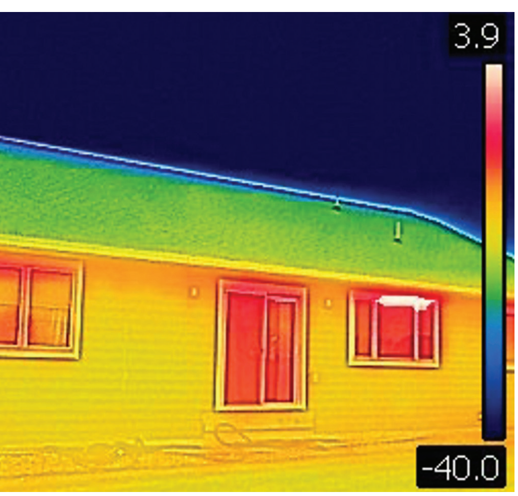
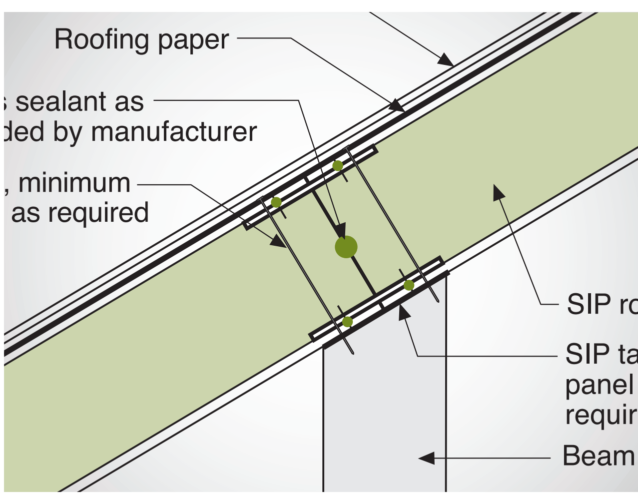
SIP DESIGN-BP 1:

High-Performance SIP Building Envelope





SIPA

Structural Insulated Panel Association

SIP DESIGN-BP 1:

High-Performance SIP Building Envelope

This document is created specifically for design professionals by the manufacturing members of the Structural Insulated Panel Association (SIPA). It dives deeper and provides more background into each of the summarized topics presented in the *Design with SIPs: DESIGN CONSIDERATIONS* overview which highlights important considerations during the design phase of a Structural Insulated Panel (SIP) structure. Decades of combined knowledge from SIPA manufacturers will help reduce the learning curve and leverage SIPs' exceptional qualities to achieve the high-performance results owners expect when building with SIPs. The considerations of how and why the best practices were developed as the common industry platform for SIP design are explored here.

The index below outlines ten topical areas, listed in sequence to match the order of design considerations and construction. The details in each chapter provide a deeper understanding of the subject matter to facilitate successful SIP design and later implementation. The current chapter is highlighted in blue.

SIP DESIGN-BP 1:

High-Performance SIP Building Envelope

As a starting point, the American Institute of Architects considers a *high-performance building* one that integrates and optimizes all major high-performance building attributes, including energy efficiency, durability, life cycle performance and occupant productivity (which includes health). SIP building envelopes provide an important basis for enabling all these elements to be economically achieved.

SIP DESIGN-BP 1.1:

SIPs meet and exceed building code thermal envelope requirements and eliminate additional continuous insulation needs on the building exterior.

The 2018 International Energy Conservation Code (IECC) defines three paths to compliance: Prescriptive, U-factor, and the Building Performance path. Sections C402 and R402 describe the total building performance requirements. The Prescriptive path describes various assemblies and continuous insulation requirements. U-factor requirements are component based, i.e., a summation of the U-factor for each individual layer.

The SIPA-recommended path is to use the U-factor method to demonstrate SIP compliance with the building envelope requirements of the IECC. It is helpful to review a few key definitions from the 2018 IECC:

Continuous Insulation (ci): insulating material that is continuous across all structural members without thermal bridges other than fasteners and service openings. It is installed on the interior, exterior, or is integral to any opaque surface of the building envelope.

R-value (thermal resistance): the inverse of the time rate of heat flow through a body from one of its bounding surfaces to the other surface for a unit temperature difference between the two surfaces, under steady state conditions, per unit area ($h*ft^{2}*^{0}F/Btu$).

U-factor (thermal transmittance): the coefficient of heat transmission (air to air) through a building component or assembly, equal to the time rate of heat flow per unit area and unit temperature difference between the warm side and cold side air films ($Btu/h*ft^{2}*^{0}F$).

Sections C402 and R402 of the 2018 IECC require that the building envelope meet either the Prescriptive R-value requirements or the assembly U-factor requirements for the building envelope insulation assembly. The Prescriptive requirements for the envelope assembly in some climate zones may require the addition of exterior continuous insulation (ci). The Prescriptive path aims to eliminate thermal bridging energy losses from dimensional framing inside a wall which for opaque walls is typically high at 24 percent[1] framing factor for 2 x 4 framing at 16 inches on center or 22 percent[2] for 2 x 6 framing at 24 inches on center. Although the framing factor of SIPs is very low at only 3 percent[3], it still does not meet the IECC strict definition of continuous insulation because of the modest thermal bridging that occurs at various locations in the SIPs including plating around openings, wall top and bottom plates, corners and SIP roof connection details.

SIPs comply with the intention of continuous insulation for building envelope requirements in both the commercial and residential IECC by using the U-factor

[1] *ASHRAE Handbook of Fundamentals, 2010*

[2] Ibid.

[3] *2600 sq. ft. Home that has 50% Energy Savings in the Mixed-Humid Climate; ZEH5 2-Story, ORNL/TM-10081/08*

alternative path allowed by both sections C402 and R402. Section R402.1.5 of the 2018 IECC describes how to develop the UA method to demonstrate compliance using the U-factor method.

Versions of the IECC other than the 2018 have similar language regarding the UA alternative method of complying with the building envelope insulation requirements. Section references may be slightly different for code years other than 2018, but the concepts are similar. Tables 1.1 and 1.2 show the minimum thicknesses of SIPs for walls and roofs required to achieve the mandated U-factor by climate zone. Detailed scenario calculations supporting these tables can be found in the *Appendix* of this document.

TABLE 1.1

MINIMUM SIP THICKNESSES* TO MEET RESIDENTIAL IECC TABLE R402.1.5

	Roof/Ceiling		Wall	
Climate Zone	**Roof/Ceiling U-factor**	**Minimum SIP thickness***	**Frame Wall U-factor**	**Minimum SIP thickness***
1	0.035	10-1/4-in.	0.084	4-1/2-in.
2	0.030	10-1/4-in.	0.084	4-1/2-in.
3	0.030	10-1/4-in.	0.060	6-1/2-in.
4 except Marine	0.026	12-1/4-in.	0.060	6-1/2-in.
5 and Marine 4	0.026	12-1/4-in.	0.060	6-1/2-in.
6	0.026	12-1/4-in.	0.045	6-1/2-in.
7 and 8	0.026	12-1/4-in.	0.045	6-1/2-in.

*Assumes standard Type I EPS foam cores; alternative foam type information available by consulting manufacturers. SIP thicknesses are nominal inches.

TABLE 1.2

MINIMUM SIP THICKNESSES* TO MEET COMMERCIAL IECC TABLE C402.1.4

Climate Zone	1		2		3		4	
	All Other	Group R	All Other	Group R	All Other	Group R	All Other	Group R
Roofs								
Insulation entirely above roof deck	U=0.048	U=0.039	U=0.039	U=0.039	U=0.039	U=0.039	U=0.032	U=0.032
Minimum SIP thickness	6-1/2”	8-1/4”	8-1/4”	8-1/4”	8-1/4”	8-1/4”	10-1/4”	10-1/4”
Walls, above grade								
Wood framed and other	U=0.064	U=0.064	U=0.064	U=0.064	U=0.064	U=0.064	U=0.064	U=0.064
Minimum SIP thickness	4-1/2”	4-1/2”	4-1/2”	4-1/2”	4-1/2”	4-1/2”	4-1/2”	4-1/2”

Climate Zone	5		6		7		8	
	All Other	Group R	All Other	Group R	All Other	Group R	All Other	Group R
Roofs								
Insulation entirely above roof deck	U=0.032	U=0.032	U=0.032	U=0.032	U=0.028	U=0.028	U=0.028	U=0.028
Minimum SIP thickness	10-1/4”	10-1/4”	10-1/4”	10-1/4”	12-1/4”	12-1/4”	12-1/4”	12-1/4”
Walls, above grade								
Wood framed and other	U=0.064	U=0.064	U=0.051	U=0.051	U=0.051	U=0.051	U=0.036	U=0.036
Minimum SIP thickness	4-1/2”	4-1/2”	6-1/2”	6-1/2”	6-1/2”	6-1/2”	8-1/4”	8-1/4”

*Assumes standard Type I EPS foam cores; alternative foam type information available by consulting manufacturers. SIP thicknesses are nominal inches.

SIP DESIGN-BP 1.2:
SIPs provide extremely airtight structures, a key component improving indoor air quality (IAQ).

A handy building science mantra *'build tight and ventilate right'* is often spoken as a requirement of energy-efficient, high-performance structures. Many think a building envelope can be 'too tight' not allowing in any fresh air. This is not true. The correct statement is that efficient, low-air-leakage buildings require make-up fresh-air supplies which come from intentional routes and not from arbitrary holes, gaps and leaks. Unfiltered air leaking into structures often unintentionally brings dust and other external contaminates which lower indoor air quality (IAQ).

Building air leakage is measured by performing a blower door test using specially designed fans to pressurize the structure. Home Energy Rating System (HERS) technicians are specially trained and credentialed by the Residential Services Network (RESNET) to perform these tests which measure the amount of air leakage expressed in air changes per hour at the standard air pressure of 50 pascals (ACH50). The resulting leakage information is used to properly size HVAC equipment. Without realistic air leakage data, HVAC systems are usually oversized to accommodate high leakage rates (10.0 to 20.0 ACH50) typical in decades of leaky older structures. SIPs provide high-performance enclosures with very little air leakage, usually less than 2.0 ACH50. The HVAC systems historically installed in older homes will be oversized for SIP structures, so the proper ACCA Manual J sizing calculation must be computed using the actual air leakage values.

Air leakage information is so important that it is required for above-code performance programs like the U.S. Department of Energy's ENERGY STAR and Zero Energy Ready Home certifications, Passive House, U.S. Green Building Council's LEED, Green Building Initiative's Green Globes, or NAHB's National Green Building Standard.

Illustrating how mainstream low-air-leakage SIP installations are, several typical examples from SIPA's recent 2020 Building Excellence Awards with blower door test data show air leakage rates much less than 2.0 ACH50. Examples include the South Dakota Indian reservation's Thunder Valley CDC affordable 1,400 sq. ft. home with 1.0 ACH50; the Minnesota 3,500 sq. ft. Tholke home with 0.54 ACH50; the Kansas 866 sq. ft. Wright small house with 1.59 ACH50; the commercial Minnesota 8,200 sq. ft. Invictus Brewing restaurant with 1.39 ACH50; and North Dakota's only LEED Platinum Perkins 2,500 sq. ft. residence with 0.42 ACH50. Read their detailed project case studies at www.SIPs.org/building-excellence-awards.

SIP research homes built by the Department of Energy's Oak Ridge National Laboratory (ORNL) have infiltration rates as low as 0.03 natural air changes per hour (ACHnat) or approximately 0.9 ACH at 50 pascals (Pa) of pressure differential (ACH50). Similarly sized stick framed homes in the same subdivision averaged blower door test results ranging from 6.0 to 7.5 ACH50. Current 2018 IECC codes require air leakage rates equal to or less than 5.0 ACH50 in the warmer, southern climate zones and equal to or less than 3.0 ACH50 in cooler climate zones. More current IECC codes are tightening the requirements to no more than 3.0 ACH50.

Commercial projects also benefit from using SIPs. The renowned energy-efficient Rocky Mountain Institute selected SIPs for its 2016 Innovation Center located high in the mountains of Basalt, Colorado. At almost 15,610 sq. ft., this building is net-zero, LEED Platinum and the largest Passive Certified structure in the world, with an air leakage rate of 0.36 ACH50 (97 percent less leakage than typical commercial buildings). With an energy use intensity of 15.9 kBtu/sq.ft./year, the building is designed to deliver two times more energy than it uses. The 10.8 percent premium to achieve net-zero is paid back in less than four years with the help of its high-performance SIPs. With virtually airtight envelopes, SIPs improve IAQ creating healthier homes and businesses.

Reducing unwanted air leakage requires sealing and precise alignment of framing, insulation and air-barriers – which is easier when building with large SIPs with fewer joints, and can be extremely difficult to achieve with traditional enclosures made of many pieces and layers.

ASHRAE standards 62.1 for commercial and 62.2 for low-rise residential building are referenced by building codes to properly calculate requirements for mechanical ventilation systems to provide minimum amounts of fresh air and exhaust strategies depending on occupant loads intended for various building types. Both fresh air dilution and stale indoor air extraction are needed to lower fumes from combustion appliances, adhesives, cleaning agents, radon, formaldehyde and other gases and particulates. Regular carbon dioxide and moisture from people breathing, cooking and showering must be managed continuously.

Mechanical ventilation or air exchange systems control purposeful introduction of fresh outdoor air into the conditioned space. Two methods of controlled mechanical ventilation are predominant.

Heat Recovery Ventilator (HRV)
An air to air heat exchanger unit that continually exchanges stale inside air for fresh outside air. As the two separate air streams pass through the unit, the heat from the exhaust air raises the temperature of the incoming air. This exchange creates a healthier indoor environment while providing energy recovery and savings. No moisture is exchanged between the air streams. HRVs are typically a predominantly cold, dry climate device.

Energy Recovery Ventilator (ERV)
An air to air heat exchanger unit that continually exchanges stale inside air for fresh outside air. As the two separate air streams pass through the unit, the heat and moisture from the exhaust air raises the temperature and humidity of the incoming air. This exchange creates a healthier indoor environment while providing energy recovery and savings. No moisture is exchanged between the air streams. ERVs are typically a predominantly warm, humid (or mixed-humid) climate device.

More information on the air leakage, air exchange, and the HRV/ERV topic can be found in *SIP Design Best Practices 2: HVAC Systems* and in the *Builder's Guide to Structural Insulated Panels (SIPs)* by Joseph Lstiburek, Chapter 11–HVAC (book available for purchase at www.sips.org or www.amazon.com).

SIP DESIGN-BP 1.3:
SIPs are available in a range of thicknesses delivering exceptional thermal performance.

SIPs are commonly manufactured in 4-1/2-inch, 6-1/2-inch, 8-1/4-inch, 10-1/4-inch and 12-1/4-inch nominal thicknesses with the 4-1/2-inch and 6-1/2-inch-thick SIPs typically used for walls and the thicker SIPs typically used for roofs. Thicker SIPs have higher R-values with correspondingly higher energy efficiency ratings.

Insulation is one of the key components of any energy-efficient home or commercial building. With heating and cooling accounting for 50 percent of energy use in the average home, the insulation type used can save thousands of dollars in utility bills over the building's life. SIPs use rigid foam core insulation, typically expandable polystyrene (EPS) or sometimes polyurethane (PU), while traditional lumber-framed construction typically uses fiberglass batts or other similar insulating materials.

Insulation is typically rated by R-value, which measures a material's thermal resistance. An insulating material with a higher R-value forms a more effective thermal barrier between the outside temperature and the conditioned space inside the home.

In the U.S., the R-value of insulation is determined using a standard testing method conducted in a controlled environment where there is no air movement and at a mean temperature of 75°F. Minimum R-values for SIPs using this test method as the basis are shown in Table 1.3. It is noted that R-values for SIPs may vary slightly from manufacturer to manufacturer but EPS foam performance is stable over time and does not degrade with age, unlike other foams with blowing agents.

TABLE 1.3
SIP THERMAL PERFORMANCE WITH EPS CORES

SIP Total Thickness* (EPS Type I)	R-value @ 75°F	U-factor @ 75°F	R-value @ 40°F	U-factor @ 40°F	R-value @ 25°F	U-factor @ 25°F	R-value @ 0°F	U-factor @ 70°F	R-value @ -25°F	U-factor @ -25°F	R-value @ -50°F	U-factor @ -50°F
4-1/2-in.	13.9	0.072	15.3	0.065	15.3	0.065	17.1	0.058	18.2	0.055	18.9	0.053
6-1/2-in.	21.1	0.047	23.3	0.043	23.3	0.043	26.1	0.038	27.8	0.036	28.9	0.035
8-1/4-in.	27.4	0.036	30.3	0.033	30.3	0.033	34.0	0.029	36.2	0.028	37.6	0.027
10-1/4-in.	34.6	0.029	38.3	0.026	38.3	0.026	43.0	0.023	45.8	0.022	47.6	0.021
12-1/4-in.	41.8	0.024	46.3	0.022	46.3	0.022	52.0	0.019	55.4	0.018	57.6	0.017

Note: R-values are based on 7/16-in. OSB Facers on the Panels
*SIP thicknesses are nominal inches

R-value alone does not tell the whole story. While laboratory tests that determine R-values provide a theoretical measure for comparing the thermal performance of roof and wall assemblies, they do not reflect how entire installed, insulated assemblies perform in a building. When real-world factors such as air infiltration (air leakage), extremely low temperatures, cavity convective looping and thermal bridging are present, field-installed fiberglass insulation in assemblies performs at less than half the predicted R-value. Research from numerous Department of Energy's Oak Ridge National Laboratory studies and side by side building installations has validated that installed SIP projects closely match the theoretically predicted R-value performance of the building and outperform traditional fiberglass insulation's error-prone theoretical vs. actual performance.

Current Federal Trade Commission truth-in-advertising regulations require the performance of all insulation types to be tested and compared at a reference mean temperature of 75°F. However, for some insulations, the R-value improves when tested at lower temperatures (more closely reflecting real-world conditions for when insulation is needed in cold climates) as shown in Table 1.3 for EPS foams. Some other insulation types perform worse at colder temperatures. Values from other SIP foam cores are available upon request from SIPA or manufacturers.

The Department of Energy's Oak Ridge National Laboratory has studied and tested the performance of entire wall assemblies in large sections. The resulting whole-wall R-value data reveals that a 4-1/2-inch SIP wall with EPS core rated at R-14 performed equally with a 2 x 6 wall with R-19 fiberglass insulation. For comparison the whole-wall R-value of SIPs versus conventional 2x framing is shown in Table 1.4.

A comparison of the whole-wall R-values from Table 1.4 for the two most common thicknesses of walls shows that SIPs are at least 50 percent more efficient than the conventional stud walls for the same thickness.

By supplying SIPs with varying thicknesses and corresponding R-values, the SIP industry allows design professionals to easily specify SIPs that will meet any end use energy code demands.

TABLE 1.4

SIP VS. FIBERGLASS WALL ASSEMBLY WHOLE-WALL R-VALUES

Wall assembly nominal thickness (inches)		Whole-wall R-value
4-1/2-in	SIP with EPS	14.0
4-1/2-in	2 x 4 fiberglass wall at 16-in. o.c.	9.8
6-1/2-in	SIP with EPS	21.6
6-1/2-in	2 x 6 fiberglass wall at 24-in. o.c.	11.0*

* Note: ORNL data: 2 x 6 at 24 inches on center with fiberglass batts with rounded shoulders, 2 percent cavity voids, no compression around wiring, paper facer stapled to inside of stud.

SIP DESIGN-BP 1.4:
Various SIP connections are available which minimize thermal bridging, lower installation costs, and install and seal with ease.

SIP connections can be achieved with single or double 2x conventional lumber, LVL's, I-joists, surface splines and box/block splines. Box/block and surface splines are ideal as they minimize thermal bridging when connecting two SIPs.

Unlike conventional framing at the joints, SIP joints are sealed to eliminate the flow of moisture and air. Some SIPA manufacturers also install splines in their factories, effectively reducing the cost of site time. Splines can be pre-drilled to connect with the adjacent wire chase, again allowing the SIP to be sealed and nailed off immediately in the field, minimizing electrician costs.

SIPs are more efficient than conventional framing because they do not have dimensional lumber framing members every 16 to 24 inches. This effect is measured by the framing factor or percentage of the wall assembly where wood studs displace insulation. In a typical 2 x 4 stud wall at 16 inches on center, 24 percent[4] of the wall is solid wood leaving less available space for insulation. In advanced framing where the studs are at 24 inches on center the framing factor falls to approximately 22 percent[5] solid wood. In a typical SIP wall, the framing factor is much lower at only 3 percent[6]. The lower the framing factor, the less thermal bridging and the more insulation in the wall.

What is Thermal Bridging?
In Images 1.1 and 1.2 of an 8-1/2-inch SIP roof in Washington state, the SIP spline joints have I-joist splines for added structural strength. During the winter, the I-joist spline acts as a thermal bridge or short circuit. Heat from inside the home flows outward and melts the roof frost at each panel joint connected by the I-joist splines. By contrast, the higher-insulating solid EPS foam cores of the SIPs to each side of the joint connections (with an approximate R-4/inch insulating value) resist the heat flow from the warm inside conditions and do not melt the frost.

IMAGE 1.1:
SIP ROOF WITH I-JOIST SPLINES

IMAGE 1.2:
SIP ROOF WITH I-JOIST SPLINES

[4] ASHRAE Handbook of Fundamentals, 2010

[5] Ibid.

[6] 2600 sq. ft. Home that has 50% Energy Savings in the Mixed-Humid Climate; ZEH5 2-Story, ORNL/TM-10081/08

While thermal bridging does occur in both SIP and traditionally framed construction, the larger distances between SIP splines connecting wider panels is typically less than closer spaced roof rafters or trusses. These photos help to train one's eyes to spot the difference in real-world conditions.

Images 1.3 and 1.4 are of home garages in Minneapolis, MN taken the same day. Image 1.3 has a 10-1/4-inch-thick SIP roof with I-joist splines connecting the SIPs. Like the SIP roof in Images 1.1 and 1.2, the reduced insulating value of the wooden I-joist acts as a thermal bridge transmitting the heat from inside the home to the roof surface and melting the frost. To each side of the I-joists, the solid foam cores insulate much better and don't melt the frost.

Using a better insulating box/block spline instead would eliminate the thermal bridging; see Details 1.1 and 1.2.

Contrastingly, Image 1.4, with no insulation between the studs, illustrates the opposite effect. The frost is melting between the trusses due to poorer insulating performance in that space, allowing heat to escape from inside the garage. There is still frost above the wooden trusses which are insulating better than no insulation and just the roof decking material.

The message from nature here is that **more** roof frost means **better** insulation and fewer thermal bridges; **less** frost means **worse** insulation or more thermal bridging.

IMAGE 1.3:

SIP GARAGE ROOF

IMAGE 1.4:

TRADITIONAL GARAGE ROOF

Thermographic Image 1.5 below shows the lower R-value dimensional lumber as thermal bridges with a blue color in the wall transmitting much more energy at each stud compared to the higher R-value insulation to each side with a warmer green color depicting less energy transmission. By contrast, the SIP wall and roof surfaces in Image 1.6 illustrate a uniform temperature surface with minimal thermal bridging/energy leaks of dimensional lumber except at the top wall/roof juncture. Notice the contrasting thermographic red color depicting the heat generated from the center ceiling light. The uniform temperature of SIP walls improves the sense of comfort for occupants due to less radiant effects of the wall surface temperature differing significantly from the room air temperatures.

Images 1.7 and 1.8 are of the same SIP house in Minnesota on a 15°F winter morning. Notice no thermal bridging in the walls or roof and very uniform, consistent temperatures shown by the same colors along the wall and roof. The superior SIP energy performance of low framing factors providing minimal thermal bridging can be easily recognized in Image 1.7.

IMAGE 1.5:
DIMENSIONALLY FRAMED WALL WITH THERMAL BRIDGING AT STUDS (IN BLUE)

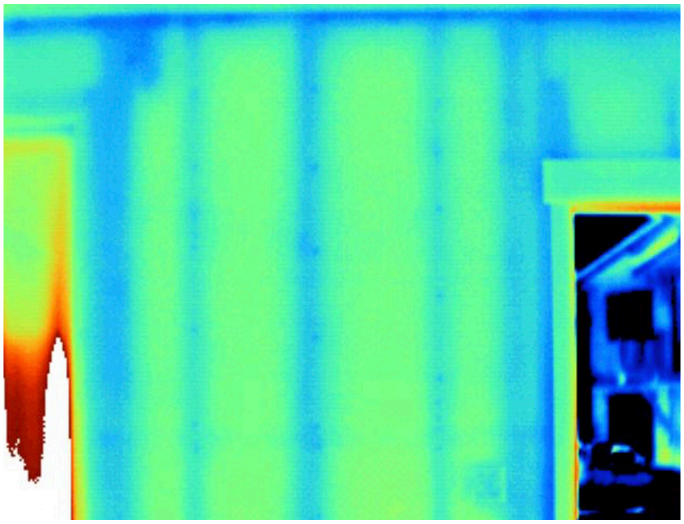


IMAGE 1.6:
SIP GARAGE WITH LOW THERMAL BRIDGING IN WALL/ROOF

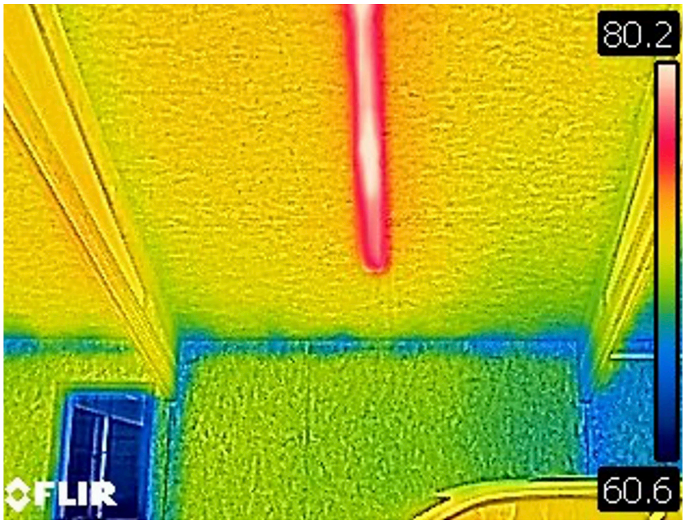


IMAGE 1.7:
MINNESOTA SIP HOUSE (THERMAL)

IMAGE 1.8:
MINNESOTA SIP HOUSE (PHOTO)

Since SIP roofs provide both the structure and the insulation all in one assembly, there is no need for attics, ceiling insulation, soffit vents, attic vent chutes, ridge vents or attic ventilation. Elimination of these saves construction time, complexity and money. Moreover, not having attic vents keeps insects, rodents and burning fire embers from entering the attic.

Images 1.9 and 1.10 contrast a neighboring stick frame wall and truss roof home the same winter morning. Notice the roof thermal bridging lines between the truss locations. The warmer, red color along the roof eaves illustrates heat loss from the top of the wall into the attic ventilation chutes. Warm air from the top of the wall enters into the attic through the eave soffit melting the frost.

In Image 1.10, notice that the melted frost lines across the roof surface uniformly align with the location of the air chutes.

In Images 1.11 and 1.12 of a Minnesota SIP wall and roof home with cathedral ceilings, the gable ends all show very consistent surface temperatures with no thermal bridges evident.

IMAGE 1.9:
MINNESOTA STICK HOUSE (THERMAL)

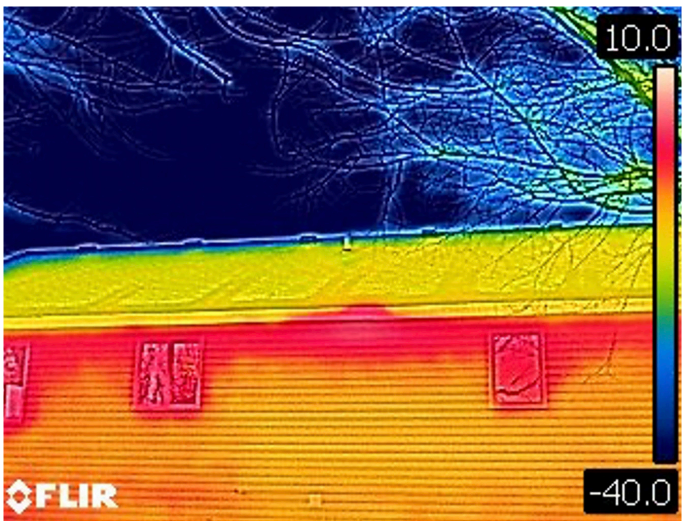


IMAGE 1.10:
MINNESOTA STICK HOUSE (PHOTO)

IMAGE 1.11:
SIP WALL (THERMAL)

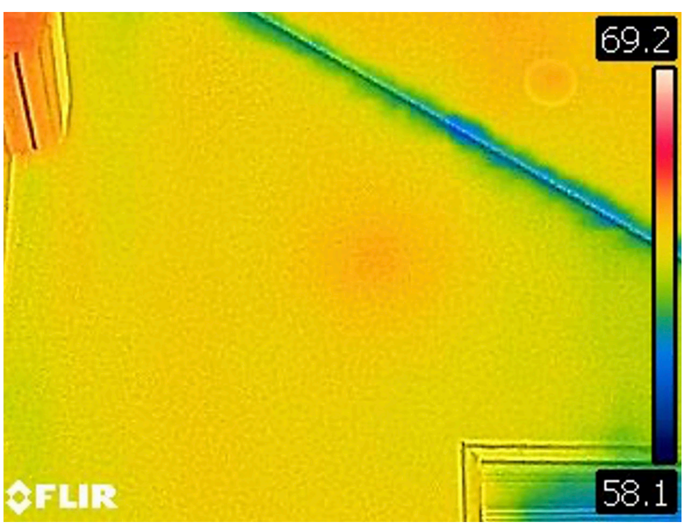
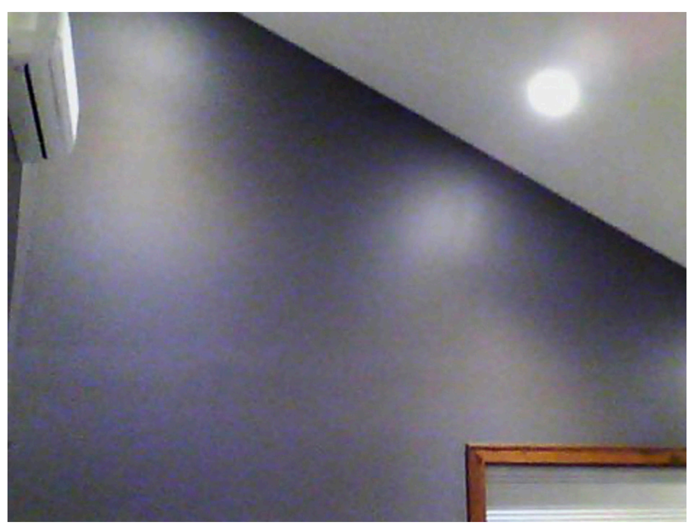


IMAGE 1.12:
SIP WALL (PHOTO)



Figures 1.1 and 1.2 depict the temperature gradient in the SIP wall compared to the traditional stick framed wall. Notice how the temperature profile along the SIP wall surfaces is very constant while the fiberglass insulated cavity stud wall assembly varies widely.

These figures graphically illustrate the temperature gradient due to the thermal bridging and higher heat transfer at the studs, explaining the melting frost in earlier images.

FIGURE 1.1:

SIP WALL CROSS-SECTION WITH SURFACE SPLINE*

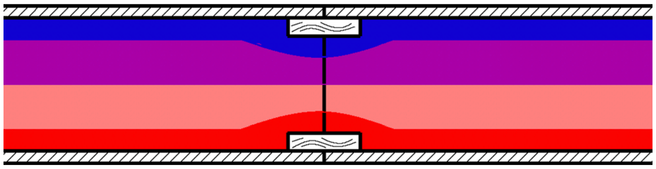
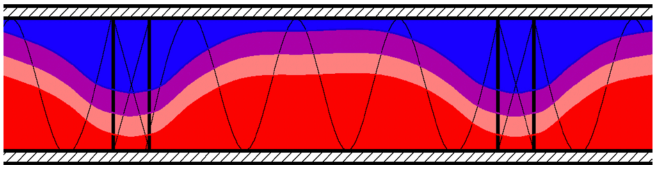


FIGURE 1.2:

TRADITIONAL STICK FRAMED WALL CROSS-SECTION WITH FIBERGLASS*



* red = hotter and blue = cooler temperatures

Joint Splines Systems

When designing with SIPs, a variety of panel joining spline technologies are available: surface splines, box/block splines, lumber splines, I-joists, etc. as illustrated in Details 1.1 – 1.7 which follow. Sealant applications around and inside these various joining spline technologies depend on geography, climate zone, seismic zone and manufacturer recommendations. Careful adherence to the specific referenced details is crucial to minimize air leakage and moisture infiltration with continuous sealant. Further discussion is available in *SIP Design Best Practices 7: SIP Installation.*

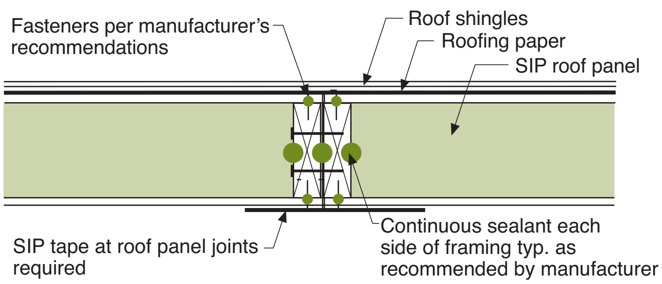
Many SIP installers report being able to install 2,000 sq. ft. of wall and roof panels per day with SIP ready-to-assemble (RTA) assemblies which include timesaving factory embedded components.

SIP connections are spelled out in shop drawings and provided to the client and builder to take away the guesswork from the installation process. This allows both the installer and the building official to review and approve the installation procedures.

Note that the following Details show typical recommendations. Consult manufacturer for job-specific requirements.

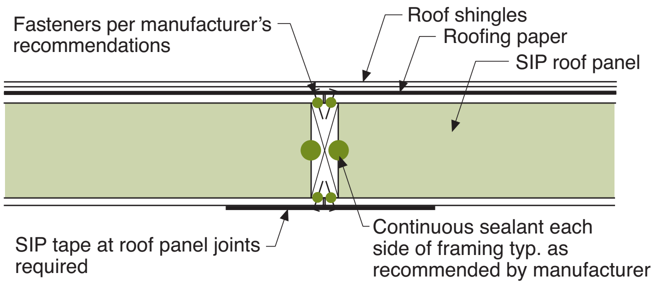
DETAIL 1.1:

SIP ROOF – DIMENSIONAL LUMBER DOUBLE SPLINE JOINT[7]



DETAIL 1.2:

SIP ROOF – DIMENSIONAL LUMBER SINGLE SPLINE JOINT[8]

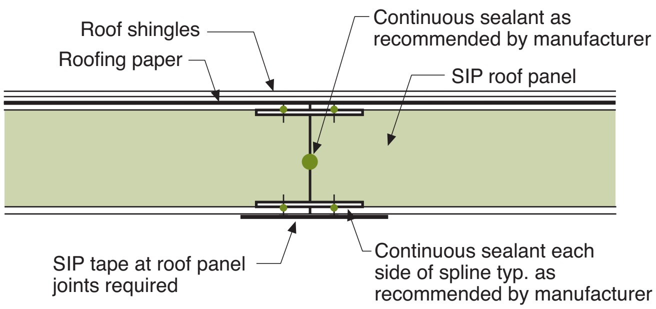


[7] Joseph Lstiburek, *Builder's Guide to Structural Insulated Panels (SIPs)*, (Building Science Corporation, 2008), Page 218, Figure 10.24b. Detail shows typical recommendations; consult manufacturer for job-specific requirements.

[8] Ibid., Page 218, Figure 10.24b. Detail shows typical recommendations; consult manufacturer for job-specific requirements.

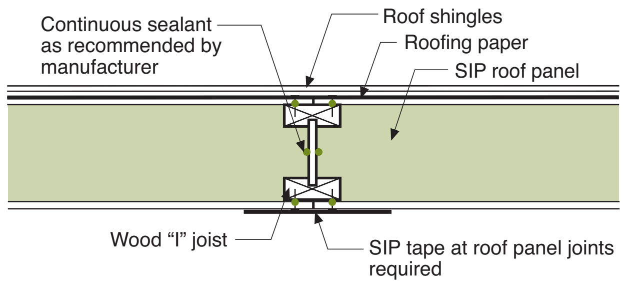
DETAIL 1.3:

SIP ROOF – SURFACE SPLINE JOINT[9]



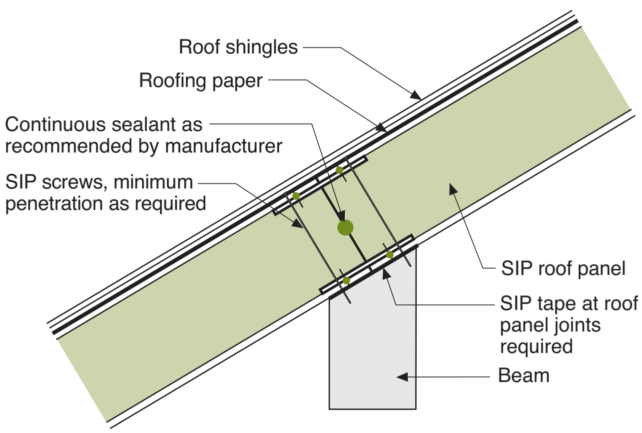
DETAIL 1.4:

SIP ROOF – I-JOIST SPLINE JOINT[10]



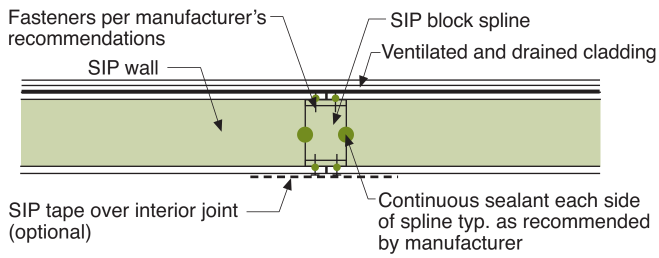
DETAIL 1.5:

SIP ROOF – BOX/BLOCK SPLINE JOINT[11]



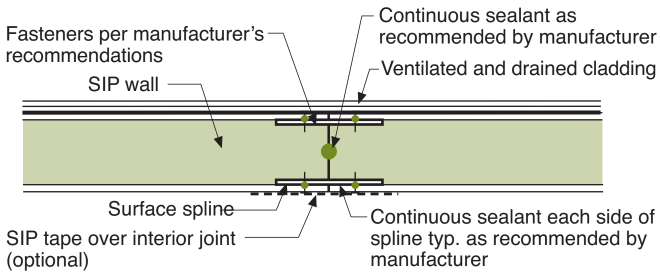
DETAIL 1.6:

SIP WALL – BOX/BLOCK SPLINE JOINT[12]



DETAIL 1.7:

SIP WALL – SURFACE SPLINE JOINT[13]



Details 1.1 through 1.7 depict different types of spline joints connecting panels. As previously mentioned, solid lumber insulates less and transfers energy. Wood typically has an R-value of 1/inch compared to EPS foam at 3.6/inch minimum R-value as per ASTM C578 Type I foam. This is why the box/block and surface splines are more thermally efficient than solid wood. A box/block and surface spline can be thought of as an 'insulating spline.'

For more detailed information, be sure to reference *SIP Design Best Practices 8: Roof and Wall Assemblies.*

[9] Ibid., Page 217, Figure 10.24a. Detail shows typical recommendations; consult manufacturer for job-specific requirements.

[10] Ibid., Page 217, Figure 10.24a. Detail shows typical recommendations; consult manufacturer for job-specific requirements.

[11] Ibid., Page 217, Figure 10.24a. Detail shows typical recommendations; consult manufacturer for job-specific requirements.

[12] Ibid., Page 209, Figure 10.14. Detail shows typical recommendations; consult manufacturer for job-specific requirements.

[13] Ibid., Page 208, Figure 10.11. Detail shows typical recommendations; consult manufacturer for job-specificrequirements.

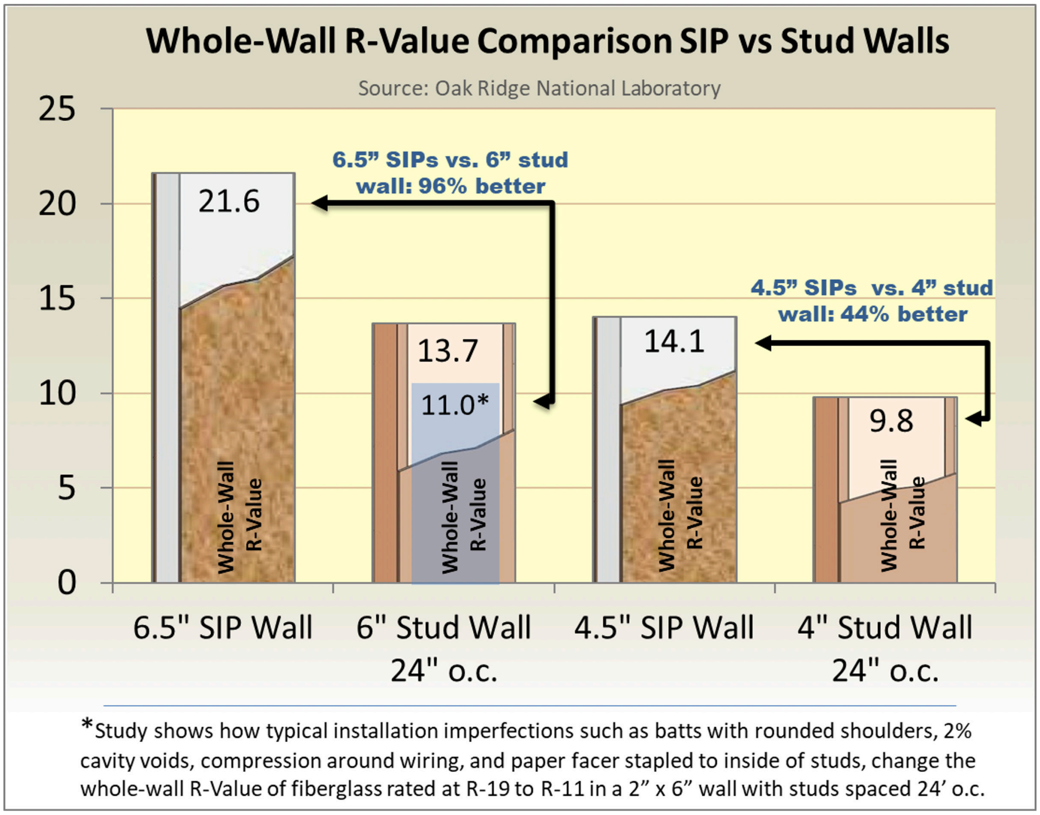
SIP DESIGN-BP 1.5:
Factory applied rigid foam insulation cores eliminate concerns over quality insulation installation (QII).

Many products insulate residential and commercial buildings. Most are factory produced and plant inspected under industry standards. Some are produced on the project site during application to the structure (e.g., spray foam) and are made from factory produced chemicals under industry standards. However, incorrect contractor field application of many insulation products into structural framing cavities jeopardizes attaining the predicted insulating performance due to often sloppy field installation and poor attention to detail or training. Short filling, voids, slumping and compressions/thickness variations are just some of the field installation errors regularly occurring. Field-installed insulation products may not perform to design expectations.

Because field insulation installation is so regularly plagued with errors, field inspection while the wall is open is required by code officials and energy raters. The resulting score is called a quality insulation installation (QII) score. If the installation is not perfect or average, it will be rejected. This score is also used as an input for energy modeling software to capture real-world reduced performance from the theoretical insulation values for modeling. Even the Department of Energy's Oak Ridge National Laboratory recognizes this frequent occurrence and requires a penalty factor to reduce the R-values recommended for stud framed walls.

Figure 1.3 illustrates the 'real-world' or 'whole-wall' R-values for these assemblies measured by the hot box testing at ORNL instead of calculated theoretical R-values. Notice how the lower framing factor of SIPs with less embedded lumber from studs in the wall (and thermal bridging) reveals better tested R-value performance compared to the traditional stud wall assemblies.

FIGURE 1.3:
INSULATION COMPARISON OF SIPS TO DIMENSIONALLY FRAMED WALLS AND INSTALLATION QUALITY EFFECTS



The damaging ‘real-world’ effects of average worker installation errors is illustrated by the dual values in the bar for the 2 x 6 stud wall at 24 inches on center assembly. Moving from a theoretically ‘perfect’ QII score for field labor installation of the fiberglass batt insulation to the more realistic ‘typical’ installation further reduces the measured real-world whole-wall R-value from R-13.7 to only R-11. This 2.7 R-value difference is a 20 percent reduction just from the effect of not having a perfect QII score. More importantly, notice even the real-world SIP whole-wall R-value of the thinner 4-1/2-inch SIP wall with R-14.1 outperforms both traditional construction cases: the 6-inch stud wall with only R-11 and the 4-inch wall with R-9.8.

SIPs are made with high-performance rigid foam cores which avoid many of the recurring shortfalls of field-applied fiber insulation products. The SIP’s rigid foam core is factory manufactured under meticulous ASTM quality assurance standards and tested regularly and inspected by code recognized third-party auditing agencies. Next, the rigid foam core is factory laminated into an insulating and structural composite ensuring that the SIP’s insulating performance is reliable for the life of the structure. The rigid foam SIP core has stable, high insulating power (expressed as R-value) resisting heat movement. Better than stud frame construction with cavities filled with porous fiber or particle insulations, the SIP rigid foam core is a solid material effectively eliminating air movement through walls and roofs. With air movement eliminated through and in the SIP, the following additional performance properties are achieved:

1. Reduction of air transfer from outside to inside and inside to outside of the structure; this is expressed as airtightness.
2. Elimination of convection looping in walls that occurs in open, non-solid insulation wall cavities. This also prevents smoke movement during fires.
3. Reduction of vapor movement in walls, whether by bulk air movement or diffusion.

SIP DESIGN-BP 1.6:
Reduced HVAC requirements.

SIP buildings are very well-insulated and airtight, which results in heating ventilation and air conditioning (HVAC) systems easily being oversized if old rules of thumb are used. When the HVAC system is too large, it tends to run for only short periods, or 'short cycles.' When an air conditioner short cycles, it will not run long enough to reach peak efficiency and does not effectively reduce humidity (latent load). An oversized air conditioner will create a wave of cool air which often causes the thermostat to get too quickly to setpoint before the entire structure cools off. Another disadvantage of an oversized air conditioner is the system tends to be noisier and require more maintenance. Similar problems can occur if the heating system is oversized. The system will short cycle causing uneven temperatures, more noise and early shut-off from the wave of warm air, making the building less comfortable. To eliminate these problems, ensure HVAC systems are designed by a qualified HVAC engineer according to ACCA Manual J. Avoid using outdated rules of thumb (e.g., estimating 1-ton a/c per 600 sq. ft. area) which do not consider (a) the well-insulating and airtight nature of SIPs as compared to traditional framing and (b) frequent substandard insulation installation methods.

The key to rightsizing HVAC equipment is minimizing load. While many people focus on R-value, an additional key element is airtightness. When lowering the air leakage rate, less outside air is effectively conditioned. SIPs outperform most systems due to their low leakage, stable R-values and low framing factor (about 5 percent) from the elimination of embedded dimensional lumber reducing thermal bridging.

Installed cavity insulations, whether friction fit fiber batts, sprayed foams or blown-in cellulose, all have potentially degraded performance from poor field installation quality. Due to frequently bad quality insulation installation (QII) easily lowering the performance, code inspectors verify it visually and provide a score to pass. This score is used in the modeling and rating software to properly predict loads. SIPs do not suffer from this installation risk since they are factory built with rigid foam insulation perfectly eliminating any cavities.

Once the envelope is installed, the overall quality is not known until a blower door leakage test can be performed, which is typically after drywall is hung and taped. SIP structures regularly achieve leakage rates below 2 air changes per hour at a pressure of 50 pascals (ACH50) to as low as 0.3 ACH50 which is below the Passive House standard of 0.6 ACH50. Of course, installation and quality of other key envelope system components like windows, plumbing and HVAC equipment must be addressed to achieve these low airtightness levels. These leakage results feed back to both the ACCA Manual J calculations and REM/Rate software for adjustment with the actual enclosure performance before it is roughed in to properly calculate loads and sizing of HVAC equipment.

Be aware: when modeling software asks for input on air leakage rates for various assembly types, ***always*** enter the tightest construction (least leaky) option for SIPs. This is especially important when actual tested air leakage values are not able to be entered into the software. Air leakage rates dramatically affect energy load calculations more than insulation values. Wrong data entered or software choice selections can easily oversize mechanical equipment and negatively affect building comfort, health and material durability.

Glossary of Terms

ACCA: Air Conditioning Contractors of America.

ACH50: the abbreviation for air changes per hour at 50 pascals (Pa) pressure differential and one of the most important metrics used to determine the energy efficiency of a house. It is the measurement of the rate of air leakage: the number of times the air volume in a building exchanges per hour at 50 Pa of pressure from a blower door test. It is considered equal to wind of approximately 25 miles per hour blowing on the outside of a building.

ACHnat: the natural air changes per hour in a building, as calculated by dividing ACH50 by the LBL Factor.

ASHRAE: the American Society of Heating, Refrigerating and Air-Conditioning Engineers (www.ashrae.org) is an American professional association seeking to advance heating, ventilation, air conditioning and refrigeration systems design and construction.

ASTM: American Society for Testing and Materials (www.astm.org), an international standards organization that develops and publishes voluntary consensus technical standards for a wide range of materials, products, systems and services.

Bottom Plate: the horizontal timber nearest the foundation or floor in the frame of a building.

CLT: cross-laminated timber, an engineered wood product.

Continuous Insulation (ci): insulating material that is continuous across all structural members without thermal bridges other than fasteners and service openings. It is installed on the interior, exterior, or is integral to any opaque surface of the building envelope.

Dimensional lumber: wood lumber that is cut to pre-defined, standard sizes (e.g., 1-inch x 4-inch, 2-inch x 4-inch, etc.).

Engineered lumber: wood products which are manufactured by binding or fixing the strands, particles, fibers, or veneers, or boards of wood, together with adhesives or other methods of fixation, to form composite material. Examples include glulam, Parallam, CLT, I-joist, LVL and rim board.

EPS: expanded polystyrene foam insulation.

ERV: Energy Recovery Ventilator.

HERS: Home Energy Rating System. The HERS index measures energy consumption from heating, cooling, water heating, lights and some appliances. The lower the index, the less energy a building is consuming. A HERS rating of zero signifies a net-zero energy building.

HRV: Heat Recovery Ventilator.

HVAC: heating, ventilation and air conditioning.

IAQ: indoor air quality.

IECC: International Energy Conservation Code.

I-joist: strong, lightweight, 'I' shaped engineered wood structural member used extensively in residential and light commercial construction projects.

LBL Factor: a factor based on climate region, number of stories of a building, and sheltering from wind which is used to convert to estimated air changes in a building by natural means, without a fan.

LEED: Leadership in Energy and Environmental Design; a sustainability rating system developed by the U.S. Green Building Council (USGBC).

LVL: laminated veneer lumber, an engineered wood product.

Manual J: the HVAC load calculation method recommended by the Air Conditioning Contractors of America (ACCA) to determine the amount of heating and cooling that a home requires to keep its occupants warm in the heating months and cool and dry in the cooling months.

ORNL: the U.S. Department of Energy's (DOE) Oak Ridge National Laboratory (ORNL) is the nation's largest multi-program science and technology laboratory.

OSB: oriented strand board, a wood structural panel.

QII: quality insulation installation.

R-value (thermal resistance): the inverse of the time rate of heat flow through a body from one of its bounding surfaces to the other surface for a unit temperature difference between the two surfaces, under steady state conditions, per unit area ($h*ft^{2}*{}^{0}F/Btu$).

REM/Rate: a residential energy analysis, code compliance and HERS software used to calculate heating, cooling, hot water, lighting and appliance energy loads, consumption and costs for single and multifamily homes.

SIPA: Structural Insulated Panel Association (www.sips.org), a non-profit trade association representing manufacturers, suppliers, dealer/distributors, design professionals and builders committed to providing quality structural insulated panels for all segments of the construction industry.

SIPs: Structural Insulated Panels, a high-performance building component for residential and light commercial construction.

Spline: connection system used to connect two panels together at vertical, in-plane joints. Many different spline systems are available including box/block, surface, I-joist, dimensional lumber and engineered lumber.

Thermal bridging: the movement of heat across an object that is more conductive than the materials around it. The conductive material creates a path of least resistance for heat. Thermal bridging can be a major source of energy loss in homes and buildings.

Top Plate: a horizontal member positioned between the SIP facers above the foam. Sits under the cap plate. For illustration, refer to Details 3.1 and 3.2 in *SIP Design Best Practices 3: Structural Capabilities*.

UA alternative: a method for performing conductive energy trade-offs, trading off the R-values and U-factors of the thermal envelope, mathematically making the R-value and U-factor paths equal.

UA: the sum of U-factor times assembly area.

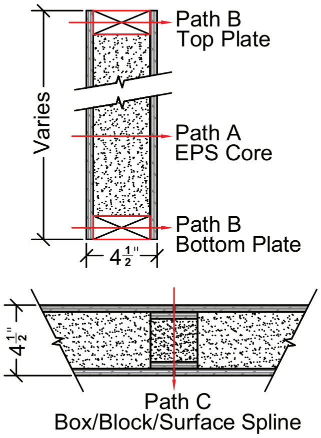
U-factor (thermal transmittance): the coefficient of heat transmission (air to air) through a building component or assembly, equal to the time rate of heat flow per unit area and unit temperature difference between the warm side and cold side air films ($Btu/h*ft^{2}*{}^{0}F$).

Appendix 1

Calculations for meeting minimal SIP thicknesses by climate zone as shown in Tables 1.1 and 1.2.

APPENDIX 1.1:

SIP 4-1/2-INCH WALL



Wood R/inch	1.25
Foam R/inch	3.85
Core Thickness	3.625"
Spline Thickness	0.875"

Area based on 4' wide x 8' tall typical section	**(sq. in.)**
Total Area	4608
EPS Core	90.82%
Top & Bottom	3.13%
Box/Block/Surface Spline	6.05%

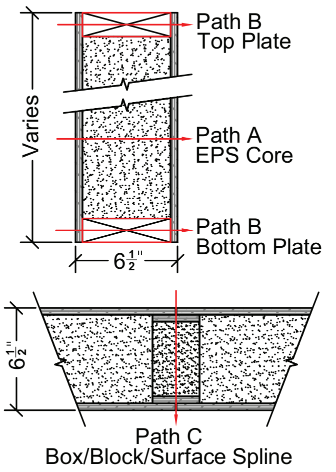
SIP Typical Nominal 4-1/2-inch Whole Wall

	Path A	Path B	Path C
R-value	EPS Core	Top & Bottom Plates	Box/Block/ Surface Spline
Inside Air Film	0.68	0.68	0.68
1/2-inch GWB	0.45	0.45	0.45
7/16-inch OSB	0.55	0.55	0.55
Framing	0.00	4.53	0.00
EPS Core	13.96	0.00	10.59
Spline	0.00	0.00	1.09
7/16-inch OSB	0.55	0.55	0.55
Exterior Finish - Vinyl	0.61	0.61	0.61
Outside Air Film (winter)	0.17	0.17	0.17
Path R-value	16.96	7.54	14.69
Path U-factor (1/Path R-value)	0.059	0.133	0.068
Weighting %	0.9082	0.0313	0.0605
U x Weighting %	0.054	0.004	0.004
Overall U-factor*	**0.062**		
Effective R-value	**16.2**		

Note: Overall U-factor = U x Weighting % added for Paths A + B + C

APPENDIX 1.2:

SIP 6-1/2-INCH WALL



Wood R/inch	1.25
Foam R/inch	3.85
Core Thickness	5.625"
Spline Thickness	0.875"

Area based on 4' wide x 8' tall typical section	**(sq. in.)**
Total Area	4608
EPS Core	90.82%
Top & Bottom	3.13%
Box/Block/Surface Spline	6.05%

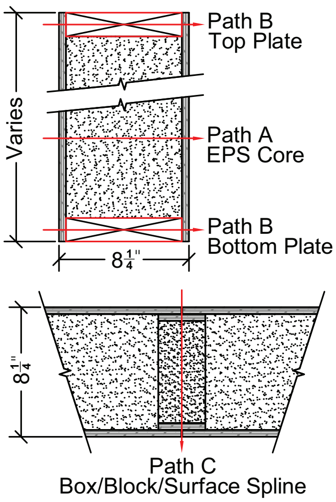
SIP Typical Nominal 6-1/2-inch Whole Wall

	Path A	Path B	Path C
R-value	EPS Core	Top & Bottom Plates	Box/Block/ Surface Spline
Inside Air Film	0.68	0.68	0.68
1/2-inch GWB	0.45	0.45	0.45
7/16-inch OSB	0.55	0.55	0.55
Framing	0.00	7.03	0.00
EPS Core	21.66	0.00	18.29
Spline	0.00	0.00	1.09
7/16-inch OSB	0.55	0.55	0.55
Exterior Finish - Vinyl	0.61	0.61	0.61
Outside Air Film (winter)	0.17	0.17	0.17
Path R-value	24.66	10.04	22.39
Path U-factor (1/Path R-value)	0.041	0.100	0.045
Weighting %	0.9082	0.0313	0.0605
U x Weighting %	0.037	0.003	0.003
Overall U-factor*	**0.043**		
Effective R-value	**23.4**		

Note: Overall U-factor = U x Weighting % added for Paths A + B + C

APPENDIX 1.3:

SIP 8-1/4-INCH WALL



Wood R/inch	1.25
Foam R/inch	3.85
Core Thickness	7.375"
Spline Thickness	0.875"

Area based on 4' wide x 8' tall typical section	**(sq. in.)**
Total Area	4608
EPS Core	90.82%
Top & Bottom	3.13%
Box/Block/Surface Spline	6.05%

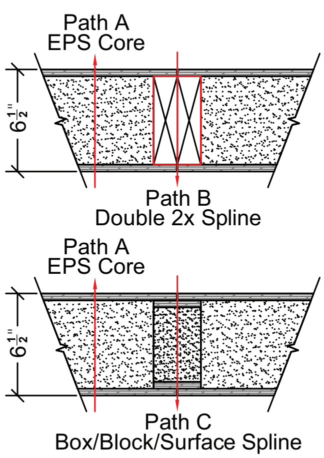
SIP Typical Nominal 8-1/4-inch Whole Wall

	Path A	Path B	Path C
R-value	EPS Core	Top & Bottom Plates	Box/Block/ Surface Spline
Inside Air Film	0.68	0.68	0.68
1/2-inch GWB	0.45	0.45	0.45
7/16-inch OSB	0.55	0.55	0.55
Framing	0.00	9.22	0.00
EPS Core	28.39	0.00	25.03
Spline	0.00	0.00	1.09
7/16-inch OSB	0.55	0.55	0.55
Exterior Finish - Vinyl	0.61	0.61	0.61
Outside Air Film (winter)	0.17	0.17	0.17
Path R-value	31.40	12.22	29.12
Path U-factor (1/Path R-value)	0.032	0.082	0.034
Weighting %	0.9082	0.0313	0.0605
U x Weighting %	0.029	0.003	0.002
Overall U-factor*	**0.034**		
Effective R-value	**29.8**		

Note: Overall U-factor = U x Weighting % added for Paths A + B + C

APPENDIX 1.4:

SIP 6-1/2-INCH ROOF



Wood R/inch	1.25
Foam R/inch	3.85
Core Thickness	5.625"
Spline Thickness	0.875"

Area based on 4' wide x 1' long panel with 2-2x Spline typical section	**(sq. in.)**
Total Area	576
EPS Core	93.75%
Double 2x Spline	6.3%
Box/Block/Surface Spline	0.0%

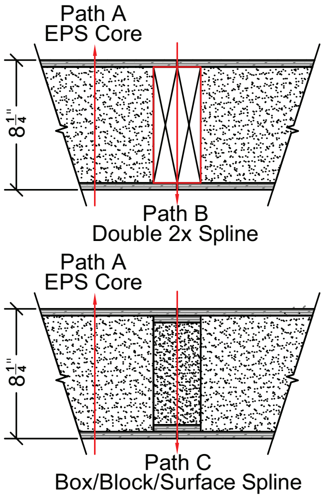
SIP Typical Nominal 6-1/2-inch Whole Roof

	Path A	Path B	Path C
R-value	EPS Core	Double 2x Spline	Box/Block/ Surface Spline
Inside Air Film	0.68	0.68	0.68
1/2-inch GWB	0.45	0.45	0.45
7/16-inch OSB	0.55	0.55	0.55
Framing	0.00	7.03	0.00
EPS Core	21.66	0.00	18.29
Spline	0.00	0.00	1.09
7/16-inch OSB	0.55	0.55	0.55
Asphalt Shingles	0.44	0.44	0.44
Outside Air Film (winter)	0.17	0.17	0.17
Path R-value	24.49	9.87	22.22
Path U-factor (1/Path R-value)	0.041	0.101	0.045
Weighting %	0.9375	0.0625	0.0625
U x Weighting %	0.0383	0.0063	0.0028
	Path A + B *(least optimum)*		Path A + C *(most optimum)*
Overall U-factor*	**0.045**		**0.041**
Effective R-Value	**22.4**		**24.3**

Note: Overall U-Factor = U x Weighting % added for Paths A + B = 0.045 for the least optimum performance with double 2x spline; Path A + C improves by using most optimum performing box/block/surface splines to a better Overall U-Factor = 0.041

APPENDIX 1.5:

SIP 8-1/4-INCH ROOF



Wood R/inch	1.25
Foam R/inch	3.85
Core Thickness	7.375"
Spline Thickness	0.875"
Area based on 4' wide x 1' long panel with 2-2x Spline typical section	**(sq. in.)**
Total Area	576
EPS Core	93.75%
Double 2x Spline	6.25%
Box/Block/Surface Spline	0.0%

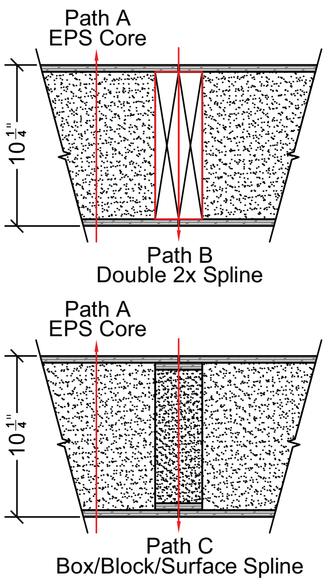
SIP Typical Nominal 8-1/4-inch Whole Wall

	Path A	Path B	Path C
R-value	EPS Core	Double 2x Spline	Box/Block/ Surface Spline
Inside Air Film	0.68	0.68	0.68
1/2-inch GWB	0.00	0.00	0.00
7/16-inch OSB	0.55	0.55	0.55
Framing	0.00	9.22	0.00
EPS Core	28.39	0.00	25.03
Spline	0.00	0.00	1.09
7/16-inch OSB	0.55	0.55	0.55
Asphalt Shingles	0.44	0.44	0.44
Outside Air Film (winter)	0.17	0.17	0.17
Path R-value	30.78	11.60	28.50
Path U-factor (1/Path R-value)	0.032	0.086	0.035
Weighting %	0.9375	0.0625	0.0625
U x Weighting %	0.0305	0.0054	0.0022
	Path A + B *(least optimum)*		Path A + C *(most optimum)*
Overall U-factor*	**0.036**		**0.033**
Effective R-value	**27.9**		**30.6**

Note: Overall U-Factor = U x Weighting % added for Paths A + B = 0.036 for the least optimum performance with double 2x spline; Path A + C improves by using most optimum performing box/block/surface splines to a better Overall U-Factor = 0.033

APPENDIX 1.6:

SIP 10-1/4-INCH ROOF



Wood R/inch	1.25
Foam R/inch	3.85
Core Thickness	9.375"
Spline Thickness	0.875"
Area based on 4' wide x 1' long panel with 2-2x Spline typical section	**(sq. in.)**
Total Area	576
EPS Core	93.75%
Double 2x Spline	6.25%
Box/Block/Surface Spline	0.0%

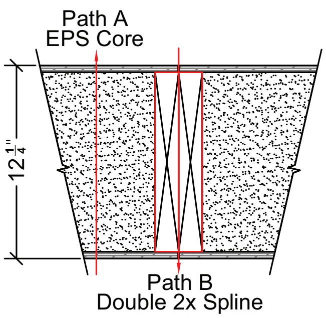
SIP Typical Nominal 10-1/4-inch Whole Roof

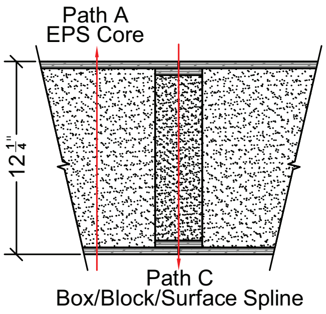
	Path A	Path B	Path C
R-value	EPS Core	Double 2x Spline	Box/Block/ Surface Spline
Inside Air Film	0.68	0.68	0.68
1/2-inch GWB	0.45	0.45	0.45
7/16-inch OSB	0.55	0.55	0.55
Framing	0.00	11.72	0.00
EPS Core	36.09	0.00	32.73
Spline	0.00	0.00	1.09
7/16-inch OSB	0.55	0.55	0.55
Asphalt Shingles	0.44	0.44	0.44
Outside Air Film (winter)	0.17	0.17	0.17
Path R-value	38.93	14.55	36.65
Path U-factor (1/Path R-value)	0.026	0.069	0.027
Weighting %	0.9375	0.0625	0.0625
U x Weighting %	0.0241	0.0043	0.0017
	Path A + B *(least optimum)*		Path A + C *(most optimum)*
Overall U-factor*	**0.028**		**0.026**
Effective R-value	**35.2**		**38.8**

Note: Overall U-Factor = U x Weighting % added for Paths A + B = 0.028 for the least optimum performance with double 2x spline; Path A + C improves by using most optimum performing box/block/surface splines to a better Overall U-Factor = 0.026

APPENDIX 1.7:

SIP 12-1/4-INCH ROOF





Wood R/inch	1.25
Foam R/inch	3.85
Core Thickness	11.375"
Spline Thickness	0.875"
Area based on 4' wide x 1' long panel with 2-2x Spline typical section	**(sq. in.)**
Total Area	576
EPS Core	93.75%
Double 2x Spline	6.25%
Box/Block/Surface Spline	0.0%

Note: Overall U-Factor = U x Weighting % added for Paths A + B = 0.024 for the least optimum performance with double 2x spline; Path A + C improves by using most optimum performing box/block/surface splines to a better Overall U-Factor = 0.022

SIP Typical Nominal 12-1/4-inch Whole Wall

	Path A	Path B	Path C
R-value	EPS Core	Double 2x Spline	Box/Block/ Surface Spline
Inside Air Film	0.68	0.68	0.68
1/2-inch GWB	0.00	0.00	0.00
7/16-inch OSB	0.55	0.55	0.55
Framing	0.00	14.22	0.00
EPS Core	43.79	0.00	40.43
Spline	0.00	0.00	1.09
7/16-inch OSB	0.55	0.55	0.55
Asphalt Shingles	0.44	0.44	0.44
Outside Air Film (winter)	0.17	0.17	0.17
Path R-value	46.18	16.60	43.90
Path U-factor (1/Path R-value)	0.022	0.060	0.023
Weighting %	0.9375	0.0625	0.0625
U x Weighting %	0.0203	0.0038	“0.0014
	Path A + B *(least optimum)*		Path A + C *(most optimum)*
Overall U-factor*	**0.024**		**0.022**
Effective R-value	**41.6**		**46.0**

PHOTOS ON THE COVER

Top:
Living Word Bible Camp, Grand Rapids MN

Structural Insulated
Panel Association

www.sips.org • P.O. Box 39848, Fort Lauderdale, FL 33339 • 253-858-7472