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

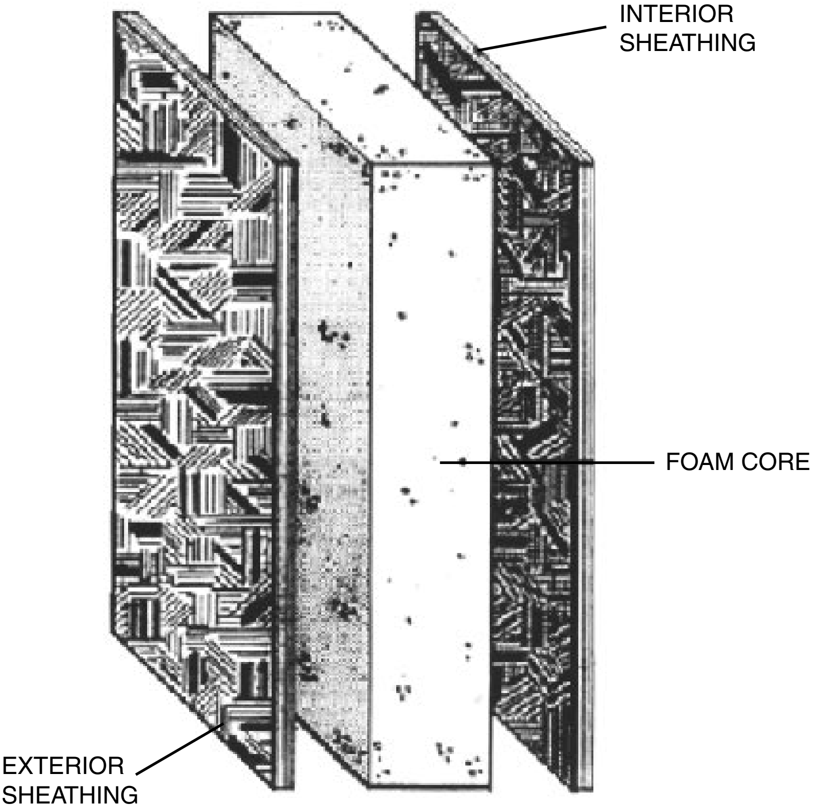

Figure 15.1 Structural insulated panel. (*SIPA*)

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 nonstructural 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 ($4\frac{1}{2}$" 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*)

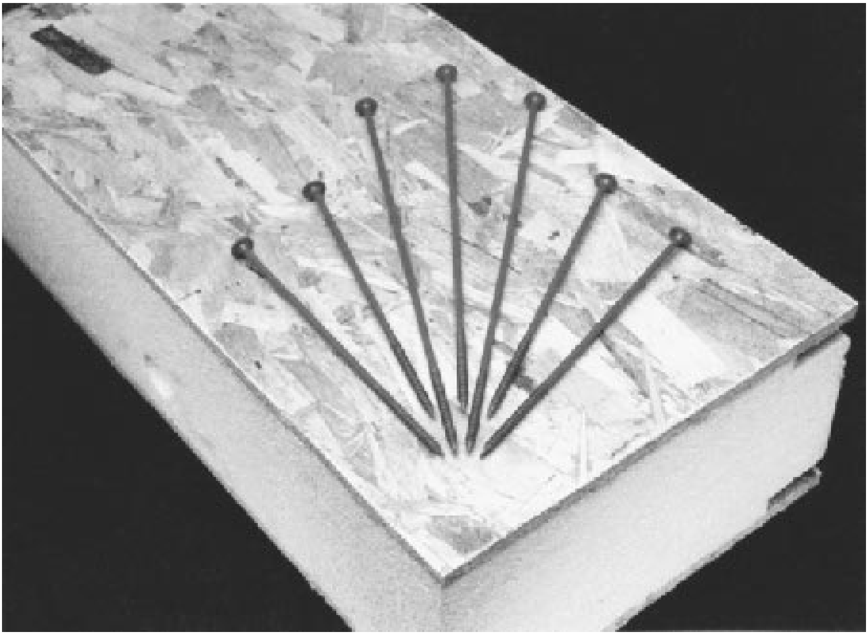

Figure 15.6 SIP screw fasteners. (*R-Control Building Systems*)

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

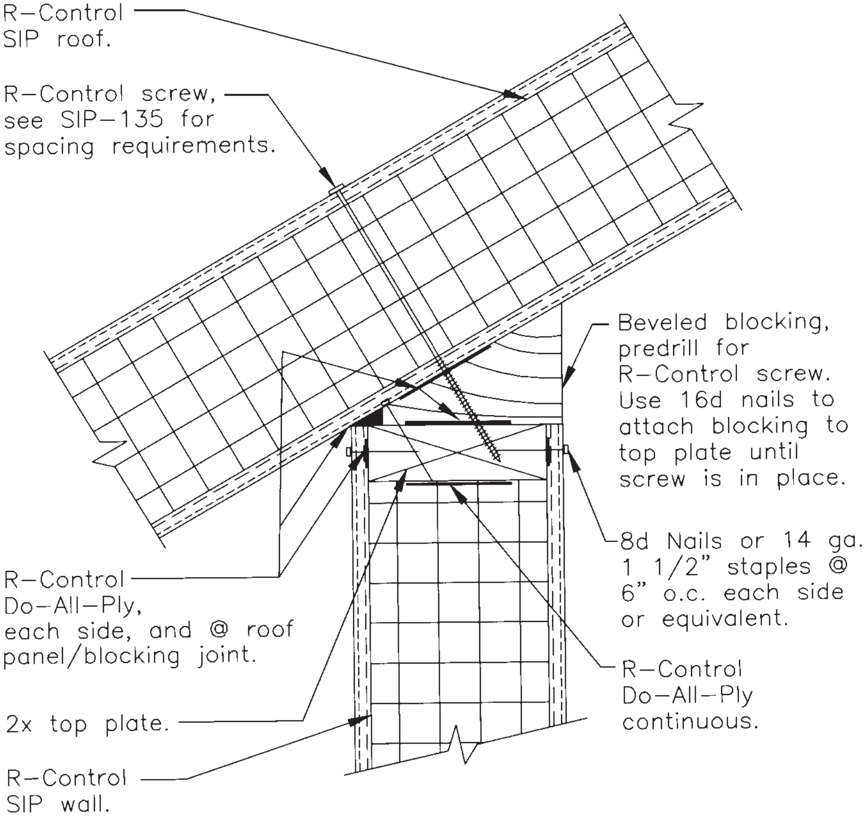

Figure 15.8 Roof panel installation. (*R-Control Building Systems*)

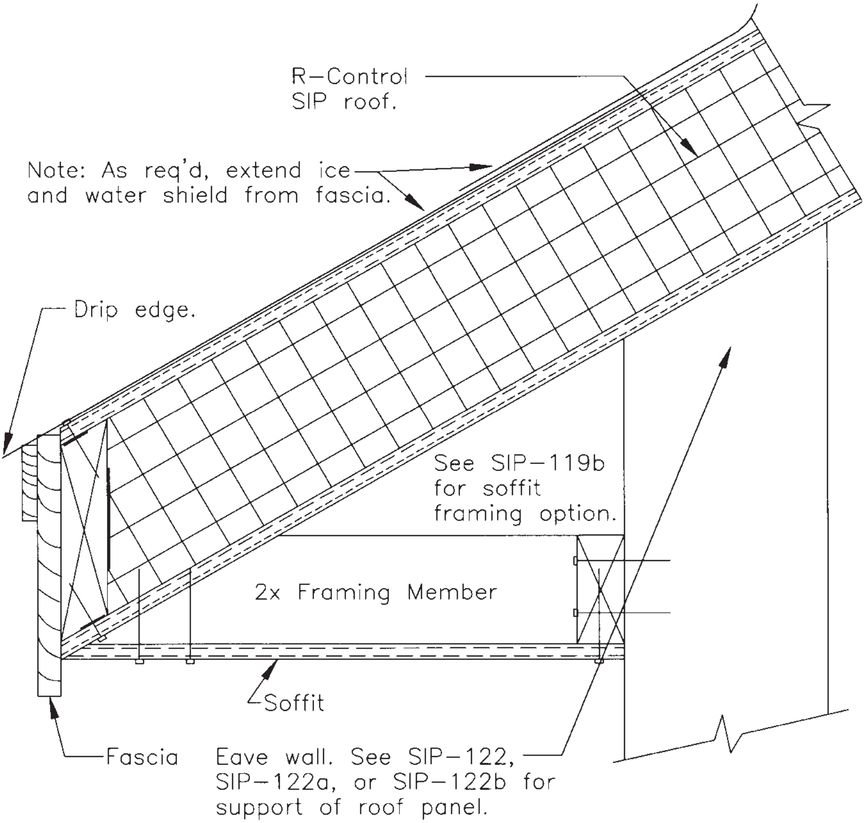

Figure 15.9 Eave detail. (*R-Control Building Systems*)

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×)

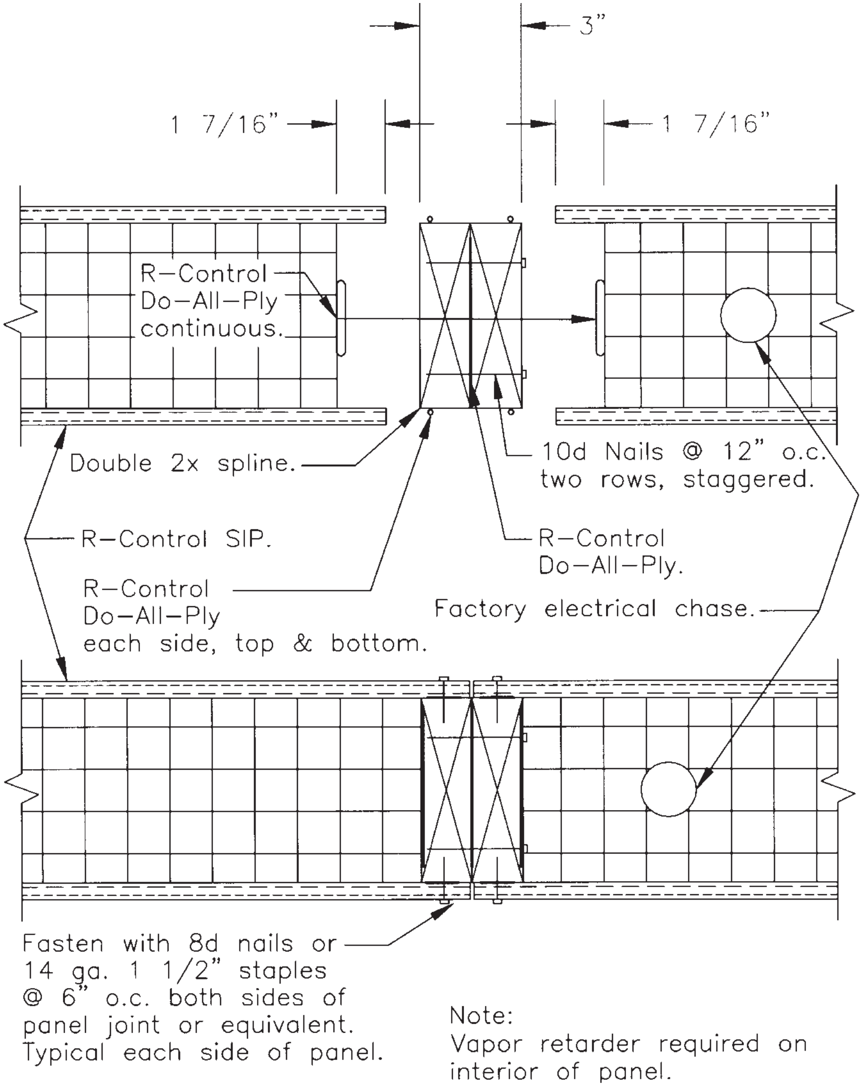

Figure 15.10 Double 2× spline connection. (*R-Control Building Systems*)

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

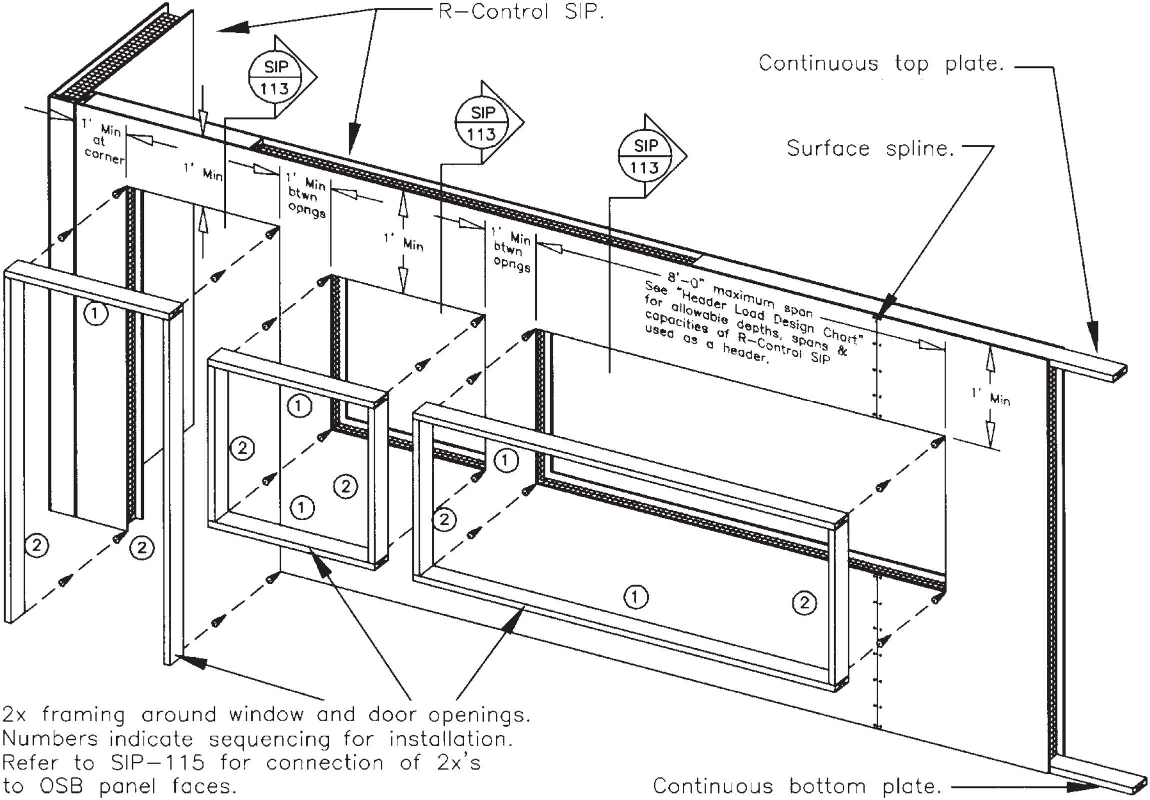

Figure 15.11 Rough openings. (*R-Control Building Systems*)

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

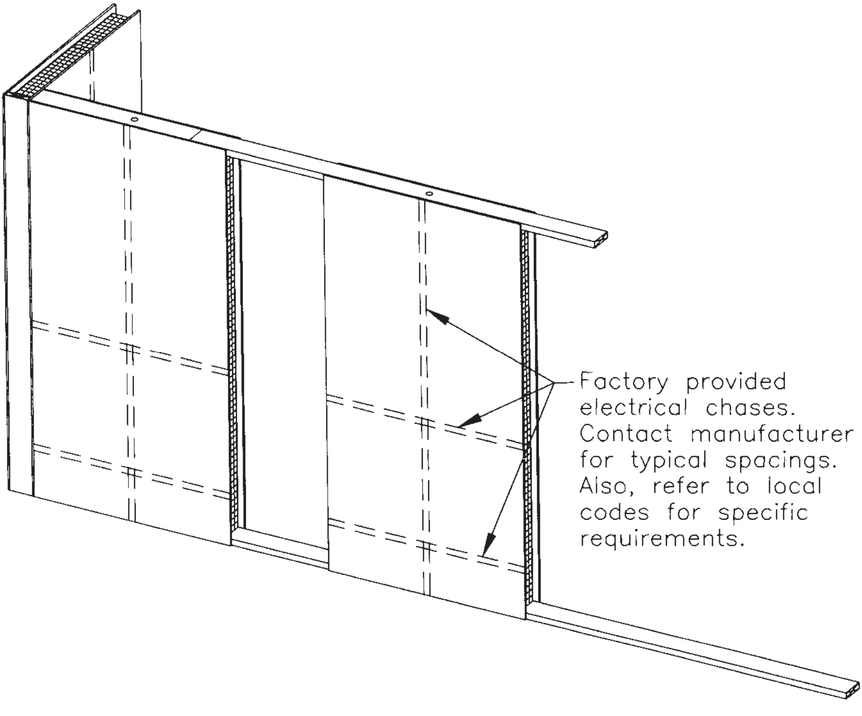

Figure 15.12 Electrical chase locations. (*R-Control Building Systems*)

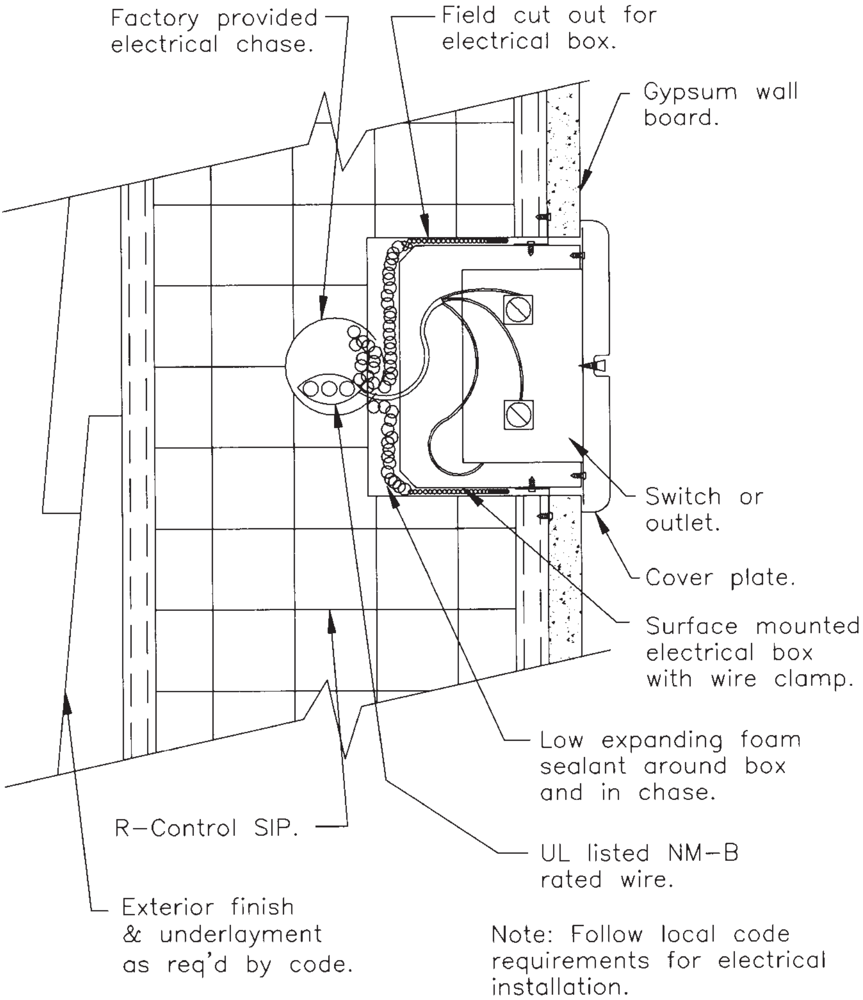

Figure 15.13 Field cut-out for electrical box. (*R-Control Building Systems*)

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

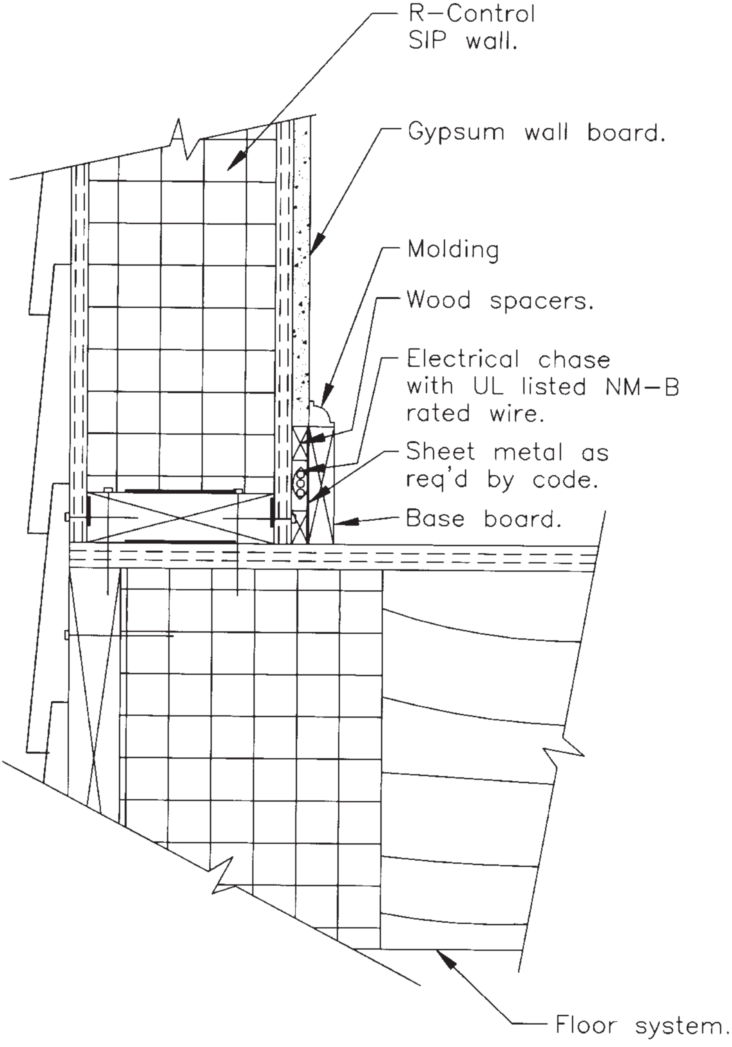

Figure 15.14 Electrical chase in baseboard. (*R-Control Building Systems*)

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*)

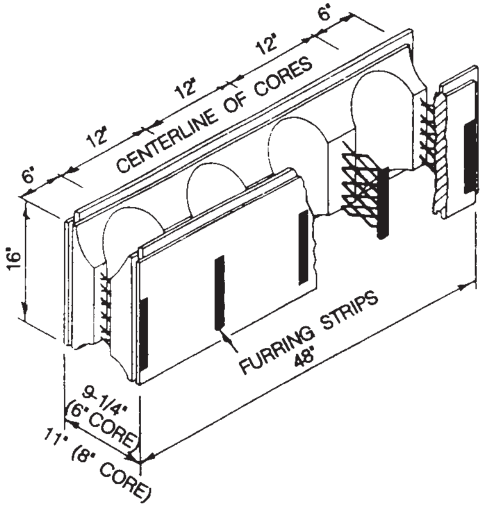

Figure 15.17 Block system. (*American Polysteel, Inc.*)

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,

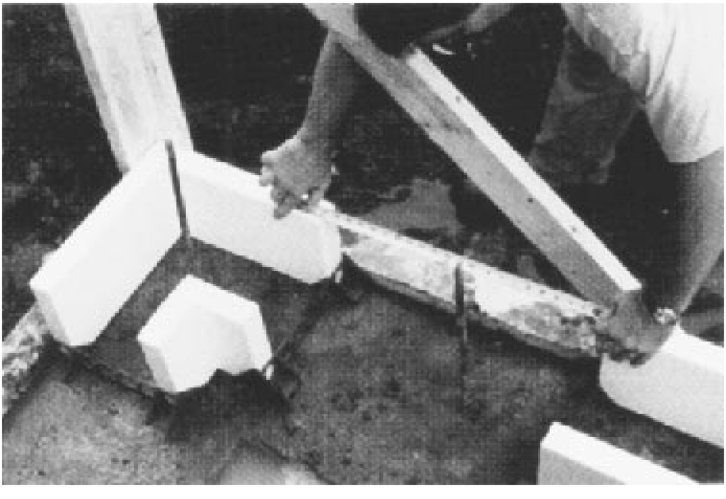

Figure 15.21 Installation of corner units. (*R-Control Building Systems*)

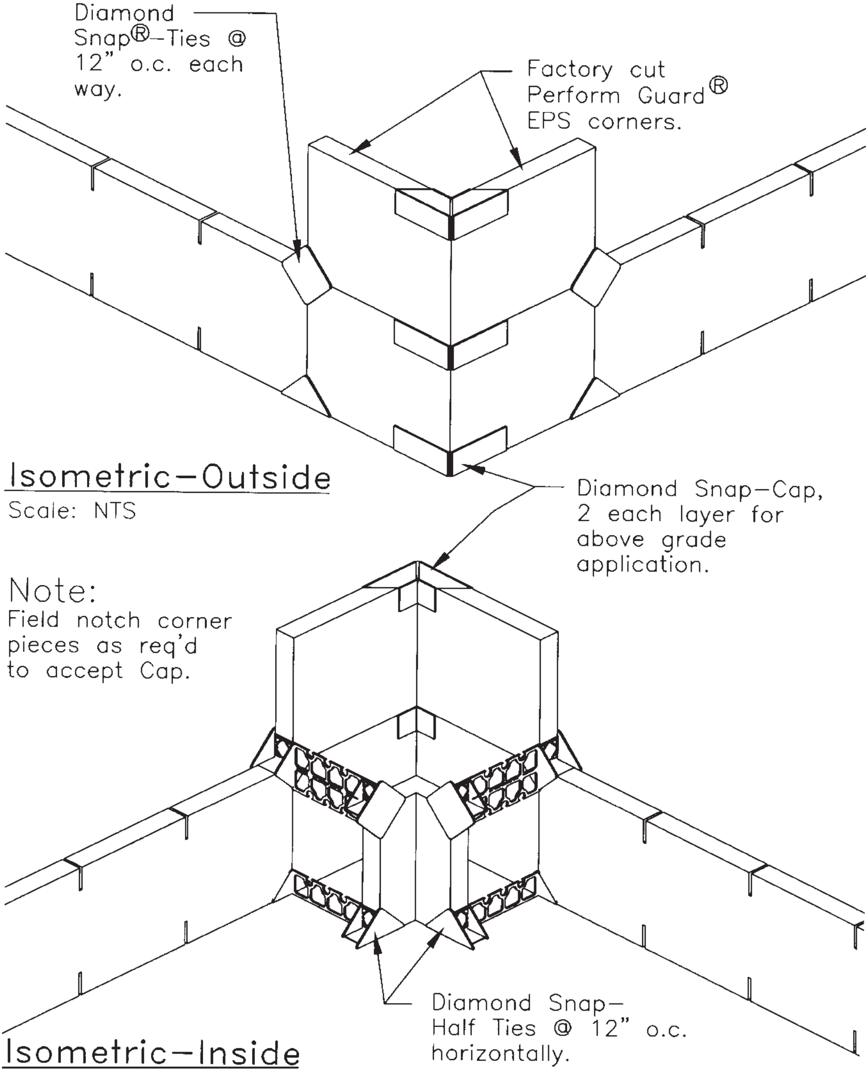

Figure 15.22 Installation of corner units. (*R-Control Building Systems*)

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).

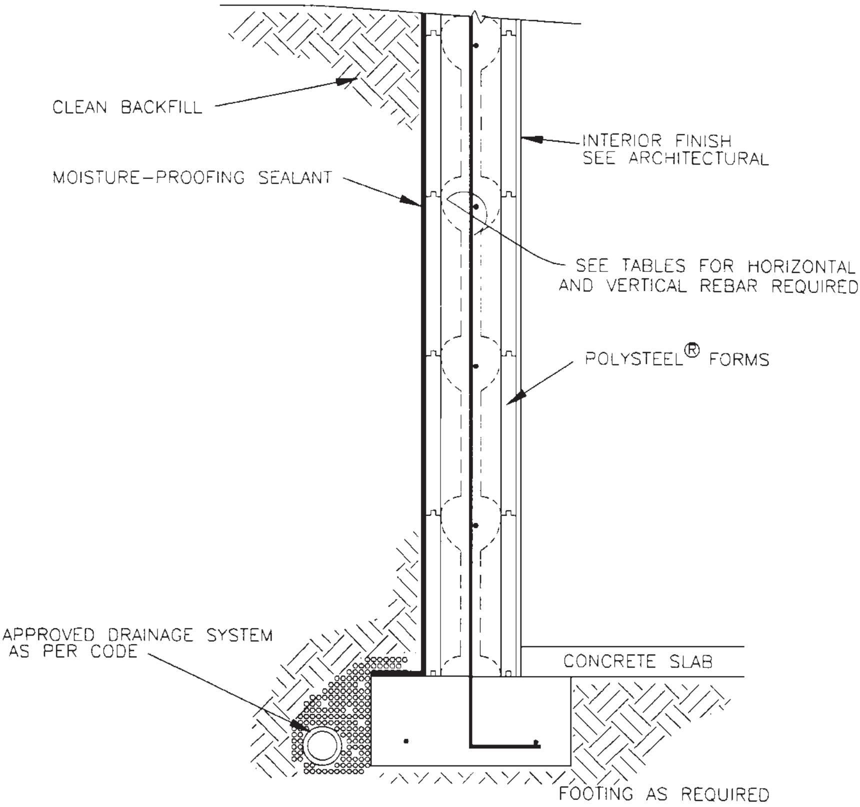

Figure 15.23 Wall-section. (*American Polysteel, Inc.*)

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,

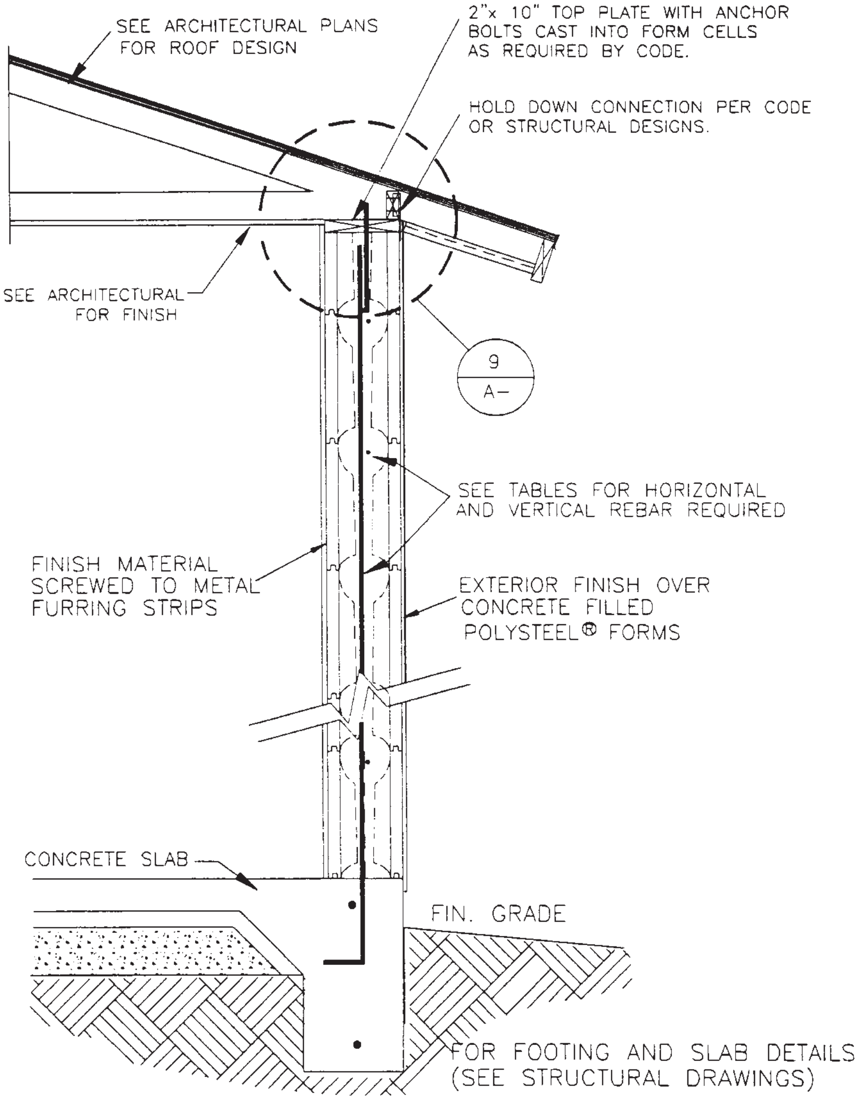

Figure 15.24 Wall-section. (*American Polysteel, Inc.*)

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*)

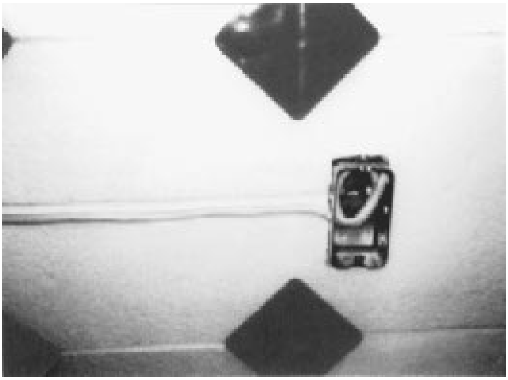

Figure 15.26 Electrical installation. (*R-Control Building Systems*)

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 $1\frac{1}{2}$ 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' × 12' storage shed (built by a fifth grade class with rice straw bales), an art gallery, a 40' × 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 *precompressing,* 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
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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
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Harvest Built Homes
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A 501(c)(3) nonprofit corporation promoting affordable straw bale home ownership for low-income families

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