Building with Structural Insulated Panels

by Joe Pasma, PE

All images courtesy Premier Building Systems

STRUCTURAL INSULATED PANELS ARE AN INCREASINGLY POPULAR CONSTRUCTION TECHNIQUE. THEY HELP CREATE A TIGHTER, WELL-INSULATED ENVELOPE, WHILE ENSURING A STRUCTURALLY SOUND BUILDING.

According to the U.S. Department of Energy (DOE), commercial buildings account for nearly a fifth of the country's total energy use. Energy demand continues to grow, increasing from 14 percent of the total national consumption in 1980 to 18 percent in 2005.[1] Today, improving building's energy efficiency is key to President Obama's initiatives to achieve energy independence. The President has described energy efficiency as "the cheapest, cleanest, fastest energy source."[2]

Design professionals can dramatically boost energy efficiency in all types of public, commercial, and residential buildings through a greater focus on the building envelope. To this end, structural insulated panels (SIPs) can be utilized in the exterior insulation envelope as wall, roof, and floor systems. Their insulating properties make them a suitable candidate for wood-based structures pursuing energy-efficient design.

An overview

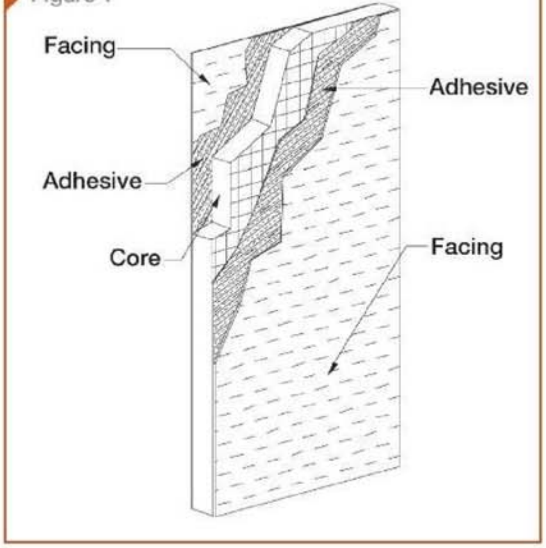
Structural insulated panels are engineered wall, roof, and floor components that can be employed in single- and multi-family homes, as well as schools, offices, retail structures, churches, and other light commercial buildings.

SIPs are composed of two outer sheathing layers (facing), or 'skins,' laminated to a rigid insulating foam core (Figure 1). Oriented strandboard (OSB) skins and expanded polystyrene (EPS) foam cores are the most common materials used in SIPs. Some structural insulated panels are made from other materials, including plywood and polyurethane insulating cores. Manufacturers typically employ OSB instead of plywood because it is available in larger sizes. Polyurethane foam cores offer higher R-values for a given thickness, but usually cost more.

Designers specify SIPs in place of stick-built framing and insulation installed onsite. As integrated structural and insulating units, the panels replace wood or steel studs, joists, sheathing, and blown-in, batt, or sprayed-in-place insulation.

The skins and foam core work together to achieve high strength in a manner comparable to other engineered structural systems such as I-joists. The skins perform like an I-joist's flanges, and the rigid foam core is similar to an I-joist's web. The individual elements work together to provide a strong, straight, and consistent structural unit with high load-bearing capacity—including axial, transverse, racking, and diaphragm capacities.

Figure 1

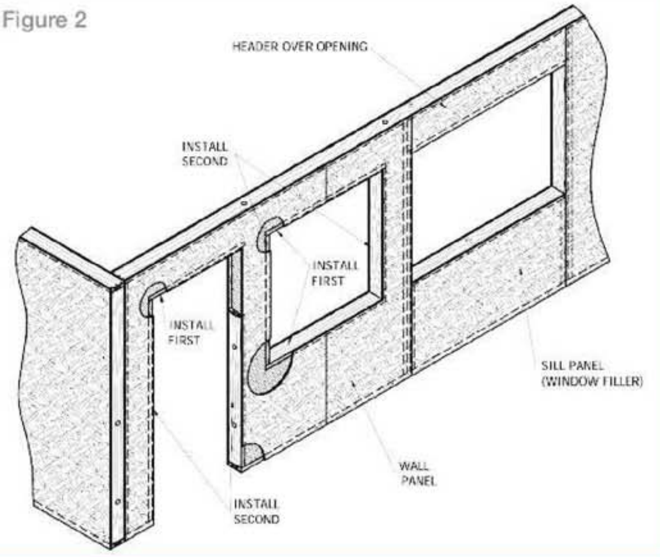


The different parts of a structural insulated panel.

Panel size and configuration

Manufacturers produce structural insulated panels in a controlled factory setting and deliver them ready-to-install at the jobsite. Typical panel lengths range from 1.2 to 7.3 m (4 to 24 ft), with standard widths

Figure 2



A typical SIP wall allows the avoidance of bowed, curved, or warped walls.

up to 2.4 or 2.7 m (8 or 9 ft). The thicknesses of the foam core can vary from 90 to 290 mm (3.5 to 11.25 in.), depending on a building's structural and insulation requirements. Large, one-piece panels allow for rapid onsite assembly and result in fewer gaps than stick-built construction, creating a tight building envelope.

The manufacturer may also pre-cut all window and door openings in the factory. Computer numerically controlled (CNC) routers can cut openings of virtually any shape, including archways and complex curves. SIPs also come with pre-cut wire chases in the foam core to help speed installation and reduce the need for onsite work.

Design process

Designing a SIP building is straightforward. Design professionals provide the project design drawings to a SIP manufacturer or dealer, who then converts them into shop drawings that detail each panel's specific dimensions. After the designers, engineers, code officials, and other relevant parties review these shop drawings, the manufacturer finalizes them and makes the panels.

Manufacturers typically provide technical support throughout the process, whether the design is for a new building based on structural insulated panels from the outset, or conversion of a prior stick-built design to one with SIPs.

Building code compliance

Most SIP manufacturers work with designers and specifiers to ensure their panels are accepted by model building codes, such as the *International Building Code (IBC)* and *International Residential Code (IRC)*. This process includes providing alternative material evaluation or listing reports for SIPs, showing evidence of code compliance as an alternate method of construction (as required). Depending on the specific manufacturer and testing completed, SIPs can meet residential and commercial code requirements for use as shear walls and diaphragms, and may offer fire resistance up to one hour.[3]

Installation time

SIP construction dramatically reduces the time needed to dry-in a building because entire wall, roof, and floor areas can be installed in large sections. As ready-to-install building components, the panels eliminate the need for separate framing, insulating, and sheathing work functions onsite.

Manufacturers can pre-cut window openings, and—depending on the dimensions—a separate header may not be required. Pre-cut chases remove the need to drill through studs for wiring, further saving time during electrical installation.

For example, contractors using SIPs in the new Jacob E. Manch Elementary School in Las Vegas, Nevada, shortened the typical framing schedule of 118–220 days to only 45 days. This meant a nearly 80 percent reduction.[4]

Costs

The installed costs of structural insulated panels are comparable to stick-built construction and may often be lower due to reduced construction times and jobsite waste.

SIPs can also decrease costs for other building systems, as their insulating properties and the reduced air leakage through the exterior building envelope allow designers to specify smaller-capacity heating and cooling equipment. These cost savings are especially notable for a building's HVAC system, and can potentially reduce requirements by up to 40 percent.

For some complex designs, the cost of structural elements may be somewhat higher with SIPs than with stick-built construction, due to the additional engineering and production requirements for the insulated panels.

Over the long-term, structural insulated panels dramatically reduce energy consumption and related costs. For example, in residential projects, SIPs work with other high-efficiency systems—such as low-emissivity (low-e), double-pane glazing and radiant floor heating—to commonly achieve between 50 and 70 percent savings over the *Model Energy Code (MEC)*.[5] In commercial applications, designers often use SIPs for zero-energy buildings.

Structural considerations

Structural insulated panels are able to bear high loads in wall, roof, and floor applications, including loads from gravity, snow, high winds, and seismic forces.

Walls

From a structural standpoint, key benefits of SIP walls include their strength, straightness, and consistency. As structural insulated panels arrive at the jobsite in large sections, they enable smooth, even walls over long distances. Structural insulated panels avoid the bows and curves that can arise with stick-built construction, as well as the possibility of warped framing lumber (Figure 2).

Smooth walls look crisper and allow for faster, easier, and higher quality installation of doors, windows, cabinets, millwork, and other finishes. They are also important for building owner satisfaction, especially in cases where artwork displays, intricate lighting designs, and other special architectural highlights could expose underlying wall flaws.

Wall assemblies must be able to withstand both axial forces and bending loads. As is the case for most other building materials—including concrete, steel, lumber, and engineered wood products—engineers can determine a structural insulated panel's ultimate load capacity for a given application by using what is known as the unity equation:

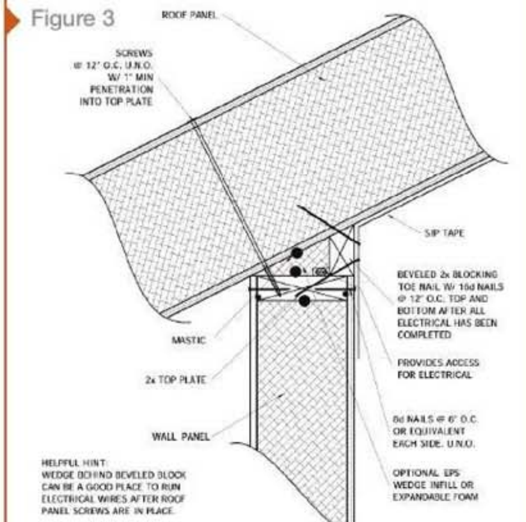
$$fa/Fa + fb/Fb < 1$$

Where:
fa is the design axial load;
Fa is the allowable axial load;
fb is the design bending load; and
Fb is the allowable bending load.

It is important to check with the SIP manufacturer for design load data on its specific panels. The data should be derived from full-scale destructive testing conducted by independent, accredited laboratories.

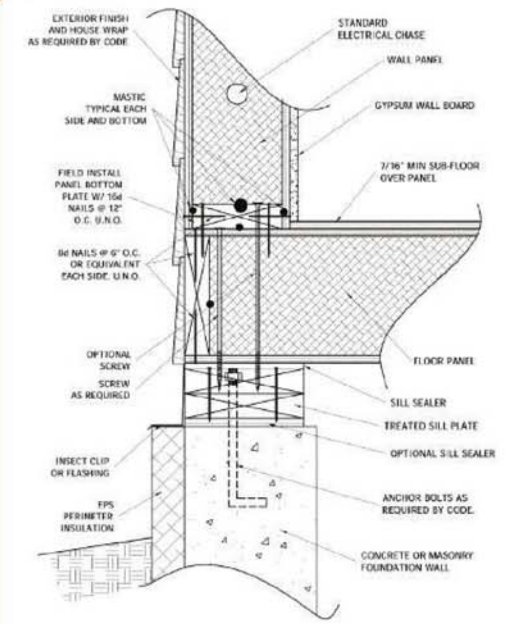
For exterior walls made with structural insulated panels, design professionals should typically specify a water-resistive barrier (WRB), along with adequate weather protection, including flashing. As with other wall assemblies, the design and materials should prevent moisture accumulation within the wall, as well as a means to drain water that penetrates the exterior wallcovering.

Figure 3



An example of a SIP wall/roof connection.

Figure 4



A typical SIP floor/foundation framing.

Shear walls

Structural insulated panels provide exceptional strength in racking and diaphragm shear capacities, making them suitable as shear walls and structural diaphragms to resist high winds and earthquakes. SIPs have been proven for use in seismic zones of all magnitudes, including zones D, E, and F. During the 1995, 6.9-magnitude earthquake that struck Kobe, Japan, buildings and homes constructed with SIPs were among the few left standing.[6]

APA–The Engineered Wood Association has conducted cyclic shear wall testing of one company's structural insulated panels, as well as a comparative analysis of the same SIPs and stick-framed shear walls. They recommend designers use the same seismic design coefficients for SIP shear walls as light-frame walls sheathed with wood structural panels rated for shear resistance. Specifically, these values are:

- response modification coefficient (R) = 6.5;
- system over strength factor (Ωo) = 3; and
- deflection amplification factor (Cd) = 4.0.[7]

It is important to check with the manufacturer for details on the seismic testing and shear resistance design coefficients of its panels.

Roofs

Structural insulated panels have been full-scale destructively tested for transverse load capacity and deflection monitoring in accordance with ASTM E 72, *Standard Test Methods of Conducting Strength Tests of Panels for Building Construction*.

In roof applications, designers can specify SIPs to create vaulted, open interior spaces. As they have long clear span capability—typically up to 6 m (20 ft)—SIPs can reduce the need for intermediate structural supports. They can also be employed in roof structures without an engineered truss system.

The results are large, soaring rooflines, open, vaulted ceilings, and overall extra indoor space for applications otherwise impossible with stick-built construction. Typical SIP roof applications include school cafeterias and gymnasiums, common areas in apartments and office buildings, and cathedral ceilings in churches or other structures (Figure 3).

Designers also commonly cantilever structural insulated panels for roof eave and gable end overhangs (up to 1.8 m [6 ft] is possible). It is important to check with the panel manufacturer for technical details when employing cantilever construction techniques. Specifying SIPs for overhangs may help speed construction as the large-section panels install faster than hand framing.

Floors

In addition to walls and roofs, structural insulated panels also work well for structural floor systems. They are often used where an insulated floor system is required, such as over a crawlspace, in a three-season porch, or above an unheated garage (Figure 4).

Design professionals must remember a few key considerations when employing SIPs for floors. First, the design should typically include an additional 11-mm (7/16-in.) sheathing layer over the floor panel to minimize puncturing of the panel skins. Second, floor panels are not able to support load-bearing walls. Third, floor panels cannot be cantilevered over a lower wall to support upper wall and roof systems. The manufacturer should be consulted for load limitations of SIPs employed in floor systems.

Insulating properties

In addition to their high strength for structural applications, SIPs provide exceptional insulation and a tighter building envelope than stick-built construction. The rigid foam core offers continuous insulation across the panels' width and length, avoiding the thermal bridging created by wall studs. Large-size panels also have significantly fewer joints that require sealing.

In blower door tests, the DOE's Oak Ridge National Laboratory (ORNL) found rooms built with SIPs have 90 percent less air leakage than stick-framed spaces.[8] ORNL also evaluated the whole-wall R-values of structural insulated panels versus stick framing. Their tests accounted for energy loss through the structural members, corners, joints, and around windows. Such assessment provides a more complete picture of the insulating capacity of a wall assembly, beyond just the insulation's R-value.

ORNL found an 89-mm (3.5-in.) thick core SIP had a whole-wall R-value of 14.09. In contrast, a wall framed with 50 x 100-mm (2 x 4-in) studs at 406 mm (16 in.) on center (oc) had a whole-wall R-value of 9.58. Therefore, the SIP wall had a 47 percent higher whole-wall R-value.[9]

The 89-mm thick core SIP wall also outperformed a wall framed with 50 x 150-mm (2 x 6-in.) studs at 610 mm (24 in.) oc. The latter assembly had a whole-wall R-value of 13.69.

Other green benefits

In addition to saving energy, building with structural insulated panel can:

- reduce construction waste;
- require fewer raw materials; and
- improve indoor air quality (IAQ).

SIPs can help a project earn points under the U.S. Green Building Council's (USGBC's) Leadership in Energy and Environmental Design (LEED) program—36 or more points in homes, and up to 23 points for commercial construction (see "LEED and SIPs", page 58).

Construction waste reduction
Stick-built construction creates large scrap volumes as builders cut stock boards to length. Framing can generate thousands of pounds of leftover bits of studs and joists. By comparison, SIPs are made in a carefully controlled setting that allows for more precise material management than is possible on a jobsite. Consequently, contractors can reduce jobsite waste by up to 60 percent.[10]

Energy and resources for manufacture
Expanded polystyrene is a lightweight insulation composed mostly of air—only two percent of it is plastic. Over a building's lifetime, the EPS insulation employed in structural insulated panels saves many times the energy embodied in the petroleum used to make EPS.[11]

The OSB skins also utilize a high percentage of each log, making efficient use of natural resources.

LEED AND SIPS

The U.S. Green Building Council's (USGBC) Leadership in Energy and Environmental Design (LEED) program includes a number of areas in which structural insulated panels (SIPs) can potentially earn points. Below is a summary of categories to consider when pursuing a LEED for New Construction (LEED–NC) rating for a SIP building. Similar point categories are available under the LEED for Homes program.

Energy and Atmosphere (EA)

A maximum of 10 points can be earned under EA Credit 1, *Optimize Energy Performance*. By reducing the energy needed for heating and cooling, SIPs contribute to overall energy savings.

Materials and Resources (MR)

One point can be gained under MR Credit 7, *Certified Wood*. If 50 percent of the wood products used in the building are Forest Stewardship Council (FSC)-certified, one point will be awarded. Some manufacturers offer SIPs with FSC-certified oriented strandboard (OSB) skins.

Indoor Environmental Quality (EQ)

One point can be earned under EQ Credit 4.1, *Low-emitting Materials: Adhesives and Sealants*. The structural adhesives used in SIP production meet the requirements for low-emitting materials defined in this category. All adhesives and sealants applied on the building interior must meet the requirements to earn this credit.

Another point can be earned under EQ Credit 4.4, *Low-emitting Materials: Wood and Agrifiber Products*. The OSB employed in SIPs meets the requirement that composite wood products used on the building interior (defined as inside the weatherproofing system) shall contain no added urea-formaldehyde resins. **CS**

Indoor air quality
Structural insulated panels can also play a significant role in improving indoor air quality. By providing a tighter building envelope than other framing methods, SIPs help reduce infiltration of common pollutants such as radon, mold, pollen, volatile organic compounds (VOCs), lead dust, and asbestos. Some manufacturers' SIPs also do not contain chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), or formaldehyde; zero-VOC mastics for attaching and sealing panels to one another are also available.

Challenges and considerations

Designers and contractors may experience an initial learning curve when using structural insulated panels. Once professionals gain familiarity with the product, the cost becomes comparable to other building methods. Experienced framing crews can usually adapt to SIPs construction relatively quickly. Structural insulated panel manufacturers and dealers often offer training and technical support in both design and construction.

Structural insulated panels may be used in a wide range of low-rise commercial structures. As with other wood-framed construction, SIPs buildings are typically limited to four stories, more so due to the fire restrictions imposed by Type V construction than load-bearing capability.

Conclusion

Structural insulated panels are a recognized advanced construction technique. Given their insulating qualities and ability to create a tight building envelope, they can dramatically improve energy efficiency in both commercial and residential buildings.

The DOE and U.S. Environmental Protection Agency (EPA) agree SIPs are significant for airtight construction—their Energy Star program even waives the blower door test for SIP homes.[12]

Further, by using structural insulated panels (as an energy-efficient building material), commercial building owners can qualify for up to $1.80 per square foot in tax deductions.[13]

Achieving zero-energy construction requires numerous integrated building systems, including emerging technologies and tested components. SIPs have been in use for many decades and are an important option for specifiers seeking to meet increasingly stringent green building goals.[14] **CS**

Notes

[1]See the U.S. Department of Energy's "Energy Efficiency Trends in Residential and Commercial Buildings," October 2008.

[2] Obtained from www.whitehouse.gov on March 6, 2009.

[3] See, for example, International Code Council Evaluation Service (ICC-ES) Report ESR-1882, October 2008.

[4] Based on this author's conversation with Gary Radzat, president of Shell Building Systems, on January 12, 2009.

[5] Obtained from the Structural Insulated Panel Association (SIPA) at www.sips.org, on March 9, 2009.

[6] Obtained from this author's organization's Web site on March 10, 2009.

[7] See, for example, this author's organization's Technical Bulletin #33B, "PBS SIPs Used as Shear Walls," October 15, 2008.

[8] Refer to Oak Ridge National Laboratory's (ORNL's) "Heating and Blower Door Tests of the Rooms for the SIPA/Reiker Project," March 15, 2002 (as reported in the "Structural Insulated Panels Product Guide," by SIPA and APA, 2007).

[9] See Jan Kosny, Andre Desjarlais, and Jeff Christian's "Whole Wall Rating/Label for Structural Insulated Panel: Steady-state Thermal Analysis," ORNL Buildings Technology Center, June 4, 1999.

[10] See note 6.

[11] Refer to SIPA's brochure, "Green Building with SIPs." Visit www.sips.org.

Attractive architectural styles of all types can rely on SIP construction.

[12] See SIPA's news release, "EPA Waives Blower Door Test for SIP Homes to Meet Energy Star Requirements," December 13, 2006.

[13] Refer to "SIPs and the Energy Efficient Tax Deduction for Commercial Buildings," a presentation to SIPA by Drury B. Crawley, technology development manager at U.S. Department of Energy (DOE), May 8, 2007. Visit www.sips.org.

[14] Design professionals who have not worked with structural insulated panels should speak to a manufacturer or dealer first. Alternatively, they can contact SIPA. For a list of SIP manufacturers in North America, visit www.sips.org.

ADDITIONAL **INFORMATION**

Author

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Abstract

By focusing on the building envelope, structural insulated panels (SIPs) can significantly increase energy efficiency in a variety of low-rise, wood-based buildings. Composed of two outer sheathing layers laminated to a rigid insulating foam core, SIPs help create a tighter, well-insulated envelope, while ensuring a structurally sound building. This article discusses their structural properties, insulating characteristics, and contribution to energy-efficient construction.

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