from gaps or moisture intrusion also indicates how important proper installation is with straw bale construction.[11] It is anticipated that additional testing will continue to ascertain a consistent R-value per inch quantity.

Straw bale selection

The success of a straw bale construction project may start with the quality of the basic unit of material to be used. Judy Knox, of Out on Bale, (un)Ltd., provides the following guidelines for selecting bales:

1. Purchase bales following the harvest when they are usually inexpensive and abundant. Make sure the bales are stored high and dry.
2. Obtain the bales from feed stores and other retail outlets, wholesale brokers, or directly from the farmer. Retail outlets are the easiest and most expensive sources. Wholesale brokers offer direct access to the bale supplier and often offer commercial transportation. Dealing directly with farmers may give you more say about bale quality and consistency, but you will likely have to address bale transportation.
3. Do not rely on hearsay concerning the size and condition of any bales you may buy. Check out the bales yourself.
4. Bales must be tightly tied with durable material, preferably polypropylene string or baling wire. Avoid bales tied with traditional natural fiber baling twine. When you lift the bale, it should not twist or sag.
5. Make sure the bales are uniformly well compacted.
6. Look for thick, long-stemmed straw that is mostly free of seed heads. Wheat, oats, rye, barley, rice, and flax are all good.
7. Test most bales to make sure that they have always been dry. Bale moisture content should be 14 percent or less.
8. An ideal bale size proportion is twice as long as it is wide. This simplifies maintaining a running bond in courses.

9. Try to get bales of equal size and length. If they do vary in length (as many will), lay 10 bales end-to-end. Measure this entire length. Then divide by 10. This is the average bale length to use for planning.[12]

Installation/details

The three basic ways to build walls with straw bales are known as *Nebraska style, in-fill,* and *mortar bale.* (A fourth style, known as *straw-clay building,* has been used historically in Europe.) Straw bales can be laid flat or laid on edge. *Laid flat* refers to stacking bales so that the sides with the largest cross-sectional area are horizontal and the longest dimension of this area is parallel with the wall plane. This would be analogous to a typical brick stretcher course laid in a running bond. *Laid on edge* refers to stacking bales so that the sides with the largest cross-sectional area are vertical and the longest dimension of this area is horizontal and parallel with the wall plane. This method is similar to a brick shiner course laid in a running bond.

Generally speaking, bale walls are commonly wrapped with stucco netting and plastered with mud, lime-sand, or cement plaster. In many cases the netting has been found to be unnecessary, and plaster is applied directly to the bales.

State building codes or construction guidelines, if applicable, should be consulted. The following text is to be used as a general guide to installation only.

Nebraska style. The oldest method of straw bale construction, Nebraska style, is also referred to as *structural bale* or *load-bearing construction.* The reference to Nebraska is an homage to straw bale's historic ancestry in buildings that originated on the Great Plains. Before 1936, all straw bale structures were built in this style.[10]

In Nebraska style construction, automatic straw balers create tight building blocks that are stacked up to one and one-half stories. The bales are typically stuccoed on the exterior and plastered on the interior to provide protection from the elements and an attractive finish. The stucco and plaster also add to the structural integrity of the wall system. This method is gaining in popularity because of its simplicity and economy of material use[12] (Fig. 15.30).

The simplest of load-bearing straw bale structures are square or rectangular buildings with hip roofs to distribute the roof load as equally as possible on all the walls. Buildings are usually limited to one story, and a relatively small number of windows and doors

Figure 15.30 Stucco application. (*Harvest Built Homes*)

are distributed fairly evenly around the building to prevent differential settling of walls.

In a typical load-bearing design, bales are stacked on a poured concrete stem wall that extends about 6" above the floor slab. A moisture barrier or capillary break (such as gravel) should be placed between the foundation and the first course of straw bales. The barrier should run vertically between the perimeter insulation and the foundation wall and should run horizontally under the straw bale and then double back to the outside edge of the foundation (Fig. 15.31).

Figure 15.31 Bottom course. (*Harvest Built Homes*)

Many builders prefer three-wire bales because they are wider than two-wire bales, thereby making the walls more stable. Bales are usually stacked in a running bond fashion and fastened to each other by driving pins, usually of wood, metal, or bamboo, down through multiple courses of bales as the walls are built. Stacking using a running bond produces a wall that is stronger and more stable. Wooden frames are installed for windows and doors as the layers of bales are installed. Lintels also can be used to transfer the loads to the bale walls on either side of an opening (Fig. 15.32).

Roof construction for bale buildings is virtually the same as for conventional construction. Bale walls usually are capped with a wooden, plywood, or concrete roof-bearing top plate. Also called a *roof plate,* this assembly serves as a structural element at the top of the wall to bear and distribute the weight of the roof, to give the top of the wall additional lateral strength, and to provide a way to securely attach the roof structure to the walls (Fig. 15.33).

Roof plates typically consist of a horizontal material that is as wide, or nearly as wide, as the bale width of the wall below. Attached to this is a vertical piece or pieces that provide strength against bowing down in the middle. One common method for 23"-wide, three-string bales uses a 24"-wide plywood sheet as the hori-

Figure 15.32 Window. (*Harvest Built Homes*)

Figure 15.33 Conventional roof. (*Harvest Built Homes*)

zontal piece and two 2 × 6s or 2 × 8s stood on edge and nailed along the long edges of the plywood sheet. Another method, termed a *ladder-type roof plate,* uses lengths of 2 × 6 or 2 × 8 lumber connected by short cross-pieces of the same lumber.

The hip roof is probably most suitable for larger load-bearing bale buildings because it offers the advantages of allowing all the exterior walls to be built to the same height and the roof load to be distributed to all four walls. To protect the bales from moisture, substantial overhangs are preferred in high-rainfall climates.

Continuous structural connections between the foundation and roof structure are necessary to resist the uplift and lateral forces caused by high winds and (in some regions) seismic activity. Various systems have been developed, including anchor bolts and threaded rods, cables, heavy wires, and straps (Fig. 15.34).

Full-height threaded rods every 6 ft is a simple but laborious method. Sections of threaded rod usually extend from the concrete stem wall to the top of the wall, and bales are installed over them. These threaded rods are bolted through the roof plate and tightened down after the roof is installed.

The traditional approach to wall compression is to put the roof on and wait at least 6 weeks for the weight of the roof to compress the

Figure 15.34 Roof detail. (*Daniel Smith & Associates, Architects*)

bales prior to plastering. Posttensioning, also referred to as *pre-compressing,* can compress the walls for increased structural stability, reduced long-term settling, and faster construction (Fig. 15.35).

In an effort to avoid the traditional method of "impaling" the bales over the full-height threaded rods, other systems have been devised. For example, a 2" × 2" steel mesh is nailed at the bottom of the wall to a wooden wall plate that is bolted to the concrete foundation. The mesh is also nailed to the roof plate at the top of the wall. A backhoe can be used to apply a force to the roof plate to compress the wall before the mesh is nailed in place.

Another method of posttensioning embeds eyebolts in the foundation on either side of the wall. A $^1/_2$" flat poly strap is threaded through the eyebolts, over the top of the roof plate, and back down to the eyebolt on the other side of the wall. The poly strap method uses small metal buckles, which allows tension to be placed on the strapping, with the overall advantages of minimal tool needs and maximum speed and ease.

In-fill. The in-fill or nonstructural bale system can be used for the construction of large structures, taller-wall heights, or where extensive diagonal bracing may be required. A vertical load-bearing

Figure 15.35 Straw-bale roof. (*Daniel Smith & Associates, Architects*)

structural frame is employed with the straw bale wall. Also called the *post and beam style,* this approach can accommodate structural systems such as concrete block, concrete, short 2 × 4 fin walls, or wood I-beams. The roof plate is actually a concrete tie beam, an engineered wood beam, or a box beam. The straw bale walls have only their own weight to support. The bales are attached to each other by piercing the bales with rebar, stakes of wood, or bamboo and attaching the bales to the pole or column.

Using straw bales as in-fill walls in post-and-beam offers several advantages. Less reinforcement of the bale walls is needed because the structural system carries the roof load. In the event the straw bales help support the posts, smaller framing members can be used than is common with timber frame construction. The roof also can be finished before erecting bale walls, keeping rain off the straw bales prior to stucco application. In-fill straw bale designs also permit greater design flexibility. Irregular roof designs, multiple-story building heights, complex floor plans, and different amounts of glazing on different orientations are possible with this system. The disadvantages include the need for more framing material, the lack of continuity in the bale fabric, and typically a diminished "bale character" in the wall edges and alignment[12] (Figs. 15.36 and 15.37).

Figure 15.36 Berkeley cottage under construction. (*Daniel Smith & Associates, Architects*)

Figure 15.37 Berkeley cottage after stucco. (*Daniel Smith & Associates, Architects*)

As summarized by Daniel Smith & Associates, Architects, there are several other systems approaches to the post and beam style. These include

1. *Post and beam with continuous bale wall alongside.* An exposed heavy timber frame with the bale wall running alongside.
2. *Bale wall with light notched-in posts.* A light post and beam frame notched into a continuous bale wall, so that the frame is not exposed. As straw bales are stacked, they are notched around the wooden frame, where they provide lateral bracing—corner bracing may not be required. (Steel frames and masonry-block or poured-concrete columns also can be used.)
3. *Bale wall wrapped around an existing shell.* The bales are typically wrapped outside the existing skin of the building and then tied to it. This is a common approach to insulating an existing house, barn, or steel industrial building.

Mortar bale. The mortar bale system uses structural mortar, made of portland cement and sand, that is applied between the straw bales. Bales are stuccoed on the exterior and plastered on the interior to protect them and provide an attractive finish. The mortared joints, stucco, and plaster also add to the structural integrity of the wall system. This system's thermal performance is not as efficient because of conductivity through the mortar joints. This method was developed in Canada in the 1980s and is compliant with Canadian building codes.[12]

Structural considerations and guidelines

Although code requirements will vary, the following is a draft prescriptive standard for load-bearing and non-load-bearing straw bale construction that has been developed by David Eisenberg of the Development Center for Appropriate Technology with input from Matts Myhrman:

- Minimum wall thickness: 13" (330 mm).
- Minimum density of straw bales: 7.5 lb/ft^3 (120 kg/m^3).
- Maximum wall height: One story with unloaded bale portion of wall not to exceed 5.6 times the wall thickness.
- Maximum unsupported wall length: 15.7 times the wall thickness.
- Allowable load on bale walls: 550 lb/ft^2 (2684 kg/m^2).
- Minimum height of foundation (stem) wall: 6" (150 mm) above grade.
- Structural anchoring to foundation: Minimum $^1/_2$" (13-mm) diameter steel anchor bolts at intervals of 6 ft (1.8 m) minimum connected to threaded rod to tie down top plate.
- Moisture barrier: One of several barrier materials between top of foundation and bottom of bale wall to block capillary moisture migration.
- For load-bearing walls, bales must be stacked flat with bales overlapping in successive courses; various options for pinning bales are acceptable. For nonstructural walls, bales may be stacked on edge.
- Roof plate: Two double 2 × 6 (or larger) horizontal top plates located at inner and outer bale edges with cross-bracing.
- Wall openings for windows and doors: Minimum of one full bale from an outside corner and framed to carry roof load (several options possible).
- Plaster/stucco: Cement stucco reinforced with woven wire stucco netting or equivalent, secured through the wall.[13]

Limitations

Moisture is probably the greatest threat to the success of any straw bale construction project. Straw is inherently resistant to rot and is resistant to but a very few organisms that are actually able to decompose straw. High moisture levels in straw bales can provide a habitat for fungi and lead to decomposition. In fact, fungus can occur in straw at humidity levels of above 20 percent (percentage of dry weight). The New Mexico standards list 20 percent as the maximum allowable moisture content, but some researchers believe that 14 percent is a more appropriate quantity.[10] Bulk moisture must be kept away from walls by using wide overhangs, sloping the ground away from the building, and installing a good capillary break between the foundation and the bale walls.[13] For obvious reasons, straw bales should not be used below grade. The foundation should be constructed so that the bottom of the lowest course of straw bales is at least 6" above final exterior grade.

There are no historical precedents for bales being used with moisture barriers, and consequently, there are no data on how the two perform together. Most historical data for unwrapped bale walls demonstrate the importance of maximum breathability of bale walls. The almost universal practice among straw bale builders, whether in California, Arizona, Washington, or Nova Scotia, is to avoid the use of sheet moisture barriers or impermeable stuccoes over the bales. Experience with straw bale structures in a variety of climates indicates that these barriers are not necessary and may even be detrimental.[14]

A mansion in Huntsville, Alabama, has successfully endured southern humidity since 1938; a 1978 building near Rockport, Washington, receives up to 75 in of rain a year; and an unplastered building near Tonasket, Washington, with no foundation and unplastered walls has shown no apparent deterioration of the bales since 1984. Of the hundreds of bale buildings standing in the Southwest, none has used a paper moisture barrier. Recent bale structures in northern New York (humid winters) and Nova Scotia (cold humid winters) have been monitored and demonstrate good performance in these difficult climates.[14]

The introduction of a sheet moisture barrier, even a breathable product, inhibits the natural transpiration of the bales and may even create a surface that would concentrate moisture within the wall. Although air retarder products transmit vapor, they block liquid moisture. Consequently, vapor traveling from the building interior condensed inside the bale wall would be unable to leave the wall except as vapor and could collect at the membrane and cause rot. The straw/stucco membrane, which allows both vapor migration and transpiration of liquid, can allow such moisture to wick out to the exterior more readily.[14]

Canadian studies suggest that alkaline stuccoes, whether lime-rich or cement-rich, do not attack the straw at the interface and indeed appear to preserve it. One drawback is that the cement-rich stuccoes may be too impermeable to water vapor. This lack of breathability may not be conducive for use as exterior skins in cold areas. In contrast, the study continues, the lime-rich stuccoes may be too permeable to liquid water for the driving rain in other regions.[15]

Environmental considerations

Straw is an annually renewable crop, available wherever grain crops are grown. It is indeed a waste product, much of which is currently burned in the field. The slow rate at which straw deteriorates creates disposal problems for farmers. Unlike nitrogen-rich hay, straw cannot be used for livestock feed.[10]

Fire resistance

Although loose straw is easy to burn, baled straw chars and smolders and does not easily support a flame. Unlike stud construction, in which a series of "chimneys" (stud cavities) form the wall, bales are difficult to burn. The straw in bales is densely packed, which inhibits the oxygen flow necessary to fuel combustion. Straw bales, like heavy timbers, will char on the outside, thereby creating an insulating layer that further inhibits combustion. There have been some examples where the walls have been difficult to extinguish, since embers tend to slowly tunnel through the bales. The American Society for Testing and Materials (ASTM) Standard E119, "Small Scale Fire Tests," has even given straw bale construction a 2-hour fire rating.[7]

The tests administered by the National Research Council of Canada indicate that when jacketed by stucco and plaster, bales are even more resistant to fire. The plaster surface of the test sample withstood temperatures of up to 1850°F before a small crack developed.[10] The plastered bales hold enough air to provide good insulation but are firmly compacted and do not hold enough air to allow combustion.

Bales laid on edge leave the strings exposed unless covered with plaster or stucco. If the strings are burned, the bale will fall apart and subsequently combust. When the bales are also wrapped with wire lath, the potential danger of burned and busted baling twine is, of course, greatly reduced. Bales that potentially could be exposed to extreme heat or flame, whether in walls or roofs, must be encased in plaster or gypsum board.

Availability

Whether a straw bale building system can achieve the popularity necessary to be considered a conventional building system is not known at this time. The Straw Bale Construction Association is a fledgling trade association of straw bale builders and architects that has members in 22 states, indicating some level of interest among professionals. Availability and shipping costs may be the biggest deterrent to competitive use of straw bale construction. At present, straw bales range in price from $1.70 (material and delivery) in Alberta, Canada, up to $3.50 in parts of Arizona and British Columbia. Research indicates that straw bale residences can range in cost from $10 to $100 per square foot depending on level of finishes, complexity of plan, and amount of owner-provided labor.

Appendix

AFM Corporation
P.O. Box 246
24000 W. Highway 7
Excelsior, MN 55331
800-255-0176
R-Control Insulated Concrete Form and R-Control Building Systems
952-474-0809
Fax: 952-474-2074

American Polysteel Forms
5150-F Edith NE
Albuquerque, NM 87101
800-9PS-FORM
Fax: 505-345-8154

FischerSIPS Incorporated
1843 Northwestern Parkway
Louisville, KY 40203
502-778-5577
800-792-7477
http://www.fischersips.com

Structural Insulated Panel Association
3413 A 56th Street NW
Gig Harbor, WA 98335
253-858-SIPA (7472)
Fax: 253-858-0272
Email: *staff@sips.org*
http://www.sips.org/

Tav Commins
California Energy Commission
1516 9th Street
Sacramento, CA 95814-5504
916-654-4989
Fax: 916-654-4420
http://www.energy.ca.gov

Harvest Built Homes
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93 California Street
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541-482-8733
www.harvesthomes.org
A 501(c)(3) nonprofit corporation promoting affordable straw bale home ownership for low-income families

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505-895-5400

Center for Renewable Energy and Sustainable Technology (CREST)
777 N. Capitol St. NW
Ste. 805, Washington, DC 20002
202-289-5365
E-mail: *info@crest.org*
http://solstice.crest.org/

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Chapter

16

Historical Insulation Products

Asbestos

Asbestos is a fibrous mineral found in rocks and soil throughout the world that has been used in more than 3000 different construction materials and manufactured products. Asbestos has been used in architectural and construction applications because it is strong, durable, fire retardant, and an efficient insulator. Alone or in combination with other materials, asbestos can be fashioned into a variety of products that have numerous applications within the building industry, such as flooring, walls, ceiling tiles, decorative spray-on ceiling treatments, exterior housing shingles, insulation or fire retardant for heating and electrical systems, etc.

Chrysotile, or white asbestos, is the most widely used mineral in the asbestos family and makes up approximately 95 percent of the world's asbestos supply, three-quarters of which is mined in Quebec, Canada. Prices can range from $200 to $1300 a metric ton, depending on the quality. (The longer the fiber, the more valuable it is.[1]) Amosite, known as brown asbestos, and crocidolite, known as blue asbestos, each account for less than 5 percent of all asbestos in buildings. The remaining three kinds of asbestos, anthophyllite, tremolite, and actinolite, are rare. In addition to the strip mines in Canada, mining operations continue in Russia, China, Zimbabwe, Brazil, and King City, California.

All types of asbestos are chemically inert, noncombustible, and tend to break into very tiny fibers. These individual fibers are so small that many must be identified using a microscope. In fact, some individual fibers may be up to 700 times smaller than a human hair. Because asbestos fibers are so small, once released into the air, they may stay suspended there for hours or even days.

History

The first recorded use of asbestos was in Finland about 2500 B.C., where the material was used in the mud wattle for the wooden huts the people lived in as well as strengthening for pottery. Adverse health aspects of the mineral were noted nearly 2000 years ago when Pliny the Younger wrote about the poor health of slaves in the asbestos mines. Benjamin Franklin even carried a fireproof purse made from asbestos.[1] Although known to be injurious for centuries, the first modern references to its toxicity were by the British Labor Inspectorate when it banned asbestos dust from the workplace in 1898. Asbestosis cases were described in the literature after the turn of the century. Cancer was first suspected in the mid-1930s, and a causal link to mesothelioma was made in 1965. Because of the public concern for worker and public safety with the use of this material, several different types of analyses were applied to the determination of asbestos content.[2]

The first commercial asbestos mine, a chrysotile mine, was opened in Quebec, Canada, in the 1870s. Amosite asbestos and crocidolite asbestos were mined from Africa beginning in 1916 and 1980, respectively. Asbestos was first used in the United States in the early 1900s to insulate steam engines. While its fire-retardent and durability properties soon prompted this material's inclusion into a variety of household and construction products, the manufacturers of asbestos products were aware of the deadly dangers and health hazards by the 1930s. Workers in asbestos factories, including men, women, and children, were developing asbestos lung disease as soon as 5 or 6 years after first exposure to asbestos. By the early 1940s, medical and scientific articles were being published showing the connection between asbestos and the development of lung cancer. By the 1950s, the connection between asbestos and mesothelioma had been made, and by 1960, it was established that persons exposed to asbestos were developing mesothelioma at an alarming rate. Secret internal company documents reveal that the asbestos companies intentionally hid what they knew about the dangers and health hazards of asbestos so that workers and customers would not object to using asbestos products. In 1973, the United States used 795,000 metric tons of asbestos in consumer products. Although some asbestos-containing materials were still being installed in buildings into the late 1980s, this number had dropped to 21,700 metric tons by 1996, with predominant uses in water pipes, brake linings, and roof coatings.[3]

Asbestos products

Asbestos is found in thousands of products, including many building materials. Asbestos is most commonly found in commercial applications as sprayed-on insulation, pipe and boiler insulation, and duct insulation. In residential dwellings, it can be found in roofing and siding shingles made with asbestos cement, vinyl floor tiles and adhesives, wall and ceiling acoustical tiles, sprayed "popcorn" coatings on ceilings and walls, insulation in attics and walls, and insulation blankets on furnace ducts and hot water and steam pipes, as well as boiler door gaskets on furnaces and wood stoves.

Products containing asbestos can be very difficult, if not impossible, to visually identify unassisted. There are some general descriptions one can go by. For example, sprayed-on asbestos insulation is usually a fluffy material sprayed onto ceilings or beams and sometimes covered by ceiling tiles. Asbestos pipe and boiler insulation may be covered with paper, cloth, or metal. The actual insulation can be a cardboard-like pipe wrap or cement on pipe elbows. Asbestos duct insulation is usually a thin layer of insulation that may be painted or covered with paper, cloth, or metal. Asbestos ceiling tiles, used for sound insulation or dropped ceilings, are very similar to nonasbestos tiles.

There is not a standardized assessment of asbestos use based on chronology either. For example, cement-asbestos board siding, a very dense, brittle product, was used primarily in the 1940s, 1950s, and into the 1960s. From the mid-1960s through the early 1980s, some spray-on "popcorn" ceiling treatments contained asbestos (asbestos used in this product was banned in 1977). The product most appropriate to the scope of this book, thermal insulation in attics and walls, was used primarily in homes built between 1930 and 1950. The amount of asbestos used in construction products varied as well. Asbestos insulation used between 1910 and the early 1970s may contain up to 74 percent or more asbestos by weight.

Asbestos thermal insulation

Although not as common as many other asbestos-containing materials (ACMs), loose blown-in and batt insulations infrequently have been known to contain asbestos. These were used primarily as thermal insulation in homes built or remodeled between 1930 and 1950. Although the U.S. Environmental Protection Agency (EPA) has stated that many homes constructed in the United States during the past 20 years probably do not contain asbestos products, new discoveries have demonstrated that this may be inaccurate. As recently as February 2000, new disclosures revealed that there may be other thermal insulation products that were on the market as recently as the early 1980s that contained asbestos.

For example, W. R. Grace Company was hit with three class-action lawsuits, one filed in Boston on behalf of homeowners nationwide who have asbestos-tainted Zonolite attic insulation in their homes and the other two in Montana, where the company operated a mine and mill. The lawsuit, filed in U.S. District Court in Boston by Edward M. Lindholm, accuses W. R. Grace Company of fraud, deception, and enriching itself at the expense of homeowners by failing to warn the public that the Zonolite insulation it sold from 1963 through 1984 contained tremolite asbestos. Grace's Cambridge-based Construction Products Division oversaw its attic insulation line.[4] In 1984, the EPA estimated that this attic insulation had been installed in 940,000 homes.[5] Grace, which discontinued its attic insulation in 1984, knew as far back as 1963 about the asbestos but feared that disclosure would hurt sales, according to memos from high-ranking Grace officials.[4]

This asbestos presents a hazard only if renovation and repair work disturbs it. If asbestos-containing materials are discovered, be sure certified and/or qualified contractors/workers are consulted and hired so that asbestos fibers are not spread further throughout the home.

Identification

As mentioned earlier, asbestos fibers were added to a variety of products to increase durability, insulation properties, and fire resistance. There are several types of asbestos fibers that may be found in a home, and typically an ACM cannot be recognized simply by looking at it, unless it is labeled. Until a product is tested it is best to assume that the product contains asbestos, unless the label or the manufacturer verifies that it does not. If there is a possibility that the house contains asbestos, the only sure way to tell is to take a sample from the specific area in question and have it tested by an EPA-approved laboratory.

Unlike thermal insulation, pipe insulation typically is easier to identify. Asbestos pipe insulation looks white and chalky and is wrapped in a thin canvas. Another type looks like corrugated paper wrapped with tape or paper that has been cut to fit around the pipes or furnace ducts.

Removal

Asbestos removal has been called the biggest environmental cleanup project in the United States. It has cost over $50 billion over the past 20 years.[3] If the asbestos is in good condition, it is best not to remove it. If the material is friable, it could be a health hazard, and other steps needs to be taken. (The means test for friability suggests that when the material is dry, it may be crumbled, pulverized, or reduced to powder by hand pressure, flakes off, or is deteriorating.) Similarly, if the material has been sanded, cut, or sawed, it is also a hazard and needs to be removed or immobilized.

Although the reaction to the health hazards of asbestos workers initially accelerated public concerns, the EPA also has slowly changed its position. For example, in 1979 the EPA stated that the only permanent solution to asbestos in buildings was to take it out. In 1983, the EPA said "removal was always appropriate, never inappropriate." In 1985, the EPA issued an updated statement in the "Purple Book" that emphasized managing asbestos rather than removing it. The issue of asbestos removal was further downplayed in 1990. The EPA's "Green Book" noted that improper asbestos removal could increase exposure by stirring up dust unnecessarily.[3]

The EPA currently requires asbestos removal only to prevent significant public exposure to asbestos, such as during building renovation or demolition. In fact, an improper removal can create a dangerous situation where none existed previously. EPA does recommend in-place management whenever asbestos is discovered. Instead of removal, a conscientious in-place management program usually will control fiber releases, particularly when the materials are not significantly damaged and are not likely to be disturbed.

The EPA has produced many guidance documents on asbestos in buildings. Some of the most pertinent are

1. "Guidance for Controlling Asbestos-Containing Materials in Buildings (Purple Book)," EPA 560/5-85-024.
2. "A Guide to Respiratory Protection for the Asbestos Abatement Industry (White Book)," EPA-560-OPTS-86-001.

3. "Managing Asbestos in Place: A Building Owner's Guide to Operations and Maintenance Programs for Asbestos-Containing Materials (Green Book)," EPA 20T-2003.
4. *Asbestos Abatement and Management in Buildings: Model Guide Specifications,* 2d ed., August 1988. New sections on asbestos-containing resilient flooring and a new introduction and instructions-for-use section were published in early 1992.[6]

EPA also maintains an asbestos information "hot line" and publications ordering number: 202-554-1404. For school-related asbestos information, call 800-835-6700. Information is also available from the National Institute of Building Sciences (NIBS), Washington, D.C.: 202-289-7800.

Home inspection. If immediate identification of the material is not possible, one alternative is to hire a house inspector specifically trained in handling asbestos material. The house inspector should have an identification card that has been dated within the last year. The cost is typically $100 plus the laboratory fee.

A professional asbestos inspector also may be available depending on the locale. The homeowner should review several items prior to the hire. First of all, make sure that the inspection will include a complete visual examination and careful collection and laboratory analysis of samples. If asbestos is present, the inspector should provide a written evaluation describing its location and extent of damage and give recommendations for correction or prevention. The homeowner also should verify that the inspecting firm makes frequent site visits if it is hired to ensure that a contractor follows proper procedures and requirements. The inspector may recommend and perform checks after the correction to ensure that the area has been cleaned properly.

Asbestos contractor. If the asbestos product is in poor condition, it is highly recommended that the homeowner hire a state-certified asbestos contractor to minimize all health risks in removing or immobilizing it properly. Asbestos professionals can conduct an inspection, take samples of suspected material, assess their condition, and advise about what corrections, if any, are needed and who is qualified to make these corrections. Asbestos abatement contractors can be found in the Yellow Pages or at Web sites. The homeowner also should check with the local air pollution control board, the local agency responsible for worker safety, and the Better

Business Bureau. Ask if the firm has had any safety violations, and find out if there are legal actions filed against it. Each person performing such work should provide proof of training and licensing in asbestos work, such as completion of EPA-approved training. State and local health departments or EPA regional offices may have listings of licensed professionals in specific areas. The EPA also has published a summary guide in order to guarantee that homeowners are protected during any asbestos inspection or removal[6] (see the Appendix at the end of this chapter for regional offices).

Before work begins, the homeowner should receive a written contract specifying the work plan, cleanup, and applicable federal, state, and local regulations that the contractor must follow (such as notification requirements and asbestos disposal procedures). The homeowner also should contact the state and local health departments, the EPA's regional office, and the Occupational Safety and Health Administration's (OSHA's) regional office to find out what the regulations are. Be sure the contractor follows local asbestos removal and disposal laws. At the end of the job, the homeowner should get written assurance from the contractor that all procedures have been followed.

The homeowner needs to verify that the contractor avoids spreading or tracking asbestos dust into other areas of the home. The contractor should seal the work area from the rest of the house using plastic sheeting and duct tape, turn off the heating and air-conditioning system, and tape over all vents. For some repairs, such as pipe insulation removal, plastic glove bags may be adequate. They must be sealed with tape and properly disposed of when the job is complete.

The homeowner should verify that the contractor clearly marks the work site as a hazard area. Household members and pets will not be allowed into the area until work is completed. On completion, the homeowner should make sure that the contractor cleans the area well with wet mops, wet rags, sponges, or HEPA (high-efficiency particulate air) vacuum cleaners. A regular vacuum cleaner must never be used. Wetting helps reduce the chance of spreading asbestos fibers in the air. All asbestos materials and disposable equipment and clothing used on the job must be placed in sealed, leakproof, and labeled plastic bags. The work site should be visually free of dust and debris. Air monitoring (to make sure there is no increase in asbestos fibers in the air) may be necessary to ensure that the contractor's job is done properly. This should be done by someone not associated with the contractor.[6]

Homeowner sampling. Although not recommended, a homeowner may want to do his or her own sampling in order to save a lot of money in consulting fees. The EPA has presented a few guidelines:

1. Make sure no one else is in the room when sampling is done.
2. Wear disposable gloves or wash hands after sampling.
3. Shut down any heating or cooling systems to minimize the spread of any released fibers.
4. Do not disturb the material any more than is needed to take a small sample.
5. Place a plastic sheet on the floor below the area to be sampled.
6. Wet the material using a fine mist of water containing a few drops of detergent before taking the sample. The water-detergent mist will reduce the release of asbestos fibers.
7. Carefully cut a piece from the entire depth of the material using, for example, a small knife, corer, or other sharp object. Place the small piece into a clean container (e.g., a 35-mm film canister, small glass or plastic vial, or high-quality resealable plastic bag).
8. Tightly seal the container after the sample is in it.
9. Carefully dispose of the plastic sheet. Use a damp paper towel to clean up any material on the outside of the container or around the area sampled. Dispose of asbestos materials according to state and local procedures. (One should never vacuum loose asbestos because the vacuum cleaner will only distribute the very fine, virtually invisible fibers throughout the house, thus exposing the whole household to asbestos.)
10. Label the container with an identification number and clearly state when and where the sample was taken.
11. Patch the sampled area with the smallest possible piece of duct tape to prevent fiber release.[6]

The cost should be around $30 for the laboratory work. Send the sample to an EPA-approved laboratory for analysis. The National Institute for Standards and Technology (NIST) has a list of these laboratories (see the Appendix at the end of this chapter).

Health concerns

The Health Effects Institute, in an EPA-financed report ordered by Congress in 1991, conducted a comprehensive study on the risks of asbestos in buildings. The study revealed that the lifetime risk of cancer for someone who works in a building containing asbestos is 1 in 250,000. Ironically, outdoor air in urban areas causes a 1 in 25,000 lifetime risk of cancer.[3]

As mentioned earlier, intact and undisturbed asbestos materials generally do not pose a health risk. ACMs, however, can become hazardous by releasing fibers due to damage or deterioration over time. These fibers can be up to 1200 times thinner than a human hair. When inhaled, they become trapped and aggravate the lung tissues, which causes the tissues to scar. Because the material is durable, it persists over tissue and concentrates as repeated exposures occur over time. Unfortunately, medical researchers state that up to 30 years after inhalation, asbestos fibers can cause diseases such as asbestosis, lung cancer, or mesothelioma. Disease generally occurs in workers and others who have experienced prolonged work-related exposure to asbestos; the health effects of lower exposures in the home are less certain. However, experts are unable to provide assurance that any level of exposure to asbestos fibers is completely safe.

Asbestosis. Asbestosis is a serious, chronic, noncancerous respiratory disease. Symptoms of asbestosis include shortness of breath and a dry crackling sound in the lungs while inhaling. In its advanced stages, the disease may cause cardiac failure. The risk of asbestosis is minimal for those who do not work with asbestos; the disease is rarely caused by neighborhood or family exposures. Those who renovate or demolish buildings that contain asbestos may be at significant risk, depending on the nature of the exposure and the precautions taken. There is no effective treatment for asbestosis; the disease is usually disabling or fatal.

Lung cancer. Lung cancer causes the largest number of deaths related to asbestos exposure. Asbestos exposure is responsible for 4 to 7 percent of lung cancer cases in the United States.[1] The most common symptoms of lung cancer are coughing and a change in breathing. Other symptoms include shortness of breath, persistent chest pains, hoarseness, and anemia. The incidence of lung cancer in people who are directly involved in the mining, milling, manufacturing, and use of asbestos and its products is much higher than in the general population. Research indicates that people who have been exposed to asbestos and are also exposed to some other carcinogen, such as cigarette smoke, have a significantly greater risk of developing lung cancer than people who have only been exposed to asbestos. One study found that asbestos workers who smoke are about 90 times more likely to develop lung cancer than people who neither smoke nor have been exposed to asbestos.

Mesothelioma. Mesothelioma is a rare form of cancer that occurs most commonly in the thin membrane lining of the lungs, chest, abdomen, and sometimes the heart. About 200 cases are diagnosed each year in the United States. Virtually all cases of mesothelioma are linked with asbestos exposure. Approximately 2 percent of all miners and textile workers who work with asbestos and 10 percent of all workers who were involved in the manufacture of asbestos-containing gas masks contract mesothelioma.[7]

Evidence suggests that cancers in the esophagus, larynx, oral cavity, stomach, colon, and kidney may be caused by ingesting asbestos. For more information on asbestos-related cancers, contact the local chapter of the American Cancer Society.

Asbestos regulation

The EPA is responsible for developing and enforcing regulations necessary to protect the general public from exposure to airborne contaminants that are known to be hazardous to human health. Although most regulations refer to commercial projects and schools, the concerns for residential asbestos installations must not be overlooked. Primary federal asbestos regulations can be found in EPA's "Green Book." Many are summarized in the following text; however, people involved in asbestos work should obtain and must follow all applicable federal and state regulations.

National emission standards for hazardous air pollutants (NESHAP), 40 CFR 61, Subpart M. The Clean Air Act (CAA) of 1970 requires EPA to develop and enforce regulations to protect the general public from exposure to airborne contaminants that are known to be hazardous to human health. In accordance with Section 112 of the CAA, EPA established national emission standards for hazardous air pollutants (NESHAP). Asbestos was one of the first hazardous air pollutants regulated under Section 112. On March 31, 1971, EPA identified asbestos as a hazardous pollutant, and on April 6, 1973, EPA promulgated the asbestos NESHAP in 40 CFR Part 61, Subpart M. The asbestos NESHAP has been amended several times, most recently in November 1990.[6]

The asbestos NESHAP is intended to minimize the release of asbestos fibers during activities involving the handling of asbestos.

Accordingly, it specifies removal of asbestos and work practices to be followed prior to renovations and demolitions of buildings that contain a certain threshold amount of friable asbestos. Residential buildings having four or fewer dwelling units are generally exempt from the rules. Most often, the asbestos NESHAP requires action to be taken by the person who owns, leases, operates, controls, or supervises the facility being demolished or renovated (the “owner”) and by the person who owns, leases, operators, controls, or supervises the demolition or renovation (the “operator”). The regulations require owners and operators subject to the asbestos NESHAP to notify delegated state and local agencies and/or their EPA regional offices before demolition or renovation activity begins. The regulations restrict the use of spray-on asbestos and prohibit the use of wet-applied and molded friable insulation (i.e., pipe lagging) that contains commercial asbestos. The asbestos NESHAP also regulates asbestos waste handling and disposal.[6]

Asbestos abatement projects, worker protection, final rule, 40 CFR 763, Subpart G. The EPA’s worker protection rule extends the OSHA standards to state and local employees who perform asbestos work and who are not covered by the OSHA asbestos standards or by a state OSHA plan. The rule parallels OSHA requirements and covers medical examinations, air monitoring and reporting, protective equipment, work practices, and record keeping. In addition, many state and local agencies have more stringent standards than those required by the federal government. People who plan to renovate a structure that will result in disturbing a certain amount of asbestos or who plan to demolish any building are required to notify the appropriate federal, state, and local agencies and to follow all federal, state, and local requirements for the removal and disposal of regulated asbestos-containing material.[6]

TSCA. In 1979, under the Toxic Substances Control Act (TSCA), EPA began an asbestos technical assistance program for building owners, environmental groups, contractors, and industry. In May 1982, EPA issued the first regulation intended to control asbestos in schools under the authority of TSCA; this regulation was known as the *asbestos-in-schools rule.* Starting in 1985, loans and grants have been given each year to aid local education agencies (LEAs) in conducting asbestos abatement projects under the Asbestos School Hazard Abatement Act (ASHAA).[6]

Asbestos Hazard Emergency Response Act (AHERA), asbestos-containing materials in schools, final rule and notice, 40 CFR 763, Subpart E. In 1986, the Asbestos Hazard Emergency Response Act (AHERA) was signed into law as Title II of TSCA. AHERA is more inclusive than the May 1982 asbestos-in-schools rule. AHERA requires LEAs to inspect their schools for asbestos-containing building materials and prepare management plans that recommend the best way to reduce the asbestos hazard. Options include repairing damaged ACM, spraying it with sealants, enclosing it, removing it, or keeping it in good condition so that it does not release fibers. The plans must be developed by accredited management planners and approved by the state. LEAs must notify parent, teacher, and employer organizations of the plans, and then the plans must be implemented. AHERA also requires accreditation of abatement designers, contractor supervisors and workers, building inspectors, and school management plan writers. Those responsible for enforcing AHERA have concentrated on educating LEAs in an effort to ensure that they comply with the regulations. Contractors who improperly remove asbestos from schools can be liable under both AHERA and NESHAP.[6]

Asbestos ban and phaseout rule. In 1989, EPA published the "Asbestos: Manufacture, Importation, Processing, and Distribution in Commerce Prohibitions: Final Rule" (40 CFR Part 763, Subpart I). The rule eventually would have banned about 94 percent of the asbestos used in the United States (based on 1985 estimates). However, in 1991, the U.S. Court of Appeals, Fifth Circuit, vacated and remanded the majority of the rule. Currently, the manufacture, importation, processing, and distribution of most asbestos-containing products is still legal.

The Occupational Safety and Health Administration. OSHA is also responsible for regulating environmental exposure and protecting workers from asbestos exposure. Asbestos-related information and procedures can be found in OSHA's construction industry asbestos standard (29 CFR 1926.58 and 29 CFR 1926.1101). These standards apply to activities involving demolition, removal, or renovation.

Litigation

Recent studies have revealed that in many cases the government, the EPA, the media, and even the public may have overreacted to asbestos building products–related health hazards. The high-profile cases involved workers who had spent years in clouds of asbestos dust. Nevertheless, the inexcusable fact that asbestos companies had actual knowledge of the dangers and health hazards of their asbestos products many years ago has formed the basis for the award of punitive damages against a number of asbestos manufacturing companies. These punitive damages are awarded by juries to punish the asbestos companies for their conduct of concealing the dangers and health hazards of asbestos from their workers, customers, the public, and the government, thereby bringing about unnecessary injury and death to a great number of people. Juries have awarded punitive damages against the following asbestos companies: Owens Corning, Owens Illinois, W. R. Grace, Armstrong World Industries, GAF, and U.S. Gypsum. To date, over 40,000 lawsuits have been resolved, with another 200,000 pending.[3]

Conclusion

In summary, it is well established that one should take every precaution necessary to avoid contact with asbestos materials. If asbestos-containing materials such as walls, ceilings, pipes, and boilers have been identified, the homeowner should perform routine inspections to verify that the material does not become damaged or friable. One government agency has assembled a simple checklist to use in the home.[2]

1. Do not touch or disturb asbestos material on walls, ceilings, pipes, or boilers.
2. Do not allow children to play near pipes or furnaces that have friable asbestos insulation around them. Just tossing a ball against asbestos material could release many invisible fibers.
3. Do not let the dog or cat run free in a basement with asbestos materials. The animal can pick up asbestos fibers on its fur and shake them off in other areas of the home.
4. Do not dust, sweep, or vacuum debris you think contains asbestos. (Remember: A regular vacuum cleaner allows asbestos fibers to pass right through it and reenter the room.)
5. Do not hang plants or other things from ceilings that may contain asbestos.
6. Do not tack or hammer nails into walls made from asbestos.
7. Do not allow curtain rods or room dividers hanging on ceiling tracks to bump or brush into walls or ceilings.

8. Do not brush, sweep, or sand ceilings and walls that contain asbestos insulation.
9. Do not knock the plaster or ceiling panels loose when replacing light bulbs or fixtures.
10. Do not saw or drill holes in asbestos materials.
11. Keep activities to a minimum in any areas having damaged materials that may contain asbestos.
12. Have analysis and corrective-type work performed by licensed asbestos professionals.
13. Do not dust, sweep, or vacuum debris that may contain asbestos. These actions will disturb tiny asbestos fibers and may release them into the air.
14. Change shoes before going back upstairs from the basement if there are damaged asbestos materials present in the basement.
15. Use a wet mop or wet cloth when cleaning areas that may contain asbestos fibers. Dispose of the mop or cloth when done.
16. Take care not to run into or hit the asbestos material with anything.[2]

Insulating Board

Structural insulating board, or insulating board, may have been a misnomer because it was more wallboard than insulating board. Nevertheless, most early wallboard products were used either as insulation or sheathing beneath exterior cladding or as a finish material for secondary spaces, such as attics and basements. The distinguishing characteristic of insulation board is that it combines strength with thermal and sound-deadening properties.[8] Although still available as an exterior sheathing product, it has largely been replaced by plywood, oriented strandboard, and other exterior sheathing products. Interior applications are also a far cry from its popularity experienced in the homebuilding industry during the 1940s and 1950s.

Since the generic term *insulating board* encompasses a wide variety of materials, the historical products discussed in the scope of this book will be limited to those also known as *fiber wallboards* or *interior fiberboard.* Popular manufacturers included Celotex, Insulite Division of M. & O. Paper Company, Homasote, and Upson Companies. Although structural fiberboard is a present-day "cousin" to these interior products, the gypsum wallboard market appears to have replaced the once-popular use of insulating board.

Product description

Insulating board is made by processing wood, cane, or other vegetable fibers to a pulp and then reassembling the fibers into boards. Although there were a variety of manufacturing processes, the majority of fiberboard was formed by mechanical processing. Typically, sawmill waste or logs were processed into pulp chips and then sized and moved onto the grinder and exposed to steam pressure. Water was then used to soften the fiber bonds of the wood and permit better natural bonding in the consolidation stage. The pulp matter was allowed to flow in a current of water onto a screen, where heavy pressure was applied to remove excess water and form pulp sheets. The sheets were then compressed between platens with a uniform force generated by hydraulic rams. Platens contained either steam or hot water, and they provided plain, smooth surfaces against which the fiberboard was molded. Pressure reduced the mass of wood fibers to a stiff, strong, dense board of interlocked fibers. The last step included drying, trimming, and fabricating to produce special finishes, colors, beveling, kerfing, laminating, and packaging.

The greatest changes in the manufacturing process of insulation board related to the speed with which boards could be produced. In 1910, insulation boards $^1/_2$" thick needed 36 hours to dry; by 1947, the drying process had been reduced to 50 minutes.

According to a 1947 text on insulation products, the principal insulating board interior products were referred to as building board, tileboard (panels), and planks. Building board products were 4 ft in width and varied in length from 6 to 12 ft. Thicknesses were $^1/_2$ or 1". Tileboard was manufactured from the same basic stock as building board but in much smaller sizes. Insulating board planks were long, narrow units produced in several widths ranging from 8 to 16" and lengths up to 12 ft.

Low-density boards were generally of greater thickness and also used for thermal and sound insulating purposes. Products such as Celotex's building board were used as exterior finishes or as sheathing under roofing materials or wall veneers of brick, siding, wood shingles, or stucco. In 1937, Celotex introduced Cemesto, a fire-resistant insulation board surfaced on one or both sides with asbestos cement, which was used in low-cost housing, service stations, and industrial drying plants, as well as for partitions in office and commercial buildings.

The post-World War II construction industry required mass production of insulation boards to meet American and international demand for this material. In turn, this encouraged continued research and development of rapid production and finishing techniques, including application of paints, lacquer, plastics, and metals to make boards better suited for interior and exterior finishing of houses.

Installation/details

Contractors generally applied insulation boards to the studs in any frame construction on 12 or 16" centers. Then 2 × 4 headers were inserted flush between the wood studs to provide a nailing surface for panel edges. Nails typically were spaced 3" apart and not less than $^3/_8$" from the panel edge. Wood battens often were used to cover the nails at the board edges unless finishing nails or brads were used inconspicuously. Building boards without a factory finish were stained or painted. Insulating board lath also was used when a plaster coat was to be applied as the interior finish.

Insulation board could be installed directly beneath the roofing material or between the structural framing members of the attic floor or both. When used with flat roofs, insulation board was installed over the roof deck and under the roofing; however, in some instances it was installed in the ceiling. When insulation board was used for sound conditioning, a suspended ceiling type of construction was recommended.

Urea Formaldehyde Foam Insulation

Formaldehyde is a naturally occurring substance that is found not only in forests but also as a necessary metabolite in our body cells. Commercially, it is a chemical used widely by industry to manufacture building materials and numerous household products. For example, formaldehyde is released into the air by burning wood, running kerosene space heaters and unvented fuel-burning appliances such as gas stoves, automobile exhaust, and cigarette smoke. Formaldehyde also can off-gas from some building materials when it is used in the production process. These include the glue or adhesive in pressed-wood products (particleboard, hardwood plywood, and fiberboard); preservatives in some paints, coatings, and cosmetics; and the coating that provides permanent press-quality to fabrics and draperies.[9]

High levels of formaldehyde can be an irritant or even a health concern as well. When formaldehyde gas is present in the air at levels above 0.1 ppm, it can cause watery eyes; burning sensations in the eyes, nose, and throat; nausea; coughing; chest tightness; wheezing; skin rashes; and allergic reactions. It also has been observed to cause cancer in scientific studies using laboratory animals and may cause cancer in humans. Studies indicate that any risk of causing cancer is believed to be small at the level at which humans typically are exposed.[10]

Urea formaldehyde foam insulation (UFFI) is a low-density foam prepared at the construction site. It is produced from a mixture of urea formaldehyde resin, an acidic foaming agent solution, and a propellant, usually compressed air. This highly expandable foam-in-place insulation is machine-mixed and pumped through a tube, where it expands to fill a cavity. Until it hardens, it looks and feels like shaving cream. It is usually white or cream colored, although it may be tinted blue. After curing, UFFI looks and feels like dried-up shaving cream, resembling a crumbly structure with a powdery residue. A positive identification can only be made through laboratory testing.

This method of onsite preparation is potentially dangerous because the chemicals are not always combined in the right proportions. In many homes the foam ingredients were improperly mixed, which resulted in excessive formaldehyde gas being released in the house. If too much formaldehyde was used, gas would seep into the home. Some formaldehyde gas also is released during the onsite mixing and curing, which mandates adequate ventilation for the installer. Although formaldehyde is colorless, it has a very strong odor, which generally can be detected at concentrations above 1 ppm. It is this by-product of the curing of the foam that has become a controversial issue.

History

UFFI was first used in Europe but quickly became popular in Canada in the 1970s. The insulation was used most extensively from 1975 to 1978, during the period of the Canadian Home Insulation Program (CHIP), when financial incentives were offered by the government to upgrade home insulation levels. Although more than 100,000 Canadian homes were insulated with UFFI during this time, health complaints started from the occupants of UFFI-insulated homes around 1978.[11] Although the Canadian Mortgage and Housing Corporation (CMHC) gave UFFI preliminary acceptance, provided that certain criteria were met, in 1977, it was found in 1979 that formaldehyde caused cancer in laboratory rats. UFFI subsequently was banned across Canada on December 17, 1980.[11] On June 15, 1981, a government removal assistance program for homeowners was announced that ran until September 1986.

Similar action was taken in the United States. By 1979, the Consumer Product Safety Commission (CPSC) had received several hundred complaints, the majority from Massachusetts homeowners. (It is believed that about 10,000 homes in Massachusetts also were insulated with UFFI.[12]) In February 1982, the CPSC ordered a ban on all sales of UFFI for homes and schools. The CPSC ruled that because formaldehyde gas often is released from the foam after installation, UFFI presents an "unreasonable health risk." In April 1983, however, a federal appellate court struck down this ban. The court ruled that there was not sufficient scientific evidence to justify the ban. Litigation in Canada yielded similar results. After the longest and most expensive civil case ever held in Canada, lasting 8 years and concluded in the Quebec Superior Court, not only was there no basis for a settlement found, but the plaintiffs also were obliged to pay for most of the costs.[13]

In 1985, Massachusetts enacted legislation that required sellers to disclose if UFFI had ever been installed at a property. Still in effect today, the seller has to provide the lending institution with a form disclosing any knowledge of the insulation's presence.[14]

Since the sale of urea formaldehyde foam insulation has largely stopped, the CPSC has modified the warnings against UFFI. The CPSC still believes that the evidence shows that risks are associated with UFFI; CPSC officials now advise consumers to leave insulation alone if they have not experienced any health problems.[15] In a 1990 technical document, the CPSC stated that formaldehyde released from UFFI decreases rapidly after the first few months and reaches background levels in a few years. Therefore, urea-formaldehyde foam insulation installed 5 to 10 years ago is unlikely to still release formaldehyde.[10]

History now shows that even though the U.S. Court of Appeals struck down the law because there was no substantial evidence clearly linking UFFI to health complaints, the marketability of UFFI already had been destroyed.[13] Even today, in many states, real estate agents must inform prospective buyers if a house contains UFFI. Whether it is a problem in a particular house or not, it is going to be viewed as a liability.[16] UFFI is still used in Europe, where it was never banned and is considered by some as one of the better retrofit insulations.

Product identification

As mentioned earlier, UFFI is usually white, cream colored, or has a bluish tint. Resembling dried-up shaving cream, it has a crumbly structure and a powdery residue. If UFFI is suspected in a dwelling, more extensive testing should be undertaken by an environmental specialist. If the gases are below the prescribed levels of 0.1 ppm, no further remedial action is necessary. Formaldehyde gas levels typically decline rapidly to below this level after the first year. Since UFFI generally was installed years ago, any vapors from the insulation would be negligible.

Installation

Many of the problems eventually caused by UFFI were due to faulty installation. This was due in large part to the fact that the installed product could not effectively be standardized because it was prepared on site. Even though the foam's ingredients may have been of the highest quality, the composition of the installed material was largely dependent on the skill of the installer.

UFFI was installed by using a pumpset and hoses with a mixing gun to mix the foaming agent and the resin. Installed under air pressure up to 100 lb/in^2, UFFI was injected through $^1/_2$ to 2" holes in mortar joints, gypsum wallboard, wood siding, aluminum siding, concrete blocks, etc. UFFI was particularly suitable for use in cavities of existing buildings because it foamed to full dimension before injection into the cavity. The danger of expanding foam thereby was eliminated. Shrinkage of UFFI was common, usually between 1 and 3 percent. Canadian sources state that almost all types of construction had UFFI installed during the 1970s. UFFI was used in attics, common walls of row houses or semidetached homes, office walls, apartment buildings, condominiums, and garage ceilings where rooms are over garages. Applications also included sound insulation as well as air sealant in commercial and industrial structures.[17]

Once again, UFFI insulation should not be confused with other foam insulations that are often installed by homeowners as a sealant around windows, doors, and foundation sills. These foams, usually urethane from aerosol cans, harden to tough, plastic materials, whereas UFFI sets to a friable material that turns to dust when touched.

Health considerations

Formaldehyde is currently considered by OSHA and the National Institute for Occupational Safety and Health (NIOSH) to be a category 1 potential occupational carcinogen, which means that formaldehyde potentially may cause cancer in humans. No federal standard has been set for formaldehyde; however, OSHA now regulates formaldehyde as a carcinogen. OSHA has adopted a permissible exposure level (PEL) of 0.75 ppm and an action level of 0.5 ppm. OSHA also requires labeling informing exposed workers about the presence of formaldehyde in products entering workplaces that can cause levels to exceed 0.1 ppm. Some states have established a standard of 0.4 ppm in their codes for residences; others have established much lower recommendations (e.g., the California guideline is 0.05 ppm). Based on current information, it is advisable to mitigate formaldehyde that is present at levels higher than 0.1 ppm.[18]

Formaldehyde is normally present at low levels, usually less than 0.03 ppm, in both outdoor and indoor air. (This number will vary because the outdoor air in rural areas has lower concentrations, whereas urban areas have higher concentrations.) By comparison, typical levels in the smoking section of a cafeteria are 0.16 ppm.[13] Products such as carpets or gypsum board do not contain significant amounts of formaldehyde when new, but they may trap formaldehyde emitted from other sources and later release the formaldehyde into the indoor air when the temperature and humidity change.

Residences or offices that contain products that release formaldehyde to the air can have formaldehyde levels of greater than 0.03 ppm. Products that may add formaldehyde to the air include particleboard used as flooring underlayment, shelving, furniture, and cabinets; MDF in cabinets and furniture; hardwood plywood wall panels; and urea-formaldehyde foam used as insulation. As formaldehyde levels increase, illness or discomfort is more likely to occur and may be more serious.[10]

A number of studies have been done examining the health effects of UFFI. In a study in Britain, people who worked in environments with high formaldehyde levels, such as morticians and laboratory technicians, were studied for possible health effects. These subjects were found to have a less-than-average number of respiratory diseases and actually lived slightly longer, on average. Studies using a random sampling of UFFI and non-UFFI homes, done before the ban, showed no impact of UFFI on health. However, studies done after the ban showed increased reporting of symptoms, even for such things as constipation and deafness, which have no biologic basis.[13]

As mentioned earlier, formaldehyde emissions from building materials decrease as the materials age, particularly over the first 2 or 3 years. Older urea-formaldehyde building materials most probably will not be a significant source of formaldehyde emissions. If the presence of formaldehyde is suspected, a qualified building inspector should be hired to examine the home for the presence of formaldehyde-emitting materials. In addition, home monitoring kits are currently available for testing formaldehyde levels in the home. Be sure that the testing device will monitor for a minimum of 24 hours to ensure that the sampling period is truly representative.[18] Inexpensive passive samplers, which usually run for several days, and detector tubes also have been developed, whereas the more accurate method of collecting formaldehyde is by impingers. Technically known as the *chromatropic acid test,* it usually takes about 90 minutes. Testing should be performed when the relative humidity is over 50 percent and the temperature is above 70°F.[19]

Conclusion

UFFI has been referred to as the most thoroughly investigated and most innocuous building product in Canada. Whether this is true or not, it has certainly gained notoriety for all the wrong reasons. Its virtual elimination from the marketplace also may prove to have been for “the wrong reason”; however, when it comes to a question of personal health, few homeowners are willing, or should be forced, to take unnecessary risks.

Appendix

For further information on asbestos and UFFI, contact

U.S. Consumer Product Safety Commission
Washington, DC 20207
800-638-2772
http://www.cpsc.gov

The regional offices of the EPA are perhaps the best sources of additional information about environmental hazards in specific states and local areas. Each EPA regional office has information on states and areas within a single geographic area.

U.S. Environmental Protection Agency
Public Information Center
401 M Street, SW
Washington, DC 20460
202-475-7751

EPA Region 1 (Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, and Vermont)
John F. Kennedy Federal Building
Room 2203
Boston, MA 02203
617-565-3715

EPA Region 2 (New Jersey, New York, Puerto Rico, and the Virgin Islands)
26 Federal Plaza
New York, NY 10278
212-264-2515

EPA Region 3 (Delaware, Maryland, Pennsylvania, Virginia, Washington, D.C., and West Virginia)
841 Chestnut Street
Philadelphia, PA 19107
800-438-2474

EPA Region 4 (Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina, and Tennessee)
345 Courtland Street, NE
Atlanta, GA 30365
800-282-0239 in Georgia
800-241-1754 in other Region 4 states

EPA Region 5 (Illinois, Indiana, Michigan, Minnesota, Ohio, and Wisconsin)
230 South Dearborn Street
Chicago, IL 60604
800-572-2515 in Illinois
800-621-8431 in other Region 5 states

EPA Region 6 (Arkansas, Louisiana, New Mexico, Oklahoma, and Texas)
1445 Ross Avenue
Suite 1200
Dallas, TX 75202
214-655-2200

EPA Region 7 (Iowa, Kansas, Missouri, and Nebraska)
726 Minnesota Avenue
Kansas City, KS 66101
913-236-2803

EPA Region 8 (Colorado, Montana, North Dakota, South Dakota, Utah, and Wyoming)
999 18th Street
Suite 500
Denver, CO 80202
800-759-4372

EPA Region 9 (Arizona, California, Hawaii, and Nevada)
215 Fremont Street
San Francisco, CA 94105
415-974-8076

EPA Region 10 (Alaska, Idaho, Oregon, and Washington)
1200 Sixth Avenue
Seattle, WA 98101
206-442-5810

J. May Home Inspections, Inc.
1522 Cambridge St
Cambridge MA 02139
617-354-0152
Fax: 617-354-0749
E-mail: *jmhi@shell.cybercom.net*

NCI Public Inquiries Office
Cancer Information Service
Building, 31, Room 10A03
31 Center Drive, MSC 2580
Bethesda, MD 20892-2580
301-435-3848

Laboratory Accreditation Administration
NIST
Gaithersburg, MD 20899
301-975-4016

Restoration Environmental Contractors (REC)
Don Bremner
Vice President of Operations and Project Manager
Box 746
10 Stalwart Industrial Drive, Unit 5
Gormley, Ontario, Canada
L0H 1G0
800-894-4924
http://www.environmentalhazards.com/contact/index.htm

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Chapter

17

Future Insulation Products and Technologies

Advances are being made in the development of technologically superior insulation products. Some of these products include aerogels, powder-filled panels, evacuated panels, vacuum insulation panels, and phase-change materials. Not only are these technologies a significant departure from thermal mass–type materials, they are generally thinner, lighter, and possess much higher R-values than common insulation materials available today.

Aerogels

Aerogels have great potential in a wide range of applications that include energy-efficient insulation and windows, acoustics, gas-phase catalysis, battery technology, and microelectronics. Besides being the best thermal, electrical, and acoustic insulators known, aerogels are finding application as filters for seawater desalination, micrometeoroid collectors, and subatomic particle detectors. In the future, aerogels could be used in windows, building insulation, automobile catalytic converters, and high-efficiency battery electrodes.

Aerogels, on a per-weight basis, may be the strongest, lightest, and most transparent building material ever produced. Aerogels are one of the few existing materials that are both transparent and porous. Typically produced from silicon or carbon, aerogels are solid with a porous, spongelike structure in which 99 percent of the volume is empty space. Weighing as little as three times as much as air, a single 1"-thick piece of this silica-based material has the internal surface area of a basketball court.[1] It can be formed into almost any useful shape and makes an excellent insulator.[2]

Most important are the thermal dissipation properties possessed by aerogels. For example, a piece of chocolate resting on a cracker-sized aerogel disk will not melt when torched by a blue flame 1 cm beneath the disk.[2] In more relative terms, 1" of a type of aerogel in a vacuum offers insulation equivalent to 10" of fiberglass.[3]

History

Aerogels were first discovered in 1931 by physicist Steven S. Kistler of the College of the Pacific, in Stockton, California. He proved experimentally that liquid-based gels (or jellies) were an open solid network of cells permeated by liquid. Kistler stated, "…if one wishes to produce an aerogel, one must replace the liquid with air by some means in which the surface of the liquid is never permitted to recede within the gel. If a liquid is held under pressure always greater than the vapor pressure, and the temperature is raised, it will be transformed at the critical temperature into a gas without two phases having been present at any time."[4]

Kistler made the first aerogel by soaking a water-based gel in alcohol to replace the water. Then he heated the alcohol and gel in a closed container to a high temperature and pressure and slowly depressurized the vessel. This allowed the alcohol, now a vapor, to escape, leaving an air-filled cellular matrix.[2]

Aerogel research was largely abandoned until the 1980s when, using new chemicals, it was produced for elementary particle detectors. Soon after this, a new, safer method of production was developed under the leadership of Arlon J. Hunt at the Lawrence Berkeley Laboratory, leading to identification of applications for aerogels as insulators and later as cosmic dust collectors on two space missions.[5] Aerogels also were used for insulation on the Mars rover *Pathfinder*.

Product description

Aerogel starts out as a delicate three-dimensional framework of clusters of molecules linked together in a liquid medium. The liquid helps support the framework and holds the clusters in place. The linked clusters create a springy molecular mesh containing thousands of open pores filled with fluid, similar to a wet sponge.

To create aerogel, the liquid must be removed carefully from the mesh. Under normal conditions, capillary pressures generated by evaporation of the liquid cause the framework to collapse on itself. As the gel's interior walls squeeze together, reactive molecules permanently bond, leaving a compressed semiporous gel that is a fraction of its original volume.

Silica aerogel is the best known and most widely prepared aerogel. A simplified silica aerogel recipe, according to the Aerogel Research Laboratory at the University of Virginia, begins by combining a silica-based solution with 200-proof ethanol, ammonium hydroxide, and water, which form a Jello-like substance called *alcogel*. The alcogel is then soaked in ethanol for a length of time sufficient to extract the water from the alcogel. Once most of the water has been replaced by alcohol, the alcogel is ready to be supercritically dried, a process that removes liquid from the microstructure of the alcogel. The alcogel is placed in a pressure chamber that is filled with carbon dioxide. When the CO_2 replaces the alcohol, the chamber is heated and pressurized in a supercritical drying process. When it returns to room temperature and standard pressure, the process is finished, and an aerogel is the result.[5]

A typical aerogel is a solid foam consisting of 5 percent silica (SiO_2 or common sand) and 95 percent air-filled pores. Both the pores and their properties are smaller than the wavelength of light (less than 100 billionths of a meter).[5] The silica particles are 2 to 5 nm in diameter; the pores are about 20 nm wide. The unique microstructure of aerogels—nanometer-sized cells, pores, and particles—means low thermal conduction. Some silica aerogels contain as little as 0.13 percent silica, with the remainder (99.87 percent) being air.[6]

The optical properties of silica aerogels are best described as "transparent" and thus are considered most likely for window or skylight applications. This may seem obvious, since silica aerogels are made of the same material as glass but do have the same optical characteristics. While distant objects can be viewed through several centimeters of silica aerogel, the material displays a slight bluish haze when an illuminated piece is viewed against a dark background and slightly reddens transmitted light.[7] This blue color arises from the presence of large pores formed during the gellation, and the hypothesis currently being tested by the most recent NASA experiments centers on whether a more uniform and therefore transparent gel can be made in space. Since aerogel has the equivalent thermal insulating quality of 10 to 20 glass window panes, the energy-conserving effects of an aerogel window replacement would significantly lower heating bills, particularly in northern climates.[1]

The transfer of thermal conduction through the solid portion of the aerogel is limited by the small connections between the particles making up the conduction path. Gaseous conduction is limited because the cells/pores are only the size of the mean free path for molecular collisions—molecules collide with the solid network as frequently as they collide with each other. Radiative conduction is low because aerogels have small mass fractions and large surface areas—although conductivity increases with temperature.[8]

Aerogels in a partial vacuum are even better insulators because removing most of the air from their pores eliminates half to two-thirds of the material's thermal conductivity (the portion due to gas conduction). Silica aerogel in a 90 percent vacuum, which is simply and inexpensively produced, has a thermal resistance of R-20 per inch. Thus a 1-in-thick aerogel window has the same thermal resistance as a window with 10 double panes of glass. LBNL researchers have improved the performance to R-32 per inch by adding carbon to absorb infrared radiation in the material, another mechanism of heat transfer.[2]

Carbon aerogels are a variation of the extremely lightweight silica aerogels. Carbon aerogel is made by heating polymeric aerogel in a vacuum or inert gas (otherwise, it will oxidize or burn). Carbon aerogel is also a good insulator but is very black, so it must be used in applications where transparency is not needed. Stiffer and stronger than silica aerogels, carbon aerogels are electrically conductive. Advanced, thin-film carbon aerogel electrodes were developed at Lawrence Livermore National Laboratory (LLNL) in 1993, patented in 1995, and are now being produced commercially.[9] Carbon aerogels have just recently been synthesized and represent the first electrically conductive aerogel. This property, in combination with high surface area, controllable pore size, and high purity, is leading to new electrochemical applications for these unique materials.

Organic aerogels are stiffer and stronger than silica aerogels and are measurably better insulators. They have extremely high thermal resistance—six times more resistance than fiberglass insulation. Two organic aerogels developed at LLNL have equivalent R-values of R-12 when air-filled (equivalent to the insulating capacity of 6" of fiberglass batting) and greater than R-38 when evacuated (equivalent to 19" of fiberglass). Organic aerogels can be converted to pure carbon aerogels and still retain many properties of the original aerogel, in addition to becoming electrically conductive.[10]

Polymeric aerogels can be transparent or deeply colored. The resorcinol aerogels are the second most widely produced aerogels and are deep red to brown in color and somewhat stronger than silica aerogels. Melamed aerogels have been made flexible and mostly transparent but have not been studied extensively and may not withstand a vacuum to get maximum thermal performance. Scientists have produced various other aerogels from metal oxides, e.g., alumina, titania, mixed alumina and silica, etc., but they are generally only made in very small sizes, e.g., centimeter samples, and tend to be fragile or have other manufacturing difficulties.[11]

Cost

Cost for the products currently runs high because the demand is low. One source states that aerogels are five times more expensive than polyurethane foam.[12] One aerogel manufacturer produces a half-inch sheet of flexible aerogel blanket, not much bigger than a breadboard, that currently costs approximately $900. Short-term prices have been predicted to drop to approximately $35 per square foot, whereas long-term predictions drop the price of aerogel blankets to as low as $10 per square foot. The same is said to be true for the aerogel powder. One cubic foot of silica aerogel powder, available now for $2300, will fall to $60 once demand pushes production to 50,000 ft^3 per year.[5] The cost of carbon aerogels also should drop significantly as more manufacturing licensees are developed.[9]

Vacuum Insulation Panels

Vacuum insulation technology focuses on the basic physical principle that heat cannot be conducted in the absence of air. It is the absence of molecules to pass heat through a given distance that also makes a vacuum a good insulator. Known as the *Dewar principle,* vacuum insulation is best demonstrated by the glass vacuum bottle, also known as the common Thermos bottle, which has been used to transport and maintain hot or cold liquids for years. In a Dewar's flask, no insulation "material" is used because the space between the dual walls of the cylinder is completely (99.999999 percent) evacuated. This creates an extremely high R-value, typically R-250 or higher, since there are no molecules of gas available to transport heat between the two walls.[13]

There are obvious physical limitations of the Dewar's flask serving as practical insulation for residential applications. Additionally, since even a few molecules of gas will destroy its insulation value, the cylinder walls must be absolutely impermeable to gas and moisture. This limits the wall material to either specially treated glass or metal, both of which have a tendency to conduct significant amounts of heat at areas where the walls are joined together. Recent technological advances in materials and manufacturing processes have created a growing commercial market for these tough, flexible, and versatile products. Vacuum insulation now encompasses a wide range of filler materials clad in various types of gas-barrier exteriors. Uses include insulated shipping containers for distribution of food, pharmaceutical, and biomedical products; insulation panels in refrigerators, coolers, and packaging to allow mailing refrigerated items over long distances; insulation for the ceilings of truck and car cabs; and other applications where lightweight, thin, high-performance insulation is valued.

Vacuum insulation panels (VIPs) have been around since the mid-1950s. The principal advantage of VIPs over competing products such as polyurethane (closed-cell), expanded polystyrene, and fiberglass is their high R-value per inch of thickness. VIPs are three to seven times more effective than competing products. Depending on the core material, VIPs are also referred to as *powder evacuated panels* (PEPs) or simply *evacuated panels*.

Product description

As VIP researchers continue to explore new innovations, the composition of VIPs is likely to change. At present, the simplest construction of a VIP consists of the exterior walls that contain the vacuum and filler materials inside. Also known as the *membrane film,* the wall provides a barrier against atmospheric gases and moisture so that the vacuum can be maintained. Impermeable membrane materials can be glass, metal or metal foil, plastic, or a composite such as polymeric exteriors (film or sheet) with or without metallized surfaces.

For building construction applications, glass may be too fragile. Simple metal barriers can be used, but these significantly reduce the average insulation value of the finished panel owing to the conductance of heat around the edges where the walls are joined (also called the *edge effect*). Another disadvantage of a pure metal membrane is the high cost of forming and welding the panel.

In some barriers, a very thin metal film, such as aluminum, is reinforced by laminating a plastic film on each side. A special plastic with a low melting temperature is then added so as to allow the finished laminate to be “heat sealed” rather than welded. In an effort to reduce the edge effect even further, some films use a sputter-coated thin-film deposition technique to get the metal layer even thinner. When done correctly, these films offer a good compromise between the solid metal films and pure plastic laminates.[13]

The core material serves two major functions. First, it provides physical support to the membrane (or barrier) film envelope so that it does not collapse in on itself when the vacuum is applied. Second, the core material acts to interrupt the flow (free mean path) of the molecules of gas that still remain in the evacuated space, thereby reducing their ability to transfer heat between the walls of the VIP.

A number of core materials are used by different manufacturers. Powders (such as perlite, mineral powder, mineral fiber, fiberglass, silica), rigid open-celled foams (such as polyurethane and microcellular polystyrene foam board), or carbon/silica aerogels are used as fillers. While most of these materials are not very expensive in their raw form, they require considerable handling and preprocessing, which greatly increases the cost of the end-product. Aerogel panels achieve extremely high R-values with less vacuum than would be required with other types of cores.

R-value

Based on the specific combination of barrier material, fillers, and vacuum level, R-values from 16 to 40 per inch can be obtained at room temperature. At lower temperatures, the R-value increases. At −10°F, for example, the R-value is in excess of 35. (One manufacturer has obtained measurements of R-60 at dry-ice temperatures.) The selection of materials to make a panel for a particular application include issues of size, shape, thickness, longevity, ruggedness, ambient temperature, and whether pass-throughs or other design requirements are involved.

Dow Chemical, manufacturer of an open-cell foam material that is vacuum sealed within a metallized film or foil, has stated that its panels have an R-value approximately six times greater than traditional fiberglass insulation. The new product consists of a patented, 1"-thick advanced insulation panel that can produce the same R-value as 6" of fiberglass insulation.[14] Tests also have been conducted by the National Institute of Standards and Technology (NIST) that produced similar results.

Cost

The finished VIP system currently costs from $4.00 to $7.00 per square foot, depending on the density of the core board and other specifications required by the customer. These prices are expected to be reduced to $3.50 to $5.00 per square foot in the very near future. The cost of the core foam board currently ranges from $0.85 to $3.00 per square foot, depending on the density, grade, and manufacturer. Currently, the fabrication process is responsible for a major portion of the cost, but cost is expected to drop with larger volumes and more efficient fabrication.

Installation/details

Residential applications are limited at the present. It is obvious that any mishandling or nail punctures of the relatively fragile metallized envelope during the home construction process can lead to a loss of vacuum and insulating capability of the VIP. For the same reason, it is important during the installation process that any bending of the joined flanges of the barrier envelope surrounding the core panel occur adjacent to, rather than on, the seal. Current trends seem to suggest that it is only a matter of time before more durable products will be available for home construction. Processes are currently in development that apply a polyurethane coating to the panels to provide greater strength, durability, and specification consistency.

Limitations

The life expectancy of a vacuum insulation panel is determined by a number of factors. These include the outgassing (if any) of the core material and membrane film, the permeation rate of the membrane film and sealing edge, the quantity and effectiveness of the getter and desiccant, and the effect of pressure rise on the specific core material.[13] (Getters are used to absorb gases, and desiccants are used to absorb moisture within the evacuated envelope. These processes prevent or delay an elevation of the internal pressure and a degradation in R-value.)

Current VIP systems will not meet minimum insulation requirements as required by the International Energy Conservation Code

(IECC) for wall or roof insulation because of the relatively short life of the vacuum. Various sources suggest that the longest expected life of the VIP in its current form is estimated to be between 10 and 20 years. This is too low for consideration in use as wall or roof insulation, but door or window frame insulation could be a possible use. By combining silica core materials or by using certain combinations of films and getters with newer, less permeable membrane materials, projected life spans of 50+ years can be realistic. Unfortunately, high cost remains a major barrier to wide-scale adaptation of silica-based VIPs.[13]

Gas-Filled Panels

Another advanced insulation product that is under development is *gas-filled panels* (GFPs). This concept uses multiple reflective cells and gas in a sealed panel to retard heat transfer. This technology was developed by the E. O. Lawrence Berkeley National Laboratory in 1989 and should be available commercially in the future.

Product description

GFPs are composed of hermetic plastic bags with a boxlike shape that enclose a honeycomb baffle of thin polymer film and a low-conductivity gas. The panel interior consists of a multilayer baffle that is bonded to both faces of the barrier envelope, which is forced apart by the gas fill. This bonded assembly uses metalized, low-emissivity film, producing a cellular structure within the panel. Moderate levels of performance are obtained with air as the fill gas. The resistance obtained with air is an R-value of 5 per inch. Higher-performance designs use low-diffusion gas barrier films to provide the hermetic barrier, whose purpose is to retain the panel's gas fill, and can take on a variety of shapes and sizes. The best candidate gases to fill GFPs are argon and krypton because both have lower conductivities than air. Argon gas filling provides an effective thermal resistance level of R-7 per inch, krypton gas provides R-12.5 per inch, and xenon gas provides R-20 per inch.[15]

Installation/details

GFPs are basically flexible and self-supporting. Manufacturers could fabricate GFPs in a variety of shapes and sizes to fill most types of cavities in building walls and roofs. For a typical installation of GFPs in a wood-frame wall assembly, panels are fastened to studs with staples through panel flaps. Adhesive-backed tape seals adjacent panels across the stud, so the insulation also becomes an air-barrier/moisture-retarding component. The far face of the panel adheres to the exterior sheathing to provide added air sealing and to keep the panel expanded. Researchers indicate that gas could even be added to unfilled panels on site.[16]

Cost

Since GFPs are not yet being manufactured, researchers provide estimated panel costs for building applications based on current material component costs. For example, an argon-filled, 3.5"-thick (89-mm) panel may cost $0.69 per square foot to manufacture, whereas a 10"-thick (254-mm) panel may cost $1.46 per square foot.[16]

Cost is comparable with that of CFC blown foam insulation for argon-filled GFPs that achieve similar insulation levels. Cost for air-filled GFPs is greater than fiberglass insulation for a given wall thickness, but such GFPs allow attainment of significantly greater R-values for a given wall thickness.

Argon gas may be the best choice based on price. Although krypton-filled panels yield a lower conductivity, the scarcity and high cost of krypton gas ($0.35 per liter) make it better suited for refrigerator insulation than for a building envelope. Xenon yields panels with the lowest conductivity, but its cost ($4.00 per liter) makes it useful only in exotic applications.

Limitations

Testing has been limited as compared with market-established insulation materials. For example, flame-spread and smoke-generation testing needs to be performed. Full-scale wall assembly measurements that better demonstrate thermal performance in actual building installations also need to be performed.[16]

Environmental considerations

Argon-filled GFPs can achieve insulation values similar to those of chlorofluorocarbon (CFC) blown foams, without the use of CFCs. Gas fills are also inert and harmless. Any other environmental effects will depend on the character of the barrier and baffle materials.

Availability

The technology appears to be versatile enough for widespread use in traditional wood-frame construction, although some difficulties need to be overcome for site-built construction to make GFPs fit oddly shaped cavities. Initial uses will likely be in manufactured housing and panelized building systems.[16]

Phase-Change Materials

Phase-change materials (PCMs) are substances that store and release energy by changing phase. Most store energy when they turn liquid at a certain temperature and release energy when they turn solid at a certain temperature; some remain solid but undergo chemical changes that store and release energy. The change of phase occurs during the melting, solidification, or sublimation of the specific material. A PCM has the ability to absorb large amounts of energy when it undergoes a change of phase. During this change of phase, the material remains at nearly a constant temperature. PCM-based devices have been used mainly for electronics cooling, telecommunication systems, and also on U.S. spacecraft, including some shuttle-launched missions.

PCMs now under research and development for commercial building applications can smooth daily fluctuations in room temperature by lowering the peak temperatures resulting from extremes of external daily temperature changes. The main advantage of PCMs for thermal storage is that the mass (and hence volume) required for a given storage capacity is small compared with rocks, concrete, water, or other passive solar materials.

Product description

As mentioned earlier, materials undergoing a phase change by freezing, melting, condensing, or boiling store and release large amounts of heat with small changes in temperature. PCMs allow the thermal storage to become part of the building's structure, permitting substantial energy storage without changing the temperature of the room envelope.[17] PCMs are solid at room temperature, but when temperature becomes warmer, they liquefy and absorb heat. Conversely, when the temperature drops, the material will solidify and give off heat energy. The possible use of PCMs in the building envelope would absorb the heat of higher exterior temperature and retard the heating of the interior, which is equivalent to cooling the house, during the day. As the temperature declines in the evening, the PCMs would warm the home at night as they give off heat.

Phase-change gypsum wallboard

Phase-change gypsum wallboard is one example of a building-integrated heat storage material. PCMs are incorporated into the gypsum wallboard panels to moderate the thermal environment within the building. The function of the PCM gypsum wallboard is very basic. As the air temperature in a room rises, so does the temperature of the wall. As the wall temperature climbs above the PCM's transition temperature (the point at which the material changes phase), the PCM absorbs heat and melts inside the gypsum wallboard. As the room temperature decreases, the PCM releases heat and returns to a solid again. A less costly and less bulky replacement of the standard thermal mass (e.g., masonry or water) used in solar heating, it is at the present only produced for research.

Researchers believe phase-change gypsum wallboard can shift much of the summer air-conditioning load to later time periods, allowing customers to take advantage of cool night air and off-peak utility rates. The household temperatures remain relatively stable until all the PCM melts. In the winter, warming the PCMs from a conventional furnace could reduce furnace cycling and increase efficiency. Computer simulations show that PCM-treated wallboard can eliminate the need for air conditioners in mild climate zones, such as portions of California. This means that such residences will cost less to cool and possibly eliminate the cost of installing air conditioners. PCM gypsum wallboard also has an advantage over conventional thermal mass in solar heating applications. Because the exposed surface is so large and the PCM absorbs heat over a narrow temperature range, the gypsum wallboard need not receive direct sunlight. PCM gypsum wallboard has a much greater heat-storage capacity than does conventional thermal mass and provides excellent heat transfer. It demands no extra structural support, and any added installation cost is minimal.[18]

Researchers suggest that there are several important considerations relevant to combining PCM into gypsum wallboard. First, the transition temperature, or melting temperature, of the PCM must be near standard or suggested room temperatures. These would be 65 to 72°F for heating-dominated climates or 72 to 79°F for cooling-dominated climates. Because the PCM uses the exchange of heat energy from its environment to drive the phase change, this change of state from solid to liquid or liquid to solid characteristically occurs within a temperature range of only a few degrees. Second, the PCM product must be effective, offering good heat transfer, and be economical. Claims are that the PCM wallboard under development could save up to 20 percent of house space-conditioning costs.[17]

Paraffins, or waxes, may be the best choice for the PCM in gypsum wallboard. They are readily available, inexpensive, and melt at different temperatures relating to their carbon chain length. At present, paraffin is incorporated into gypsum wallboard in two ways, either by direct immersion or by permeated plastic pellets that are added to the gypsum wallboard mixture during the manufacturing process.[18]

Immersion is the simplest, lowest-cost method for making PCM gypsum wallboard. Although gypsum wallboard dipped in paraffin becomes water-resistant, PCM gypsum wallboard is quite flammable unless treated with fire-retardant chemicals. (This process is not recommended for do-it-yourselfers.) Polyethylene pellets, saturated with melted paraffin and then mixed with wet gypsum and compressed in sheet form, also yield production-quality gypsum wallboard. Compared with immersed gypsum wallboard, this material is more fire-resistant, less water-resistant, and conforms to the current gypsum wallboard manufacturing process. Both versions work well for heat transfer and storage, and the paraffin remains permanently in the gypsum wallboard.[18]

Other methods and PCMs are currently being studied, such as fatty acids, which come from meat by-products and vegetables. Cheap, renewable, and readily available different types of fatty acids also have different melting points. Fatty acids are also incorporated into the gypsum wallboard by immersion or encapsulation and yield the same heat and stability characteristics as paraffin-based PCM wallboard.[18]

A fundamental problem in the development of phase-change storage is that the range of temperatures over which some of the materials change phase can be quite narrow or may be a single ideal temperature, limiting the material's use in climates where both heating and cooling are important. Researchers must resolve some issues and provide documentation before commercialization can proceed. Issues relate to proof of fire safety, perceived comfort factor, and economic payback from energy savings. With regard to PCM gypsum wallboard, the correct transition temperature for one region will not be appropriate for another. Gypsum wallboard manufacturers may be reluctant to complicate their manufacturing processes in order to take these regional variations into account.

The extended storage capacity of PCM-treated double gypsum wallboard (two sheets of gypsum wallboard attached together) can keep room temperatures close to the upper comfort limits without mechanical cooling. In climates with large diurnal temperature swings, night-time ventilation can be used to discharge the latent storage of the wallboard.[17]

Phase-change attic insulation

A private company, with the help of the U.S. Department of Energy's (DOE's) Oak Ridge National Laboratory, has developed another building envelope application. It has tested an attic insulation that absorbs heat in the daytime and then releases it at night. Called RCR, the PCM consists of perlite embedded with hydrogenated calcium chloride. This PCM changes phase from solid to liquid at 82°F, absorbing heat from the hot attic during the day, before it can penetrate the home. When attic temperatures cool at night, the PCM solidifies and releases heat back into the attic, moderating outdoor temperatures. The PCM attic insulation would be hermetically sealed for installation between two layers of certain insulation materials such as extruded polystyrene, urethane, or cellulose.[17]

A computer model of the laboratory tests of the attic PCM insulation showed that it reduced the total heat flow by 22 percent, and the peak heat flow was 42 percent lower than with an equal thickness of fiberglass insulation. It reduced the air-conditioning load by 40 percent and shifted the peak load up to 8 hours, depending on the climate. PCM insulation may be most effective in climates that have sharp variations between day and night temperatures.[17]

Plastic Fiber Insulation

According to the DOE, another new type of insulation entering the residential marketplace is plastic fiber insulation. Plastic fiber batts are made from recycled polyethylene terephthalate (PET), commonly used to make milk containers known under the trademark name, Mylar. PET-covered insulation products have been used extensively in the aviation industry. Residential products have thick fibers, making extremely soft batt insulation that looks like high-density fiberglass. R-values vary with batt density:

3.8 per inch at 1.0 lb/ft^3 density

4.3 per inch at 3.0 lb/ft^3 density

The recycled content and clean manufacturing process help make this polyester insulation material a good addition to the market. The insulation also does not irritate the skin. It does not burn when exposed to an open flame, but it melts at a low temperature—a definite disadvantage. The batts are also difficult to cut with standard job-site tools, and the insulation tends to accordion when handled. Major U.S. insulation manufacturers are expected to produce plastic fiber insulation products within the next few years.[18]

Appendix

Energy Efficiency and Renewable Energy Clearinghouse (EREC)
P.O. Box 3048
Merrifield, VA 22116
800-DOE-EREC
E-mail: *doe.erec@nciinc.com*
http://www.eren.doe.gov/consumerinfo/refbriefs/db3.html

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Compressed Air Magazine
253 E. Washington Ave.
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Fax: 908-689-5580
http://www.ingersoll-rand.com/compair/julyaug96/aero.htm

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E-mail: *vacupanel@erinet.com*
http://www.vacupanel.com/

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Appendix

A

Miscellaneous Figures and Tables

Chapter #	Method of Installation	Type	R-value per inch	Approximate Cost (Contractor installed)
4	Vapr and Air Retarders	Polyethylene Vapor Retarder	N/A	4 mil; $0.10 per square foot
		Polyethylene Vapor Retarder	N/A	6 mil; $0.10 per square foot
		Asphalt Felt, 15 #	N/A	$0.10 per square foot
		Polypropylene Housewrap	N/A	$0.18 per square foot
7	Loose- Fill (Pour or Blown)	Cellulose	3.2 - 3.8	$1.81 per cubic foot
		Expanded Polystyrene	4.0	$3.20 per cubic foot
		Fiber glass	2.2 - 4.0	$1.63 per cubic foot
		Perlite	2.7	$2.91 per cubic foot
		Rock Wool	2.5 - 3.1	$1.64 per cubic foot
		Vermiculite	2.1 - 3.0	$ 2.91 per cubic foot
		Sawdust	2.2	N/A
		Slag Wool	2.2 - 3.0	$1.64 per cubic foot
8	Blankets: Batts or Rolls	Cotton	3.0 - 4.3	
		Fiber glass	3.0-3.8	3 1/2" thick, Kraft faced, $0.37 per square foot
				5 1/2" thick, unfaced., $0.51 per square foot
		Rock Wool	3.0-3.7	3 1/2" thick, Kraft faced, $0.40 per square foot
		Plastic Fiber	3.8 - 4.3	

Figure A.1 Quick reference insulation chart. (*R.S. Means Residential Cost Data-1999*)

Chapter #	Method of Installation	Type	R-value per Inch	Approximate Cost (Contractor Installed)
9	Sprayed-in-Place	Air Krete	3.9	
		BIBS (Blow-in-Blanket System)	4.0	
		DS Fiber Glass	4.0 - 4.27	
		Wet spray Cellulose	3.5 - 3.8	
		Wet spray Rock Wool	4.1	
10	Foamed-in-Place	Air Krete	3.9	
		Icynene	3.6 - 4.0	
		Closed Cell Phenolic	8.0	
		Open cell Phenolic	4.4	
		Polyisocyanurate	5.8 - 6.2	
		Polyurethane	5.8 - 6.2	
		Open cell Polyurethane	3.6 - 3.8	
		Tripolymer	4.6	
		UFFI	4.2	

Figure A.2 Quick reference insulation chart. (*R.S. Means Residential Cost Data-1999*)

Chapter #	Method of Installation	Type	R-value per inch	Approximate Cost (Contractor installed)
11	Rigid Board	Cellular Glass	2.63	
		Expanded Polystyrene (EPS)	3.6 - 4.4	$0.49 per square foot, 1" thick board
		Extruded Polystyrene (XPS)	5.0	$0.67 per square foot, 1" thick board
		Polyurethane Foam	5.6	
		Polyisocyanurate Board Foil faced	7.0 -8.0	$0.70 per square foot, 1" thick board
		Polyisocyanurate Board- Un-faced	5.6-6.2	
		Fiber glass	3.5 - 4.4	$0.51 per square foot, 1" thick board
		Fiberboard Sheathing Blackboard	2.6	
		Phenolic Foam	8.3	
		Cane Fiberboard	2.5	
		Perlite	2.8	$0.61 per square foot, 1" thick board
12	Radiant Barriersand Reflective Insulation Systems	Foil faced polyethylene bubbles		$0.46 per square foot
		Foil faced cardboard		
		Foil faced plastic film		$0.29 per square foot

Figure A.3 Quick reference insulation chart. (*R.S. Means Residential Cost Data-1999*)

EPA's Recommended Recovered Materials Content Levels for Building Insulation[1]

Product	Material	Postconsumer Content (%)	Total Recovered Materials Content (%)
Rock Wool	Slag	--	75
Fiberglass	Glass Cullet	--	20-25
Cellulose Loose-Fill and Spray-On	Postconsumer Paper	75	75
Perlite Composite Board	Postconsumer Paper	23	23
Plastic Rigid Foam, Polyisocyanurate/ Polyurethane:			
Rigid Foam	--	--	9
Foam-in-Place	--	--	5
Glass Fiber Reinforced	--	--	6
Phenolic Rigid Foam	--	--	5
Plastic, Non-Woven Batt	Recovered and/or Postconsumer Plastics	--	100

[1]The recommended recovered materials content levels are based on the weight (not volume) of materials in the insulating core only.

Figure A.4 Material content recovered or diverted from solid waste. (*EPA*)

Permeability of Materials to Water Vapor (Perms)

Material	Perms
Vapor Retarders	
Aluminum foil, 1 -mil	0.0
Polyethylene plastic film. 4-mil	0.08
Polyethylene plastic film. 6-mil	0.06
Kraft and asphalt building paper	0.3
Two coats of aluminum paint (in varnish) on wood	0.3- 0.5
Two coats exterior	0.9
Three coats latex	5.5- 11.0
Common building materials	
Housewrap type air retarder	
Expanded polyurethane, 1"	1.5- 5.0
Extruded polystyrene, 1"	1.1- 1.6
Polyisocyanurate	2-3
Tar felt building paper, 15-lb.	4.0
Insulation board, uncoated, 1/2"	50.0- 90.0
3-ply exterior plywood, 1/4"	0.7
3-ply interior plywood, 1/4"	1.9
Gypsum Wallboard, 3/8"	50
Brick masonry, 4"	0.8
Plaster, ¾"	15.0
Poured concrete wall, 4"	0.8
Glazed tile masonry, 4"	0.12
Concrete block, 8"	2.4

Figure A.5 Permeability of materials to water vapor.

Emissivity of Building Materials

Material	Emissivity
Anodize Black Coating	0.88
Carbon Black Paint NS-7	0.88
3M Black Velvet Paint	0.91
Catalac White Paint	0.90
Sherwin Williams White Paint	0.87
Brilliant Aluminum Paint	0.31
Epoxy Aluminum Paint	0.81
Finch Aluminum Paint	0.23
Anodized Aluminum	
Black	0.82
Blue	0.87
Brown	0.86
Clear	0.76
Green	0.88
Gold	0.82
Plain	0.04
Blue Anodized Titanium Foil	0.13
Aluminum	
Highly Polished	0.039-0.057
Commercial Sheet	0.09
Heavily Oxidized	0.20-0.31
Surface Roofing	0.216
3M Aluminum Foil	0.03
Brass	
Highly Polished	0.028-0.037
Dull Plate	0.22
Buffed Copper	0.03
Constantan-Metal Strip	0.09
Buffed Aluminum	0.03
Polished Copper	0.023
Thick Oxide Layer Copper	0.78
Steel, Polished	0.066
Stainless Steel	
Polished	0.11
Machined	0.14
Sandblasted	0.38
Boom-Polished	0.10
Vapor Deposited Coatings	
Aluminum	0.02
Aluminum on Fiberglass	0.07
Aluminum on Stainless Steel	0.02

Figure A.6 Emissivity of building materials.

Identifying Old Insulation

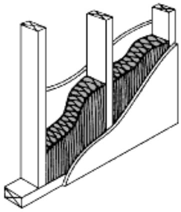
Material	Description	R-Value per inch
Asbestos	Mixed with other insulation materials; requires testing	1
Fiberglass blanket	Pink, yellow, or white	3.2
Loose-fill cellulose	Shredded newspaper, gray, "dusty"	3.5
Loose-fill fiberglass	Pink, yellow, or white loose fibrous material	2.2
Loose-fill rockwool	Denser than fiberglass, "wooly", usually grey with black specks (some newer products are usually white)	2.9
Perlite	White or yellow granules	2.7
UFFI	Whitish grey or yellow, very brittle foam	4
Vermiculite	Gray or brown granules	2.2
Wood products	Sawdust, redwood bark, balsa wood	1

Note: R-values are for old insulation only. They take into account settling as well as r-values for old materials that may have changed with new products.

Figure A.7 Identifying old insulation. *(Home Energy Magazine)*

2 x 4 Wood Stud Partition

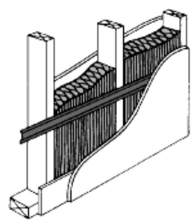
2 x 4 wood studs 16″ o.c.
CertainTeed 3½″ (R-15) Fiber Glass Batts
½″ regular gypsum wallboard



STC 39
Fire Rating 1 hr.

2 x 4 Wood Stud Resilient Channel Partition

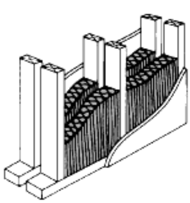
2 x 4 wood studs 16″ o.c.
CertainTeed 3½″ CertaSound Batts
Resilient channels 24″ o.c. one side
⅝″ type "X" gypsum wallboard



STC 50
Fire Rating 1 hr.

Double Wood Stud Partition

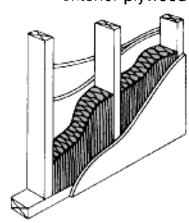
2 x 4 wood studs 16″ o.c. (double row)
Separate 2 x 4 wood plates
CertainTeed 3½″ CertaSound Batts all stud spaces
½″ regular gypsum wallboard



STC 57
Fire Rating 1 hr.

Exterior Wood Stud Wall

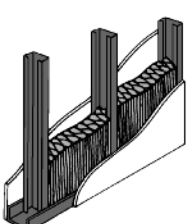
2 x 4 wood studs 16″ o.c.
CertainTeed 3½″ CertaSound Batts
Interior: ½″ regular gypsum wallboard
Exterior: ½″ gypsum sheathing
⅜″ exterior plywood



STC 38
Fire Rating 1 hr.

Steel Stud Partitions

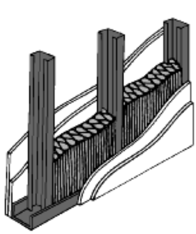
2½″ or 3⅝″ steel studs 24″ o.c.
CertainTeed 2½″ or 3½″ CertaSound Batts
⅝″ type "X" gypsum wallboard



STC 47 w/2½″ studs
STC 50 w/3⅝″ studs
Fire Rating 1 hr.

Steel Stud Partitions

2½″ steel studs 24″ o.c.
CertainTeed 2½″ CertaSound Batts
2 layers ½″ type "X" gypsum wallboard each side

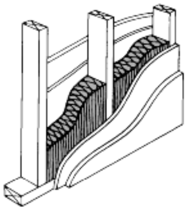


STC 54
Fire Rating 2 hrs.

Figure A.8 STC and fire ratings. (*CertainTeed*)

2 x 4 Wood Stud Partition

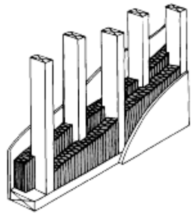
2 x 4 wood studs 24″ o.c.
CertainTeed 3½″ CertaSound Batts
2 layers ⅝″ type “X” gypsum wallboard each side



STC 46
Fire Rating 2 hrs.

Staggered Wood Stud Partition

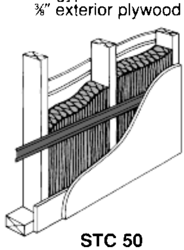
2 x 4 wood studs staggered 16″ o.c.
2 x 6 wood plates
CertainTeed 2½″ CertaSound Batts all stud spaces
½″ regular gypsum wallboard



STC 50
Fire Rating 1 hr.

Exterior Wood Stud Wall

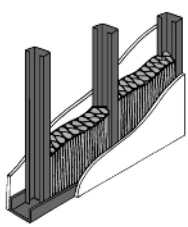
2 x 4 wood studs 16″ o.c.
CertainTeed 3½″ CertaSound Batts
Interior: resilient channel ⅝″ type “X” gypsum wallboard
Exterior: ½″ gypsum sheathing
⅜″ exterior plywood



STC 50
Fire Rating 1 hr.

2½″ & 3⅝″ Steel Stud Partitions

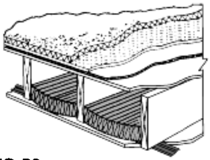
2½″ or 3⅝″ steel studs 24″ o.c.
CertainTeed 2½″ or 3½″ CertaSound Batts
½″ regular gypsum wallboard



STC 45 w/2½″ studs
STC 47 w/3⅝″ studs

Floor/Ceiling Construction

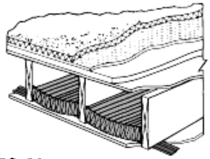
Wood Joists 16″ o.c.
CertainTeed 3½″ CertaSound Batts
Resilient channel
½″ type “X” gypsum wallboard
⅝″ plywood subfloor
¾″ particle board underlayment
Carpet & pad



STC 53
IIC 73
Fire Rating 1 hr.

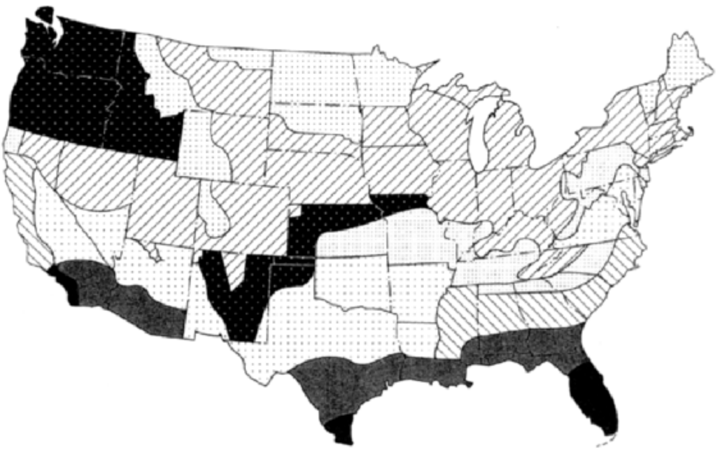
Floor/Ceiling Construction

Wood Joists 16″ o.c.
CertainTeed 3½″ CertaSound Batts
Resilient channel
½″ type “X” gypsum wallboard
⅝″ plywood subfloor
1½″ cellular or light weight concrete
Carpet & pad



STC 60
IIC 73
Fire Rating 1 hr.

Figure A.9 STC and fire ratings. (*CertainTeed*)



Insulation zone	Ceilings below ventilated attics: Electric resistance	Ceilings below ventilated attics: Gas, oil, or heat pump	Floors over unheated crawl spaces, basements	2×4 exterior walls	2×6 walls for new construction	Crawl space walls
			All fuel types		*All fuel types*	
1	R-49	R-49	R-19	R-13 or R-11	R-19	R-19
2	R-49	R-38	R-19	R-13 or R-11	R-19	R-19
3	R-38	R-38	R-19	R-13 or R-11	R-19	R-19
4	R-38	R-38	R-19	R-13 or R-11	R-19	R-19
5	R-38	R-30	R-19	R-13 or R-11	R-19	R-19
6	R-38	R-30	R-19	R-13 or R-11	R-19	R-19
7	R-30	R-30		R-13 or R-11	R-19	R-19
8	R-30	R-19		R-13 or R-11	R-19	R-11

Figure A.10 Recommended R-values and fuel types. (*U.S. Department of Energy*)

		R-value	
Material Description	**Density (lb/ft^3)**	**Per-Inch Thickness**	**For Listed Thickness**
Building Boards, Panels, Flooring			
Gypsum or plaster board, 3/8 in.	50	—	0.32
Gypsum or plaster board, 1/2 in.	50	—	0.45
Gypsum or plaster board, 5/8 in.	50	—	0.56
Plywood (Douglas Fir)	34	1.25	—
Plywood or wood panels, 3/4 in.	34	—	0.93
Hardboard, medium density	50	1.37	—
Particle board			
Low density	37	1.85	—
Medium density	50	1.06	—
High density	62.5	0.85	—
Wood subfloor, 3/4 in.		—	0.94
Finish Flooring Materials			
Carpet and rubber pad		—	1.23
Cork tile, 1/8 in.		—	0.28
Terrazzo, 1 in.		—	0.08
Tile—asphalt, linoleum, vinyl, rubber		—	0.05
Wood, hardwood finish, 3/4 in.		—	0.68
Insulating Materials			
See Appendix A			
Masonry Materials—Concretes			
Cement mortar	116	0.20	—
Gypsum-fiber concrete			
87.5% gypsum, 12.5% wood chips	51	0.60	—
Lightweight aggregates including expanded shale, clay or slate; expanded slags; cinders; pumice; vermiculite; also cellular concretes (by density)	120	0.19	—
	100	0.28	—
	80	0.40	—
	60	0.59	—
	40	0.86	—
	20	1.43	—
Sand and gravel or stone aggregate			
oven dried	140	0.11	—
not dried	140	0.08	—
Stucco	116	0.20	—

Figure A.11 R-value of common building materials. (*Clemson University*)

Material Description	Density (lb/ft^3)	R-value: Per-Inch Thickness	R-value: For Listed Thickness
Masonry Units			
Brick, common	120	0.20	—
Brick, face	130	0.11	—
Concrete blocks, rectangular core			
Sand and gravel aggregate			
2 core, 8 in., 36 lb.		—	1.04
same with filled cores		—	1.93
Lightweight aggregate (expanded shale, slate or slag, pumice)			
3 core, 6 in., 19 lb.		—	1.65
same with filled cores		—	2.99
2 core, 8 in., 24 lb		—	2.18
same with filled cores		—	5.03
3 core, 12 in., 38 lb.		—	2.48
same with filled cores		—	5.82
Stone, lime or sand		0.08	—
Plastering Materials			
Cement plaster, sand aggregate	116	0.20	—
Sand aggregate, $\frac{3}{8}$ in.		—	0.08
Sand aggregate, $\frac{3}{4}$ in.		—	0.15
Gypsum plaster			
Lightweight aggregate, $\frac{1}{2}$ in.	45	—	0.32
Lightweight aggregate, $\frac{5}{8}$ in.	45	—	0.39
Lightweight aggregate on metal lath, $\frac{3}{4}$ in.		—	0.47
Perlite aggregate	45	0.67	—
Sand aggregate	105	0.18	—
Sand aggregate, $\frac{1}{2}$ in.	105	—	0.09
Sand aggregate, $\frac{5}{8}$ in.	105	—	0.11
Sand aggregate on metal lath, $\frac{3}{4}$ in.		—	0.13
Vermiculite aggregate	45	0.59	—
Roofing Materials			
Asbestos-cement shingles	120	—	0.21
Asphalt roll roofing	70	—	0.15
Asphalt shingles	70	—	0.44
Built-up roofing, $\frac{3}{8}$ in.	70	—	0.33
Slate, $\frac{1}{2}$		—	0.05
Wood shingles		—	0.94
Siding Materials			
Shingles			
Wood, 16 in., 7.5 exposure		—	0.87
Wood, double, 16 in., 12 in. exposure		—	1.19
Siding			
Asphalt roll siding			0.15
Hardboard siding, $\frac{7}{16}$ in.	40	—	0.67
Wood, drop, 1 × 8 in.		—	0.79
Wood, bevel, $\frac{1}{2}$ × 8 in., lapped		—	0.81
Wood, bevel, $\frac{3}{4}$ × 10 in., lapped		—	1.05
Wood, plywood, $\frac{3}{8}$ in., lapped		—	0.59
Aluminum or steel, over sheathing		—	0.61
Woods			
Maple, oak, and similar hardwoods	45	0.91	—
Fir, pine, etc.	32	1.25	—
.... $\frac{3}{4}$ in.	32	—	0.94
.... 1.5 in.	32	—	1.88
.... 5.5 in.	32	—	7.14

Figure A.12 R-value of common building materials. (*Clemson University*)

AIR SURFACES

Position of Surface	Direction of Heat Flow	Type of Surface: Non-Reflective Materials	Reflective Aluminum Coated Paper	Highly Reflective Foil
		Resistance (R)	Resistance (R)	Resistance (R)
STILL AIR				
Horizontal	Upward	0.61	1.10	1.32
45° slope	Upward	0.62	1.14	1.37
Vertical	Horizontal	0.68	1.35	1.70
45° slope	Down	0.76	1.67	2.22
Horizontal	Down	0.92	2.70	4.55
MOVING AIR (any position)				
15 mph wind	Any	0.17 (winter)	–	–
7½ mph wind	Any	0.25 (summer)	–	–

AIR SPACES

Position of Air Space and Thickness (inches)		Heat Flow Dir.	Season	Types of Surfaces on Opposite Sides: Both Surfaces Non-Reflective Materials	Aluminum Coated Paper/ Non-Reflective Materials	Foil/ Non-Reflective Materials
				Resistance (R)	Resistance (R)	Resistance (R)
Horizontal	¾	Up	W	0.87	1.71	2.23
	¾		S	0.76	1.63	2.26
	4		W	0.94	1.99	2.73
	4		S	0.80	1.87	2.75
45° slope	¾	Up	W	0.94	2.02	2.78
	¾		S	0.81	1.90	2.81
	4		W	0.96	2.13	3.00
	4		S	0.82	1.98	3.00
Vertical	¾	Down	W	1.01	2.36	3.48
	¾		S	0.84	2.10	3.28
	4		W	1.01	2.34	3.45
	4		S	0.91	2.16	3.44
45° slope	¾	Down	W	1.02	2.40	3.57
	¾		S	0.84	2.09	3.24
	4		W	1.08	2.75	4.41
	4		S	0.90	2.50	4.36
Horizontal	¾	Down	W	1.02	2.39	3.55
	1½		W	1.14	3.21	5.74
	4		W	1.23	4.02	8.94
	¾		S	0.84	2.08	3.25
	1½		S	0.93	2.76	5.24
	4		S	0.99	3.38	8.08

Figure A.13 Air R-values. (*D. Richard Stroup*)

Building Part	Construction Materials	R-value
Roof/Ceiling	Outside Air Film	0.17
	Shingles	0.44
	Building Paper	0.06
	Plywool ½″	0.62
	Attic Air Film	0.61
	Insulation	19.00
	Gypsum Board, ½″	0.45
	Inside Air Film	0.61
	Total R-value (R_T)	21.96
	U-value ($^1/R_T$)	**0.045**
Wall	Outside Air Film	0.17
	Siding, Wood ½″ x 8″ Lapped	0.81
	Sheathing, Plywood ½″	0.62
	Insulation	11.00
	Interior Finish Gyp. Bd. ½″	0.45
	Inside Air Film	0.68
	Total R-value (R_T)	13.73
	U-value ($^1/R_T$)	**0.073**
Header Joist	Outside Air Film	0.17
	Siding	0.81
	Sheathing	0.62
	Header, Wood 1½″	1.88
	Insulation	11.00
	Inside Air Film	0.68
	Total R-value (R_T)	15.16
	U-value ($^1/R_T$)	**0.066**
Sill	Outside Air Film	0.17
	Siding	0.81
	Sheathing	0.62
	Sill — Wood 5½″	6.88
	Inside Air Film	6.88
	Total R-value (R_T)	9.16
	U-value ($^1/R_T$)	**0.109**
Foundation	Outside Air Film	0.17
	Conc. Blk 8″	1.11
	Insulation	5.00
	Interior Finish Gyp. Bd. ⅜″	0.32
	Inside Air Film	0.68
	Total R-value (R_T)	7.28
	U-value ($^1/R_T$)	**0.137**

Figure A.14 Typical R- and U-value calculations. (*Harold B. Olin, AIA*)

WALL DESCRIPTION	U VALUE (WINTER)	HEAT GAIN BTU/HR/SQ FT (DARK COLOR) AVERAGE ORIENTATION	WEST ORIENTATION	TIME LAG (HR)	AMPLITUDE DECREMENT FACTOR
8″ brick and lightweight concrete (100 lb density) block 2″ polystyrene insulation board ½″ gypsum wallboard	0.073	2.06	1.75	4	0.40
6″ precast concrete (140 lb density) sandwich panel 2″ polyurethane core	0.065	1.82	1.55	4	0.40
½″ plywood siding ½″ insulation board sheathing, wood studs. Full batt (R-11) insulation ½″ gypsum wallboard	0.076	3.05	4.60	2	0.75
4″ brick veneer ½″ insulation board sheathing. Wood studs full batt (R-11) insulation ½″ gypsum wallboard	0.077	2.18	1.95	4	0.62
8″ brick wall (hollow units) 1″ x 2″ furring. ½″ gypsum wallboard	0.316	7.37	5.90	6	0.25

Figure A.15 Thermal time lag of typical wall assemblies. (*Donald Watson / Kenneth Labs*)

SOLAR INTENSITY AND SOLAR HEAT GAIN FACTORS FOR 40°N LATITUDE

DATE	SOLAR TIME (A.M.)	DIRECT NORMAL (BTUH/SQ FT)	SOLAR HEAT GAIN FACTORS (BTUH/SQ FT)					SOLAR TIME (P.M.)
			N	E	S	W	HOR	
Jan 21	8	142	5	111	75	5	14	4
	10	274	16	124	213	16	96	2
	12	294	20	21	254	21	133	12
Feb 21	8	219	10	183	94	10	43	4
	10	294	21	143	203	21	143	2
	12	307	24	25	241	25	180	12
Mar 21	8	250	16	218	74	16	85	4
	10	297	25	153	171	25	186	2
	12	307	29	31	206	31	223	12
Apr 21	6	89	11	88	5	5	11	6
	8	252	22	224	41	21	123	4
	10	286	31	152	121	31	217	2
	12	293	34	36	154	36	252	12
May 21	6	144	36	141	10	10	31	6
	8	250	27	220	29	25	146	4
	10	277	34	148	83	34	234	2
	12	284	37	40	113	40	265	12
June 21	6	155	48	151	13	13	40	6
	8	246	30	216	29	27	153	4
	10	272	35	145	69	35	238	2
	12	279	38	41	95	41	267	12
Jul 21	6	138	37	137	11	11	32	6
	8	241	28	216	30	26	145	4
	10	269	35	146	81	35	231	2
	12	276	38	41	109	41	262	12
Aug 21	6	81	12	82	6	5	12	6
	8	237	24	216	41	23	122	4
	10	272	32	150	116	32	214	2
	12	280	35	38	149	38	247	12
Sep 21	8	230	17	205	71	17	82	4
	10	280	27	148	165	27	180	2
	12	290	30	32	200	32	215	12
Oct 21	8	204	11	173	89	11	43	4
	10	280	21	139	196	21	140	2
	12	294	25	27	234	27	177	12
Nov 21	8	136	5	108	72	5	14	4
	10	268	16	122	209	16	96	2
	12	288	20	21	250	21	132	12
Dec 21	8	89	3	67	50	3	6	4
	10	261	14	113	146	14	77	2
	12	285	18	19	253	19	113	12
			N	W	S	E	HOR	PM

Figure A.16 Solar heat gain factors: sample. (*John I. Yellott*)

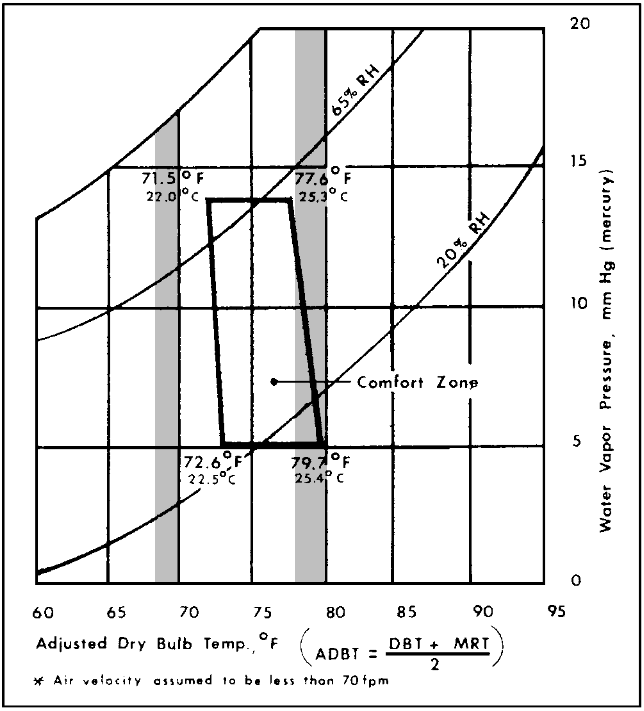


Figure A.17 ASHRAE comfort envelope. (*Harold B. Olin, AIA*)

1. Wrap and tape ductwork with fiber glass duct wrap.

2. Patch rips or tears in vapor retarders before installing the interior finish.

3. Pack insulation into small cracks around doors and window frames to help eliminate cold spots. (If using faced insulation, peel off the facing material before filling in small areas.)

4. Wrap water heater with a fiber glass Water Heater Blanket. (Use fiber glass Water Heater Top on electric water heaters only!)

Figure A.18 Miscellaneous insulation applications. (*Owens Corning*)

5. The first step in an exterior wall or sound control project is to seal all penetrations in the walls, such as those for electrical wires and outlets, using an application of Owens Corning *PinkSeal* foam sealant. Any place that air could leak through is a place where sound could leak through also. (Note: Do not use expanding foam sealants around windows and doors because they might cause jamming or misalignment.)

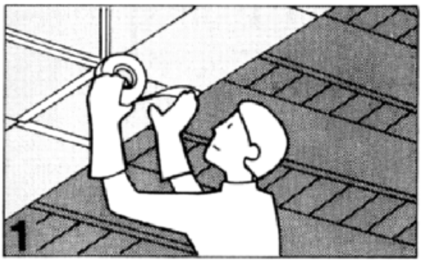
6. Insulation must be fitted properly around pipes, wiring, electrical boxes and heating ducts. On the exterior walls, the insulation must always be installed behind the water supply pipes. There should be no gaps or spaces between insulation pieces. These are places where energy would be lost for the life of the house.

7. Insulate pull-down stairways with fiber glass blanket insulation laid on and around a built-up framework. Scuttle holes can be insulated by attaching insulation directly to the board with an adhesive.

8. Caulking and sealing all penetrations can help to stop air infiltration.

Figure A.19 Miscellaneous insulation applications. (*Owens Corning*)

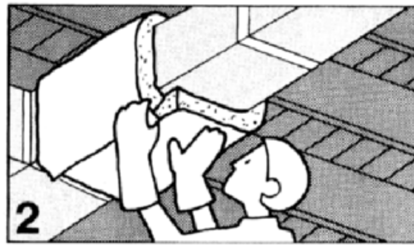
You should wrap all ducts with insulating blankets. At least two inches of insulation is desirable. If the supplier does not have the two-inch foil-backed duct insulation, then you can use a combination of 1" unfaced (no foil) and 1" foil or vinyl backed duct insulation.



Tape all duct joints and seams before you insulate the ducts to prevent any air leakage.

Cut the insulation long enough to have a two-inch overlap of vapor barrier. You need this overlap to staple the insulation. Place the vapor barrier (foil or vinyl side) away from the ducts.

If your ducts already have some insulation, check to see if any moisture has collected in it. If so, it would be best to replace it with new insulation. But, if the old insulation is still in good condition, and you need to add more to get the desired two-inch protection, be sure you make a number of slashes at six inch intervals through the old foil vapor barrier before you add the new foil-backed insulation.



Pull the insulation snug, *not tight,* to reduce air pockets. If you pull the insulation tight, you will reduce its insulating value.

After you have wrapped the ducts, tape the edges of the various pieces of insulation with special duct tape. This foil vapor barrier will keep moist air from reaching the cool ducts in summer and will protect the insulation from moisture damage. Note: Remove part of the insulation cover foil and make sure it overlaps where the two ends of insulation join together. Then after taping, staple the tape so it won't come loose and seal the holes made from stapling with insulation tape.

Figure A.20 HVAC duct insulation. (*Edison Electric Institute*)

Duct Insulation R-Value Requirements

Zone Number	Ducts in Unconditioned Spaces (i.e. Attics, Crawl Spaces, Unheated Basements and Garages, and Exterior Cavities)	Ducts Outside the Building
Zones 1-4	R-5	R-8
Zones 5-14	R-5	R-6.5
Zone 15-19	R-5	R-8

Figure A.21 Duct insulation. (*1995 Model Energy Code*)

Minimum Insulation Thickness for HVAC Pipes[a]

Piping System Types	Fluid Temp Range (°F)	Insulation Thickness in Inches by Pipe Sizes[b]			
		Runouts 2 in.[c]	1 in. and Less	1.25 in. to 2 in.	2.5 in. to 4 in.
Heating Systems					
Low Pressure/Temperature	201-250	1.0	1.5	1.5	2.0
Low Temperature	120-200	0.5	1.0	1.0	1.5
Steam Condensate (for feed water)	Any	1.0	1.0	1.5	2.0
Cooling Systems					
Chilled Water	40-55	0.5	0.5	0.75	1.0

(a) The pipe insulation thicknesses specified in this table are based on insulation R-values ranging from R-4 to R-4.6 per inch of thickness. For materials with an R-value greater than R-4.6, the insulation thickness specified in this table may be reduced as follows:

$$\text{New Minimum Thickness} = \frac{4.6 \times \text{Table Thickness}}{\text{Actual R-Value}}$$

For materials with an R-value less than R-4, the minimum insulation thickness must be increased as follows:

$$\text{New Minimum Thickness} = \frac{4.0 \times \text{Table Thickness}}{\text{Actual R-Value}}$$

(b) For piping exposed to outdoor air, increase thickness by 0.5 in.

(c) Applies to runouts not exceeding 12 ft in length to individual terminal units.

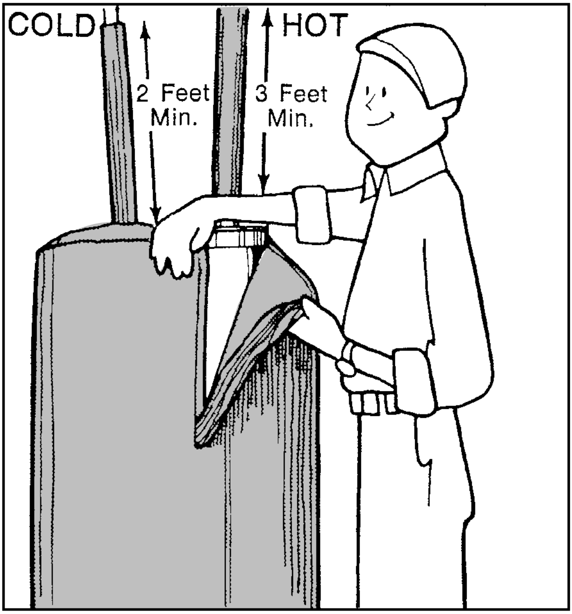
Figure A.22 Insulation thickness for HVAC piping. (*1995 Model Energy Code*)

Minimum Insulation Thickness for Circulating Hot Water Pipes

Heated Water Temperature (°F)	Insulation Thickness in Inches by Pipe Sizes[a]			
	Non-Circulating Runouts	Circulating Mains and Runouts		
	Up to 1 in.	Up to 1.25 in.	1.5 - 2.0 in.	Over 2 in.
170-180	0.5	1.0	1.5	2.0
140-160	0.5	0.5	1.0	1.5
100-130	0.5	0.5	0.5	1.0

(a) Nominal pipe size and insulation thickness.

Figure A.23 Insulation thickness for hot-water piping. (*1995 Model Energy Code*)



In addition, you might want to investigate a relatively inexpensive water heater insulation kit. Hot water tanks (except super-insulated tanks) generally are not insulated very well, so an extra layer of protection will keep the heat from being lost through the walls of the tank. *Be sure to read the instructions on the kit carefully,* especially for directions on keeping uncovered any doors, vents or relief valves. This is especially true for gas and oil-fired water heaters—a proper mixture of additional air with combustion or exhaust gases is needed to assist in the safe passage of combustion products to the outside. For instance on gas-fired water heaters, the draft hood on the vent pipe should be kept free of blockage. If your hot water piping runs any long distances and is exposed, you probably are losing expensive heat from your hot water system. You can wrap the pipes with thermal tape and eliminate this wasted energy.

Figure A.24 Water heater insulation. (*Edison Electric Institute*)

Air Leakage	Joints, penetrations, and all other such openings in the building envelope that are sources of air leakage must be caulked, gasketed, weatherstripped, or otherwise sealed. The maximum leakage rates for manufactured windows and doors are shown on the reverse side. Recessed lights must be type IC rated and installed with no penetrations or installed inside an appropriate air-tight assembly with a 0.5-in. clearance from combustible materials and 3-in. clearance from insulation.
Vapor Retarder	Vapor retarders must be installed on the warm-in-winter side of all non-vented framed ceilings, walls, and floors. This requirement does not apply to the following locations nor where moisture or its freezing will not damage the materials. • Texas — Zones 2-5 • Alabama, Georgia, N. Carolina, Oklahoma, S. Carolina — Zones 4-6 • Arkansas, Tennessee — Zones 6-7 • Florida, Hawaii, Louisiana, Mississippi — All Zones
Materials and Insulation Information	Materials and equipment must be identified so that compliance can be determined. Manufacturer manuals for all installed heating and cooling equipment and service water heating equipment must be provided. Insulation R-values, glazing and door U-values, and heating and cooling equipment efficiency (if high-efficiency credit is taken) must be clearly marked on the building plans or specifications.
Duct Insulation	Supply and return ducts for heating and cooling systems located in unconditioned spaces must be insulated to the levels shown on the reverse side of this sheet. Exceptions: Insulation is not required for exhaust air ducts, ducts within HVAC equipment, and when the design temperature difference between the air in the duct and the surrounding air is 15°F or less.
Duct Construction	Ducts must be sealed using mastic with fibrous backing tape. For fibrous ducts, pressure-sensitive tape may be used. Other sealants may be approved by the building official. Duct tape is not permitted. The HVAC system must provide a means for balancing air and water systems.
Temperature Controls	Thermostats are required for each separate HVAC system in single-family buildings and each dwelling unit in multifamily buildings (non-dwelling portions of multifamily buildings must have one thermostat for each system or zone). Thermostats must have the following ranges: Heating Only — 55°F - 75°F Cooling Only — 70°F - 85°F Heating and Cooling — 55°F - 85°F A manual or automatic means to partially restrict or shut off the heating and/or cooling input to each zone or floor shall be provided for single-family homes and to each room for multifamily buildings.
HVAC Piping Insulation	HVAC piping in unconditioned spaces conveying fluids at temperatures above 120°F or chilled fluids at less than 55°F must be insulated to the levels shown on the reverse side of this sheet.
Swimming Pools	All heated swimming pools must have an on/off pool heater switch. Heated pools require a pool cover unless over 20% of the heating energy is from non-depletable sources. All swimming pool pumps must be equipped with a time clock.
Circulating Hot Water	Circulating hot water systems must have automatic or manual controls and pipes must be insulated to the levels shown on the reverse side of this sheet.
Electric Systems	Each multifamily dwelling unit must be equipped with separate electric meters.

Figure A.25 1995 *Model energy code* basic requirements. (*1995 Model Energy Code*)

	Requirement	Installed (Y/N)	Comments
Pre-Inspection			
• Approved Building Plans on Site (104.1)	______	______	______
Foundation Inspection	*Inspection Date* ______		*Approved: Yes* ___ *No* ___ *Init.* ___
• Slab-Edge Insulation (502.2.1.4)	______	______	Depth: ______
• Basement Wall Exterior Insulation (502.2.1.6)	______	______	Depth: ______
• Crawl Space Wall Insulation (502.2.1.5)	______	______	Depth: ______
Framing Inspection	*Inspection Date* ______		*Approved: Yes* ___ *No* ___ *Init.* ___
• Floor Insulation (502.2.1.3)	______	______	______
• Glazing and Door Area (502.2.1.1)	______	______	______
• Mass Walls (502.1.2)	______	______	______
• Caulking/Sealing Penetrations (502.4.3)	______	______	______
• Duct Insulation (503.9.1)	______	______	______
• Duct Construction (503.10.2)	______	______	______
• HVAC Piping Insulation (503.11)	______	______	______
• Circulating Hot-Water Piping Insulation (504.7)	______	______	______
Insulation Inspection	*Inspection Date* ______		*Approved: Yes* ___ *No* ___ *Init.* ___
• Wall Insulation (502.2.1.1)	______	______	______
• Basement Wall Interior Insulation (502.2.1.6)	______	______	Depth: ______
• Ceiling Insulation (502.2.1.2)	______	______	______
• Glazing and Door U-Values (502.2.1.1)	______	______	______
• Vapor Retarder (502.1.4)	______	______	______
Final Inspection	*Inspection Date* ______		*Approved: Yes* ___ *No* ___ *Init.* ___
• Heating Equipment (102.1)			
Make and Model Number	______	______	______
Efficiency (AFUE or HSPF)	______	______	______
• Cooling Equipment (102.1)			
Make and Model Number	______	______	______
Efficiency (SEER)	______	______	______
• Multifamily Units Separately Metered (505.2)	______	______	______
• Thermostats for Each System (503.8.3)	______	______	______
• Heat Pump Thermostat (503.4.2.3)	______	______	______
• Window and Door Air Leakage (502.4.2)	______	______	______
• Weatherstripping at Doors/Windows (502.4.3)	______	______	______
• Equipment Maintenance Information (102.2)	______	______	______

Figure A.26 MEC field inspection checklist. (*1995 Model Energy Code*)

Appendix B

Directory of Manufacturers, Suppliers, and Associations

The information contained within this directory has been obtained from an extensive list of sources during the research for this book. This directory is not intended to be an all-inclusive source; however, the information is presented as a service to the reader and to facilitate further research or education. Every effort has been made to ensure the accuracy of the material. The authors and the publisher will not accept any liability for omissions or errors.

Manufacturer's Associations

Blow-in-Blanket Contractors Association (BIBCA)
1051 Kennel Drive
Rapid City, SD 57701
800-451-8862
Email: *info@bibca.org*
http://www.bibca.org

Cellulose Insulation Manufacturers Association (CIMA)
136 South Keowee Street
Dayton, OH 45402
937-222-2462
Fax: 937-222-5794

Central States Insulation and Abatement Contractors Association
136 South Keowee Street
Dayton, OH 45402
937-222-1024
Fax: 937-222-5794

Eastern States Insulation Contractors Association
2250 Hickory Road, Suite 100
Plymouth Meeting, PA 19462
610-940-4999
Fax: 610-940-4994

EPS Molders Association
2128 Espey Court
Suite 4
Crofton, MD 21114
800-607-3772
410-451-8341
Fax: 410-451-8343
Email: *bdecampo@aol.com*
http://www.epsmolders.org/

Home Ventilating Institute
30 West University Drive
Arlington Heights, IL 60004
847-394-0150
Fax: 847-253-0088

Institute for Research in Construction
National Research Council of Canada
Ottawa, Ontario, K1A 0R6
613-993-2607
Fax: 613-952-7673
Email: *Irc.Client-Services@nrc.ca*

Insulating Concrete Form Association
960 Harlem Avenue, Suite 1128
Glenview, IL 60025
847-657-9730
Fax: 847-657-9728

Insulation Contractors Association of America
1321 Oak Street
Alexandria, VA 22314
703-739-0356

National Association of Home Builders (NAHB)
1201 15th Street NW
Washington, DC 20005
202-822-0200

North American Insulation Manufacturers Association (NAIMA)
44 Canal Center Plaza, Suite 310
Alexandria, VA 22314
703-684-0084
Fax: 703-684-0427
http://www.naima.org

Polyisocyanurate Insulation Manufacturers Association (PIMA)
1331 F Street, NW, Suite 975
Washington, DC 20004
202-628-6558
Fax: 202-628-3856
Email: *pima@pima.org*
http://www.pima.org/contactus.html

Reflective Insulation Manufacturers Association
P. O. Box 90955
Washington, DC 20090
800-279-4123

Society of the Plastics Industry, Inc.
1801 K Street NW, Suite 600K
Washington, DC 20006-1301
202-974-5200
Fax: 202-296-7005

Spray Polyurethane Foam Division
1275 K Street NW
Washington, DC 20005
800-523-6154

Southeastern Insulation Contractors Association
101 Pinehurst Drive
Franklin, TN 37064
615-662-2871
Fax: 615-662-2871

Southwest Insulation Contractors Association
P. O. Box 570353
Houston, TX 77257
713-977-0909
Fax: 713-781-1321

Structural Insulated Panel Association
3413 A 56th Street NW
Gig Harbor, WA 98335
253-858-SIPA (7472)
Fax: 253-858-0272
Email: *staff@sips.org*
http://www.sips.org/

Thermal Insulation Association of Canada
371A Richmond Road, Unit 8
Ottawa, Ontario, Canada K2A 0E7
613-724-4834
Fax: 613-724-4943

Thermal Insulation Manufacturer's Association
29 Bank Street
Stamford, CT 06901
203-224-3930

The Perlite Institute Inc.
88 New Dorp Plaza
Staten Island, NY 10306-2994
Tel: 718-351-5723
Fax: 718-351-5725
http://www.perlite.org/

The Vermiculite Association
Whitegate Acre
Metheringham Fen
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Email: *tva@vermiculite.org*

Western Insulation Association
669 South 200 East
Salt Lake City, UT 84111
801-364-0050

Fax: 801-531-7725

Reference Sources

Conservation and Renewable Energy Inquiry and Referral Service
P. O. Box 8900
Silver Spring, MD 20907
800-523-2929

Electric Power Research Institute
P. O. Box 10412
Palo Alto, CA 94303
415-855-2000

Florida Solar Energy Center
State University System of Florida,
300 State Road 401
Cape Canaveral, FL 32920-4099

Institute for Research in Construction
National Research Council of Canada
Ottawa, Ontario, Canada K1A 0R6
613-993-2607
Fax: 613-952-7673
Email: *Irc.Client-Services@nrc.ca*

NAHB Research Center HomeBase Hotline
400 Prince George's Boulevard
Upper Marlboro, MD 20774-8731
800-638-8556
http://www.nahbrc.org

National Institute of Building Sciences
1201 L Street NW, Suite 400
Washington, DC 20005
202-289-7800
Fax: 202-289-1092

Southface Energy Institute
241 Pine Street
Atlanta, GA 30308
404-872-3549
Fax: 404-872-5009
http://www.southface.org

U.S. Department of Commerce
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161

U.S. Department of Energy
Energy Efficiency and Renewable Energy Clearing House (EREC)
P. O. Box 3048
Merrifield, VA 22116
800-363-3732
Fax: 703-893-0400

U.S. Department of Energy
Office of Scientific and Technical Information (OSTI)
P. O. Box 62
Oak Ridge, TN 37831
423-576-2268
423-576-840

U.S. Department of Energy
National Appropriate Technology Assistance Service
P. O. Box 2525
Butte, MT 59702-2525
800-428-2525

U.S. Environmental Protection Agency
Atmospheric Pollution Prevention Division APPD
401 M Street, Mail Code 6202J SW
Washington, DC 20460
888-STAR-YES
Energy Star fact sheets
Builder guides

Model Energy Code
Council of American Building Officials
5203 Leesburg Pike
Falls Church, VA 22041
703-931-4533

ASHRAE Standard 90.2-1993
“Energy-Efficient Design of New Low-Rise Residential Buildings”
American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.
1791 Tullie Circle, NE
Atlanta, GA 30329

Manufacturers

Air retarders

ASTRO-FOIL Innovative Energy
10653 W. 181st Avenue
Lowell, IN 46356
800-776-3645
219-696-3639
Fax: 800-551-3645
Email: *ie@astrofoil.com*
http://www.insul.net/common.html

Celotex Corporation
One Metro Center
4010 Boy Scout Blvd.
Tampa, FL 33607
813-873-4000
Fax: 813-873-4430

Dryvit Systems
House Wrap
1 Energy Way
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800-556-7752

Du Pont
Tyvek House Wrap
Chestnut Run Plaza
Laurel Run
Wilmington, DE 19808
800-448-9835

Foam Enterprises, Inc.
13630 Watertower Cir.
Dept. AR
Minneapolis, MN 55441-3785
888-900-FOAM (3626)
612-559-9390
Fax: 612-559-0945

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Owens Corning World Headquarters
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http://www.owenscorning.com

Pactive Corporation
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Atlanta, GA 30328
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678-589-7337
Fax: 678-589-7325
http://www.tennecobuildingprod.com/index.html

W. R. Meadows, Inc.
300 Industrial Drive
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847-683-4500
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Cellulose

Cellulose Insulation Manufacturers Association (CIMA)
136 South Keowee Street
Dayton, OH 45402
937-222-2462
Fax: 937-222-5794

Applegate Insulation Mfg., Inc.
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Webberville, MI 48892
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517-521-3545
Fax: 517-521-3597

Central Fiber Corporation
4814 Fiber Lane
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800-654-6117
785-883-4600
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Central Fiber Corporation
1525 Waynesburg Drive, S.E.
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216-452-2630
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http://www.hmi-mfg.com

Insul-Tray, Inc.
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Redmond, WA 98073-3111
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International Cellulose Corporation
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713-433-6701
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National Fiber
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Nu-Wool Insulation Co., Inc.
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Tascon Inc.
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Thermocon Inc.
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http://www.thermocon.com

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Tampa, FL
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Ronda, NC
800-992-2468
Delphos, OH
419-692-7015
Portland, OR
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http://www.nationwidecoatings.com

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http://www.earthshipbiotecture.com

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www.simplex-products.com

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www.stocorp.com

Tec Specialty Products, Inc.
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Teifs Wall Systems
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San Antonio, TX 78202
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Fax: 210-472-2946
www.teifs.com

USG Corporation
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Chicago, IL 60606
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312-606-4000
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http://www.usg.com

Fiberglass

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44 Canal Center Plaza, Suite 310
Alexandria, VA 22314
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http://www.naima.org

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303-934-7772
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Blow-in-Blanket Contractors Association (BIBCA)
1051 Kennel Drive
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E-mail: *info@bibca.org*
http://www.bibca.org

CertainTeed Corporation
750 E. Swedesford Road
Valley Forge, PA 19482
800-233-8990
800-782-8777
http://www.certainteed.compro/insulation/
http://www.cphome.com

Guardian Fiberglass, Inc.
1000 East North Street
Albion, MI 49224
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517-629-6361
Fax: 800-748-0437
Email: *fiberglass_webmaster@guardian.com*

Insul Binder Inc.
2190 South Klammath Street
Denver, CO 80223
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303-934-7772
Fax: 303-934-5240
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Knauf Fiber Glass
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317-398-4434
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Email: *gab2@knauffiberglass.com*

Johns Manville
P. O. Box 5108
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800-654-3103
303-978-2000
Fax: 303-978-3661
http://www.jm.com

Owens Corning
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http://www.owenscorning.com

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AAB Building System
840 Division Street
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905-373-0004

AFM Corporation
P. O. Box 246
Excelsior, MN 55331
800-255-0176
Diamond Snap-Form

American ConForm Industries
1820 South Santa Fe Street
Santa Ana, CA 92705
800-CONFORM
SmartBlock

American Polysteel Forms
5150-F Edith NE
Albuquerque, NM 87101
800-9PS-FORM
Fax: 505-345-8154

Superior Walls of America, Ltd.
P. O. Box 427
Ephrata, PA 17522-0427
800-452-9255

Perlite

Airlite Processing Corporation of Florida
3505 65th Street
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561-562-3518
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Email: *rsmith9179@aol.com*

Carolina Perlite Company, Inc.
P. O. Box 158
Gold Hill, NC 28071
704-279-2325
Fax: 704-279-8818

Chemrock Corporation
4269 Edgewood Drive
Jacksonville, FL 32254
904-355-0096
Fax: 904-356-3030

Chemrock Corporation
Buttermilk Lane
Thomaston, ME 04861
207-594-8225
Fax: 207-594-8225

Cornerstone Ind. Minerals Corp.
P. O. Box 1287
Lakeview, OR 97630
503-947-5755
Fax: 541-947-5770

Eagle-Picher Minerals, Inc.
6110 Plumas Street
Reno, NV 89509
702-824-7600
Fax: 702-824-7694
Email: *codym@minerals.epcorp.com*

Filter-Media Co.
P. O. Box 19546
Houston, TX 77224-9156
713-780-9000

Harborlite Corporation
1450 Simpson Way
Escondido, CA 92029
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Harborlite Corporation
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Youngsville, NC 27596
919-562-0031
Fax: 919-554-0870

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Nor-Cal Perlite, Inc.
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Persolite Products, Inc.
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201 South Robertson
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303-572-3222 (Denver area)
719-784-6531 (Florence plant)
Fax: 719-784-4855

Renaissance Perlite
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Brunswick, GA 31520
912-264-6372
Fax: 912-267-6096

Schundler Company
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Metuchen, NJ 08840
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Supreme Perlite Company
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Whittemore Company, Inc.
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2115 Loose Moose Loop
North Pole, AK 99705
907-488-0900
Email: *fnu@mosquitonet.com*
http://www.mosquitonet.com/~fnu

Flexible Products/Premium Polymers Group
2050 N. Broadway
Joilet, IL 60435
800-800-3626
Fax: 815-741-6912

Foam Enterprises, Inc.
13630 Watertower Circle
Minneapolis, MN 55441
888-900-3626
Fax: 612-559-0945
Email: *foament@aol.com*
http://www.foamenterprises.com

Foam Enterprises, Inc.
Comfort Foam
13630 Watertower Circle
Minneapolis, MN 55441
800-888-3342
Fax: 763-559-9045
Email: *info@comfortfoam.com*
http://www.comfortfoam.com

Foam Enterprises, Inc.
1752 Millerwood Drive
New Albany, IN 47150
812-945-0919
Fax: 812-949-0567
Email: *l.faith3084@aol.com*
http://www.foamenterprises.com

Foam Enterprises, Inc.
2640 East Hale Street
Mesa, AZ 85213
602-402-4440
Fax: 602-898-1586
Email: *tom_shackelford@foamenterpises.com*
http://www.foamenterprises.com

Foam Material and Equipment
5125 N. 2nd Street
St. Louis, MO 63147
314-231-6712
Fax: 314-231-6448

FOAM-TECH
P. O. Box 87
North Thretford, VT 05054
802-333-4333
http://supergreenfoam.com

Gaco Western Inc.
18700 Southcenter Parkway
Tukwila, WA 98188
206-575-0450
Email: *info@gaco.com*
http://www.gaco.com

Great Northern Insulation
Sealection 500
935 Keyes Drive
Woodstock, Ontario, Canada N4V 1C3
800-265-1914
519-537-5873
Fax: 519-539-7946
http://www.gni.on.ca/noframes.html

H.C. Fennell, Inc.
dba/Foam-Tech Div. 1
P. O. Box 87
Route 5
N. Thretford, VT 05054
802-333-4333
Fax: 802-333-4364
Email: *foamtech@sover.net*
http://www.supergreenfoam.com

Hess Polyurethanes, Inc.
40 Enterprise Blvd.
Atlanta, GA 30336
404-699-1960
Fax: 404-699-0036
Email: *mhess@hesspoly.com*

North Carolina Foam Industries
1515 Carter Street
Mt. Airy, NC 27030
336-789-9161
Fax: 336-787-9586
Email: *rogerm@ncfi.net*
http://www.ncfi.com

Polycoat Systems Inc.
5 Depot Street
Hudson Falls, NY 12839
800-547-4004
Fax: 518-747-5894
Email: *info@polycoat.com*
http://www.polycoat.com

Polycoat Systems, Inc.
5110-H Fulton Industrial Boulevard
Atlanta, GA 30336
800-229-4509
Fax: 404-696-9626
Email: *info@polycoat.com*
http://www.polycoat.com

Polyfoam Products, Inc.
P. O. Box 1132
2400 Spring Stuebner Road
Spring, TX 77389
281-350-8888
Fax: 281-288-6450

Polythane Systems, Inc.
2400 Spring Stuebner Road
Spring, TX 77389
800-221-3626
281-350-9000
Fax: 281-288-6450
Email: *tsparkspsi@aol.com*
http://www.polythane.com

Polythane Systems, Inc.
2119 NW 65th Avenue
Bell, FL 32619
407-341-3913
Email: *tompsi@aol.com*
http://www.polythane.com

Polythane Systems, Inc.
7167 Willowood Drive
Cincinnati, OH 45241
513-759-9420
Fax: 513-759-9421
Email: *ohiopsi@email.msn.com*
http://www.polythane.com

Polythane Systems, Inc.
930 Tahoe Boulevard, #802, Suite 379
Incline Village, NV 89451
775-832-8065
Fax: 775-832-6859
Email: *converse@polythane.com*
http://www.polythane.com

Polythane Systems, Inc.
1712 Wilshire Blvd.
Wilson, NC 27893
252-237-6900
Fax: 252-237-6960
Email: *psinc@cocentral.com*
http://www.polythane.com

Polythane Systems, Inc.
35 East 30th Street, Suite 7A
New York, NY 10016
212-689-4440
Fax: 212-685-9262
Email: *psinyc@aol.com*
http://www.polythane.com

Quantum Coatings, Inc.
12243 Branford Street
Sun Valley, CA 91352
818-896-1101
Fax: 818-897-0180
http://www.quantum.com

Quantum Coatings, Inc.
9200 Latty Avenue
Hazelwood, MO 63042
314-522-3510
Fax: 314-524-6522
Email: *bschenke@isofoam.com*
http://www.quantum.com

Resin Technology Co.
2270 Castle Harbor Place
Ontario, Canada 91761
800-729-0795
Fax: 909-923-9617
Email: *sellrtc@aol.com*
http://www.permax.com

Stepan Company
22 West Frontage Road
Northfield, IL 60093
847-446-7500
Fax: 847-441-1466
Email: *bbeauchamp@stepan.com*
http://www.stepan.com

SWD Urethane Company
222 South Date Street
Mesa, AZ 85201
480-969-8413
Fax: 480-461-6926
Email: *whip@swdurethane.com*
http://www.swdurethane.com

Technical Roofing Solutions, Inc.
1600 Airport Road
Waukesha, WI 53188
414-820-8939
Fax: 410-820-8949
Email: *gevance23@aol.com*

UCSC
1208 North Grand
Roswell, NM 88201
505-623-9726
Fax: 505-623-1908
Email: *ucsc@ucscurethane.com*
http://www.ucscurethane.com

UCSC
3010 W. Lincoln Street
Phoenix, AZ 85009
602-269-9711
Fax: 602-269-9115
Email: *ucsc@ucscurethane.com*
http://www.ucscurethane.com

Unique Urethanes, Inc.
906 H. D. Atha Road
Monroe, GA 30655
770-207-4534
Fax: 770-207-4535

Universal Coatings, Inc.
1220 E. North Avenues
Fresno, CA 93725
559-233-6300
Fax: 559-233-6200
Email: *uci@qnis.net*

Utah Foam Products, Inc.
3609 South 700 West
Salt Lake City, UT 84119
801-269-0600
Fax: 801-269-0620
Email: *info@utahfoam.com*
http://www.utahfoam.com

Radiant Barriers

R+ Heatshield Radiant Barrier
ASTRO-FOIL Innovative Energy
10653 W. 181st Avenue
Lowell, IN 46356
800-776-3645
219-696-3639
Fax: 800-551-3645
Email: *ie@astrofoil.com*
http://www.insul.net/common.html

ChemRex, Inc.
889 Valley Park
Shakopee, MN 55379
800-766-6776
612-496-6001
Fax:612-496-6058
Email: *pault@chemrex.com*
www.radiancecomfort.com

Florida Solar Energy Center
300 State Road 401
Cape Canaveral, FL 32920-4099

Environmentally Safe Products, Inc.
313 West Golden Lane
New Oxford, PA 17350
800-289-5693
717-624-3581
Fax: 717-624-7089
Email: *espinc@low-e.com*
www.low-e.com

Fibrex Insulations, Inc.
561 Scott Road
Sarnia, Ontario, Canada N7T 7L4
800-265-7514
Fax: 800-363-4440

Pactive Corporation
(formerly Amocor, Amofoam, Tenneco)
2100 RiverEdge Parkway, Suite 175
Atlanta, GA 30328
800-227-7339
678-589-7337
Fax: 678-589-7325
http://www.tennecobuildingprod.com/index.html

Simplex Products
P. O. Box 10
Adrian, MI 49221
800-345-8881
517-263-8881
Fax: 517-265-3752

Thermal Design, Inc.
P. O. Box 468
Madison, NE 68748
800-255-0776
402-454-6591
Fax: 402-454-2708

Reflective insulation

Astro-Foil Reflective Insulation
R+ Heatshield Radiant Barrier
ASTRO-FOIL Innovative Energy
10653 W. 181st Avenue
Lowell, IN 46356
800-776-3645
219-696-3639
Fax: 800-551-3645
Email: *ie@astrofoil.com*
http://www.insul.net/common.html

Environmentally Safe Products, Inc.
313 West Golden Ln.
New Oxford, PA 17350
800-289-5693
717-624-3581
Fax: 717-624-7089
Email: *espinc@low-e.com*
www.low-e.com

Innovative Insulation, Inc.
6200 W. Pioneer Parkway
Arlington, TX 76013
800-825-0123
817-446-6200
Fax: 817-446-6222
Email: *insulation@earthlink.net*

Parsec, Inc.
P. O. Box 551477
Dallas, TX 75355-1477
800-527-3454
Fax: 214-553-0983

Ply-Foil, Inc.
P. O. Box Q
Elkhart Lake, WI 53020
800-558-5895

Polyair, Inc.
4525 Frederick Drive
Atlanta, GA 30336
1-888-POLYAIR
404-505-8742
404-505-1198

Sailshade
P. O. Box 3935
Westport, Ma 02790
888-600-3858
Fax: 508-677-3160
Email: *susan@sailshade.com*

Sealed Air Corporation
Park 80 East
Saddle Brook, NJ 07663
201-791-7600

TechShield
Louisiana-Pacific Corp.
Headquarters/Corporate Office
111 S.W. Fifth Avenue
Portland, OR 97204
800-648-6893
Email: *customer.support@LPCorp.com*

Solar Energy Corporation
Box 3065
Princeton, NJ 08543-3065
609-883-7700
LO/MIT I and II radiant barrier paints

Solar Shield, Inc.
1264 Old Alpharetta Road
Alpharetta, GA 30005
800-654-3645
Fax: 770-343-8093

Solec
129 Walters Avenue
Ewing Township, NJ 08638
609-883-7700
Fax: 609-497-0182

Tenneco Building Products
242 North Thistle Down
Kennett Square, PA 19348
800-422-1284, ext. 338
610-444-6218
Fax: 610-444-6217

Rockwool

American Rockwool
1000 Patty Hamilton Road
Nolanville, TX 76559
800-792-3539 (TX)
800-762-9665 (other)

Rock Wool Manufacturing Company
P. O. Box 506
Leeds, AL 35094-0506
205-699-6121
Fax: 205-699-3132

Roxul, Inc.
551 Harrop Drive
Milton, Ontario Canada L9T-3H3
800-265-6878
Fax: 905-878-8077

Sloss Industries Corporation
3500 35th Avenue North
Birmingham, AL 35207
205-808-7803
Fax: 205-808-7805

Thermafiber Mineral Wool
3711 W. Mill Street
Wabash, IN 46992
219-563-2111
Fax: 219-563-8979
Email: *jshriver@thermafiber.com*

SIPs

Structural Insulated Panel Association
3413 A 56th Street NW
Gig Harbor, WA 98335
253-858-SIPA (7472)
Fax: 253-858-0272
Email: *staff@sips.org*
http://www.sips.org/

AFM Corporation
R-Control Building Systems
Box 246
24000 W. Highway 7
Excelsior, MN 55331
800-255-0176

Apache Products Company
Industrial Park
P. O. Box 160
Union, MS 39365
800-530-7762

FischerSIPS, Inc.
1843 Northwestern Parkway
Louisville, KY 40203
502-778-5577
800-792-7477
Fax: 502-774-5644
Email: *markv@fischergrp.com*
www.fischersips.com

Insulspan SIPS
Perma “R” Products, Inc.
Johnson City, TN
800-251-7532

Winter Panel Corporation
RR 5, Box 168B
Glen Orne Drive
Brattleboro, VT 05301
802-254-3435

Straw

California Straw Building Association (CASBA)
115 Angelita Avenue
Pacifica, CA 94044
805-546-4274
http://www.strawbuilding.com

Daniel Smith & Associates, Architects
1107 Virginia Street
Berkeley, CA 94702
510-526-1935
Fax: 510-526-1961
Email: *info@dsaarch.com*
http://www.dsaarch.com/

Development Center for Appropriate Technology
P. O. Box 41144
Tucson, AZ 85717
520-326-1418
Email: *strawnet@aol.com*

Harvest Built Homes
Nancy Richardson, Executive Director
93 California Street
Ashland OR 97520
541-482-8733
www.harvesthomes.org

GreenFire Institute
1509 Queen Anne Avenue North, #606
Seattle, WA 98109
206-284-7470

Straw Bale Construction Association (SBCA)
Star Route 2, Box 119
Kingston, NM 88042
505-895-5400

Straw Bale Association of Nebraska (SBAN)
c/o Joyce Coppinger
2110 South 33rd Street
Lincoln, NE 68506-6001
800-910-3019.

Straw Bale Association of Texas (SBAT)
P. O. Box 4211
Austin, TX 78763-4211
512-302-6766

The Last Straw
HC 66 Box 119
Hillsboro, NM 88042
505-895-5400
Email: *thelaststraw@zianet.com*
www.strawhomes.com

The Staw Bale House
by Althena Swntzell Steen, Bill Steen, and David Bainbridge
Chelsea Green Publishing Company
White River Junction, VT
1994, ISBN: 0-930031-71-7
http://www.amazon.com
http://www.powells.com

Tripolymer foam

C. P. Chemical Co., Inc.
Tripolymer Foam
25 Home Street
White Plains, NY 10606
914-428-2517
Fax: 914-428-3630
Email: *Info@Tripolymer.com*
http://www.tripolymer.com

USA Energy Consultants
Tripolymer Foam
Central and Southern Ohio
5411 Franklin Street
Hilliard, OH 43026
614-529-2440
Fax: 614-529-2445
888-894-1024
Email: *info@tripolymer.com*

Vapor Retarders

Grace Construction Products
62 Whittemore Avenue
Cambridge, MA 02140
617-876-1400
Fax: 617-498-4311
800-354-5414

Owens Corning World Headquarters
One Owens Corning Parkway
Toledo, OH 43659
800-GET-PINK
Fax: 419-248-7506
Email: *answers@owenscorning.com*
http://www.owenscorning.com

Pactive Corporation
(formerly Amocor, Amofoam, Tenneco)
2100 RiverEdge Parkway, Suite 175
Atlanta, GA 30328
800-241-4402
http://www.tennecobuildingprod.com/index.html

Reef Industries, Inc.
P. O. Box 750250
Houston, TX 77275-0250
800-231-6074
713-507-4200
Fax: 713-507-4295

Sealflex Industries
2925 College Avenue, B4
Costa Mesa, CA 92626
800-651-2098
714-708-0850
Fax: 714-708-2711

Vermiculite

American Vermiculite Corp.
1000 Cobb Place Blvd.
Bldg. 100, Suite 190
Kennesaw, GA 30144
770-590-7970
Fax: 770-590-0239

Isolatek International
41 Furnace Street
Stanhope, NJ 07874
219-356-2040, ext. 317
Fax: 219-356-2337
Email: *junderwood@isolatek.com*

Vermiculite Industrial Corp.
731-733 Washington Road
P. O. Box 11999
Pittsburgh, PA 15228-0999
412-344-9900
Fax: 412-344-9909
Email: *bognar5@adelphia.net*

W. R. Grace & Co.
62 Whittemore Avenue
Cambridge, MA 02140
617-498-4346
Fax: 617-547-7663
Email: *eric.m.moeller@grace.com*

Appendix

C

Directory of Historical Insulation Products

The information contained within this directory has been obtained from *The Thermal Insulation of Buildings*, by Paul Dunham Close (New York: Reinhold, 1947). This directory is not intended to be an all-inclusive source; however, the information is presented as a service to the reader and to facilitate further research or education. Every effort has been made to ensure the accuracy of the material. The author and the publisher will not accept any liability for omissions or errors.

Trade name	Manufacturer or distributor	Description or basic materials
Air-cell-board	Waldorf Paper Products Co., St. Paul, MN	Single layer of corrugated board with liner both surfaces
Air-Flo-Board	Waldorf Paper Products Co., St. Paul, MN	Double layer of corrugated board with flat paper between and on both surfaces, $^3/_8$" thick
Air-Met	H. D. Catty Corporation, New York, NY	Reflective insulation
Airseal Mineral Wool	Insulation Products, Ltd., Toronto, Ontario, Canada	Mineral wool
Airtite Corkboard	Cork Import Company, New York, NY	Corkboard
Alfol	Alfol Insulation Co., New York, NY	Aluminum foil blanket
Ankarboard	Ankarsviks Angsags A/B, Sundsvall, Sweden	Wood fiber

Trade name	Manufacturer or distributor	Description or basic materials
Anti-Pyre Quilt	Samuel Cabot, Inc., Boston, MA	Blanket insulation consisting of eelgrass between fire-resistant paper
Armstrong's Insulating Wool	Armstrong Cork Co., Lancaster, PA	Glass wool
Asbestos Quilt	Samuel Cabot, Inc., Boston, MA	Blanket insulation consisting of eelgrass between layers of sheet asbestos
Balsam Wool	Wood Conversion Company, St. Paul, MN	Blanket insulation consisting of wood fibers encased on both sides and edges with kraft liners
Banroc	Johns-Manville Sales Corp., New York, NY	Rock wool
Barrett	Barrett Company, New York, NY	Rock wool
Beaver Insulating Lath	CertainTeed Products Corp., Chicago, IL	Reflective insulation consisting of gypsum lath with aluminum foil surface
BH	Baldwin-Hill Company, Trenton, NJ	Mineral wool
Bildrite sheathing	Insulite, Division of M. & O. Paper Co., Minneapolis, MN	Wood fiber insulating board sheathing
Blendtex	United States Gypsum Co., Chicago, IL	Wood fiber insulating board
Cabots Quilt	Samuel Cabot, Inc., Boston, MA	Blanket insulation consisting of eelgrass between layers of paper
Canasco	Canadian Asbestos Co., Montreal, Quebec, Canada	
Canec	Hawaiian Cane Products, Ltd., San Francisco, CA	Cane fiber insulating board
Capital	Standard Lime & Stone Co., Baltimore, MD	Rock wool
Cardinal Insulating Felt	American Hair & Felt Co., Chicago, IL	Animal hair blanket insulation
Carney	Carney Rock Wool Co., Mankato, MN	Rock wool
Cell-U-Blanket	Masonite Corporation, Chicago, IL	Blanket insulation consisting of wood fiber insulation between layers of paper
Cellufoam	Masonite Corporation, Chicago, IL	Semirigid wood fiber product
Cellulite	Gilman Bros. Co., Gilman, CT	Cotton blanket insulation

Trade name	Manufacturer or distributor	Description or basic materials
Celo-Block	Celotex Corporation, Chicago, IL	Cold storage insulation made from cane fiber insulating board
Celobric	Celotex Corporation, Chicago, IL	Cane fiber insulating board with asphalted surface embedded on one side with mineral granules in brick pattern
Celo-Siding	Celotex Corporation, Chicago, IL	Cane fiber insulating board, asphalt-coated, mineral granules embedded on one side
Celotex	Celotex Corporation, Chicago, IL	Cane fiber insulating board
Celotex rock wool	Celotex Corporation, Chicago, IL	Rock wool, granulated, loose, and batts
Cemesto	Celotex Corporation, Chicago, IL	Insulating board between layers of asbestos cement board
Cemex	Structural Insulation Corp., Quincy, IL	Excelsior wood fiber and Portland cement
Century	Keabey & Mattison Co., Ambler, PA	Rock wool
Colorkote	Fir-Tex Insulating Board Co., Portland, OR	Wood fiber insulating board
Columbia	U.S. Mineral Wool Co., Chicago, IL	Mineral wool
Corkduc	Cork Import Company, New York, NY	Corkboard
Decoblend	The Flintkote Co., New York, NY	Wood fiber insulating board
Denesen	Denesen Company, Minneapolis, MN	Rock wool products
Domster Board	Made in Sweden	Wood fiber insulating board
Donnacona	Donnacona Paper Co., Donnacona, Quebec, Canada	Laminated wood fiber insulating board
Dry Zero	American Hair & Felt Co., Chicago, IL	Kapoc blanket insulation
Dubble-Seal Sheathing	Masonite Corporation, Chicago, IL	Wood fiber insulating board sheathing
Eagle	Eagle-Picher Sales Co., Cincinnati, OH	Mineral wool
Ecod Metal Lath	Reynolds Metal Co., Richmond, VA	Plaster base of steel reinforcing wire backed with aluminum foil on kraft paper
Ehret Rock Wool Batts	Ehret Magnesia Mfg. Co., Valley Forge, PA	Rock wool batts

Trade name	Manufacturer or distributor	Description or basic materials
Enso Board	Enso-Gutzeit Co., Enso, Finland	Wool fiber insulating board
Feltrok Mineral Wool	Independent Insulations, Inc., Tacoma, WA	Mineral wool
Ferrotherm	American Flange & Mtg. Co., New York, NY	Reflective insulation, sheet iron with alloy coating
Fesco Board	F.E. Schundler & Co., Joliet, IL	Slab insulation, vermiculite with asphalt binder
Fiberglas	Owens-Corning Fiberglas Corp., Toledo, OH	Glass wool, batts, blankets, and blowing and pouring wool
Fiberglas AE Board	Owens-Corning Fiberglas Corp., Toledo, OH	Slab insulation, compressed glass fibers, asphalt-enclosed
Fiberglass PF Insulation	Owens-Corning Fiberglas Corp., Toledo, OH	Slab insulation, compressed glass fibers with binder
Fiberlite	Insulite Division M. & O. Paper Co., Minneapolis, MN	Wood fiber insulating tile
Firkote	Fir-Tex Insulating Board Co., Portland, OR	Wood fiber insulating board sheathing
Fir-Tex	Fir-Tex Insulating Board Co., Portland, OR	Wood fiber insulating board
Five Point Mineral Wool	R. Laidlow Lumber Co., Ltd., Toronto, Ont., Canada	Mineral wool
Flintkote Insulation Board	The Flintkote Co., New York, NY	Wood fiber insulating board
Flintkote Insulating Wool	The Flintkote Co., New York, NY	Glass wool
Flintlock Sheathing	The Flintkote Co., New York, NY	Insulating board sheathing
Foamglas	Pittsburgh Corning Corp., Pittsburgh, PA	Cellular glass slab
Gimco	National Gypsum Co., Buffalo, NY	Rock wool
Gold Bond Aluminum Foil Insulating Board and Lath	National Gypsum Co., Buffalo, NY	Gypsum wallboard and lath with aluminum foil laminated to one surface
Gold Bond Insulating Board	National Gypsum Co., Buffalo, NY	Wood fiber insulating board
Gold Bond Sealed Blanket, Batts, and Rock Wool	National Gypsum Co., Buffalo, NY	Rock wool

Trade name	Manufacturer or distributor	Description or basic materials
Gold Bond Dry Fill Insulation	National Gypsum Co., Buffalo, NY	Powdered gypsum fill insulation
Graylite	Insulite Division of M. & O. Paper Co., Minneapolis, MN	Wood fiber insulating board
Gyproc	Gypsum, Lime & Alabastine, Ltd., Toronto, Ontario, Canada	Mineral wool
Handcraft	Wilson & Co., Chicago, IL	
Hairinsul	American Hair & Felt Co., Chicago, IL	Blanket insulation made from cattle hair or hair and jute
Handi-Batts	National Gypsum Co., Buffalo, NY	Rock wool batts
Hilite	United States Gypsum Co., Chicago, IL	Wood fiber insulating board
Homart Loose Rock Wool and Batts	Sears-Roebuck & Co., Chicago, IL	Rock wool
Homart Mineral Fill	Sears-Roebuck & Co., Chicago, IL	Vermiculite
Homeguard	Gamble Stores, Inc., Minneapolis, MN	Fill insulation made from wood fiber
Infra	Infra Insulation Co., New York, NY	Accordion-type aluminum foil
Insl-Cotton	Taylor Bedding Mfg. Co., Taylor, TX	Cotton insulating blanket
Ins-Lite	Insulite Division of M. & O. Paper Co., Minneapolis, MN	Wood fiber insulating board
Insulite	Insulite Division of M. & O. Paper Co., Minneapolis, MN	Wood fiber insulating board
Insulroc	Rock Products Co., Nashville, TN	Rock wool
Insul-Wool	Insul-Wood Corporation, Wichita, KS	Wood fiber insulation
Insulwool	General Insulating Products Co., Brooklyn, NY	
Isorel	Isorel, Paris, France	Wood fiber insulating board
Ivrykote Building Board (Fir-Tex)	Fir-Tex Insulating Board Co., Portland, OR	Wood fiber insulating board

Trade name	Manufacturer or distributor	Description or basic materials
J-M Insulating Board	Johns-Manville Sales Corp., New York, NY	Wood fiber insulating board
Jiffy Blanket	Jiffy Mfg. Co., Hillside, NJ	Blanket insulation consisting of macerated paper between kraft paper
Johns-Manville Rock Wool	Johns-Manville Sales Corp., New York, NY	Rock wool
Jointite	Mundet Cork Co., Brooklyn, NY	Corkboard
Kimsul	Kimberly-Clark Corporation, Neenah, WI	Wood fiber blanket insulation
Kolorfast	Wood Conversion Co., St. Paul, MN	Wood fiber insulating board
L-W Insulating Board	Ljusne-Woxna Co., Ljusne, Sweden	Wood fiber insulating board
Lockaire	Plastergon Wallboard Co., Buffalo, NY	Licorice root insulating board
Lo-K	Lockport Cotton Batting Co., Lockport, NY	Cotton insulating blanket
Lok-Joint	Insulite Division of M. & O. Paper Co., Minneapolis, MN	Wood fiber insulating board lath
Maftex	See Lockaire	
Maizewood	Maizewood Insulation Co., Dubuque, IA	Insulating board made from corn stalks
Masonite	Masonite Corporation, Chicago, IL	Wood fiber insulating board
Masterfill	B.F. Nelson Mfg. Co., Minneapolis, MN	Vermiculite
Metallation	Reynolds Metals Co., Richmond, VA	Aluminum foil reflective insulation
Micafil	Munn and Steele, Inc., Newark, NJ	Vermiculite
Mico	Mineral Insulation Co., Chicago, IL	Mineral wool
Mineral Wood Board	Armstrong Cork Company, Lancaster, PA	Slab insulation made from rock wood with asphalt binder
Mitchell & Smith	Mitchell & Smith Co., Detroit, MI	Corkboard
Multicell	Multicell Sales Corp., Minneapolis, MN	Blanket insulation consisting of layers of newspapers stiched together

Trade name	Manufacturer or distributor	Description or basic materials
Nat Rock	National Rock Wool Sales, Inc., Lagro, IN	Rock wool
Natur-Temp	Barnhardt Mfg. Co., Charlotte, NC	Cotton insulating blanket
Naturzone	Wilson & Company, Chicago, IL	Slab insulation made from hog hair and asphalt
Novoid	Cork Import Corp., New York, NY	Corkboard
Novoid Mineral Wool Board	Cork Import Corp., New York, NY	Slab insulation made from mineral wool
Nu-Wood	Wood Conversion Company, St. Paul, MN	Wood fiber insulating board
Ozite All-Hair Building Blanket	American Hair & Felt Company, Chicago, IL	Cattle hair insulating blanket
Palmatex	Palmatex Corporation, Pinellas Park, FL	Insulating board made from palm fibers
Pal-o-Pak	Hines Lumber Co., Chicago, IL	Fill insulation
Partemp	Firestone Tire & Rubber Co., Akron, OH	Cotton insulating blanket
Perfection	Riverton Lime & Stone Co., Riverton, WV	Rock wool
Poeco	C. W. Poe Company, Cleveland, OH	Rock wool
Porete	Porete Mfg. Company, North Arlington, NJ	Slab insulation made from wood fiber and Portland cement
Porex Slabs	Porete Mfg. Company, North Arlington, NJ	Slab insulation made from wood fiber and Portland cement
Pyrofill	U.S. Gypsum Company, Chicago, IL	Powdered gypsum fill insulation
Red Top Batts, Blanket, and Insulating Wood	U.S. Gypsum Company, Chicago, IL	Glass wool (see Fiberglas)
Reyn-O-Cell	Reynolds Metals Company, Richmond, VA	Cotton blanket insulation
Rock Cork	Johns-Manville Sales Corporation, New York, NY	Slab insulation consisting of rock wool with asphalt binder
Rocktex	Philip Carey Mfg. Company, Cincinnati, OH	Rock wool
Rubatex	Virginia Rubatex Division Great Industries, Inc., Bedford, VA	Slab insulation made from rubber

Trade name	Manufacturer or distributor	Description or basic materials
Rocklath, Insulating	U.S. Gypsum Company, Chicago, IL	Gypsum lath with aluminum foil laminated to one surface
Ru-Ber-Oid Rock Wool Insulation	Ruberoid Company, New York, NY	Rock wool
Salisco	Salem Lime & Stone Company, Salem, IN	Rock wool
Satincote	Insulite Division of M. & O. Paper Co., Minneapolis, MN	Wood fiber insulating board
Seal-O-Wool	U.S. Roofing Company, St. Paul, MN	Mineral wool
Sheetrock, Insulating	U.S. Gypsum Company, Chicago, IL	Gypsum wallboard with aluminum foil laminated to one surface
Silvercote	Silvercote Products Company, Chicago, IL	Reflective fabric consisting of sheets coated with oxide composition
Simpson Insulating Board	Simpson Logging Co., Seattle, WA	Wood fiber insulating board
K-25	Wood Conversion Co., St. Paul, MN	Made from balsam wool fiber
Sisalation	Sisalkraft Company, Chicago, IL	Reflective moisture barrier paper
Smoothcote	Insulite Division of M. & O. Paper Co., Minneapolis, MN	Wood fiber insulating board
Sonotherm	Sonotherm Mfg. Co. Inc., San Francisco, CA	Slab insulation made from wood fiber and cement
Sprayo-Flake	Sprayo-Flake Company, Chicago, IL	Fibrous flakes projected with anatomized adhesive against surfaces to be insulated
Spun Rock Wool	Spun Rock Wools, Ltd., Thorold, Ont, Canada	Rock wool
Sta-Lite Tile	Wood Conversion Company, St. Paul, MN	Wood fiber insulating board tile
Standard Cotton Insulation	Standard Cotton Products Co., Flint, MI	Cotton insulating blanket
Stonefelt	Johns-Manville Sales Corp., New York, NY	Rock wool
Stud-Pak Wool	United States Mineral Wool Co., Chicago, IL	Mineral wool
Summit	Ohio Valley Rock Asphalt Co., Louisville, KY	Rock wool

Trade name	Manufacturer or distributor	Description or basic materials
Super-Felt	Johns-Manville Sales Corp., New York, NY	Rock wool
Supertemp Block	Eagle-Picher Sales Co., Cincinnati, OH	Mineral wood slab insulation
Temlok	Armstrong Cork Company, Lancaster, PA	Wood fiber insulating board
Temseal Insulating Sheathing	Armstrong Cork Company, Lancaster, PA	Wood fiber insulating board sheathing
Ten Test	International Fibre Board, Ltd., Gatineau, Quebec, Canada	Wood fiber insulating board
Textolite Foam	General Electric Company, Pittsfield, MA	Liquid rosin that foams to light, cellular mass many times original volume
Thermax	Celotex Corporation, Chicago, IL	Slab insulation made from wood fiber and magnesite cement
Therminsul	The Therminsul Corporation, Kalamazoo, MI	Rock wool
Thermofelt	American Hair & Felt Co., Chicago, IL	Blanket insulation made from cattle hair and asbestos fiber
Therm-O-Proof	Therm-O-Proof Ins. Mfg. Co., Chicago, IL	Mineral wool
Thermotex	A/B Varjag, Stockholm, Sweden	Wood fiber insulating board
Tomhave	Northern Home Improvement Co., Sandstone, MN	Rock wool
Torex	Torefors A/B, Tore, Sweden	Wood fiber insulating board
Treetex	Mo and Domsjo Treetex A/B, Ornskolsdvik, Sweden	Wood fiber insulating board
Union Rock Wool	Union Rock Wood Corporation, Wabash, IN	Rock wool
U.S. Royal Insulation Board	U.S. Rubber Company, Akron, OH	Slab insulation made from rubber
United States Wool	United States Mineral Wool Co., Chicago, IL	Mineral wool
Ward Brand Rock Wool	Montgomery, Ward & Company, Chicago, IL	Rock wool
Waukesha	Waukesha Lime & Stone Co., Waukesha, WI	Rock wool

Trade name	Manufacturer or distributor	Description or basic materials
Weathertie Sheathing	Johns-Manville Sales Corp., New York, NY	Wood fiber insulating board sheathing
Weatherwood	U.S. Gypsum Company, Chicago, IL	Wood fiber insulating board
Western Rock Wool	Western Rock Wool Corp., Huntington, IN	Rock wool
Wyolite	Wyolite Insulating Products Co., Cleveland, OH	Vermiculite
Yamaska	Yamaska Mills, Inc., St. Pierde-Bagot, Quebec, Canada	Wood fiber insulating board
Zonolite	Universal Zonolite Insulation Co., Chicago, IL	Vermiculite

Insulation Handbook

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For my wife, Valerie, and
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and boundless patience.

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PREFACE

All around us exists the constant transfer of energy, heat, air, and moisture. And yet human beings, in a pervasive attempt to obtain thermal comfort, are always trying to stop nature from doing what it has always done, is doing now, and will continue to do. Thermal energy will always "move" from a hot source to a cold source. The predominant building constituent that is intended to retard this process is thermal insulation. This is a seemingly daunting challenge for a material that possesses the duality of being so modest but so indispensable, all too often anonymous yet so essential. Simply put, thermal insulation is the intrinsic component in construction that determines the nonsuperficial, experiential success and elemental enjoyment of a home.

Etymologic experts trace the origins of the English word insulate back to the Latin word *insula*, meaning "isle." Historical references suggest this was attributed to the fact that an isle was "insulated" by water. In the same way that water was a barrier to nomadic warriors invading an isle, insulation is a barrier to the "invaders" of thermal or acoustical energy.

Functioning as the barrier between the conditioned volume of a building and the exterior, insulation materials are designed primarily to resist heat flow, whether the energy is moving from outside to inside or inside to outside (or, in some applications, inside to inside). The function of mass insulations and reflective insulations, although designed to address the thermal transfer in two ways, remain basically the same:

1. Control temperature of inside surfaces that affect the comfort of occupants and aid or deter condensation

2. Conserve energy by reducing heat transmission through building sections that determine the energy requirements for both heating and cooling

Physical properties and envelope design also may allow thermal insulations to perform additional functions. These include

1. Adding structural strength to a wall, ceiling, or floor section
2. Providing support for a surface finish
3. Impeding water vapor transmission
4. Preventing or reducing damage to equipment and structure from exposure to fire and freezing conditions
5. Reducing noise and vibration[1]

It is not just the thirtieth anniversary of Earth Day, celebrated on April 22 of this year (2000), that has given the noble cause of saving energy such prominence. It is because rising energy costs, especially heating oil, have begun to affect homeowners in their purses. "Spend a dollar on insulation, save $12 in energy costs" is a quote from a technical paper reporting on the impact of global climate change.[2]

Insulation has become big business. Statistics published by the Department of Energy indicate that these trends will continue. Total energy consumption is projected to increase from 94.9 to 120.9 quadrillion Btu between 1998 and 2020, an average annual increase of 1.1 percent. The energy end use in U.S. residential and commercial buildings for space heating and cooling was 9.5 quadrillion Btu in 1990 and will be over 11 quadrillion Btu in the year 2010.[3]

Electric bills, gas bills, oil bills, HVAC repair bills, etc. are an everyday part of homeownership. As most homeowners, contractors, designers, and architects already know, there is no magic pill to swallow to avoid the monetary realities of obtaining thermal comfort. However, there is joy to be found in knowing that the homeowner's most precious commodity is constructed using the most efficient, most environmentally responsible, most vermin resistant, or maybe even the least expensive method available.

This book, it is hoped, will provide readers with the necessary tools to evaluate the many different types of insulation materials. Each insulation product discussed herein possesses properties that are suitable for certain applications while being unsuitable for others. Even the old faithful R-value is no longer the only consideration when choosing residential insulation. Other properties that now demand and deserve proper review are the material's cost, fire resistance, mold resistance, insect resistance, vermin and moisture transmission, environmental benefits, health impact, and the ease and appropriateness of its application.

Not only are contemporary insulation materials discussed in this book, but historical products are reviewed as an aid to the renovator or preservationist. Future technologies and products that may one day be used as conventionally as the mass insulation products sold today in home improvement stores are also examined.

In addition to a review of solitary insulation materials, insulation systems are also addressed in this book. These hybrid, composite, or engineered products work in unison with other elements. For example, adjacent airspaces are necessary for the proper performance of radiant barriers. New systems serve as envelope components for the building shell, such as structural insulated panels (SIPs) or insulated concrete formwork (ICF). Unconventional materials such as straw bales or rammed earth also demonstrate effectiveness within certain parameters.

It is important to point out that the specific use of trade names in this book is solely for the purpose of providing specific information. References made in this book do not signify unconditional approval, nor does the exclusion of other products signify disapproval. Mention of a company name does not imply endorsement, nor does failure to mention an organization imply criticism.

Although this work is designed as a reference book, the reader is encouraged to read the entire book to be able to make educated decisions based on either the insulation material type or the installation method preferred. Product data and installation guidelines are presented in this book for general information only. For additional research, a specific manufacturer's product literature is always a good place to start when evaluating thermal insulation; however, it should be balanced with other information sources such as independent testing, contrary perspectives, and when possible, qualified first-hand opinions by actual users or installers.

The 1990s saw a housing boom that may have established an unintended legacy: Residential building predominantly has become a production-oriented process. All too often design decisions are based on the short-run implications of initial cost, without respect or consideration for actual long-term, life-cycle costs. Failure to consider the most appropriate material for a specific application or in response to a specific climate is equally irresponsible.[4]

Residential architects repeatedly work with clients who wish to renovate their homes, remodel a kitchen, or maybe just add on a few rooms and a bath. Rare is the client who chooses to or is able to "remodel" his or her existing home's insulation. It may be impractical, too expensive, or not even considered, yet the proper selection of a home's thermal insulation is essential to the holistic success of the design, functionality, and enjoyment of the home. It is anticipated that this book will edify the homebuilder, designer, architect and homeowner who are in the pursuit of good design. Unlike the brick, the glass, or the shingle, it is sometimes the "stuff" that is unseen that makes the difference.

Rick Bynum, AIA
May 2000

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